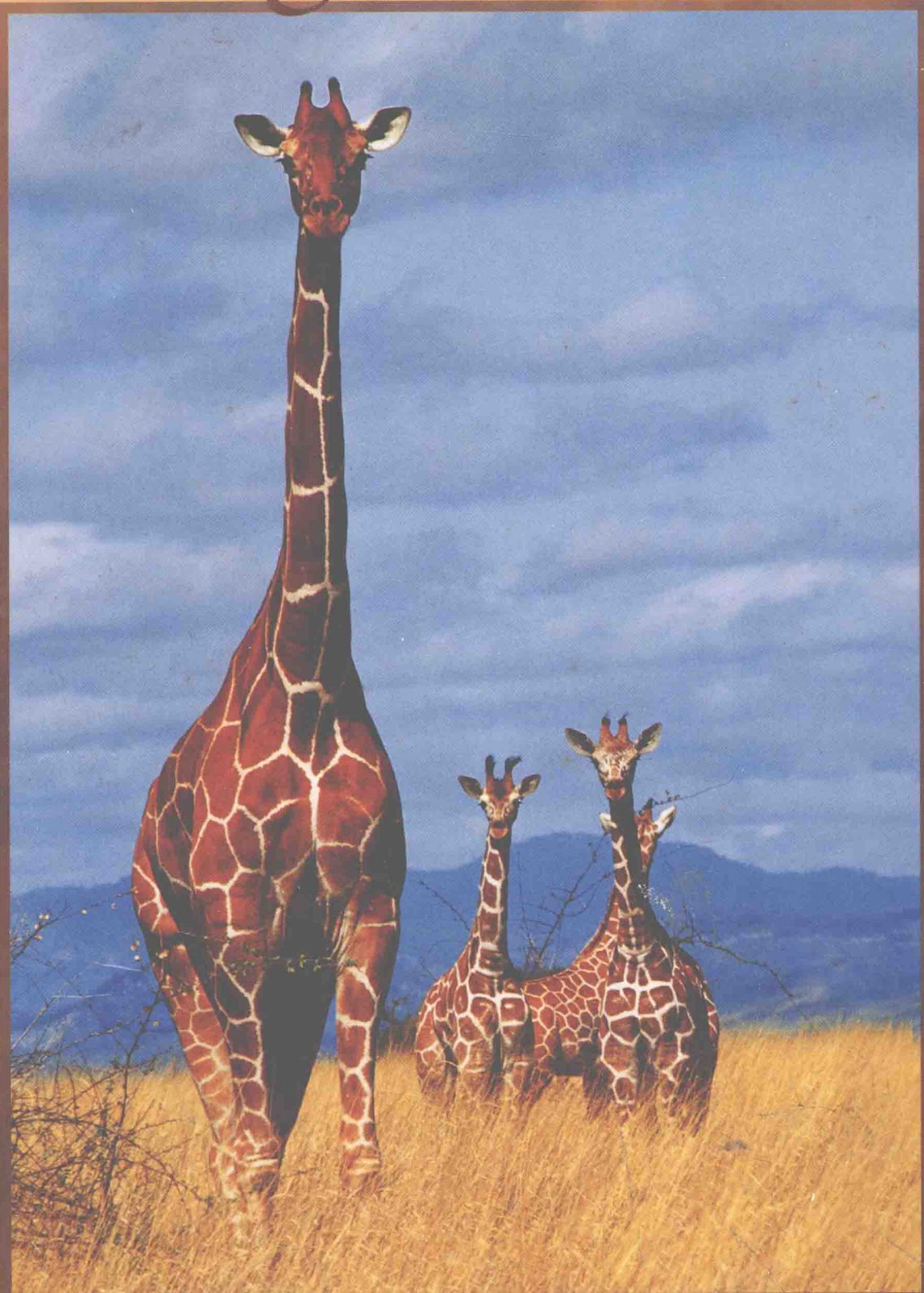


# Asking About Life



TOBIN & DUSHECK

# Asking About Life

江苏工业学院图书馆  
藏书章

**Allan J. Tobin**

*University of California,  
Los Angeles*

**Jennie Dusheck**

*Santa Cruz, California*



Saunders College Publishing  
Harcourt Brace College Publishers

Fort Worth Philadelphia San Diego New York Orlando Austin  
San Antonio Toronto Montreal London Sydney Tokyo



Copyright © 1998 by Saunders College Publishing

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the publisher.

Requests for permission to make copies of any part of the work should be mailed to: Permissions Department, Harcourt Brace & Company, 6277 Sea Harbor Drive, Orlando, Florida 32887-6777.

Publisher: Emily Barrosse  
Executive Editor: Edith Beard Brady  
Product Manager: Erik Fahlgren  
Developmental Editor: Lee Marcott  
Project Editor: Elizabeth Ahrens  
Production Manager: Charlene Catlett Squibb  
Art Director: Caroline McGowan  
Text and Cover Designer: Ruth A. Hoover  
Art Development: Elizabeth Morales

#### ABOUT THE COVER

Like humans, many animals are curious about the world around them. These giraffes are obviously intrigued by the activities of the photographer and seem to be studying the reader. Three hang back hesitantly, but the fourth has moved forward, fearless and determined to find out what's up. That attitude typifies the best science and exemplifies the questioning theme of *Asking About Life*.

The giraffes also remind us of Lamarck's theory of evolution and how human is the scientific enterprise. Like many modern scientists, Lamarck suffered humiliating rejection by his peers. Charles Darwin's efforts to avoid a similar fate inspired him to build an irrefutable and monolithic theory of evolution that modern biologists accept nearly as Darwin wrote it. (Mitch Reardon/Tony Stone Images)

Frontispiece Credit: Yoshio Otsuka/Photonica

Chapter 3 Opener: *The LEGO® Brick is a Trademark of the LEGO Group. © Models protected by Copyright owned by the LEGO Group. Both used here with special permission.*

Chapter 14 Opener: *David Hanover/Tony Stone Images (woman); Douglas Struthers/Tony Stone Images (DNA). Concept and design by Mycoff Advertising Inc. for New England Biolabs Inc. Used with permission.*

Chapter 22 Opener: © 1997 *The Georgia O'Keeffe Foundation/Artists Rights Society (ARS), New York. Photo courtesy Colorado Springs Fine Arts.*

Printed in the United States of America

ASKING ABOUT LIFE

0-03-072046-X

Library of Congress Catalog Card Number: 97-68078

90123456 032 10 9876543

Saunders College Publishing may provide complementary instructional aids and supplements or supplement packages to those adopters qualified under our adoption policy. Please contact your sales representative for more information. If as an adopter or potential user you receive supplements you do not need, please return them to your sales representative or send them to

Attn: Returns Department  
Troy Warehouse  
465 South Lincoln Drive  
Troy, MO 63379

---

FOR GEORGE DUSHECK AND EVE TOBIN  
AND IN LOVING MEMORY OF NINA DUSHECK AND MAURICE TOBIN





# P R E F A C E

When Charles Darwin published *The Origin of Species* in 1859, the first edition sold out overnight. His revolutionary theory of evolution was of interest not only to his fellow scientists, but to great numbers of ordinary people, who avidly read *The Origin* and argued over the details of the theory.

