

Villee,
Solomon & Davis

BIOLOGY



BIOLOGY

CLAUDE A. VILLEE
HARVARD UNIVERSITY

ELDRA PEARL SOLOMON
HILLSBOROUGH COMMUNITY COLLEGE

P. WILLIAM DAVIS
HILLSBOROUGH COMMUNITY COLLEGE

RBL69/01



SAUNDERS COLLEGE PUBLISHING

Philadelphia New York Chicago
San Francisco Montreal Toronto
London Sydney Tokyo Mexico City
Rio de Janeiro Madrid

12487

Address orders to:
383 Madison Avenue
New York, NY 10017

Address editorial correspondence to:
West Washington Square
Philadelphia, PA 19105

Text Typeface: Palatino
Compositor: York Graphic Services
Acquisitions Editors: Michael Brown and Ed Murphy
Developmental Editor: Don Reisman
Project Editor: Carol Field
Copy Editor: Elizabeth Galbraith
Art Director: Carol Bleistine
Art/Design Assistant: Virginia A. Bollard
Text Design: Emily Harste
Cover Design: Lawrence R. Didona
Text Artwork: J & R Technical Services
Production Manager: Tim Frelick
Assistant Production Manager: Maureen Iannuzzi

Cover: The brooding anemone, *Epiactis prolifera*, from
Washington State, © Charles Seaborn.

Library of Congress Cataloging in Publication Data

Villee, Claude A. (Claude Alvin), 1917–
Biology.

Includes index and bibliography.

1. Biology. I. Solomon, Eldra Pearl.
I. Solomon, Eldra Pearl. II. Davis, P. William.
III. Title.

QH308.2.V56 1985 574 84-22234

ISBN 0-03-058477-9

© 1985 by CBS College Publishing.
All rights reserved. Printed in the United States of America.

67 071 9876543

CBS COLLEGE PUBLISHING
Saunders College Publishing
Holt, Rinehart and Winston
The Dryden Press

Preface

The goal of BIOLOGY is to give the reader, the beginning biology student, an understanding and appreciation of the vast diversity of living things, their special adaptations to their environment, and their evolutionary and ecological relationships. We have emphasized the basic unity of life and the fundamental similarities of the problems that are faced by all living organisms. Along with this, we have been very conscious of our responsibility to impress upon students that we are not alone on earth. We share our home with many thousands of varieties of living things. Indeed we are dependent upon countless organisms for our very survival, and such is our position of ecological domination of the biosphere that they in turn depend on us. This interdependence is stressed throughout the text.

FOCUS. The principles of biology can be learned using as a model the frog, dogfish, daisy, and even the colon bacillus. We have chosen a comparative approach. A large number of students have a special interest in human biology—in the structure, function and development of the human body—generated perhaps by their plans for a career in medicine, dentistry, or one of the allied health sciences, or simply by an interest in how their body is put together and how it works. For this reason, we have, as have other textbook authors, made frequent use of the human being as a biological model, and we have given attention to the human aspects of biology. These very same students, however, are those who stand to benefit most from our comparative, principles-oriented approach; for as they continue their professional education, they may have little additional exposure to such subjects as plant biology, invertebrate biology, ecology, and evolution.

This book attempts neither to be encyclopedic nor cursory, but presents the concepts of biology and their relevance to human beings in interesting and understandable fashion. There is no general agreement among biologists as to the sequence in which the several major topics in a general biology course should be taught. This is understandable, for reasonable arguments can be advanced for each of the many possible combinations and permutations. The various aspects of biology are intimately related, and each could be grasped much more readily if all the other aspects had been learned previously. Since this cannot be done (except perhaps by a student repeating the course!), each instructor must choose the sequence that seems optimal to him or her. Because of this, we have taken special pains to write each chapter and each part so that they do not depend heavily upon preceding chapters and parts. The various parts and chapters can be taken up in any of a number of sequences with pedagogical success.

ORGANIZATION. An appreciation of science requires not only a grasp of the content of science but also an insight

into the processes by which scientific knowledge is acquired. An introduction to the methods of science is given in Chapter 1 of Part I, and throughout the text examples of experimental work are presented to illustrate modern methods of biological research.

Part I continues with a discussion of the molecular basis of biology, and the architecture of cells and tissues. The chemistry chapters (Chapters 2 and 3) have been designed to be clear and biologically relevant. Too often a student turns to the first chapters of a biology book and develops the notion that he or she has actually enrolled in an introductory chemistry course. Chapters 4 and 5 (Cells and Cell Membranes) include the highest quality electron and light micrographs available; many of these are accompanied by detailed line drawings that clarify the fine points of cell organization. From Chapter 2 (Atoms and Molecules), through Chapter 3 (Macromolecules), on to Chapters 4 and 5 (Cells and Organelles), we have introduced the student to increasing large levels of organization in biological systems. In Chapter 6, we discuss multicellularity, tissues, and organ systems. However, since not all instructors will want to begin a discussion of these subjects early in the course, the chapter has been conveniently divided along the lines of plants and animals, so that the separate sections can be used immediately preceding the units on The Structures and Life Processes of Plants (Part V) and The Structures and Life Processes of Animals (Part VI).

Part II discusses the properties and constituents of enzyme systems, the flow of energy through the world of life, and the grand metabolic adaptations by which living systems obtain and utilize energy by photosynthesis and cellular respiration. Both in Part II and elsewhere in the book we have attempted to integrate the fundamental details of cellular energetics with the broad patterns of energy flow throughout the world of life.

Part III, Genetics, begins with a discussion of mitosis (first introduced in Chapter 4) and meiosis, and then presents the principles of classical Mendelian genetics. Chapter 12 emphasizes research and clinical applications in human genetics and genetic disease. The chapter includes information on population genetics that helps the student better understand how genetic variation is maintained through generations. This information, however, can be adapted easily to a curriculum that covers population genetics along with evolution (the fundamentals of the Hardy-Weinberg law are summarized at the beginning of Chapter 45).

