Life

FOURTH EDITION

Lewis · Gaffin · Hoefnagels · Parker

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LIFE, FOURTH EDITION

3 4 5 6 7 8 9 0 VNH/VNH 0 9 8 7 6 5 4 3 2

ISBN 0–07–027134–8

Publisher: *Michael D. Lange*
Sponsoring editor: *Patrick E. Reidy*
Developmental editors: *Margaret B. Horn/Suzanne Guinn*
Senior marketing manager: *Lisa L. Gottschalk*
Project manager: *Joyce M. Berendes*
Production supervisor: *Kara Kudronowicz*
Coordinator of freelance design: *Michelle D. Whitaker*
Freelance cover/interior designer: *Kathy Cunningham*
Cover photo: *Kevin Schafer/Tony Stone Images*
Photo research coordinator: *John C. Leland*
Photo research: *Mary Reeg*
Supplement producer: *Jodi K. Banowetz*
Compositor: *Precision Graphics*
Typeface: *10/12 Minion*
Printer: *Von Hoffmann Press, Inc.*

The credits section for this book begins on page 936 and is considered an extension of the copyright page.

Library of Congress Cataloging-in-Publication Data

Life / Ricki Lewis . . . [et al.]. — 4th ed.
p. cm.
Rev. ed. of: Life / Ricki Lewis. 3rd. © 1998.
Includes bibliographical references and index.
ISBN 0–07–027134–8
1. Biology. 2. Human biology. I. Lewis, Ricki. II. Lewis, Ricki. Life.

QH308.2 .L485 2002
570—dc21 00–053382
CIP

www.mhhe.com

PREFACE

The Changing Face of Biology—And *Life*

To say that the field of biology is changing rapidly is certainly an understatement. Only 50 years ago, James Watson and Francis Crick deciphered the three-dimensional structure of DNA. Now, with just a small DNA sample, biologists can decipher entire genomes—from the simplest bacterium whose genes hold clues to what it is to be alive, to species that seemingly straddle evolutionary leaps, to the most complex plant or animal. On a more practical level, DNA technology and the new life science of genomics have confirmed certain historical references, unraveled the tangled ancestries of wine grapes, and even helped prove the innocence of death row inmates.

Biologists continue to use the molecules of life to reveal new glimpses of the evolutionary relationships that bind all organisms, even species that once thrived in a long-ago, vastly different world. As a result, the way in which biologists classify life is fundamentally different from what it was just a generation ago. Everywhere we look, it's easy to find evidence that these are exciting times for biologists. To reflect these profound shifts in the field, *Life* also has changed.

New Author Team

The fourth edition of *Life* brings together four outstanding biologists. Our team begins with Ricki Lewis. She is well known for her ability to weave together solid biology content with interesting stories, real-life case studies, and applications to student life. With expertise in genetics and science communication, she has published countless articles in magazines, journals, newspapers, and encyclopedias. Her role as contributing editor to *The Scientist* gives her a heads up on much ongoing research, which finds its way into the pages of *Life.* She is also the author of a human genetics textbook and a collection of essays on discovery in the life sciences, and coauthor of human anatomy and physiology textbooks. Ricki has taught a variety of courses at the University at Albany, Empire State College, and Miami University and is a genetic counselor.

Joining forces with Ricki Lewis for the fourth edition of *Life* are three new coauthors, and we are proud to introduce ourselves: Douglas Gaffin and Mariëlle Hoefnagels of the University of Oklahoma, and Bruce Parker of Utah Valley State College. We are all active instructors who use multimedia approaches to teach undergraduate biology to hundreds of majors and nonmajors each semester.

Devotion to, and passion about, teaching unite our team. We thoroughly enjoy telling those interesting stories that are so easy to find at all levels of biology, from molecules to ecology—the stories that, when told correctly, mesmerize even the most reluctant students, causing them to perk up and think "Wow, I never knew that! So that's why . . . !" We all love to watch students get excited about learning a subject they once viewed as too hard or too intimidating. Our enthusiasm for teaching and respect for students have earned us all recognition on our campuses as outstanding teachers.

Our areas of scientific expertise—animal physiology, plant-microorganism interactions, and molecular biology and biochemistry—provide an excellent complement to Ricki's extensive knowledge of genetics. As a result, the fourth edition of *Life* has comprehensive, up-to-date content in all subject areas. But we were careful not to sacrifice Ricki's wonderful way with words.

Life has always had a unique style, reflecting a mix of scientific expertise and journalistic experience. The writing style is neither an authoritative voice talking down to the reader, nor an attempt to water down complicated science—nor a hodgepodge of the two. *Life*'s voice is uniquely clear and exciting. The result is a textbook with substantial content that is accessible to students by mixing in interesting stories and practical applications that make biology relevant to student life.

Our complementary areas of interest and dedication to sharing the wonder of biology with students led the four of us to a united vision for *Life.* We wanted to produce the excellent textbook we were waiting for ourselves—one that is readable, accurate, up-to-date, interesting, and presented in an attractive format that appeals to students. We believe the fourth edition of *Life* meets our goals. Consider the other changes to this edition.

New Content

To keep up with the shifts reverberating throughout biology, and to bring the book more in line with the order in which many instructors teach biology, we overhauled *Life*'s Table of Contents. The first five units have been reorganized and rolled into three (Cell Biology, Genetics and Biotechnology, and Evolution). These new units emphasize the concepts that are common to all life. In the next three units, the book introduces the diversity of life and explores the structures and processes unique to plant and animal life. The final unit considers ecology, concluding with a chapter that addresses environmental challenges today's students may well have to solve.

Life's revamped Table of Contents also introduces several new and reorganized chapters. New chapter 16 is devoted to speciation and extinction, with many fascinating examples of evolution in action. Another new chapter, on viruses and other infectious agents (chapter 19) explores the significance of viruses as emerging pathogens, as useful tools in biotechnology, and also as windows on evolutionary change. To expand coverage of plant life, we added a chapter on transport systems in plants (chapter 27). We moved coverage of animal reproduction and development (chapter 40) to close the unit on animal organ systems, in response to many requests. In addition, animal diversity is now covered in two chapters (24 and 25). Finally, numbered sections throughout reveal at a glance the major themes of each chapter.

Perhaps the greatest change and challenge in *Life* is also the greatest change in the science of life—how to categorize organisms. We completely rewrote Unit 4, The Diversity of Life, to reflect new classification schemes that combine traditional and molecular approaches to taxonomy. Yet we were careful to explain along the way that the molecular data currently providing such a wealth of new information have also thrown the classification of life into upheaval—and acknowledge that the classification schemes we present in this

book are provisional. It is important for students to realize that biological facts and concepts are not written in stone. Although we know that the next edition may see even more changes in this unit, we would rather present the current state of taxonomic thought than perpetuate out-of-date classification schemes.

In revising Unit 4, we evaluated and reevaluated the traditional order in which textbooks typically present life's diversity—prokaryotic organisms (bacteria and archaea), followed by protista, fungi, plants, and animals. However, much new scientific evidence suggests that fungi are actually more closely related to animals than to plants. In response to the current state of the science, we placed the chapter on fungi (chapter 23) after plants and before animals, better reflecting how evolution probably unfolded. It is a seemingly minor change, but an important one because it reflects a philosophical shift in how biologists classify life.