Today, public interest in biology is even greater. When a previously unknown Scottish biologist cloned the first mammal, a sheep, in February of 1997, the story made front-page headlines all over the world and sharply increased the value of biotechnology stocks overnight.

Biology is a discipline in full flower. Biologists now have the capacity to understand the workings and the interactions of organisms and—at the cellular level—to alter them, almost at will. Biologists have bred new crops, discovered the frailties and strengths of precious ecosystems, developed new treatments for diseases, and begun to solve many puzzles of the human mind.

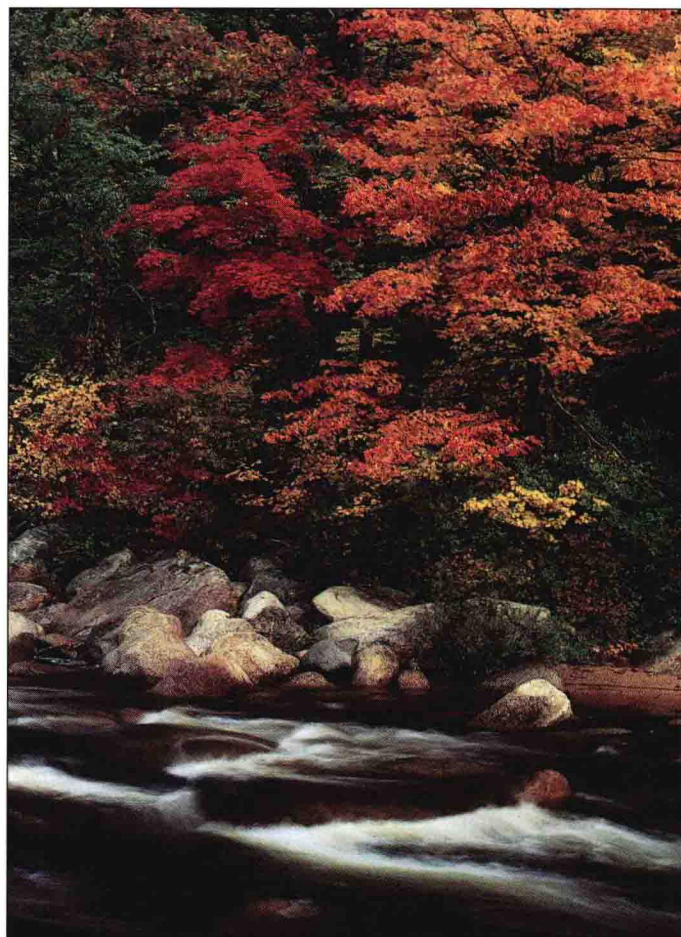
Spectacular as these developments are, they are a mixed blessing for instructors and their students. The sheer numbers of facts can be overwhelming. How, for example, can we remember the difference between a missense mutation and a nonsense mutation? Between a plasmodial slime mold and a cellular slime mold? And why should we care?

Yet, to make the simplest decisions in the 21st century, you will need to understand how science works and, at least, the basics of biology. If you are sick, should you take an antibiotic? If one of your parents has a genetic disease, should you be tested for the disease-causing allele? If the vacant lot down the road is to be turned into a playing field, should the creek that runs through it be preserved? Is there any harm in running the creek through an underground, concrete culvert? The answers to all of these questions and hundreds of others depend on the ability to understand and evaluate scientific arguments.

The greatest barrier to understanding science is the common perception that science is inaccessible to ordinary folks. We know that it is accessible. It's about asking questions, getting a partial answer, then asking another question.

## What Is *Asking About Life* About?

*Asking About Life* is about curiosity. Our very title stresses our conviction that questions are what drive the process of science. The history of science reveals that while the answers to ques-



Stephen J. Krasemann/Photo Researchers

tions change over time, the questions themselves, if they are good ones, remain the same. One good question has been “How do new species form?” Biologists have been trying to answer this question for 150 years. But it is a question with many answers. And the answers that seemed correct in 1880 or 1960 continue to be refined, expanded, or even overthrown.

*Asking About Life* consistently emphasizes the importance of questions and the process of finding answers. To remind ourselves and our readers of this, headings and subheadings are more often questions than statements.

The task of student and scientist alike is to ask questions as insistently as possible and to answer them as cleverly as possible. While we understand that the “facts” of biology are important, science progresses only by discovering new relationships of facts to questions: the difference between a nonsense mutation and a missense mutation takes on pressing significance if a relative has a disease caused by a genetic mutation. Suddenly, we find it much easier to remember why a missense mutation often does no harm, while a nonsense mutation nearly always does harm. Just hearing a story about someone with a genetic disease would help us remember why this distinction is important. In learning, story and context (whether emotional or historical) are everything.

Throughout our book, we have emphasized the story behind scientific discoveries. *Asking About Life* illustrates the passion of the scientific enterprise by beginning each chapter with a story about a piece of research. Each story illustrates how an individual biologist pursued a scientific question, often in the face of intellectual or social adversity—how, for example, Barry Marshall convinced first himself and then others that bacteria, not stress, cause ulcers; and how Rosalind Franklin struggled in deep social isolation to elucidate the structure of DNA. Our anecdotes are about real people—their triumphs, their frustrations, their genius, and their persistence.

The story of how biologists came to ask a question and how they went about answering that question helps us remember not just one fact, but all the facts and ideas associated with that question. All the stories illustrate that science is both an intellectual endeavor and a social one. Scientists must not only ask and answer questions, they must also persuade their colleagues that their answers are correct and interesting. The most successful scientists are often the most sociable ones—though not always.

We have tried to make our stories lively and engaging. Asking and answering questions about life is a job for the most lively and engaged of humans. Biology is not a mysterious activity performed by those who are remote, calculating, or cold. It is an exquisitely human endeavor in which enthusiastic beginning students can participate as fully as veteran scientists. In fact, the fresh view of the engaged beginner sometimes unlocks puzzles that have stumped seasoned scientists for years, as illustrated in the story about Walter Sutton in Chapter 9.

The flowering of biology in the late 20th century has already produced new seeds for the 21st. It is our hope that student readers of *Asking About Life* will be able to nurture and appreciate the growth of new ideas that we feel will dominate the intellectual and economic landscape of the next generation.

## What Is the Philosophy Behind *Asking About Life*?

In some respects, the philosophy of our text runs counter to current trends in textbook construction. Many textbooks now break information up into self-contained units. Each bit of in-

formation is presented as if unrelated to the information in the rest of the book. Much information is tucked into separate illustrations, with no text to weave disparate facts together. The rationale for this is that today's students belong to the “visual-information” generation and are incapable of sustained reading.

We have more faith in students. We know they can read, and even enjoy reading, provided the reading is interesting and rewarding. Our philosophy is that biology is a story, and, as such, it must be presented as continuously as possible. Each section of the book includes background information, usually historical, that provides a context for current research.