Chapter 13 discusses in depth the genetic code and the transfer of biological information in DNA molecules from generation to generation. Chapter 14 is devoted to RNA and protein synthesis; Chapter 15 discusses gene control, with attention to possible regulatory mechanisms in eukaryotes. Chapter 16 emphasizes research in molecular

genetics and its possible applications. New advances in this rapidly expanding field are discussed throughout the genetics unit. Every chapter of BIOLOGY has been subjected to review by leading specialists; however, the chapters on molecular genetics (Chapters 13 to 16) are unique in the contributions made to the art and text by Drs. Roger McMacken and Jeffrey Corden of The Johns Hopkins University. Our knowledge in the subject of molecular genetics seems to be growing exponentially; the input of these two researchers has proven invaluable in making the chapters accurate, up to date, and exciting for students to read.

Part IV is devoted to the diversity of living organisms. It begins with a discussion of how and why living things are classified. Separate chapters are devoted to the viruses, monerans, protists, and fungi. The plant kingdom is given a comprehensive survey in two chapters: Chapter 22 presents the primitive land plants and discusses the evolution of mosses and ferns, and Chapter 23 describes the gymnosperms and angiosperms. The last three chapters of Part IV survey the invertebrate and vertebrate animals living today, their structural and functional adaptations, and their evolution. These are not, however, the only comparatively organized chapters in the book. The range of adaptations present in a variety of organisms is summarized in succeeding chapters in Parts V and VI on the systems and life processes of plants and animals.

Part V is devoted to a discussion of structure and life processes in plants. Separate chapters discuss in detail the physiological and morphological attributes of plants, plant growth and development, plant hormones, plant nutrition, and plant reproduction.

Part VI describes structure and life processes in animals. Each chapter begins with a comparative study of the particular adaptations of representatives of various animal phyla. Both structure and physiology are discussed in an evolutionary framework (that is, how different attributes might have evolved in response to stresses from the environment). Accompanying the discussions of human beings as biological models are a large number of high quality medical illustrations. These drawings are a unique learning aid in an introductory biology textbook.

The final section of this book, Part VII, explores the biology of populations. Evolution, animal behavior and ecology are the subjects of this unit. Chapters 45 and 46 discuss the general principles of evolution and the evidence for evolution. Chapter 47 introduces the student to the possible mechanisms of the origin of life itself on this planet. This chapter also summarizes some of the information in Part IV by giving a chronological history of the evolution of life on earth through an examination of the fossil record. Appropriately, since much of this knowledge is inexact, the chapter closes by presenting some of the important controversies in evolutionary theory today (such as the debate on punctuated equilibrium).

Behavior is discussed as a complex of adaptations in Chapters 48 and 49. Chapter 48 discusses behavior at the level of the individual organism, while Chapter 49 discusses the adaptive value of social behavior. Both these chap-

ters are necessarily selective in their focus; their emphasis on adaptation, evolution, and the biological basis of behavior is designed to complement knowledge the student has acquired from other sections of the book.

Chapters 50 and 51 present principles of ecology from the standpoint of populations and communities and include discussion of adaptations, ecosystems, and the various types of biomes. Chapter 52, Human Ecology, emphasizes the impact of human beings upon the biosphere. Since, however, ecological themes are so much an integral part of the textbook, these chapters are, in part, a synthesis of the information the student has encountered elsewhere.

LEARNING AIDS. Many pedagogic aids have been included to help the student with the challenging task of mastering the principles of biology. Both **learning objectives** and a **chapter outline** are included at the beginning of each chapter. These help students as they begin to read a chapter and are useful later as a way to organize knowledge and study for an examination. Important new terms are set in **boldface** for emphasis throughout the text. Illustrations have been carefully designed to support and clarify concepts presented in the text, and tables are frequently employed to organize and summarize information.

Focus boxes present subjects in greater depth, introduce applications of material presented in the text, or integrate knowledge from the various subdisciplines of biology and related sciences. At the end of each chapter a **summary** in outline form is provided. There is also a **Post-test** (with answers at the back of the book) so that the student can evaluate his or her mastery of the factual material in the chapter. **Review questions** help the student to focus upon important concepts. At the end of each part there is a list of **supplementary readings**. These readings are selected specifically for the undergraduate biology major, and include numerous articles written at a level that the student can readily understand. A **glossary** giving the definitions of many important biological terms is integrated with the very comprehensive **index**. This feature is useful in enhancing student recall and allows the student to conveniently find references and examples in the text. Preceding the glossary/index is an **appendix summarizing the classification system** used in the text; this appendix also outlines minor phyla not covered in Part IV. Also included is an **appendix on common prefixes, suffixes, and word roots used in biology**.

SUPPLEMENTS. Many supporting materials have been provided to accompany this text. These include a comprehensive set of supplements for the use of both instructor and student: an **instructor's manual**, a **laboratory manual**, a **study guide** that includes additional review and self-tests, **overhead color transparencies** for classroom use, slides of **electron micrographs**, and a **test bank**.

CLAUDE A. VILLEE
ELDRA PEARL SOLOMON
P. WILLIAM DAVIS

Acknowledgments

We would like to express our deep appreciation and gratitude to the members of the editorial staff of Saunders College Publishing who have helped so much in developing this book and guiding it through the maze of details involved in transforming the initial manuscript to the final text. Most important was our Developmental Editor Don Reisman who pushed us—and himself—to what seemed like the very limits of our endurance (many over-fourteen-hour days and seven-day working weeks) in meeting an almost interminable series of tough deadlines and in striving for the highest possible quality. Don labored with us over every paragraph and every illustration. He is responsible in large part for the extensive, complex photograph program that supports and beautifully illustrates the text. His sharp eye and keen aesthetic instinct have spared the reader many a “slightly out of focus” photograph (which otherwise would surely have been included since we had taken them). We are most grateful for Don’s deep involvement in every aspect of this project. We also thank Don’s Developmental Assistant Amy Leary for her patient tracking of the many details of illustrations and permissions.