New Art and Photo Program

As we examined every word of text in the book, we also scrutinized every piece of art with a critical look at how it works with the text. We added many figures to support the new textual material, and modified many others—then professional biological illustrators rendered each piece anew. The new art is not only visually spectacular, but also pedagogically sound, and it gives *Life* a consistent look from cover to cover. Repeating themes provide continuity, from biochemical reactions to life cycles to feedback loops in animal physiology to evolutionary tree diagrams. Use of color, arrows, and symbols is standardized throughout the text, easing learning. So, for example, DNA, membranes, and other cell structures have a consistent look and color throughout. We have also selected unusual and interesting photos to show students glimpses of the natural world that they may never have seen before. The new art and photos are combined in page layouts that are attractive and interesting—and above all, help students learn.

Highlights on Health, Biotechnology, and Scientific Inquiry

We believe that understanding science and scientific thought is one of the most important things that students should gain from their college experience. *Life* has always emphasized the practical side of biology, and the fourth edition continues that tradition. Each chapter begins with a compelling essay describing a real-life scientific issue, ranging from the worldwide decline of amphibian populations to the evolutionary impact of the varied shapes of male genitalia (in beetles). The content in each chapter supports and expands upon the ideas presented in the opening essays.

Each chapter features one or more boxes highlighting the relevance of the content to health, biotechnology, or scientific inquiry. "Health" boxes provide a human touch. Health 19.1, for example, explores how birds brought influenza and West Nile virus infection to human populations. "Biotechnology" boxes showcase how science segues into practical applications, with looks at such diverse tools as PCR, gene therapy, in vitro evolution, artificial photosynthesis, and molecular taxonomy. A new technique explored in Biotechnology 27.1, for example, is rhizosecretion, a method to coax plants growing in hydroponic culture to secrete useful proteins—some encoded by genes from other species—through their roots. "Investigating Life" features help remove some of the mystique of science, leading the reader through the ways that scientists think when carrying out real investigations and experiments. Investigating Life 14.1, for example, presents compelling evidence of evolution among animals inhabiting a polluted river, taking the reader through the critical experiments and the logic that inspired them step by step. Along different lines, Investigating Life 28.1 invites students to predict the structures of mutant flowers, given a few simple rules governing the interaction between three flower development genes.

New Innovative and Integrative Media Support

The fourth edition of *Life* includes an innovative, comprehensive support package. As we wrote *Life*, we talked a lot about which supplements we would use as instructors. At the top of our list were computer files of textbook art, presented in a format that we could really USE in our multimedia lectures. Most textbooks offer bitmapped files of text art, but small text size and image contrast that is not optimized for large lecture halls often limit the utility of these computer files in the classroom. As instructors, we wanted more flexibility—files we could manipulate ourselves so we could tell our own stories in our own way. As a result, *Life* now offers PowerPoint-compatible, vectorized art files that the instructor can manipulate as he or she sees fit. *Life* is among the first textbooks to offer this feature.

The vectorized art is just one component of an innovative and integrated new program of media support for faculty and students. Instructor presentations will come alive with CD-ROMs that include not only the vectorized art, but also *Life*'s photos and animations. The online Essential Study Partner, which links to *Life's* Online Learning Center, enhances learning, and the new BioCourse.com site rounds out *Life*'s integrated ancillaries.

A Word of Thanks

No single person, no matter how educated, "knows" all of biology. Even an author team whose collective expertise covers most of the field must rely on an almost unimaginable amount of feedback. We greatly appreciate the help of the many reviewers, consultants, and focus group members—committed teachers who went the extra mile to help make this book what it is. We could not have done it without them. We are indebted to Randy Moore and Fred Spiegel for their contributions to the plant life unit. And we are grateful to the students in Dr. Gaffin's Spring 2000 Zoology Capstone Course for their valuable insights as they critiqued portions of the manuscript.

We thank the team at McGraw-Hill who guided us in this new view of *Life*—Michael Lange, Publisher; Patrick Reidy, Sponsoring Editor; Margaret Horn and Suzanne Guinn, Developmental Editors; and Joyce Berendes, Project Manager. We also thank the talented artists and media wizards at Precision Graphics who so beautifully translated our vision. Finally, we hope that both faculty and students will enjoy using our text as much as we loved creating it.We encourage readers to contact us with questions, comments, and suggestions. For at the pace at which biology is

progressing, the next edition is just around the corner!

We offer special thanks to the reviewers who spent hours poring over chapter drafts in meticulous detail, spotting errors and inconsistencies, confirming what works and gently critiquing what doesn't, and pointing out sections that we could clarify.

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In November 1998, at the NABT convention in Reno, NV, a talented group of instructors helped us map out a plan for the revision.

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Charlene Waggoner, *Bowling Green State University*
Courtenay N. Willis, *Youngstown State University*
Calvin Young, *Fullerton College*

At a focus group in April 1999 in Chicago, we had the opportunity to develop a plan for an extensive new supplements package due to some tremendous advice from a talented and wise group of experienced educators.

Lynn Fancher, *College of DuPage*
Merrill Gassman, *University of Illinois at Chicago*
Sandra Latourelle, *SUNY—Plattsburgh*
Darrel L. Murray, *University of Illinois at Chicago*
Bruce Parker, *Utah Valley State College*
Linda Tichenor, *University of Arkansas*

The following individuals contributed to both the quality of our new supplements and the wide range of outstanding new options for students and faculty.

Jennifer Carr Burtwistle, *Northeast Community College*
Art Animations

Edward Cawley, *Loras College*
Course Integration Guide

Lynn Fancher, *College of DuPage*
Essential Study Partner

Donald P. French, *Oklahoma State University*
Art Animations

Douglas Gaffin, *University of Oklahoma*
Vectorized Art

Sandra Latourelle, *SUNY—Plattsburgh*
Student Study Guide

John Merrill, *Michigan State University*
Online Learning Center

Bruce Parker, *Utah Valley State University*
Instructor's Manual and Test Item File

Nancy Pencoe, *State University of West Georgia*
Instructor PowerPoint Displays

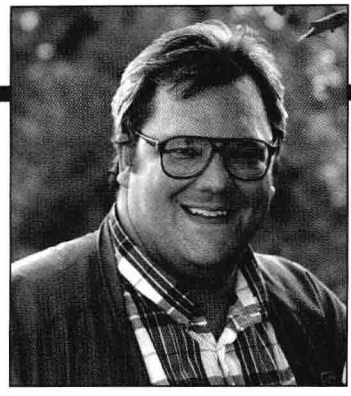
Calvin Young, *Fullerton College*
Art Animations

ABOUT THE AUTHORS

Ricki Lewis has built a multifaceted career around communicating the excitement of life science, especially genetics and biotechnology. She earned her Ph.D. in genetics in 1980 from Indiana University, working with homeotic mutations in *Drosophila melanogaster.* She is an adjunct professor at Miami University and the University at Albany, and has also taught at Empire State College and several community colleges. Ricki has published more than 3,000 articles in publications such as *The Scientist, Genetic Engineering News, BioScience,* and *Discover.* She is a frequent invited speaker, and is a member of the National Association of Biology Teachers, the National Society of Genetic Counselors, and the National Association of Science Writers. Ricki is also a genetic counselor for a large private medical practice, where she helps people make decisions concerning new technologies stemming from genetic research. She lives in upstate New York with chemist husband Larry, three daughters, four cats, two guinea pigs, and a rat, tortoise, and hedgehog. rickilewis@nasw.org