For example, in the introductory chapter to the section on Diversity, where we discuss different systems of classification, we show students that biologists have been arguing about the definition of a species for nearly 200 years. In the previous section, we have emphasized Darwin's frustration in defining species of barnacles when he could see that many species blended one into the next. In that context, the opening story in the Diversity section about the current and highly politicized debate over whether the red wolf is a species or a hybrid makes sense. At the same time, the red wolf story brings to life what would otherwise be an abstract discussion of classification.

In this context of questions and process, we naturally emphasize the experimental nature of science. Relying on headings that are phrased as questions, we lead students from one critical experiment to the next. Students learn not only the results of experiments, but why biologists asked certain questions and how they discovered the answers. In Chapter 10, for example, we do not content ourselves with describing the structure of DNA, but lay out for the student all the clues that Rosalind Franklin, James Watson, and Francis Crick used to deduce DNA's structure. The reader thus experiences anew the excitement of the original discovery.

Throughout the book we emphasize current research wherever appropriate. As a result, instructors have the opportunity to discuss with their students topics appearing in the daily news. The chapter on human genetics, for example, focuses heavily on current debates about policy and ethics in the application of genetic techniques to human disease and reproduction.

Naturally, we also try to minimize abstract discussions through the use of metaphors and analogies. For example, in our discussion of the movements of chromosomes during mitosis and meiosis, we compare the pairs of chromosomes to pairs of socks going through the laundry. In our discussion of osmosis, we compare the swelling of cells in a hypotonic solution to the swelling of raisins in a pot of water. And in Chapter 3, we compare functional groups—the small chemical groups that give molecules their characteristic chemistries—to the different parts of a Swiss Army knife.

More than in other texts, the art program in *Asking About Life* makes such metaphors visual—leaving the student with memorable and often amusing images. Vivid illustrations help fix otherwise abstract ideas in our minds in the same way a



mordant fixes a dye. For example, many books compare the structure of tRNA to a clover leaf. Only *Asking About Life* actually shows the clover leaf—complete with stem and leaflets—folded into the classic “L” shape. In the same chapter, Chapter 11, the ribosome is depicted as a sewing machine that stitches together amino acids to form polypeptides.

In Chapter 34, a drawing of a mouse with an 8-inch fur coat helps students remember that the metabolic rates of small animals must be much higher than those of large ones. Whenever possible, we have used visual metaphors and other striking images that act as icons for ideas.

Each chapter begins with an image, either a photograph or drawing, that was chosen to complement the opening story or to sum up a theme of the chapter. These are not captioned and are intended to be brain-teasers for the reader, who may find it fun and interesting to guess the connection being made.

For instance, the opening image for Chapter 1—the dinosaur in the egg—represents evolution and the continuity of life. The dinosaur, not unlike a modern barnyard chick, illustrates how life continues from generation to generation. Life changes and yet stays the same.

In Chapter 3, the thousands of Lego™ pieces in the Legoland elephant symbolize the building blocks of life. Similarly, just a few molecules combine to make the large molecules that make up all organisms.

In Chapter 5, the rusting car symbolizes entropy, the concept that ordered systems and structures tend to become disordered over time.

The chapter-opening images for all 44 chapters are identified and their significance is explained in the Teaching Suggestions section of each chapter in the *Instructor's Manual*.

We regard illustration as a teaching tool in its own right, not just a backup for the text. In this, we have been privileged to work closely with two outstanding illustrators—Elizabeth Morales and Elizabeth McClelland—whose skill, attention, and insight have contributed not only to the art manuscript but to the text as well. Morales, the book's art developmental editor, created a friendly style that perfectly complements our informal text. Her clean designs and simple illustrations greatly clarify sometimes difficult material. In addition, Elizabeth McClelland contributed dozens of beautifully rendered illustrations of animals and plants, as well as many excellent diagrams throughout the book.

## What Kinds of Pedagogy Does *Asking About Life* Employ?

*Asking About Life* has a variety of features designed to engage the reader and to aid student learning:

Each chapter begins with a story about a piece of research that draws students into the subject of the chapter and also introduces the key questions and ideas that are discussed.

Within or after each chapter story, readers will find a list of **Key Concepts**, which are some of the most important and basic ideas covered in the chapter.

Headings are often posed in the form of questions throughout each chapter. These question headings focus the reader's attention on the most significant question to be explored in that section.

Subsections are followed by **Summary Statements**—brief summaries of the take-home message. These provide students with a reality check. If the student doesn't understand the summary statement, that is a cue to study the preceding material more closely.

Drawings and photographs support concepts covered in the text and help students visualize the structures of objects as diverse as molecules and ecological communities. Photographs of structures that are too small to be seen with the naked eye are accompanied by size bars to give a sense of scale.

Figure legends are designed to stand alone, so that even a student flipping through the chapter for the first time, glancing at the diagrams and reading the captions, will come away with some important information.

Visual metaphors in the illustrations drive home key points introduced in the text.

**Boldface terms** throughout the text help students to locate key terms and their definitions.

**Tables and graphs** summarize key facts and additional material.

Most chapters feature one or more **Boxes**, which discuss some topics in greater depth or bring into sharper focus a piece of especially important research. In Chapter 12, which focuses on viruses and jumping genes, a box discusses current interest in the old idea of using bacteriophages as a therapeutic treatment for bacterial infections in humans. Chapter 26, on ecological succession, features a box on forensic ecology—the technique by which coroners determine when a person died by using the stages of development of different insect larvae found on a corpse.

The end of each chapter features a **Study Outline with Key Terms**. All of the boldface terms found in the chapter are used again in a highly compressed summary. This provides students with another opportunity to check their understanding of the chapter. If they encounter terms they don't remember or ideas that seem unfamiliar, they can return to the main text and illustrations.

The Study Outline is followed by a set of **Review and Thought Questions**. Our Thought Questions are especially engaging, frequently bringing ideas in the chapter into the everyday world.

**Selected Readings** emphasize readings in science that are accessible to a general audience and available in any good library. The majority of the readings are books, most of which the authors of *Asking About Life* have themselves enjoyed. The readings are intended as thought-provoking pleasure reading, not as grist for term papers. Class papers can always be researched in the conventional way—at the library, or increasingly, online.

An appendix on standard weights and measures is provided for student reference (Appendix B).

A **Glossary** provides a complete list of Key Terms and their definitions.



## Supplements

To further facilitate learning and teaching, a supplements package has been carefully designed for the student and instructor.

The **Study Guide** by Lori Garrett of Danville Area Community College includes Chapter Objectives that restate the Key Concepts of the text as material to be mastered, Key Concepts, an Extended Chapter Outline that gives an overview of the most important topics covered in the chapter, Vocabulary Building exercises, and Chapter Tests. Each Chapter Test has five parts: Multiple Choice; True/False; Matching; Short Answer; and Essay/Thought Questions. All answers are provided, with the exception of the Essay/Thought Questions.

The **Instructor's Manual** by Michael Ulrich of Elon College includes an introductory section of classroom teaching suggestions, research paper grading criteria, and evaluation procedures. Each chapter has Lecture Outlines; all the answers to the Review and Thought Questions from the text; and Teaching Suggestions, which include how to use the opening stories to motivate student interest and the significance of the chapter-opening images.