We are much indebted to Carol Field, our Project Editor, for her care and expertise in the difficult task of guiding the book through the production phase. We also want to thank Art Director Carol Bleistine and Manager of Editing, Design, and Production, Tim Frelick. We appreciate the continued support of our Publisher, Don Jackson, and our Acquisitions Editors Michael Brown and Ed Murphy. We are grateful to all of these dedicated experts who believed in this project and gave us the support necessary to make BIOLOGY a reality.

We want to thank Kathleen Callinan for typing portions of the manuscript. We are grateful to Phala Pesano for her dedication and hard work in word processing, rendering some of the preliminary drawings, and helping us prepare the glossary/index. We thank Harold Levin for the use of several of his illustrations in the chapters on evolution. We also want to acknowledge the help of Forrest Hearst of Microcomputer Systems, Inc., who patiently and generously helped us join the computer age.

Lastly, we acknowledge the patience and support of our families. Amy Solomon’s and Belicia Efros’s help in word processing, proofreading, bursting endless reams of computer paper, and in many other aspects of the project was important to us. We especially appreciate Mical Solomon’s role in persuading us to make the big leap from type-

writer to word processor and his continual help in keeping our computers’ systems working.

REVIEWERS OF BIOLOGY. We want to express our thanks to the instructors and researchers who have helped shape BIOLOGY. They have shared with us both their talent and the pressures of meeting deadlines. Their suggestions have been invaluable.

John H. Adler, Michigan Technological University
Lester Bazinet, Community College of Philadelphia
William L. Bischoff, University of Toledo
George Bowes, University of Florida
W. H. Breazeale, Jr., Francis Marion College
Jeffrey Corden, The Johns Hopkins University
Harry O. Corwin, University of Pittsburgh
Stephen J. Dina, St. Louis University
Lee C. Drickamer, Williams College
Milton Fingerman, Tulane University
Elizabeth A. Godrick, Boston University
Peter Gregory, Cornell University
Thomas Hanson, Temple University
Mark Jacobs, Swarthmore College
Robert W. Korn, Bellarmine College
Victor Lotrich, University of Delaware
Arthur Mange, University of Massachusetts, Amherst
Roger McMacken, The Johns Hopkins University
Robert E. Moore, Montana State University
Thomas L. Naples, Delaware Community College
David O. Norris, University of Colorado, Boulder
Frank G. Nordlie, University of Florida
Jeanne S. Poindexter, The Public Health Research Institute of The City of New York, Inc.
Susan Pross, University of South Florida
Florence Ricciuti, Albertus Magnus College
Martin Roeder, Florida State University
Rodney A. Rogers, Drake University
Marvin J. Rosenberg, California State University, Fullerton
John A. Schmitt, Ohio State University
Richard C. Snyder, University of Washington
Charles L. Stevens, University of Pittsburgh
Daryl Sweeney, University of Illinois at Urbana-Champaign
Joseph W. Vanable, Purdue University
Jack Waber, West Chester State University
Lawrence Winship, Hampshire College
Drew H. Wolfe, Hillsborough Community College
John L. Zimmerman, Kansas State University

Contents

part I

THE ORGANIZATION OF LIFE

1

1 A View of Life

What is life?

Specific Organization

Metabolism

Homeostasis

Growth

Movement

Responsiveness

Reproduction

Adaptation

Focus on The Evolutionary Perspective

The Organization of Life

Organization of the Organism

Ecological Organization

The Variety of Organisms

Kingdom Monera

Kingdom Protista

Kingdom Fungi

Kingdom Plantae (plants)

Kingdom Animalia (animals)

How Biology is Studied

Systematic Thought Processes

Designing an Experiment

How a Hypothesis Becomes a Theory

The Ethics of Science

2 Atoms and Molecules: The Physical Basis of Life

Chemical Elements

Atomic Structure

Isotopes

Focus on Matter and Energy

Atomic Mass

Electrons and Orbitals

Chemical Compounds

Chemical Equations

Chemical Bonds

Covalent Bonds

Polar Covalent Bonds

Ionic Bonds

Hydrogen Bonds

Other Interactions Between Atoms

Molecular Mass

Oxidation-Reduction

Water and Its Properties

Cohesive and Adhesive Forces

Temperature Stabilization

Ionization

Acids and Bases

pH

Buffers

Salts

3 Biologically Important Molecules

Carbohydrates

Monosaccharides

Disaccharides

Polysaccharides

Modified and complex carbohydrates

Focus on Some Functional Groups Important in

Biochemistry

Lipids

Neutral fats

Phospholipids

Carotenoids

Steroids

Proteins

Subunit structure

Focus on Amino Acids Present in Proteins

Protein structure: levels of organization

Functions of proteins

Focus on Classifying Proteins

Nucleic acids

Subunit structure

Related nucleotides

4 The Life of Cells

The cell theory

Viewing the cell

General characteristics of cells

Inside the cell

Endoplasmic reticulum and ribosomes

The Golgi complex

Lysosomes

Mitochondria

Plastids

Peroxisomes

Microtubules and microfilaments

The microtrabecular lattice

Centrioles

Cilia and flagella

Vacuoles

The cell nucleus

Focus on Acetabularia: The Mermaid's Wineglass and the Secret of Life

Differences in some major cell types

Plant and animal cells

Prokaryotic and eukaryotic cells

The cell cycle

Interphase

Mitosis

Factors that affect the cell cycle

5 The Cell Membrane

Functions of the cell membrane

The structure of the cell membrane

The lipid bilayer

Membrane proteins

Membrane receptors

Focus on Splitting the Lipid Bilayer

Microvilli

44

45

45

47

47

48

50

51

51

51

53

53

55

55

56

58

58

60

61

61

62

66

67

67

70

71

73

75

76

77

77

78

78

79

81

82

82

83

85

89

89

91

92

93

93

97

101

102

102

102

104

104

105

106

ix

Cell walls	106
How materials pass through membranes	106
Diffusion	107
Active transport	111
Endocytosis and exocytosis	112
Cell junctions and communications	115
Desmosomes	115
Tight junctions	116
Gap junctions	117
6 Tissues, Organs, and Organ Systems	120
Why are so many living things multicellular	121
Animal tissues	122
Epithelial tissues	122
Connective tissues	124
<i>Focus on Neoplasms—Unwelcome Tissues</i>	132
Muscle tissue	133
Nervous tissue	134
Animal organs and organ systems	135
Plant tissues	138
Meristematic tissues	138
Permanent tissues	138
Plant organs and plant systems	144
Recommended Readings	147