Douglas Gaffin holds a bachelor of science degree from the University of California at Berkeley, and he earned his Ph.D. in zoology from Oregon State University in Corvallis in 1994. His research interests are in sensory neurobiology, where his special focus is on the behavior and sensory physiology of sand scorpions. He has extensive biology teaching experience and has taught students in courses ranging from junior high school to graduate school levels. Doug is currently associate professor and director of undergraduate studies for the Department of Zoology at the University of Oklahoma, and he has the privilege of teaching introductory zoology to thousands of undergraduates each year. His innovative teaching style and ability to inspire students have been recognized with awards both regionally and nationally. Among other organizations, he is a member of the Society for Neuroscience, the International Society for Neuroethology, the American Arachnological Society, and the National Association of Biology Teachers. In his spare time he enjoys traveling, riding his bike, playing volleyball, and picking the banjo. One of his favorite activities is going to the desert each summer to observe and conduct field research on sand scorpions in their native habitat. ddgaffin@ou.edu

Mariëlle Hoefnagels was raised near San Francisco, and received her B.S. in environmental science (1987) from the University of California at Riverside. After working in a soil analysis lab in Oregon for two years, she earned her master's degree in soil science from North Carolina State University (1991). Her research, on interactions between beneficial fungi and salt marsh plants, led her to return to Oregon to complete her Ph.D. in plant pathology (Oregon State University, 1997). Mariëlle's dissertation work focused on the use of bacterial biological control agents to reduce the spread of fungal pathogens on seeds. She is now assistant professor at the University of Oklahoma, where she teaches nonmajors courses in biology and microbiology, and a course on fungi for advanced botany and microbiology majors. Her current research is on the interactions between plants and beneficial microorganisms in prairie soils, and she particularly enjoys involving undergraduates in her research during the summer. She is a member of the National Association of Biology Teachers, and the American Phytopathological Society. Her hobbies include reading, traveling, photography, and playing volleyball. hoefnagels@ou.edu



Bruce Parker received his Ph.D. in molecular biology/biochemistry from Utah State University in 1988. His areas of expertise include virology, molecular cell biology and biochemistry, and he spent two years in London working on research into viruses that cause cancer, followed by another two years on the same project at St. Jude Children's Research Hospital in Memphis. He has taught general biology for nonmajors and majors at Utah Valley State College since 1992 and has been nominated for Faculty of the Year for six of those years. Bruce currently serves as department chairperson at Utah Valley State College and is included in *Who's Who Among America's Teachers* for 1998. His hobbies include computer programming and amateur radio, when he is not fishing somewhere. parkerbr@uvsc.edu

ILLUSTRATION TEAM

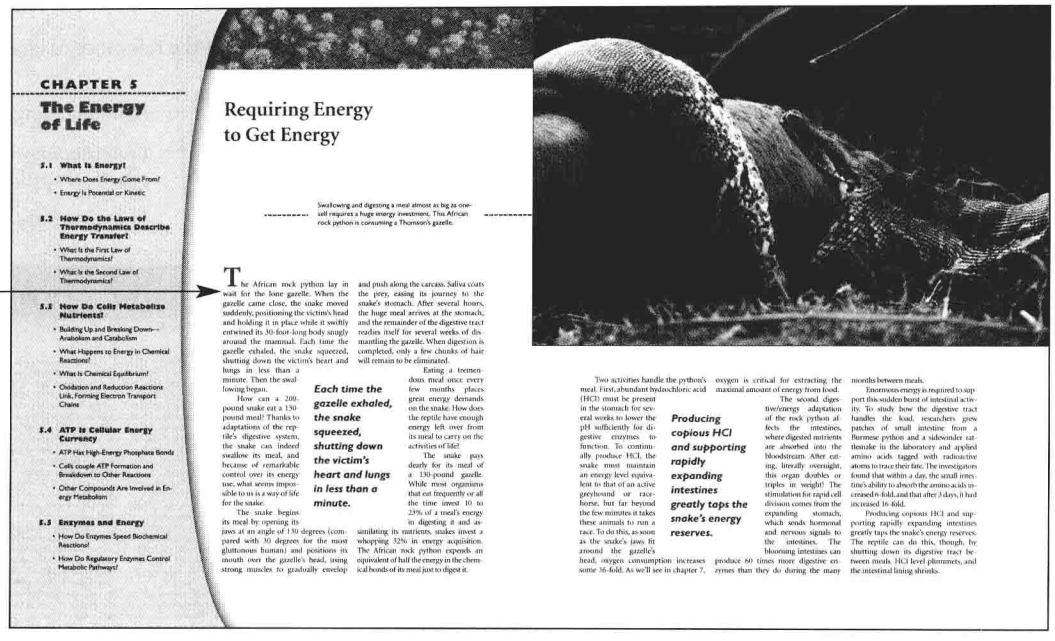
Precision Graphics of Champaign, Illinois, is a specialized composition house. Their own staff of illustrators developed the art program for the fourth edition of *Life.* Each person on the team brought her own skills and strengths to the subject matter. **Connie Balek,** the lead developer at Precision Graphics, not only has a degree in biology, but she also holds a master of fine arts degree in medical and biological illustration from the University of Michigan. **Joanne Bales** has been a medical illustrator at Precision Graphics since 1992 and utilizes her extensive health-care and nursing background in developing illustrations. And **Jan Troutt,** the natural science art director, brings many years of unparalleled experience in rendering art for many of today's leading biology titles. This team collaborated on each piece of art to build an accurate and solid program that will help students learn about life.

THE LEARNING SYSTEM

These pages are a brief guide to tools that *Life* uses to facilitate students' study of biology.

Chapter Opening Vignettes

Each chapter begins with a compelling vignette describing a real-life scientific issue related to the chapter topic.



CHAPTER 5

The Energy of Life

5.1 What Is Energy?
- Where Does Energy Come From?
- Energy Is Potential or Kinetic

5.2 How Do the Laws of Thermodynamics Describe Energy Transfer?
- What Is the First Law of Thermodynamics?
- What Is the Second Law of Thermodynamics?

5.3 How Do Cells Metabolize Nutrients?
- Building Up and Breaking Down—Anabolism and Catabolism
- What Happens to Energy in Chemical Reactions?
- What Is Chemical Equilibrium?
- Oxidation and Reduction Reactions Link, Forming Electron Transport Chains

5.4 ATP Is Cellular Energy Currency
- ATP Has High-Energy Phosphate Bonds
- Cells couple ATP Formation and Breakdown to Other Reactions
- Other Compounds Are Involved in Energy Metabolism

5.5 Enzymes and Energy
- How Do Enzymes Speed Biochemical Reactions?
- How Do Regulatory Enzymes Control Metabolic Pathways?

Requiring Energy to Get Energy

Swallowing and digesting a meal almost as big as oneself requires a huge energy investment. This African rock python is consuming a Thomson's gazelle.

The African rock python lay in wait for the lone gazelle. When the gazelle came close, the snake moved suddenly, positioning the victim's head and holding it in place while it swiftly entwined its 30-foot-long body snugly around the mammal. Each time the gazelle exhaled, the snake squeezed, shutting down the victim's heart and lungs in less than a minute. Then the swallowing began.

How can a 200-pound snake eat a 130-pound meal? Thanks to adaptations of the reptile's digestive system, the snake can indeed swallow its meal, and because of remarkable control over its energy use, what seems impossible to us is a way of life for the snake.

The snake begins its meal by opening its jaws at an angle of 150 degrees (compared with 30 degrees for the most gluttonous human) and positions its mouth over the gazelle's head, using strong muscles to gradually envelop and push along the carcass. Saliva coats the prey, easing its journey to the snake's stomach. After several hours, the huge meal arrives at the stomach, and the remainder of the digestive tract readies itself for several weeks of dismantling the gazelle. When digestion is completed, only a few chunks of hair will remain to be eliminated.

Each time the gazelle exhaled, the snake squeezed, shutting down the victim's heart and lungs in less than a minute.

Eating a tremendous meal once every few months places great energy demands on the snake. How does the reptile have enough energy left over from its meal to carry on the activities of life?