The **Test Bank** by Frederick Peabody of University of South Dakota comprises 2000 questions of assorted type (multiple choice, fill-in-the-blank, and short-answer essay questions) that are organized by the main chapter headings as well as keyed to the Key Concepts as they appear at the start of chapters. The **Computerized Test Bank** is available for Windows™ and Macintosh platforms.

Other important components of the supplements package for *Asking About Life* include a set of 200 **Overhead Transparencies** based on the drawings from the book and **Bio-Art**, which is a set of 100 black-and-white unlabeled line drawings from the text.

**Thinking Toward Solutions: Problem-Based Learning Activities in General Biology** by Deborah Allen and Barbara Duch, of the University of Delaware, presents complex, open-ended problems for introductory biology covering all aspects of the discipline from cells to the environment. Problems address real-world applications of biology to questions of ethics, economy, and daily living. Problems foster critical thinking, cooperative learning, and problem-solving skills. A detailed Instructor's Manual provides practical suggestions on how to use the problems in any size course and in a variety of teaching styles. *Thinking Toward Solutions* also has an Internet component, which provides links to resources to aid students in solving each problem.

The **Process of Science: Discovering Biology™** CD-ROM has been developed to reflect the spirit of inquiry that characterizes *Asking About Life*. It allows students to explore the discoveries of some of the most important concepts in biology. In the *Interactive Investigations*, students retrace the steps of scientists' experiments and discoveries using the scientific process as their road map. An *Investigator's Notepad* allows the students to track their progress through each investigation, to pose new questions for themselves to pursue, or to initiate a discussion with the instructor or other students via an Internet connec-

tion. *Concept Tutorials* provide students with essential background information in general biology for the course and the investigations. The CD will be available for use with classes in the fall of 1998; a demonstration disk on the topic of transmission genetics will be available to preview in January 1998.

The **Biology Survival Kit CD-ROM** is available for both IBM and Macintosh formats. The Biology Survival Kit includes **BioXL+™** and **Biology A<sub>2</sub>Z™ The Dynamic Glossary**. The BioXL+™ CD-ROM program presents a series of interactive animations that illustrate essential biological concepts. These simulations ensure a better retention of important concepts because students are actively engaged in a visual and dynamic way. BioXL+™ focuses on the basics, while guiding students through the concepts and providing real-world applications. Biology A<sub>2</sub>Z™ The Dynamic Glossary CD-ROM provides text definitions, audio pronunciations, graphics, and animations for approximately 800 key terms traditionally presented in introductory biology courses. In addition to the definitions and audio, terms are supported by the text explanations, figures, and animations that put the key term in a conceptual context. Students will access the audio glossary from an extensive table of contents organized by concepts.

**Biology MediaActive, Version III (Version III 1998).** The CD-ROM Biology Media Bank contains imagery from Tobin/Dusheck: *Asking About Life*, Goodenough/Wallace/McGuire: *Human Biology*, Karleskint: *Marine Biology*, and Raven/Berg/Johnson: *Environment*, Second Edition. This CD-ROM is available as a presentation tool to be used in conjunction with commercial presentation packages, such as PowerPoint™ and Persuasion™, and will be available on the Biology MediaActive CD-ROM. Available for both Windows and Macintosh platforms.

Please visit our *Asking About Life Website* at

<http://www.saunderscollege.com/lifesci/>

Click on Tobin/Dusheck: *Asking About Life*. It offers an on-line study section for students and a continually updated resource for instructor materials.

## A Textbook Is Born

Our developmental editor, Lee Marcott, has been a true midwife to this book, and both authors are extremely grateful to her. In addition to editing the manuscript and choosing excellent reviewers, artists, and photo researcher, Lee has also tactfully managed the two authors—pushing us to meet deadlines, calming us down when we panicked, organizing us, and giving us pep talks.

We also thank photo researcher Amy Ellis Dunleavy, who consistently found just the right photo, or had it shot, and project editor Beth Ahrens, who managed the endless details during the production of this first-edition book. We deeply appreciate, as well, the work of all the other people at Saunders College Publishing who made this book happen—including Donald Jackson, Michael Brown, and Edward Murphy, who

nursed the manuscript in its infancy; and Elizabeth Widdicombe, Julie Levin Alexander, Edith Beard Brady, and Emily Barrosse, who supported and nurtured this project as it developed.

We are also grateful to the art and production people at Saunders College Publishing: Beth Ahrens, of course, and Carol Bleistine, Joanne Cassetti, Ruth Hoover, Sue Kinney, Sally Kusch, Caroline McGowan, and Charlene Squibb, to name only some of the dozens of people who helped to shepherd this book into being. We thank Erik Fahlgren for his enthusiastic support of the book and his creative marketing strategy. We also thank our copy editors, Toni Wrighton and Sue Nelson; proofreader, Beth Morel; layout artists, Claudia Durrell and Julie Anderson; and indexer, Kathi Unger. We thank Don Lovett for calculating the scale bars found throughout the book and for fact checking many of our captions. Special thanks also to Leslie Sweeney, Jonathan Knight, Mari Jensen, Nili Kirschner, Don Ellis, Lydia Okelberry, and Chelsea Forbes.

We thank all the reviewers who took the time to read and comment on this manuscript—correcting our errors, asking thought-provoking questions, and suggesting examples, alter-

native wordings, or new ways of thinking. Although we never met any of our reviewers in person, working with them has been a rewarding intellectual experience. Both the process of writing this book and the resulting book itself would not have been the same without the reviewers.

Finally, we thank the following individuals, who took the time to talk to us or to answer our letters: Seymour Benzer, of Caltech; Harry Greene, of UC Berkeley; Ross Koning, of Eastern Connecticut State University; Gail Martin, of UC San Francisco; James Patton, of UC Berkeley; Peter Radetsky, of UC Santa Cruz; Gunther Stent, of UC Berkeley; and Robert Wayne, of UCLA.

We dedicate this book to our mentors in the art of communicating: Janet Hadda, David Tobin, Adam Tobin, and Eve Tobin; and to our mentors in the art of communicating science: Nina Dusheck, George Dusheck, John Dobson, and John Wilkes.