part II ENERGY IN LIVING SYSTEMS 149

7 Energy Flow Through the World of Life	151
Energy transformations	152
Chemical directions	155
The first law of thermodynamics	155
The second law of thermodynamics	155
Free energy	157
Entropy and living systems	158
Reversibility of reactions in living systems	158
Equilibrium	158
Coupled reactions	158
Factors that affect chemical reactions	159
<i>Focus on ATP: The Energy Currency of Cells</i>	160
Activation energy	160
Temperature	161
Concentration	161
Catalysts: introducing enzymes	162
<i>Focus on The Law of Mass Action</i>	162
How enzymes work	163
Cofactors	165
The role of enzymes in living cells	165
Factors affecting enzyme activity	166
Concentrations of enzyme and substrate	166
Enzyme inhibition	167
Temperature	168
pH	169
Energy flow through the biosphere	169
8 Photosynthesis	172
The hydrogen economy of the biosphere	173
Light and atomic excitation	174
Introducing chlorophyll	174
The action spectrum of photosynthesis	176
Photosynthetic membranes	179
The chemistry of photosynthesis	179
The Hill reaction	180
The reactions of photosynthesis	181

<i>Focus on Summary Equations for Photosynthesis</i>	182
Photorespiration	191
9 Cellular Respiration and Biosynthesis	194
An overview of cellular respiration	195
<i>Focus on Summary Reactions for Cellular Respiration</i>	196
Glycolysis	197
Formation of acetyl coenzyme A	199
The citric acid cycle	200
The electron transport system and chemiosmotic phosphorylation	201
Electron transport	202
Oxidative phosphorylation	202
Regulation of energy production	203
The molecular organization of mitochondria	203
The chemiosmotic theory of oxidative phosphorylation	203
Energy yield from glucose	206
<i>Focus on Shuttles Across the Mitochondrial Membrane</i>	207
Anaerobic pathways	208
Oxidation of other nutrients	209
Oxidation of amino acids	209
Oxidation of fatty acids	209
Biosynthetic reactions	211
Recommended Readings	214

part III GENETICS 215

10 Producing a New Generation: Meiosis	217
Eukaryotic chromosomes	219
Genes	220
How many chromosomes?	220
Meiosis	221
How does meiosis differ from mitosis?	221
The process of meiosis	221
Spermatogenesis	225
Oogenesis	228
11 The Basic Principles of Heredity	231
Genes and alleles	232
A monohybrid cross	234
Homozygous and heterozygous organisms	235
Phenotype and genotype	235
Test crosses	235
<i>Focus on The Work of Gregor Mendel</i>	236
Calculating the probability of genetic events	237
Types of probability	238
The product law	238
The sum law	238
Applying the laws of probability	238
Incomplete dominance	240
Deducing genotypes	241
Dihybrid and trihybrid crosses	242
Mendel's laws	242
Gene interactions	243
Polygenic inheritance	245
Multiple alleles	246
ABO blood types	247
The Rh system	248
Linkage and crossing over	248
<i>Focus on Genetic Mapping</i>	251
The genetic determination of sex	252

The Y chromosome and maleness	252	Information transfer outside the nucleus	330
Nuclear sexing	253	Focus on Four-winged Flies	331
Sex-linked and sex-influenced traits	253	A genetic heresy	333
Inbreeding, outbreeding, and hybrid vigor	254		
The mathematical basis of population genetics	255	16 Genetic Frontiers	335
The gene pool and the Hardy-Weinberg law	256	The preparation of recombinant DNA molecules	336
Estimating the frequency of genetic carriers	257	Restriction endonucleases	337
		Plasmids	338
12 Human Genetics	262	Isolating a single eukaryotic gene	339
Inherited human traits	263	Cloning synthetic DNA	340
The inheritance of mental abilities	264	Focus on Localizing a Gene by Cell Fusion	342
Human cytogenetics	264	Replacing defective genes	344
Karyotypes	265	Focus on Molecular Genetics and Cancer	344
Birth defects	265	Other uses of recombinant DNA techniques	345
Chromosome abnormalities	265	Focus on Engineering Plants	346
Genes and disease	268	Recombinant RNA	347
Sickle cell anemia	271	Some worries	347
Cystic fibrosis	271		
Diagnosis of genetic abnormalities	272	Recommended Readings	350
Genetic counseling	272		
Eugenics	274		
Negative eugenics	274	part IV	
Balanced polymorphism	275	THE DIVERSITY OF LIFE	
Positive eugenics	276	353	
13 DNA: The Secret of Life	279	17 The Classification of Living Things	355
Unraveling the genetic code	280	The development of taxonomy	356
Early clues	280	The Linnaean system	356
DNA and the transfer of genetic information	282	Categories of classification	357
DNA: a macromolecule	282	Subspecies	358
Nucleotides	282	Splitting and lumping	358
Focus on Studies with Bacterial Viruses	283	Choosing taxonomic criteria	359
The double helix	283	Focus on Why you are Homo sapiens	360
Focus on Chromosomes and Genetic Expression	289	Improving taxonomy	361
DNA replication	290	Taxonomy and ancestry	361
Focus on Replication: A Semiconservative Process	292	How many kingdoms?	362
DNA information density	294	Focus on Approaches to Taxonomy	363
		The domains	364
		Focus on Taxonomy and Biochemistry	366
14 The Bacterial Connection: Genetic Information and Protein Synthesis	296	18 Viruses	369
An overview of gene expression	297	Structure of a virus	370
Transcription: the synthesis of RNA	298	Bacteriophages	371
The initiation of transcription	300	Focus on Culturing Viruses	371
The processing of RNA	301	Viral replication in lytic infections	373
Focus on Reverse Transcription	302	DNA integration in lysogenic infections	375
Translation	303	Another form of coexistence	376
Activation of amino acids	303	Animal viruses	377
The role of transfer RNA	303	Viral diseases	377
The structure of transfer RNA	303	Viruses and cancer	377
The messenger RNA template	304	Focus on Animal Viruses	378
The ribosomes	304	Viroids	379
Protein synthesis	305		
Gene-enzyme relations	308	19 Kingdom Monera	381
Changes in genes: mutations	311	Cyanobacteria	382
Some reflections on the genetic code	314	Structure of cyanobacteria	383
Some experimental evidence for a triplet code	104	Ecological importance	384
Focus on Genetic Repair and Proofreading	315	Bacteria	384
Codon-amino acid specificity	316	Focus on Some Historical Highlights	385
		Structure of bacteria	385
15 Gene Regulation	321	Focus on The Archaeobacteria	388
Mechanisms of gene regulation	322	Bacterial metabolism	388
The operon concept: control of protein synthesis	322	Reproduction	390
Posttranscriptional gene control	326	Spore formation	390
Focus on Some Important Gene Regulation Definitions	328	Focus on Culturing Bacteria in the Laboratory	391
Gene control in eukaryotes	329	Some important groups of bacteria	392
		Bacteria in humans	395