The snake pays dearly for its meal of a 130-pound gazelle. While most organisms that eat frequently or all the time invest 10 to 23% of a meal's energy in digesting it and assimilating its nutrients, snakes invest a whopping 32% in energy acquisition. The African rock python expends an equivalent of half the energy in the chemical bonds of its meal just to digest it.

Two activities handle the python's meal. First, abundant hydrochloric acid (HCl) must be present in the stomach for several weeks to lower the pH sufficiently for digestive enzymes to function. To continually produce HCl, the snake must maintain an energy level equivalent to that of an active greyhound or racehorse, but far beyond the few minutes it takes these animals to run a race. To do this, as soon as the snake's jaws fit around the gazelle's head, oxygen consumption increases some 16-fold. As we'll see in chapter 7, oxygen is critical for extracting the maximal amount of energy from food.

Producing copious HCl and supporting rapidly expanding intestines greatly taps the snake's energy reserves.

The second digestive/energy adaptation of the rock python affects the intestines, where digested nutrients are absorbed into the bloodstream. After eating, literally overnight, this organ doubles or triples in weight! The stimulation for rapid cell division comes from the expanding stomach, which sends hormonal and nervous signals to the intestines. The blooming intestines can produce 60 times more digestive enzymes than they do during the many months between meals.

Enormous energy is required to support this sudden burst of intestinal activity. To study how the digestive tract handles the load, researchers grow patches of small intestine from a Burmese python and a sidewinder rattlesnake in the laboratory and applied amino acids tagged with radioactive atoms to trace their fate. The investigators found that within a day, the small intestine's ability to absorb the amino acids increased 6-fold, and that after 3 days, it had increased 16-fold.

Producing copious HCl and supporting rapidly expanding intestines greatly taps the snake's energy reserves. The reptile can do this, though, by shutting down its digestive tract between meals. HCl level plummets, and the intestinal lining shrinks.

New Art Program

The accurate and artistically compelling illustrations greatly enhance the student's understanding of difficult processes and concepts.

FIGURE 4.1
Cellular Architecture.
A white blood cell's inner skeleton and surface features enable it to move in the body and to recognize "foreign" cell surfaces—such as those of transplanted tissue. This T lymphocyte rejects foreign tissue.

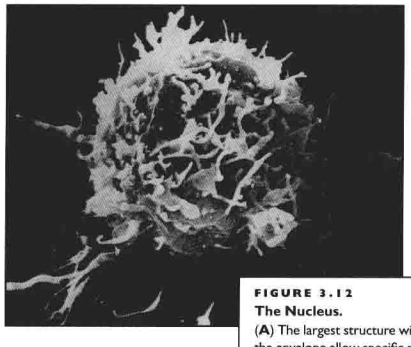


FIGURE 32.10
The Visual Pathway.
(**A**) Photons pass through the outer layers of the eye and hit the rods and cones, which transmit information to bipolar cells, which pass the message to the action potential-generating ganglion cells that form the optic nerve. (**B**) Rhodopsin consists of retinal linked to one helix of an opsin. Light energy alters the conformation of the retinal, which may ultimately alter the pattern of action potentials in the optic nerve.

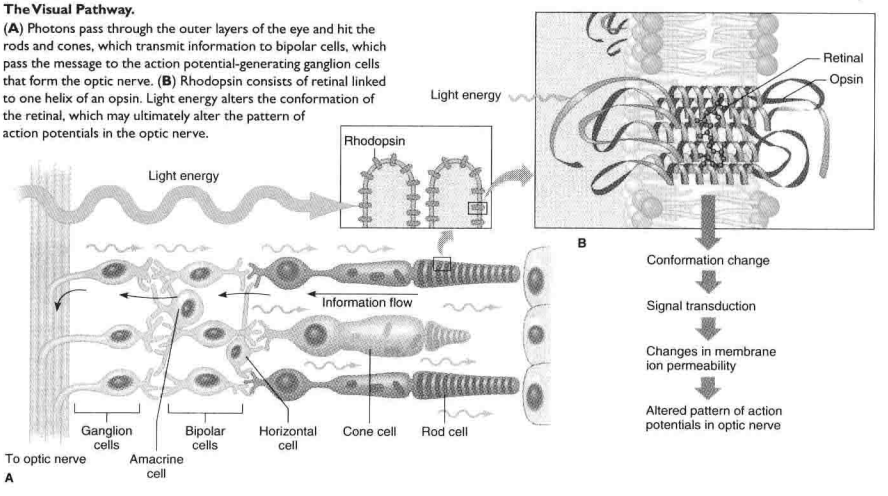
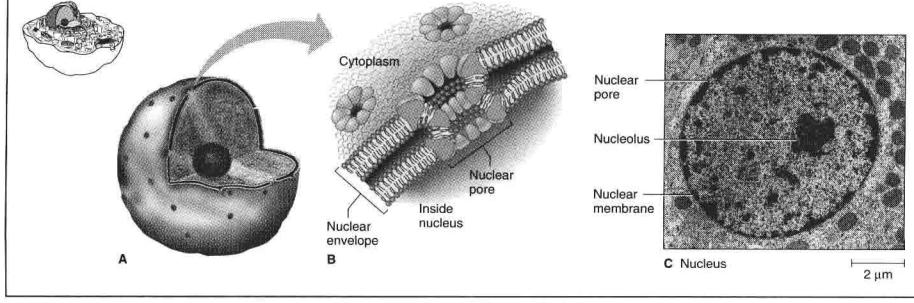


FIGURE 3.12
The Nucleus.
(**A**) The largest structure within a eukaryotic cell, the nucleus is surrounded by two membrane layers which make up the nuclear envelope (**B**). Pores through the envelope allow specific molecules to move in and out of the nucleus. The darkly staining nucleolus (**C**) is the site of ribosome manufacture and assembly.