Allan J. Tobin  
Jennie Dusheck  
November 1997

## REVIEWERS

Juan Aninao, *Dominican College of San Rafael*  
Edwin A. Arnfield, *Macomb Community College*  
Linda W. Barham, *Meridian Community College*  
George W. Barlow, *University of California, Berkeley*  
Brenda Blackwelder, *Central Piedmont Community College*  
Mildred Brammer, *Ithaca College*  
Richard B. Brugam, *Southern Illinois University, Edwardsville*  
William Bowen, *Jacksonville State University*  
Bradford Boyer, *Suffolk County Community College*  
Hara Dracon Charlier, *Miami University*  
H. Tak Cheung, *Illinois State University*  
Karen Crombie, *Fresno City College*  
Donald Cronkite, *Hope College*  
Tom Daniel, *University of Washington*  
Darleen A. DeMason, *University of California, Riverside*  
Leah Devlin, *Pennsylvania State University, Abington College*  
Ernest F. DuBrul, *University of Toledo*  
Peter Ducey, *State University of New York at Cortland*  
Steven H. Everhart, *Campbell University*  
Lynn Fancher, *College of DuPage*  
Cynthia Fitch, *Seattle Pacific University*  
Dietrich Foerstel, *Champlain Regional College & Bishop's University*  
Sally Frost-Mason, *University of Kansas*  
Jack Gallagher, *William Rainey Harper College*  
Lori K. Garrett, *Danville Area Community College*  
Ben R. Golden, *Kennesaw State College*  
Glenn A. Gorelick, *Citrus College*  
Nels H. Granholm, *South Dakota State University*  
Herbert H. Grossman, *The Pennsylvania State University*

Lonnie J. Guralnick, *Western Oregon State College*  
Ross Hamilton, *Okaloosa-Walton Community College*  
Richard Harrison, *Cornell University*  
Wiley Henderson, *Alabama A&M University*  
Bob Highley, *Bergen Community College*  
Kathleen L. Hornberger, *Widener University*  
Linda Hsu, *Seton Hall University*  
David Inouye, *University of Maryland*  
William A. Jensen, *The Ohio State University*  
J. Morris Johnson, *West Oregon State University*  
Peter Kareiva, *University of Washington*  
James Karr, *University of Washington*  
Tanseem Khaleel, *Montana State University, Billings*  
Robert Kitchin, *University of Wyoming*  
Ross Koning, *Eastern Connecticut State University*  
Dan Krane, *Wright State College*  
James W. Langdon, *University of South Alabama*  
Anton Lawson, *Arizona State College*  
Charles Leavell, *Fullerton Community College*  
Kathleen Lively, *Marquette University*  
Melanie Loo, *California State University, Sacramento*  
Linda A. Malmgren, *Franklin Pierce College*  
Nilo Marin, *Broward Community College*  
Theresa Martin, *College of San Mateo*  
Dorrie Matthews, *Sage Jr. College of Albany*  
Gary F. McCracken, *University of Tennessee, Knoxville*  
Robert J. McDonough, *DeKalb College*  
Joseph McGrellis, *Atlantic Community College*  
John Mertz, *Delaware Valley College*  
Debbie Meuler, *Cardinal Stritch College*



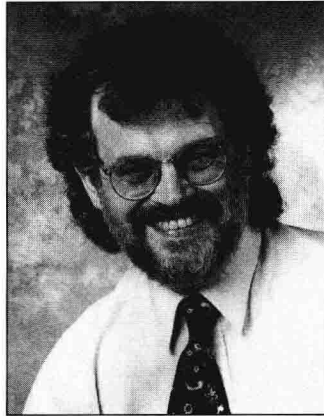
Robert Morris, *Widener University*  
 Alison M. Mostrom, *Philadelphia College of Pharmacy and Science*  
 David M. Ogilvie, *The University of Western Ontario*  
 Bruce Parker, *Utah Valley State College*  
 Lee R. Parker, *California Polytechnic State University, San Luis Obispo*  
 Frederick Peabody, *University of South Dakota*  
 Ed Perry, *Faulkner State Community College*  
 Gary Pettibone, *State College of New York at Buffalo*  
 Jay Pitocchelli, *St. Anselm College*  
 David M. Polcyn, *California State University, San Bernadino*  
 Shirley Porteous-Gafford, *Fresno City College*  
 Paul F. Ramp, *University of Tennessee, Knoxville*  
 Franklin Robinson, *Mountain Empire Community College*  
 Lyndell Robinson, *Lincoln Land Community College*  
 Earle Rowe, *Walters State Community College*  
 Donna Rowell, *Holmes Community College*  
 Andrew Scala, *Dutchess Community College*

Shirley Seagle, *Jacksonville State University*  
 Phillip R. Shelp, *Brookhaven College*  
 John Simpson, *Gadsden State College*  
 Linda Simpson, *University of North Carolina, Charlotte*  
 Michael E. Smith, *Valdosta State University*  
 Fred L. Spangler, *University of Wisconsin, Oshkosh*  
 Steven Spilatro, *Marietta College*  
 Herbert Stewart, *Florida Atlantic University*  
 Cindy Stokes, *Kennesaw State College*  
 Jeffrey Thompson, *California State University, San Bernadino*  
 Janice Toyoshima, *Bakersfield College*  
 John Tramontano, *Orange County Community College*  
 Michael J. Ulrich, *Elon College*  
 Kristin Vessay, *Bowling Green University*  
 James A. Winsor, *The Pennsylvania State University, Altoona Campus*  
 Daniel Wivagg, *Baylor University*  
 Tom Worcester, *Mt. Hood Community College*

# ABOUT THE AUTHORS

## Allan J. Tobin

is Director of the UCLA Brain Research Institute. He holds the Eleanor Leslie Chair in Neuroscience at UCLA, where he is both Professor of Neurology and Professor of Physiological Science. Tobin is also Scientific Director of the Hereditary Disease Foundation (HDF), where he helped organize the consortium that identified the gene responsible for Huntington's disease. Both at UCLA and at HDF, he has encouraged the application of cell biology and molecular genetics to disorders of the brain.



Tobin's undergraduate degree is in literature and biology (MIT, 1963), and his doctoral degree is in biophysics, with an emphasis on physical biochemistry (Harvard, 1969). Tobin did postdoctoral work at the Weizmann Institute of Science, in Israel, and at MIT. At UCLA, his active research laboratory studies the production and action of GABA, the major inhibitory signal in the brain. These studies may eventually lead to new therapeutic approaches to epilepsy, Huntington's disease, and juvenile diabetes. Tobin is the recipient of a Jacob Javits Neuroscience Investigator Award from the National Institute of Neurological Disorders and Stroke.

For more than 25 years, Tobin has taught introductory courses in cell biology, molecular biology, developmental biology, and neuroscience. He is the recipient of a Faculty Teaching and Service Award and is regarded as an excellent and highly interactive teacher.

## Jennie Dusheck

is a writer living in Santa Cruz, California, and a member of the National Association of Science Writers. Her undergraduate degree is in zoology (University of California, Berkeley, 1978) and her master's degree (by thesis) is in zoology (UC Davis, 1983). She also holds a certificate in science writing from UC Santa Cruz (1985).



Dusheck has done field and laboratory research on bird song; social behavior in field mice; food preferences of deer, cattle, and skipper butterflies (the subject of her thesis research at UC Davis); as well as axis formation in *Xenopus laevis*. While working for the Department of Molecular Biology at UC Berkeley, under a contract with NASA, she designed and wrote a protocol for an experiment that sent live frog embryos into space on the Fall 1992 Space Shuttle flight. She has taught university lab classes in introductory zoology, embryology, and comparative anatomy.

Dusheck has written for *Science News*, *Science* magazine, and other publications. From 1985 to 1993, she worked as a Principal Editor at the University of California, Santa Cruz. She has received several national awards, including the Gold Medal for Best-in-Category from the National Council for the Advancement and Support of Education.