Bacteria and food	396	Their place in the environment	481
<i>Focus on Bacteria that Infect Humans</i>	397	Animal relationships	481
Ecological importance of bacteria	398	Acoelomates and coelomates	482
Bacterial diseases of plants	399	<i>Focus on Body Plan and Symmetry</i>	483
		Protostomes and deuterostomes	483
20 Kingdom Protista	402	Homologous and analogous structures	485
Protozoa	403	Simple versus complex	487
Phylum Mastigophora	404	Phylum Porifera: the sponges	487
Phylum Sarcodina	407	Body plan of a sponge	488
Phylum Ciliata	409	Life style of a sponge	489
Phylum Suctorina	412	Phylum Cnidaria	490
Phylum Sporozoa	413	Class Hydrozoa	492
The algal protists	413	Class Scyphozoa (jellyfish)	494
Phylum Chrysophyta	415	Class Anthozoa (corals)	495
Phylum Pyrrophyta	416	Phylum Ctenophora (comb jellies)	495
Relationships of the protists	418	Phylum Platyhelminthes (flatworms)	496
		Class Turbellaria	497
21 Kingdom Fungi	421	Class Trematoda (flukes)	498
Body plan of a fungus: molds and yeasts	422	Class Cestoda (tapeworms)	498
Metabolism and growth	423	Phylum Nemertinea (proboscis worms)	501
Reproduction	424	Phylum Nematoda (roundworms)	501
Classifying fungi	425	<i>Ascaris</i> : a parasitic roundworm	502
Division Eumycophyta	425	Other parasitic roundworms	504
Class Oomycetes (water molds)	425	Phylum Rotifera (wheel animals)	505
Class Zygomycetes	427		
Class Ascomycetes: the sac fungi	428	25 The Animal Kingdom: The Coelomate	508
Class Basidiomycetes: the club fungi	430	<i>Protostomes</i>	
Class Deuteromycetes (imperfect fungi)	432	Advantages of having a coelom	509
Division Myxomycophyta (slime molds)	432	Adaptations for terrestrial living	509
Symbiotic relationships of fungi	435	Phylum Mollusca	510
The lichens	435	Relationship to the annelids	512
Mycorrhizae: fungus-roots	436	Class Polyplacophora: chitons	512
Economic importance of fungi	436	Class Gastropoda: snails and their relatives	513
Fungi for food	437	Class Bivalvia: clams, oysters, and their relatives	514
Fungi for drugs and useful chemicals	438	Class Cephalopoda: squids, octopods, and their relatives	514
Fungus diseases of plants	438	Phylum Annelida	515
Fungus diseases of animals	440	Class Polychaeta	516
		Class Oligochaeta: the earthworms	518
22 The Simpler Plants	443	Class Hirudinea: the leeches	519
Division Chlorophyta: green algae	444	Phylum Onychophora	519
Lower green algae: unicellular and colonial forms	445	Phylum Arthropoda	521
Higher green algae: multicellular (plantlike) organization	450	The arthropod body plan	522
Division Phaeophyta: brown algae	452	The trilobites	522
Division Rhodophyta: red algae	453	Subphylum Chelicerata	523
Division Bryophyta: nonvascular terrestrial plants	454	Subphylum Crustacea: lobsters, crabs, shrimp, and their relatives	525
Musci: mosses	455	Subphylum Uniramia	527
Hepaticae: liverworts	455	<i>Focus on The Principal Orders of Insects</i>	532
		26 The Animal Kingdom: The Deuterostomes	536
23 Vascular Plants: Division Tracheophyta	460	Phylum Echinodermata	537
Class Rhyniopsida: the rhinophytes	461	Class Crinoidea: feather stars and sea lilies	539
Class Lycopsida: the club mosses	461	Class Asteroidea: sea stars	540
Class Filicopsida: ferns and horsetails	463	Class Ophiuroidea: basket stars and brittle stars	541
Order Equisetophyta: the horsetails or scouring rushes	463	Class Echinoidea: sea urchins and sand dollars	541
Order Filicophyta: the ferns	464	Class Holothuroidea: sea cucumbers	541
The seed plants	466	Phylum Chordata	542
The gymnosperms	467	<i>Focus on The Hemichordates</i>	543
Class Angiospermopsida: the angiosperms	473	Subphylum Urochordata: tunicates	543
The origin and relationships of higher plants	475	Subphylum Cephalochordata: lancelets	544
The origin of the gymnosperms	476	Subphylum Vertebrata	546
The origin of the angiosperms	477	<i>Focus on Some Orders of Living Placental Mammals</i>	562
		Recommended Readings	566
24 The Animal Kingdom: Animals Without a Coelom	479		
What is an animal?	480		