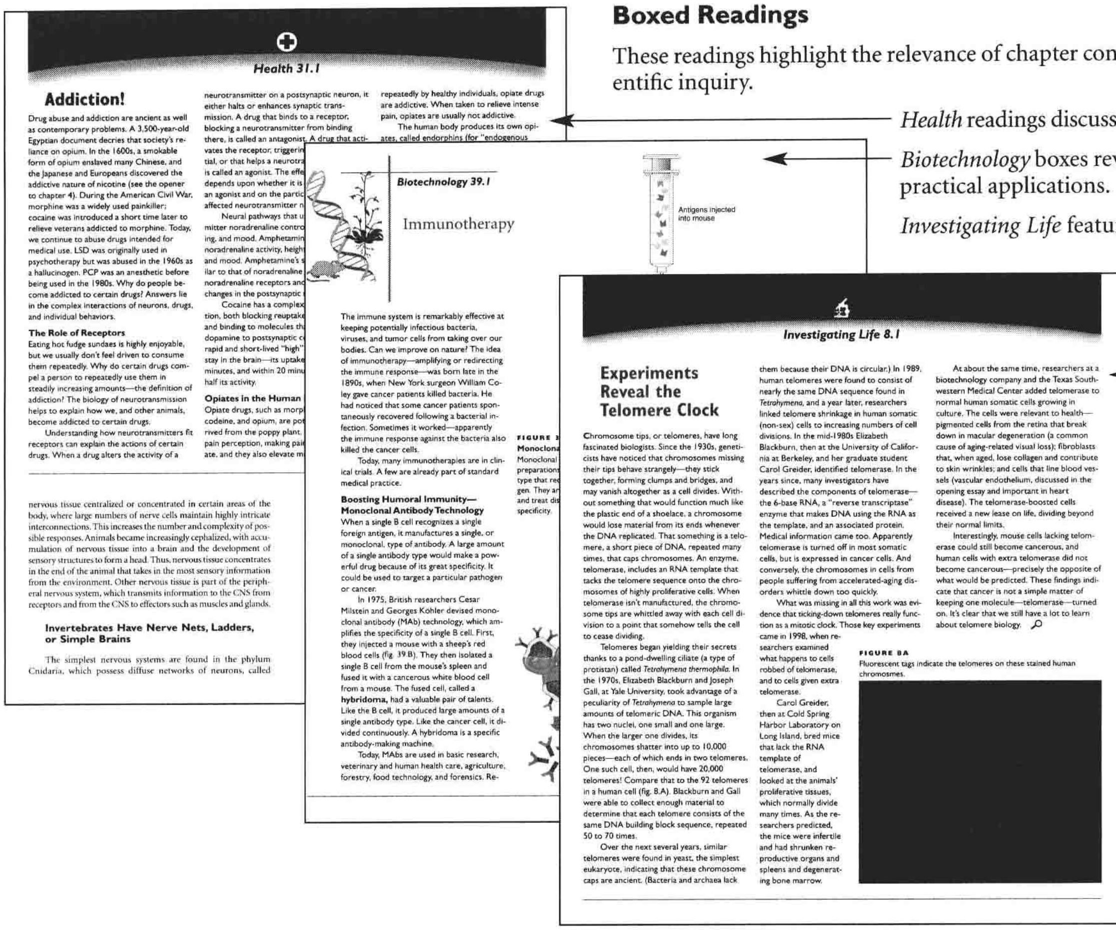
Boxed Readings

These readings highlight the relevance of chapter contents to health, biotechnology, and scientific inquiry.

Health readings discuss health issues of interest to the student.

Biotechnology boxes reveal at a glance how science segues into practical applications.

Investigating Life features help remove some of the mystique of science, leading the reader through ways that scientists think when carrying out real experiments and investigations.


Health 31.1

Addiction!

Drug abuse and addiction are ancient as well as contemporary problems. A 3,500-year-old Egyptian document decries that society's reliance on opium. In the 1600s, a smokable form of opium enslaved many Chinese, and the Japanese and Europeans discovered the addictive nature of nicotine (see the opener to chapter 4). During the American Civil War, morphine was a widely used painkiller; cocaine was introduced a short time later to relieve veterans addicted to morphine. Today, we continue to abuse drugs intended for medical use. LSD was originally used in psychotherapy but was abused in the 1960s as a hallucinogen. PCP was an anesthetic before being used in the 1980s. Why do people become addicted to certain drugs? Answers lie in the complex interactions of neurons, drugs, and individual behaviors.

The Role of Receptors

Eating hot fudge sundaes is highly enjoyable, but we usually don't feel driven to consume them repeatedly. Why do certain drugs compel a person to repeatedly use them in steadily increasing amounts—the definition of addiction? The biology of neurotransmission helps to explain how we, and other animals, become addicted to certain drugs.

Understanding how neurotransmitters fit receptors can explain the actions of certain drugs. When a drug alters the activity of a

nervous tissue centralized or concentrated in certain areas of the body, where large numbers of nerve cells maintain highly intricate interconnections. This increases the number and complexity of possible responses. Animals became increasingly cephalized, with accumulation of nervous tissue into a brain and the development of sensory structures to form a head. Thus, nervous tissue concentrates in the end of the animal that takes in the most sensory information from the environment. Other nervous tissue is part of the peripheral nervous system, which transmits information to the CNS from receptors and from the CNS to effectors such as muscles and glands.

Invertebrates Have Nerve Nets, Ladders, or Simple Brains

The simplest nervous systems are found in the phylum Cnidaria, which possess diffuse networks of neurons, called

Biotechnology 39.1

Immunotherapy

The immune system is remarkably effective at keeping potentially infectious bacteria, viruses, and tumor cells from taking over our bodies. Can we improve on nature? The idea of immunotherapy—amplifying or redirecting the immune response—was born late in the 1890s, when New York surgeon William Coley gave cancer patients killed bacteria. He had noticed that some cancer patients spontaneously recovered following a bacterial infection. Sometimes it worked—apparently the immune response against the bacteria also killed the cancer cells.

Today, many immunotherapies are in clinical trials. A few are already part of standard medical practice.

Boosting Humoral Immunity—Monoclonal Antibody Technology

When a single B cell recognizes a single foreign antigen, it manufactures a single, or monoclonal, type of antibody. A large amount of a single antibody type would make a powerful drug because of its great specificity. It could be used to target a particular pathogen or cancer.

In 1975, British researchers Cesar Milstein and Georges Kohler devised monoclonal antibody (MAb) technology, which amplifies the specificity of a single B cell. First, they injected a mouse with a sheep's red blood cells (fig. 39.B). They then isolated a single B cell from the mouse's spleen and fused it with a cancerous white blood cell from a mouse. The fused cell, called a hybridoma, had a valuable pair of talents. Like the B cell, it produced large amounts of a single antibody type. Like the cancer cell, it divided continuously. A hybridoma is a specific antibody-making machine.

Today, MAbs are used in basic research, veterinary and human health care, agriculture, forestry, food technology, and forensics. Re-

Antigens injected into mouse

Investigating Life 8.1

Experiments Reveal the Telomere Clock

Chromosome tips, or telomeres, have long fascinated biologists. Since the 1930s, geneticists have noticed that chromosomes missing their tips behave strangely—they stick together, forming clumps and bridges, and may vanish altogether as a cell divides. Without something that would function much like the plastic end of a shoelace, a chromosome would lose material from its ends whenever the DNA replicated. That something is a telomere, a short piece of DNA, repeated many times, that caps chromosomes. An enzyme, telomerase, includes an RNA template that tacks the telomere sequence onto the chromosomes of highly proliferative cells. When telomerase isn't manufactured, the chromosome tips are whittled away with each cell division to a point that somehow tells the cell to cease dividing.

Telomeres began yielding their secrets thanks to a pond-dwelling ciliate (a type of protistan) called *Tetrahymena thermophila*. In the 1970s, Elizabeth Blackburn and Joseph Gall, at Yale University, took advantage of a peculiarity of *Tetrahymena* to sample large amounts of telomeric DNA. This organism has two nuclei, one small and one large. When the larger one divides, its chromosomes shatter into up to 10,000 pieces—each of which ends in two telomeres. One such cell, then, would have 20,000 telomeres! Compare that to the 92 telomeres in a human cell (fig. 8.A). Blackburn and Gall were able to collect enough material to determine that each telomere consists of the same DNA building block sequence, repeated 50 to 70 times.

Over the next several years, similar telomeres were found in yeast, the simplest eukaryote, indicating that these chromosome caps are ancient. (Bacteria and archaea lack them because their DNA is circular.) In 1989, human telomeres were found to consist of nearly the same DNA sequence found in *Tetrahymena*, and a year later, researchers linked telomere shrinkage in human somatic (non-sex) cells to increasing numbers of cell divisions. In the mid-1980s Elizabeth Blackburn, then at the University of California at Berkeley, and her graduate student Carol Greider, identified telomerase. In the years since, many investigators have described the components of telomerase—the 6-base RNA, a "reverse transcriptase" enzyme that makes DNA using the RNA as the template, and an associated protein. Medical information came too. Apparently telomerase is turned off in most somatic cells, but is expressed in cancer cells. And conversely, the chromosomes in cells from people suffering from accelerated-aging disorders whittle down too quickly.

What was missing in all this work was evidence that ticking-down telomeres really function as a mitotic clock. Those key experiments came in 1998, when researchers examined what happens to cells robbed of telomerase, and to cells given extra telomerase.