# CONTENTS OVERVIEW

- 1 The Unity and Diversity of Life 1

## I Chemistry and Cell Biology 23

- 2 The Chemical Foundations of Life 24
- 3 Biological Molecules Small and Large 50
- 4 Why Are All Organisms Made of Cells? 80
- 5 Directions and Rates of Biochemical Processes 114
- 6 How Do Organisms Supply Themselves with Energy? 132
- 7 Photosynthesis: How Do Organisms Get Energy from the Sun? 156

## II Genetics: The Continuity of Life 179

- 8 Cell Reproduction 180
- 9 From Meiosis to Mendel 202
- 10 The Structure, Replication, and Repair of DNA 234
- 11 How Are Genes Expressed? 264
- 12 Jumping Genes and Other Unconventional Genetic Systems 290
- 13 Genetic Engineering and Recombinant DNA 308
- 14 Human Genetics 330

## III Evolution 355

- 15 What Is the Evidence for Evolution? 356
- 16 Microevolution: How Does a Population Evolve? 386
- 17 Macroevolution: How Do Species Evolve? 410
- 18 How Did the First Organisms Evolve? 446

## IV Diversity 465

- 19 Classification: What's in a Name? 466
- 20 Prokaryotes: How Does the Other Half Live? 482
- 21 Classifying the Protists and Multicellular Fungi 498
- 22 How Did Plants Adapt to Dry Land? 522
- 23 Protostome Animals: Most Animals Form Mouth First 540
- 24 Deuterostome Animals: Echinoderms and Chordates 568

## V Ecology 589

- 25 Ecosystems 590
- 26 Communities: How Do Species Interact? 608
- 27 Biomes and Aquatic Communities 624
- 28 Populations and the Human Place in the Biosphere 644
- 29 The Ecology of Animal Behavior 664

## VI Structural and Physiological Adaptations of Flowering Plants 683

- 30 Structural and Chemical Adaptations of Plants 684
- 31 What Drives Water Up and Sugars Down? 702
- 32 Growth and Development of Flowering Plants 718
- 33 How Do Plant Hormones Regulate Growth and Development? 736

## VII Structural and Physiological Adaptations of Animals 751

- 34 Form and Function in Animals 752
- 35 How Do Animals Obtain Nourishment from Food? 770
- 36 How Do Animals Coordinate Cells and Organs? 790
- 37 Blood, Circulation, and the Heart 804
- 38 How Do Animals Obtain and Distribute Oxygen? 822
- 39 How Do Animals Manage Water, Salts, and Wastes? 842
- 40 Defense: Inflammation and Immunity 860
- 41 The Cells of the Nervous System 878
- 42 The Nervous System and the Sense Organs 896
- 43 Sexual Reproduction 918
- 44 How Do Organisms Become Complex? 940

# CONTENTS

---

## 1 THE UNITY AND DIVERSITY OF LIFE 1

### *Bacteria: Enough To Give You an Ulcer* 1

#### HOW DO BIOLOGISTS ASK QUESTIONS? 3

Do Scientists Use the Scientific Method? 3

#### BOX 1-1 Reductionism 6

What Is a Theory? 9

Biologists Ask Many Different Kinds of Questions 9

#### WHAT DO WE KNOW ABOUT LIFE? 9

How Are Organisms Different from One Another? 9

#### BOX 1-2 Homeostasis and negative feedback 11

How Are Organisms Alike? 12

How Can We Tell If Something Is Alive? 12

How Do Organisms Become Different from One Another? 17

Study Outline with Key Terms 21

Review and Thought Questions 21

Selected Readings 22

---

## I Chemistry and Cell Biology 23

---

### 2 THE CHEMICAL FOUNDATIONS OF LIFE 24

#### *Alchemy and Chemistry* 24

#### WHAT IS MATTER? 26

What Is Chemistry? 28

#### WHAT DETERMINES THE PROPERTIES OF AN ATOM? 28

What Are Atoms Made Of? 28

What Is the Internal Structure of an Atom? 29

Where Are the Electrons in an Atom? 31

#### WHAT HOLDS MOLECULES TOGETHER? 33

Covalent and Ionic Bonds Are the Strong

Interactions Among Atoms 33

#### BOX 2-1 How are radioisotopes useful? 35

Weak Interactions Also Hold Atoms Together 38

#### HOW IS WATER ESPECIALLY WELL-SUITED FOR ITS ROLE IN LIFE? 39

Water Is Denser as a Liquid Than as a Solid 39

Water Absorbs More Heat Than Most Substances 41

Water Molecules Cling to One Another 41

Water Molecules Cling to Many Other Substances 41

Water Is a Powerful Solvent 43



Runk/Schoenberger from Grant Heilman

Water Participates in Many Biochemical Reactions 44

Water Molecules Continually Split into Hydrogen Ions and Hydroxide Ions 45

#### BOX 2-2 Life at low pH 47

Why Is pH Important to Organisms? 47

Buffers: How Do Organisms Resist Changes in pH? 48

Study Outline with Key Terms 48

Review and Thought Questions 49

Selected Readings 49

---

### 3 BIOLOGICAL MOLECULES SMALL AND LARGE 50

#### *Linus Pauling and the Alpha Helix* 50

#### HOW DO ORGANISMS USE BIOLOGICAL MOLECULES TO BUILD? 53

How Big Are Biological Molecules? 53

Why Are Biological Structures Made from So Few Building Blocks? 56

What Determines the Biological Properties of an Organic Molecule? 56

Cells Build Complex Molecules from Four Types of Building Blocks 59

#### SMALL BIOLOGICAL MOLECULES ARE THE BUILDING BLOCKS OF LIFE 59



Lipids Include a Variety of Nonpolar Compounds	59
<b>BOX 3-1 The biochemistry of cholesterol</b>	<b>60</b>
Most of the Fatty Acids in Organisms Are Chemically Combined with a Molecule Called Glycerol	62
Sugars Contain Many Hydroxyl Groups	64
A Nucleotide Has Three Parts, Each with Different Functional Groups	65
Amino Acids Contain Both Carboxyl and Amino Groups	67
<b>HOW DO SMALL MOLECULES LINK TOGETHER TO FORM MACROMOLECULES?</b>	<b>68</b>
What Holds Building Blocks Together in a Macromolecule?	68
How Are Sugars Held Together To Form Polysaccharides?	69
How Are Nucleotides Held Together To Form Nucleic Acids?	70
How Are Amino Acids Held Together To Form Proteins?	70
The Structure of a Polypeptide Determines Its Function	73
What Determines the Three-Dimensional Structure of a Protein?	73
<b>BOX 3-2 Molecules with similar shapes can mimic one another</b>	<b>74</b>
<b>BOX 3-3 Dorothy Crowfoot Hodgkin</b>	<b>77</b>
Study Outline with Key Terms	78
Review and Thought Questions	79
Selected Readings	79