part V
STRUCTURES AND LIFE
PROCESSES IN PLANTS
569

27 The Plant Body	571
The plant body: An overview	572
The leaf	573
Epidermis	573
Mesophyll	574
Veins	575
Water loss	576
Guard cells and their control	576
<i>Focus on Photosynthesis in Desert Plants: A Special Case</i>	578
The stem	579
The vascular tissues	579
Monocot stems	582
Dicot stems	583
Roots	585
Root structure and function	585
<i>Focus on Freeloading Plants</i>	588
Root respiration	588
28 Growth and Development in Plants	592
Seeds	593
Seed structure	593
Seed germination	594
Meristems and buds	597
Primary meristems	597
The leaf bud	598
Secondary growth	600
29 Plant Hormones and Tropisms	604
Rapid plant responses	606
Tropisms (growth responses)	606
Plant hormones	606
Auxins	606
Gibberellins	610
Ethylene	611
Cytokinins	611
Absciscic acid	612
Photoperiodism: florigens and phytochromes	613
Florigen	614
Phytochrome	615
30 Plant Nutrition	618
Limiting factors in plant nutrition	619
Plant nutrient requirements	620
The macronutrients	620
The micronutrients	621
Fertilizers	622
Origin of soil nutrients	623
History of a typical soil	623
Ecochemical cycles	624
How plants obtain minerals from the soil	628
The soil solution	628
Exchangeable nutrients	630
Mineralization of organic matter	630
Soils	632
Sand	633
Clay	633
Silt	633
Humus	633
Loam	633
31 Reproduction in Seed Plants	637

Asexual propagation in nature	638
Artificial asexual propagation	640
Sexual reproduction in seed plants	641
Sexual reproduction in gymnosperms	642
Sexual reproduction in flowering plants	643
Recommended Readings	654

part VI
STRUCTURES AND LIFE
PROCESSES IN ANIMALS
655

32 Skin, Bones, and Muscles: Protection, Support, and Locomotion	657
Skeletons and skin	658
Hydrostatic skeletons	658
External skeletons	660
The vertebrate skin	661
Internal skeletons	665
The skeleton itself	665
Muscles	669
Muscle actions	669
Posture and movement	672
Muscle physiology	672
The biochemistry of muscular contraction	675
Smooth and cardiac muscle	679
<i>Focus on Depolarization</i>	682
A muscular zoo	684
33 Processing Food	687
Modes of nutrition	688
Adaptations of herbivores	688
Adaptations of carnivores	690
Omnivores	691
Symbionts	691
Invertebrate digestive systems	691
Vertebrate digestive systems	692
Wall of the digestive tract	694
Inside the mouth	695
Through the pharynx and esophagus	697
In the stomach	698
Inside the small intestine	700
The pancreas	702
<i>Focus on Peptic Ulcers</i>	702
The liver	703
Enzymatic digestion	705
Control of digestive juice secretion	707
Absorption	707
Through the large intestine	709
34 Nutrition and Metabolism	713
Metabolic work	714
Metabolic rate	714
Energy requirement and body weight	714
Carbohydrate metabolism	716
Carbohydrate utilization by the cells	716
Glucose storage	716
Lipid metabolism	717
Lipid storage	718
Using fat as fuel	718
Other uses of lipid	719
<i>Focus on Obesity</i>	719
Protein metabolism	720
Vegetarian diets	720
Use of amino acids by the cells	722
Amino acid catabolism	722