Carol Greider, then at Cold Spring Harbor Laboratory on Long Island, bred mice that lack the RNA template of telomerase, and looked at the animals' proliferative tissues, which normally divide many times. As the researchers predicted, the mice were infertile and had shrunken reproductive organs and spleens and degenerating bone marrow.

At about the same time, researchers at a biotechnology company and the Texas Southwestern Medical Center added telomerase to normal human somatic cells growing in culture. The cells were relevant to health—pigmented cells from the retina that break down in macular degeneration (a common cause of aging-related visual loss); fibroblasts that, when aged, lose collagen and contribute to skin wrinkles; and cells that line blood vessels (vascular endothelium, discussed in the opening essay and important in heart disease). The telomerase-boosted cells received a new lease on life, dividing beyond their normal limits.

Interestingly, mouse cells lacking telomerase could still become cancerous, and human cells with extra telomerase did not become cancerous—precisely the opposite of what would be predicted. These findings indicate that cancer is not a simple matter of keeping one molecule—telomerase—turned on. It's clear that we still have a lot to learn about telomere biology.

FIGURE 8A
Fluorescent tags indicate the telomeres on these stained human chromosmes.

Chemistry Explains Biology

These brief readings, unique to the chemistry chapter, facilitate understanding of the chapter's material.

Chemistry Explains Biology

Excess Cholesterol

Lipoproteins carry cholesterol in the bloodstream. As their name suggests, lipoproteins consist of lipid and protein. Low-density lipoprotein (LDL) particles carry cholesterol to the arteries. Excess LDL cholesterol that does not enter cells accumulates on the inner linings of blood vessels, eventually impeding blood flow. High-density lipoproteins (HDL), in contrast, carry cholesterol to the liver, where it is removed from the bloodstream. High levels of LDL cholesterol increase risk of heart disease, whereas high levels of HDL cholesterol promote heart health.

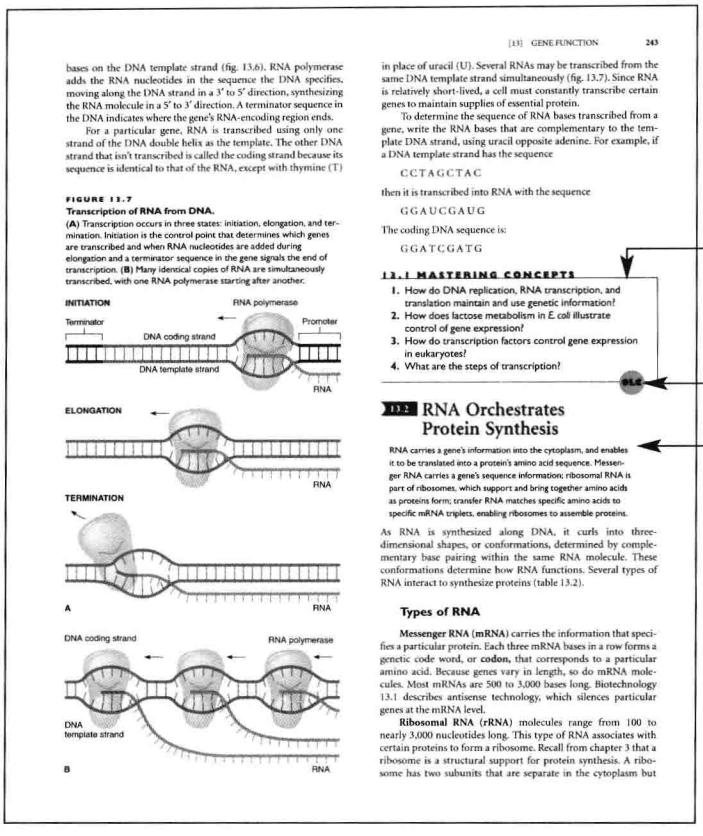
Chemistry Explains Biology

Spider Silk

Spider silk is the strongest natural fiber known. Spiders use silk to build webs to capture prey, to store prey, and to protect their eggs.

Silks are proteins, manufactured in sets of glands. A spider usually has several sets of glands, each of which produces a different type of silk. In addition to producing webs, a spider continually secretes a strand of silk called a dragline. Should danger arise, the spider can temporarily escape the web on its dragline.

Dragline silk is best studied in the golden orb weaver spider, *Nephila clavipes*. This especially strong and elastic silk consists of two types of proteins that are dry and practically indestructible once outside the animal's body. Dragline silk proteins include a few types of amino acids that repeat in short sequences. This imparts a conformation of coiled sheets, like the steps of a spiral staircase. Spider silk elegantly illustrates how a protein's shape determines its functions.



[13] GENE FUNCTION 243

bases on the DNA template strand (fig. 13.6). RNA polymerase adds the RNA nucleotides in the sequence the DNA specifies, moving along the DNA strand in a 3′ to 5′ direction, synthesizing the RNA molecule in a 5′ to 3′ direction. A terminator sequence in the DNA indicates where the gene's RNA-encoding region ends.

For a particular gene, RNA is transcribed using only one strand of the DNA double helix as the template. The other DNA strand that isn't transcribed is called the coding strand because its sequence is identical to that of the RNA, except with thymine (T) in place of uracil (U). Several RNAs may be transcribed from the same DNA template strand simultaneously (fig. 13.7). Since RNA is relatively short-lived, a cell must constantly transcribe certain genes to maintain supplies of essential protein.

To determine the sequence of RNA bases transcribed from a gene, write the RNA bases that are complementary to the template DNA strand, using uracil opposite adenine. For example, if a DNA template strand has the sequence

CCTAGCTAC

then it is transcribed into RNA with the sequence

GGAUCGAUG

The coding DNA sequence is:

GGATCGATG

FIGURE 13.7
Transcription of RNA from DNA.
(A) Transcription occurs in three states: initiation, elongation, and termination. Initiation is the control point that determines which genes are transcribed and when. RNA nucleotides are added during elongation and a terminator sequence in the gene signals the end of transcription. **(B)** Many identical copies of RNA are simultaneously transcribed, with one RNA polymerase starting after another.

13.1 MASTERING CONCEPTS

1. How do DNA replication, RNA transcription, and translation maintain and use genetic information?
2. How does lactose metabolism in *E. coli* illustrate control of gene expression?
3. How do transcription factors control gene expression in eukaryotes?
4. What are the steps of transcription?

13.2 RNA Orchestrates Protein Synthesis

RNA carries a gene's information into the cytoplasm, and enables it to be translated into a protein's amino acid sequence. Messenger RNA carries a gene's sequence information; ribosomal RNA is part of ribosomes, which support and bring together amino acids as proteins form; transfer RNA matches specific amino acids to specific mRNA triplets, enabling ribosomes to assemble proteins.

As RNA is synthesized along DNA, it curls into three-dimensional shapes, or conformations, determined by complementary base pairing within the same RNA molecule. These conformations determine how RNA functions. Several types of RNA interact to synthesize proteins (table 13.2).

Types of RNA

Messenger RNA (mRNA) carries the information that specifies a particular protein. Each three mRNA bases in a row forms a genetic code word, or **codon,** that corresponds to a particular amino acid. Because genes vary in length, so do mRNA molecules. Most mRNAs are 500 to 3,000 bases long. Biotechnology 13.1 describes antisense technology, which silences particular genes at the mRNA level.

Ribosomal RNA (rRNA) molecules range from 100 to nearly 3,000 nucleotides long. This type of RNA associates with certain proteins to form a ribosome. Recall from chapter 3 that a ribosome is a structural support for protein synthesis. A ribosome has two subunits that are separate in the cytoplasm but

Mastering Concepts

A short list of questions follows each major text section, to help the student review and understand what was just covered.