## 4 WHY ARE ALL ORGANISMS MADE OF CELLS? 80

### *Very Little Animalcules* 80

#### **BOX 4-1 How do microscopes help biologists study cells?** 82

#### **WHY ARE ALL ORGANISMS MADE OF CELLS?** 84

All Organisms Are Made of Cells 84

Every Cell Consists of a Boundary, a Set of Genes, and a Cell Body 85

What Are the Advantages of Cellular Organization? 86

#### **BOX 4-2 *Caulerpa*, the world's largest single-celled organism?** 88

#### **WHAT'S IN A CELL?** 89

What Role Does the Nucleus Play in the Life of a Cell? 92

The Cytosol Is the Cytoplasm That Lies Outside the Organelles 93

The Endoplasmic Reticulum Is a Folded Membrane 93

The Golgi Complex Directs the Flow of Newly Made Proteins 94

The Lysosomes Function as Digestion Vats 95

The Peroxisomes Produce Peroxide and Metabolize Small Organic Molecules 96

The Mitochondria Capture the Energy from Small Organic Molecules in the Form of ATP 97

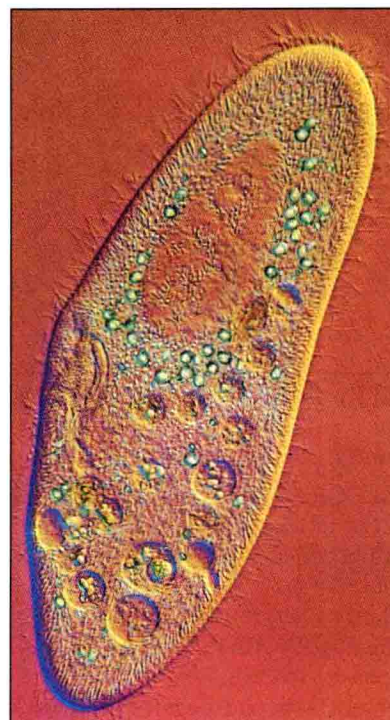
A Plant Cell's Chloroplast Is Just One Kind of Plastid 98

What Does the Cytoskeleton Do? 99

#### **BOX 4-3 The 9 + 2 structure of flagella** 101

#### **WHAT ENCLOSSES A CELL AND ITS COMPARTMENTS?** 101

What Kinds of Molecules Do Membranes Contain? 101



M.I. Walker/Photo Researchers

The Fluid Mosaic Model Summarizes Current Understanding of the Workings of Biological Membranes 103

#### **HOW DO MEMBRANES REGULATE THE SPACES THEY ENCLOSE?** 104

Why Does Water Move Across Membranes? 104

What Determines the Movement of Molecules Through a Selectively Permeable Membrane? 106

#### **HOW DO MEMBRANES INTERACT WITH THE EXTERNAL ENVIRONMENT?** 108

Membrane Fusion Allows the Uptake of Macromolecules and Particles 109

How Do Cells in Multicellular Organisms Communicate? 110

Study Outline with Key Terms 112

Review and Thought Questions 113

Selected Readings 113

## 5 DIRECTIONS AND RATES OF BIOCHEMICAL PROCESSES 114

### *Ludwig Boltzmann: A Man Left Behind or a Man Ahead of His Time?* 114

#### **WHAT DETERMINES WHICH WAY A REACTION PROCEEDS?** 116

How May Work Be Converted to Kinetic or Potential Energy? 117

How Does Thermodynamics Predict the Direction of a Reaction? 118

Free Energy Changes Predict the Direction of a Reaction 118

Where Does the Free Energy Released or Consumed During a Reaction Come From?	120
How Can One Process Provide the Energy for Another?	122
Disorder (Entropy) Always Increases in Spontaneous Processes	122
How Does the Concentration of a Substance Affect Its Free Energy?	122
<b>WHAT DETERMINES THE RATE OF A CHEMICAL REACTION?</b>	<b>124</b>
How Does Molecular Motion Help Explain Reaction Rates?	124
What Stops a Chemical Reaction?	124
What Starts a Chemical Reaction?	125
<b>HOW DO ENZYMES WORK?</b>	<b>126</b>
How Does an Enzyme Bind to a Reactant?	126
How Does an Enzyme Lower the Activation Energy of a Chemical Reaction?	126
How Do Environmental Conditions Affect the Rates of Enzymatic Reactions?	128
<b>HOW DOES A CELL OR ORGANISM REGULATE ITS OWN METABOLISM?</b>	<b>128</b>
Enzymatic Reactions Often Occur in Small Steps	128
What Inhibits an Enzyme?	129
How Does a Cell Regulate Enzyme Function?	129
Study Outline with Key Terms	130
Review and Thought Questions	130
Selected Readings	131

## 6 HOW DO ORGANISMS SUPPLY THEMSELVES WITH ENERGY? 132

### *Louis Pasteur and Vitalism* 132

#### HOW DO ORGANISMS SUPPLY THEMSELVES WITH ENERGY? 134

What Is the Common Currency of Energy for Organisms?	134
How Do Heterotrophs Extract Energy from Macromolecules?	135
What Are the Four Stages of Cellular Respiration?	135
<b>ELECTRON TRANSPORT: HOW DOES THE ENERGY IN GLUCOSE REACH ATP?</b>	<b>137</b>
What Is Oxidation?	137
How Does the Flow of Electrons from Electron Donors to Oxygen Release Energy to the Phosphate Bonds in ATP?	137
Which Molecules Serve as Electron Carriers?	138
How Do Cells Harvest the Energy of Electron Transport?	138
How Do Mitochondria Generate a Proton Gradient?	140
What Pumps Protons Out of the Mitochondrial Matrix?	141
How Does the Flow of Protons Back into the Matrix Cause the Synthesis of ATP?	141
Are Proton Pumping and ATP Synthesis Really Separate Processes?	142
<b>HOW DO CELLS EXTRACT ENERGY FROM GLUCOSE?</b>	<b>144</b>
Glycolysis: How Do Cells Capture Energy in ATP and NADH?	145
<b>BOX 6-1 Sprints, dives, and marathons</b>	<b>148</b>
The Formation of Acetyl-CoA Is the Second Stage in the Extraction of Energy from Glucose	149

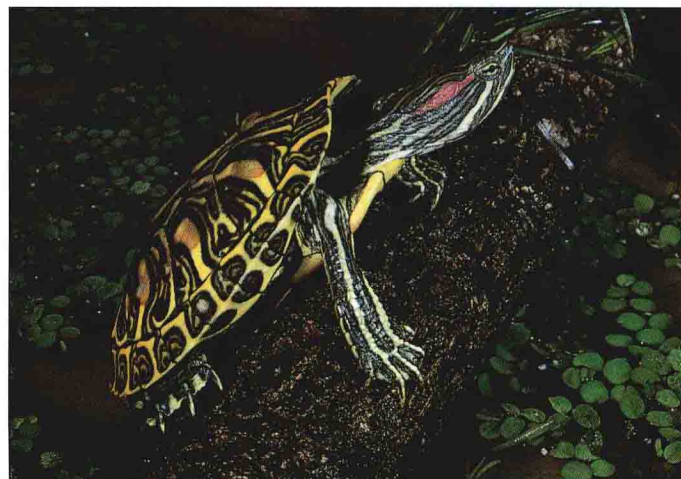
How Does a Cell Generate ATP from Acetyl-CoA?	149
<b>BOX 6-2 The metabolism of alcohol</b>	<b>153</b>
How Much Usable Energy Can a Cell Harvest from a Molecule of Glucose?	153
Study Outline with Key Terms	154
Review and Thought Questions	155
Selected Readings	155