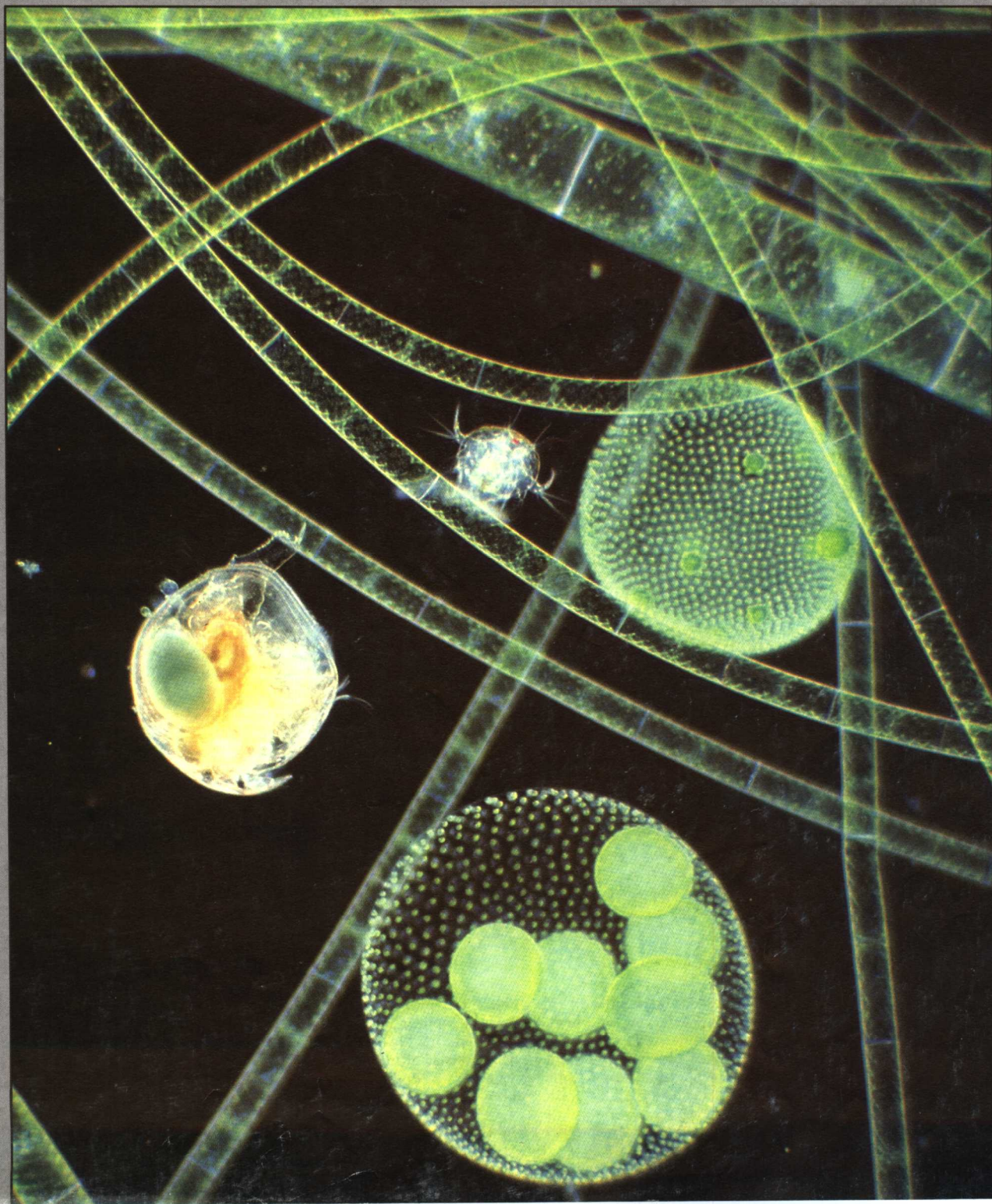
Minerals	723	Fluid balance and excretion in humans	815
Vitamins	723	The human kidney and its ducts	817
Water	728	The nephron	817
		Urine formation	817
35 Internal Transport	732	Composition of urine	822
Invertebrates with no circulatory systems	733	Fluid homeostasis	822
Invertebrates with open circulatory systems	734	<i>Focus on Kidney Disease</i>	825
Invertebrates with closed circulatory systems	735		
The vertebrate circulatory system	736	39 Neural Control: Neurons	827
Blood	736	Information flow through the nervous system	828
The blood vessels	740	Organization of the vertebrate nervous system	828
The heart	744	Structure of the neuron	829
Pulse and blood pressure	752	Dendrites	829
The pattern of circulation	755	The axon	831
<i>Focus on Cardiovascular Disease</i>	758	Nerves and ganglia	832
The lymphatic system	758	Transmission of a neural impulse	832
Design of the lymphatic system	761	The resting potential	832
Role in fluid homeostasis	761	<i>Focus on Regeneration of an Injured Neuron</i>	833
		Local changes in potential	835
36 Internal Defense	765	The action potential	835
Self and nonself	766	Saltatory conduction	837
Internal defense mechanisms in invertebrates	766	Substances that affect excitability	838
Internal defense mechanisms in vertebrates	767	Synaptic transmission	838
Nonspecific defense mechanisms	767	Direction and speed of conduction	840
Specific defense mechanisms	769	Integration	841
Primary and secondary responses	777	Organization of neural circuits	842
Active and passive immunity	777	Reflex action	843
How the body defends itself against cancer	778		
Rejection of transplanted tissue	779	40 Neural Control: Nervous Systems	847
Immunologically privileged sites	780	Invertebrate nervous systems	848
Immunological tolerance	780	Nerve nets and radial systems	848
Hypersensitivity	780	Bilateral nervous systems	848
		The vertebrate brain	850
37 Gas Exchange	784	The hindbrain	851
Adaptations for gas exchange	785	The midbrain	852
The body surface	785	The forebrain	852
Tracheal tubes	787	The human central nervous system	853
Gills	787	The spinal cord	853
Lungs	788	The brain	855
Air versus water	790	The peripheral nervous system	863
Respiratory pigments	791	The cranial nerves	863
The human respiratory system	791	The spinal nerves	864
<i>Focus on Choking</i>	794	The autonomic system	867
The mechanics of breathing	795	Effects of drugs on the nervous system	869
The quantity of air respired	796		
Exchange of gases in the lungs	796		
Oxygen transport	797	41 Sense Organs	874
Carbon dioxide transport	799	What is a sense organ?	875
Regulation of respiration	799	How sense organs are classified	875
Hyperventilation	800	How sense organs work	876
High flying and low diving	800	Sensory coding and sensation	878
<i>Focus on Cardiopulmonary Resuscitation (CPR)</i>	801	How materials pass through membranes	106
<i>Focus on Adaptations of Diving Mammals</i>	802	Mechanoreceptors	879
Effects of smoking and air pollution	803	Tactile receptors	879
<i>Focus on Facts About Smoking</i>	805	Gravity receptors: statocysts	881
		Lateral line organs	882
38 Fluid Balance and Disposal of Metabolic Wastes	808	Proprioceptors	882
Functions of the excretory system	809	Equilibrium	884
Waste products	809	Auditory receptors	887
Waste disposal and osmoregulation in invertebrates	810	Chemoreceptors: taste and smell	890
Nephridial organs	810	The sense of taste in insects	890
Antennal glands	813	The human sense of taste	892
Malpighian tubules	813	The sense of smell	893
Osmoregulation and waste disposal in vertebrates	813	Thermoreceptors	894
The vertebrate kidney	814	Photoreceptors	895
Osmoregulation	814	The human eye	895
		The compound eye	900