Summary Statements

Each major section of the chapter begins with a brief synopsis of the section's material.

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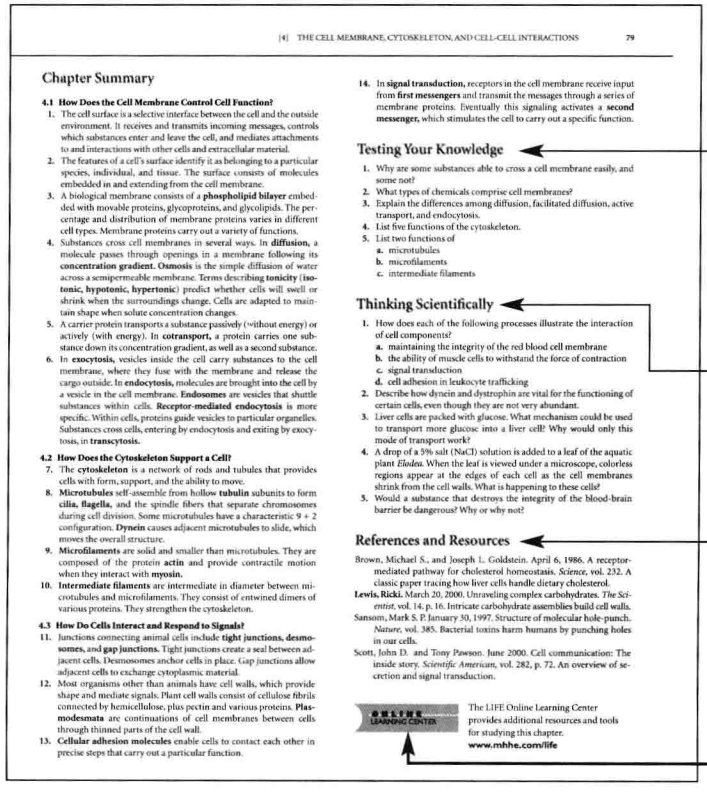
Chapter Summary

The list format of the end of chapter summary makes it easy for students to identify and review key concepts.



[4] THE CELL MEMBRANE, CYTOSKELETON, AND CELL-CELL INTERACTIONS 79

Chapter Summary

4.1 How Does the Cell Membrane Control Cell Function?

1. The cell surface is a selective interface between the cell and the outside environment. It receives and transmits incoming messages, controls which substances enter and leave the cell, and mediates attachments to and interactions with other cells and extracellular material.
2. The features of a cell's surface identify it as belonging to a particular species, individual, and tissue. The surface consists of molecules embedded in and extending from the cell membrane.
3. A biological membrane consists of a **phospholipid bilayer** embedded with movable proteins, glycoproteins, and glycolipids. The percentage and distribution of membrane proteins varies in different cell types. Membrane proteins carry out a variety of functions.
4. Substances cross cell membranes in several ways. In **diffusion,** a molecule passes through openings in a membrane following its **concentration gradient. Osmosis** is the simple diffusion of water across a semipermeable membrane. Terms describing **tonicity** (**isotonic, hypotonic, hypertonic**) predict whether cells will swell or shrink when the surroundings change. Cells are adapted to maintain shape when solute concentration changes.
5. A carrier protein transports a substance passively (without energy) or actively (with energy). In **cotransport,** a protein carries one substance down its concentration gradient, as well as a second substance.
6. In **exocytosis,** vesicles inside the cell carry substances to the cell membrane, where they fuse with the membrane and release the cargo outside. In **endocytosis,** molecules are brought into the cell by a vesicle in the cell membrane. **Endosomes** are vesicles that shuttle substances within cells. **Receptor-mediated endocytosis** is more specific. Within cells, proteins guide vesicles to particular organelles. Substances cross cells, entering by endocytosis and exiting by exocytosis, in **transcytosis.**

4.2 How Does the Cytoskeleton Support a Cell?

7. The **cytoskeleton** is a network of rods and tubules that provides cells with form, support, and the ability to move.
8. **Microtubules** self-assemble from hollow **tubulin** subunits to form **cilia, flagella,** and the spindle fibers that separate chromosomes during cell division. Some microtubules have a characteristic 9 + 2 configuration. **Dynein** causes adjacent microtubules to slide, which moves the overall structure.
9. **Microfilaments** are solid and smaller than microtubules. They are composed of the protein **actin** and provide contractile motion when they interact with **myosin.**
10. **Intermediate filaments** are intermediate in diameter between microtubules and microfilaments. They consist of entwined dimers of various proteins. They strengthen the cytoskeleton.

4.3 How Do Cells Interact and Respond to Signals?

11. Junctions connecting animal cells include **tight junctions, desmosomes,** and **gap junctions.** Tight junctions create a seal between adjacent cells. Desmosomes anchor cells in place. Gap junctions allow adjacent cells to exchange cytoplasmic material.
12. Most organisms other than animals have cell walls, which provide shape and mediate signals. Plant cell walls consist of cellulose fibrils connected by hemicellulose, plus pectin and various proteins. **Plasmodesmata** are continuations of cell membranes between cells through thinned parts of the cell wall.
13. **Cellular adhesion molecules** enable cells to contact each other in precise steps that carry out a particular function.
14. In **signal transduction,** receptors in the cell membrane receive input from **first messengers** and transmit the messages through a series of membrane proteins. Eventually this signaling activates a **second messenger,** which stimulates the cell to carry out a specific function.

Testing Your Knowledge

1. Why are some substances able to cross a cell membrane easily, and some not?
2. What types of chemicals comprise cell membranes?
3. Explain the differences among diffusion, facilitated diffusion, active transport, and endocytosis.
4. List five functions of the cytoskeleton.
5. List two functions of
   a. microtubules
   b. microfilaments
   c. intermediate filaments

Thinking Scientifically

1. How does each of the following processes illustrate the interaction of cell components?
   a. maintaining the integrity of the red blood cell membrane
   b. the ability of muscle cells to withstand the force of contraction
   c. signal transduction
   d. cell adhesion in leukocyte trafficking
2. Describe how dynein and dystrophin are vital for the functioning of certain cells, even though they are not very abundant.
3. Liver cells are packed with glucose. What mechanism could be used to transport more glucose into a liver cell? Why would only this mode of transport work?
4. A drop of a 5% salt (NaCl) solution is added to a leaf of the aquatic plant *Elodea.* When the leaf is viewed under a microscope, colorless regions appear at the edges of each cell as the cell membranes shrink from the cell walls. What is happening to these cells?
5. Would a substance that destroys the integrity of the blood-brain barrier be dangerous? Why or why not?

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This feature at the end of the chapter tests the student's recall of chapter material. The answers are found on the Online Learning Center.

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These critical thinking questions challenge the student to use concepts of the chapter to solve problems.

References and Resources

These suggested resources can be used for further study of topics covered in the chapter.