## 7 PHOTOSYNTHESIS: HOW DO ORGANISMS GET ENERGY FROM THE SUN? 156

### *The Chemical Evangelist* 156

#### HOW DO WE KNOW HOW PLANTS OBTAIN CARBON AND OXYGEN? 158

What Do Plants and Air Do for Each Other?	158
Where Do the Atoms Go in Photosynthesis?	159
<b>HOW DO PLANTS COLLECT ENERGY FROM THE SUN?</b>	<b>160</b>
What Is Light?	161
How Much Energy Does a Photon Contain?	164
The Effectiveness of Different Wavelengths Can Reveal Which Molecules Are Responsible for a Light-Dependent Process	164
Light Excites Electrons in Two Types of Reaction Centers	166
The Light-Dependent Reactions of Photosynthesis Transform Light Energy into the Chemical Bonds of NADPH and ATP	171
<b>HOW DO PLANTS MAKE GLUCOSE?</b>	<b>171</b>
What Happens to Carbon Dioxide in Photosynthesis?	172
How Much ATP and NADPH Is Required To Make a Molecule of Glucose?	175
<b>WHAT DETERMINES THE PRODUCTIVITY OF PHOTOSYNTHESIS?</b>	<b>175</b>
<b>BOX 7-1 How do some herbicides kill plants?</b>	<b>176</b>
Study Outline with Key Terms	177
Review and Thought Questions	178
Selected Readings	178



Zig Leszczynski/Animals Animals



## II Genetics: The Continuity of Life 179

### 8 CELL REPRODUCTION 180

#### *The Unfortunate Henrietta Lacks* 180

#### BOX 8-1 Cervical cancer and the Pap smear 182

#### CELL DIVISION 183

How Do Cells Divide? 183

What Did Early Biologists Discover About Chromosomes? 184

How Did Biologists Discover the Function of the Chromosomes? 185

#### HOW DOES A DIVIDING CELL ENSURE THAT EACH DAUGHTER CELL RECEIVES AN EXACT COPY OF THE PARENT CELL'S DNA? 186

How Do Prokaryotic Cells Divide? 187

How Do Eukaryotic Cells Divide? 189

#### HOW DOES MITOSIS DISTRIBUTE ONE COPY OF EACH CHROMOSOME TO EACH DAUGHTER CELL? 192

Mitosis Is a Continuous Process, But Biologists

Distinguish Four Phases 193

What Propels the Chromosomes During Mitosis? 193

#### HOW DOES A CELL FIT ALL ITS DNA INTO A NUCLEUS? 195

How Does the DNA Fold Up? 195

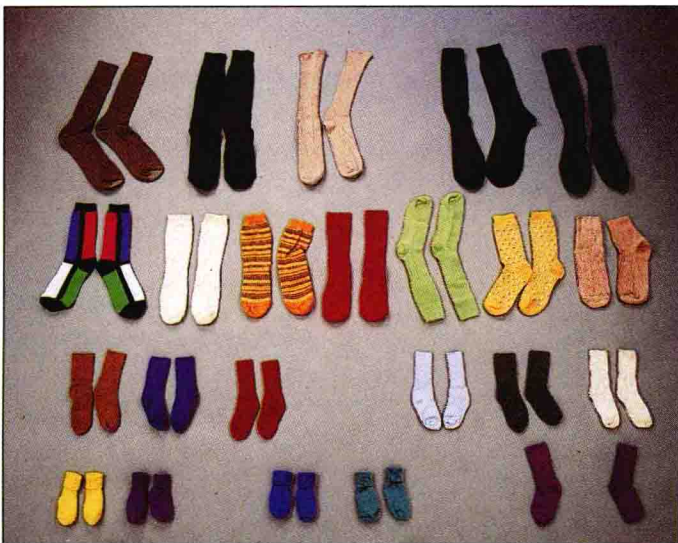
How Do DNA, Histones, and Other Proteins Form Such Compact Structures? 195

#### HOW DOES A CELL DIVIDE ITS CYTOPLASM? 196

#### HOW DOES A CELL REGULATE PASSAGE THROUGH THE CELL CYCLE? 196

How Do Normal Cells Determine When To Stop Dividing? 197

How Do Normal Cells Determine When It Is Time To Divide? 198



Paraskevas Photography

What Triggers the Main Events of Mitosis? 199

Study Outline with Key Terms 200

Review and Thought Questions 200

Selected Readings 201

### 9 FROM MEIOSIS TO MENDEL 202

#### *Why Is the Yellow Dog Yellow?* 202

#### WHY WAS THE CHROMOSOMAL THEORY OF INHERITANCE SO HARD TO ACCEPT? 204

Blending Inheritance: A Wrong Turn 204

Chromosomes Are Individually Unique and Exist Continuously from Generation to Generation 205

#### HOW DO ORGANISMS PASS GENETIC INFORMATION TO THEIR OFFSPRING? 206

What Is Phenotype? 206

The Same Laws of Inheritance Apply to All Sexually Reproducing Organisms 207

#### HOW DO SEXUALLY REPRODUCING ORGANISMS KEEP THE SAME NUMBER OF CHROMOSOMES FROM GENERATION TO GENERATION? 207

The First Cell of the New Generation Has Two Sets of Chromosomes 208

How Does Meiosis Distribute Chromosomes to the Gametes? 210

Disjunction and Nondisjunction 214

#### BOX 9-1 What happens when meiosis goes wrong? 215

#### WHY SEX? 215

Of What Value Is Genetic Variation? 216

What Are Sex Chromosomes? 216

#### THE INHERITANCE OF GENES PARALLELS THE INHERITANCE OF CHROMOSOMES 217

A Diploid Cell Has Two Copies of Every Gene 217

What Are the Genotypes and Phenotypes of the F<sub>2</sub> Generation? 218

#### GREGOR MENDEL ESTABLISHED THE PRINCIPLES OF GENETICS 218

Mendel Chose Traits and Plant Stocks Carefully 219

Mendel's Insights Came from Careful Counting 221

#### SUPPORT FOR THE CHROMOSOMAL THEORY OF INHERITANCE 223

How Did Thomas Hunt Morgan Bolster the Theory of Chromosomal Inheritance? 224

Genes on the X Chromosome Are Inherited Differently in Males and Females 225

#### BOX 9-2 Sex linkage in humans 226

Genes Lie on the Chromosomes 228

Genetic Recombination Can Arise from Independent Assortment or from Crossing Over 231

The Frequency of Crossing Over Between Two Genes Reflects the Physical Distance Between Them 231

Study Outline with Key Terms 232

Review and Thought Questions 233

Selected Readings 233