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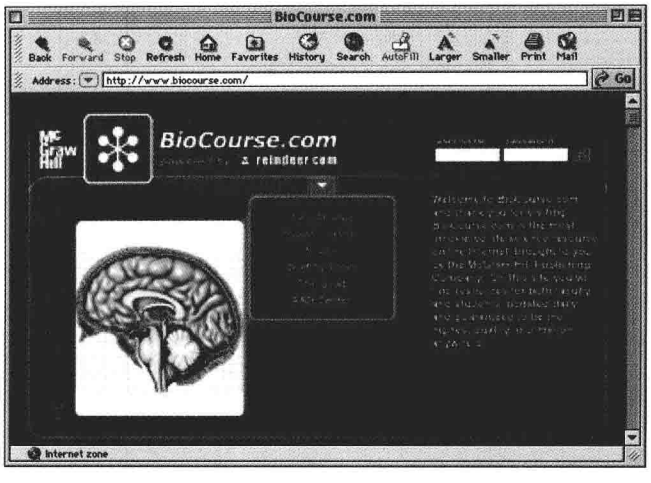

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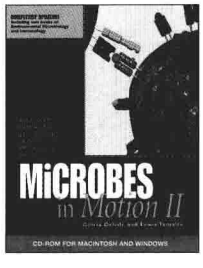

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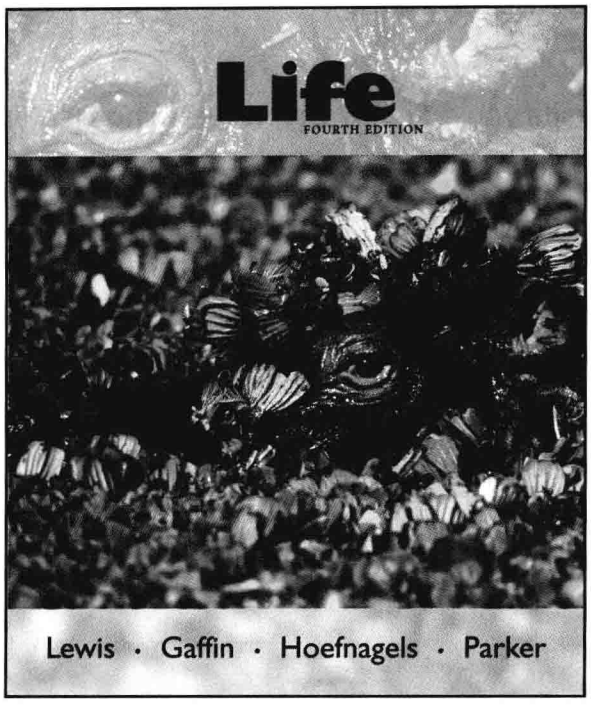

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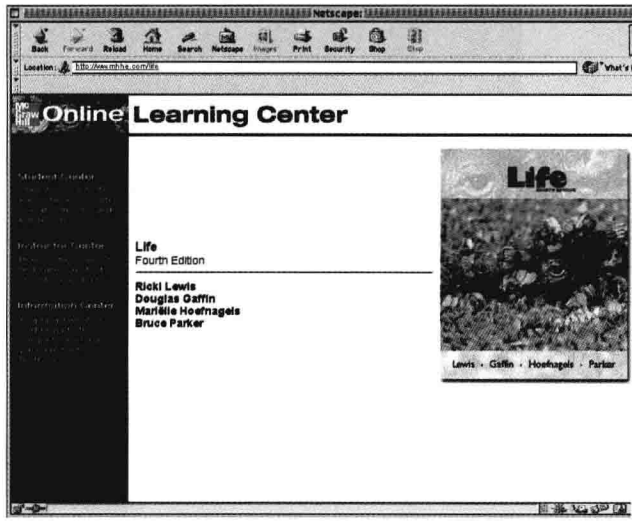

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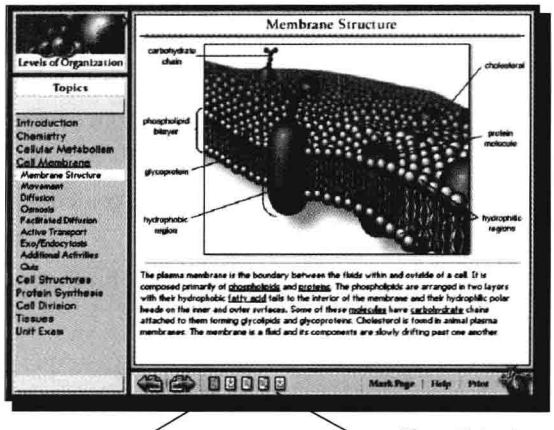

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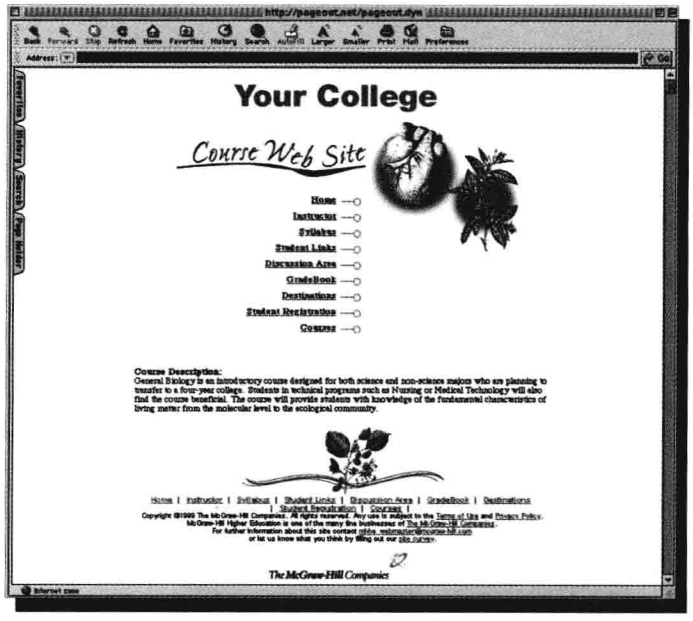

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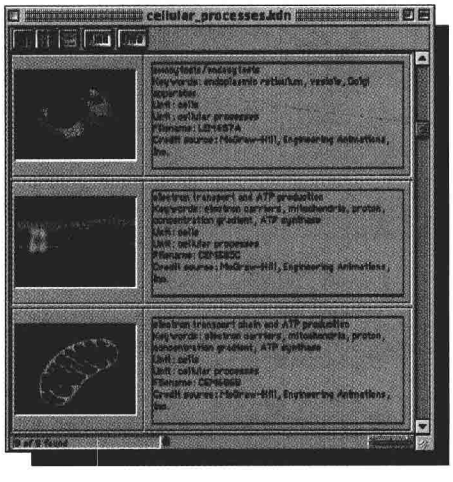
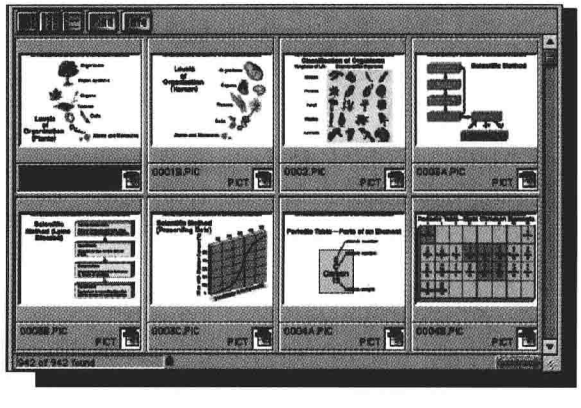


Life Science Animations Visual Resource Library CD-ROM

This instructor's tool, containing more than 125 animations of important biological concepts and processes—found in the *Essential Study Partner* and *Dynamic Human CD-ROMs*—is perfect to support your lecture. The animations contained in this library are not limited to subjects covered in the text, but include an expansion of general life science topics.

Visual Resource Library CD-ROM

This helpful CD-ROM contains ALL 1,500 photographs and illustrations from *Life*. You'll be able to create interesting multimedia presentations with the use of these images, and students will have the ability to easily access the same images in their texts to later review the content covered in class.



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