42 Animal Hormones: Endocrine Regulation	905	Influence of other cells: organizers	973
The chemical nature of hormones	907	Environmental factors	974
<i>Focus on Identification of Endocrine Tissues and Hormones</i>	907	Interaction of nongenetic with genetic factors	974
Mechanisms of hormone action	910	Environmental influences upon the embryo	975
Activation of genes	910	The human life cycle	976
Action through a second messenger	911	The aging process	978
Prostaglandins	911	Recommended Readings	981
Regulation of hormone secretion	913		
Invertebrate hormones	913		
Endocrine regulation of reproductive development in cephalopods	913		
Color change in crustaceans	914		
Hormonal control of insect development	914		
Vertebrate hormones	915		
Endocrine disorders	915		
The hypothalamus and pituitary gland	916		
<i>Focus on Consequences of Endocrine Malfunction</i>	918		
Growth and development	920		
Regulation of blood sugar level: insulin and glucagon	923		
Response to stress	925		
43 Reproduction	929		
Asexual reproduction	930		
Sexual reproduction	930		
Reproductive systems	931		
Some reproductive variations	932		
Metagenesis	932		
Parthenogenesis	933		
Hermaphroditism	933		
Human reproduction	933		
The male reproductive system	934		
The female reproductive system	935		
Reproductive hormones in the male	937		
Hormonal control of menstrual cycle	939		
Physiology of sexual response	941		
Fertilization	942		
Sterility	944		
<i>Focus on Sexually Transmitted Diseases (STD)</i>	945		
Birth control	946		
<i>Focus on Novel Origins</i>	947		
Oral contraceptives: the pill	947		
The intrauterine device (IUD)	948		
Other common methods	949		
Sterilization	949		
Abortion	950		
44 Development	953		
Early development	954		
The zygote	955		
Cleavage: from one cell to many	955		
The blastocyst	956		
Implantation	957		
Formation of germ layers	957		
Development of the nervous system	958		
<i>Focus on Early Development: A Comparative Study</i>	959		
The first month	962		
<i>Focus on Development of Organ Systems</i>	963		
Extraembryonic membranes and placenta	964		
Later development	966		
The birth process	968		
Adaptations to birth	970		
Lactation	970		
What regulates developmental processes?	971		
Cytoplasmic factors	972		
Role of the genes	973		
		part VII	
		THE BIOLOGY OF POPULATIONS: EVOLUTION, BEHAVIOR, AND ECOLOGY	
		983	
		45 The Genetic Mechanisms of Evolution	985
		Evolution and genetics	986
		Changes in gene frequency	986
		<i>Focus on The Hardy-Weinberg Law: A Review</i>	987
		Evolution: the failure to maintain genetic equilibrium	992
		<i>Focus on Special Adaptations: Symbiosis</i>	996
		Speciation	996
		Isolating mechanisms	999
		The origin of species by hybridization	1000
		Stabilizing selection	1001
		Historical development of the concept of evolution	1002
		Jean Baptiste de Lamarck	1003
		Charles Darwin and Alfred Russel Wallace	1003
		<i>Focus on Natural Selection in Bacteria</i>	1004
		The Darwin-Wallace theory of natural selection	1006
		46 Evolutionary Evidence	1009
		Interpreting evolutionary evidence	1010
		The nature of the evidence	1011
		Microevolution	1011
		Evidence from morphology	1012
		Biochemistry	1013
		Evidence from embryology	1014
		Biogeography and distribution	1016
		Structural parallelism	1018
		Adaptive radiation	1018
		Fossil record	1020
		47 The Fossil Record and the Controversies	1025
		The geological time table	1026
		The origin and history of life	1026
		How did life originate?	1026
		The origin of cells	1031
		The origin of eukaryotes	1032
		Precambrian life	1032
		The Paleozoic era	1034
		The Mesozoic era	1032
		The Cenozoic era	1040
		Fossil humans	1042
		<i>Focus on A Distinctive Human Adaptation: The Grips of the Hand</i>	1043
		Human evolution	1044
		Gaps in the fossil record: punctuated equilibrium	1048
		<i>Focus on Creationism and Evolution</i>	1052
		48 The Behavior of Organisms	1054
		What is behavior?	1055
		Behavior as adaptation	1055
		Simple behavior	1056
		Tropisms	1057

Taxes	1057	Light	1098
Biological rhythms and clocks	1058	Water	1098
Lunar cycles	1058	Other environmental factors	1098
Circadian rhythms	1059	Habitat and ecological niche	1099
What controls the biological clock?	1059	Interspecific interactions	1101
Sign stimuli	1060	Competition and cooperation	1101
The genetic basis of behavior	1060	Negative interactions	1102
Physiological readiness	1060	The ecology of stress	1103
<i>Focus on The Genetic Basis of Hygienic Behavior in</i>		Community succession	1103
<i>Bees</i>	1061	Some examples of succession	1105
Learning	1062	Why successions succeed	1105
Imprinting	1062		
Migration	1063	51 Population and Community Ecology	1108
49 Social Behavior	1067	Populations	1109
What is social behavior?	1068	The characteristics of populations	1109
Communication	1069	Population cycles	1111
Modes of communication	1069	Population dispersion	1112
Pheromones	1070	Biotic communities	1112
Dominance hierarchies	1071	Terrestrial habitats	1113
Suppression of aggression	1072	Aquatic habitats	1124
Physiological determinants	1072	Succession in aquatic communities	1135
Territoriality	1072	52 Human Ecology	1137
Sexual behavior and reproduction	1073	The ecological impact of primitive societies	1138
Pair bonds	1075	Urbanization and the industrial revolution	1140
Care of the young	1076	The ecology of agriculture	1140
Play	1076	Agricultural communities	1140
Displacement activity	1077	Insecticides and biocides	1142
Elaborate societies	1077	Use of water and wetlands	1144
Insect societies	1077	Pollution and waste disposal	1144
Vertebrate societies	1080	Cultural eutrophication	1145
Kin selection	1081	Thermal pollution	1145
Sociobiology	1082	Air pollution	1147
50 Principles of Ecology	1084	Major pollutants	1148
Ecology, communities, and ecosystems	1085	Ecological effects of air pollution	1148
The ecology of nutrition	1087	meteorology of air pollution	1149
Kinds of producers	1087	Other pollution: radioactive materials	1151
Kinds of consumers	1088	Extinction	1151
<i>Focus on Life Without the Sun</i>	1088	<i>Focus on Human Ecology: The Last Winter</i>	1152
Kinds of decomposers	1089	Human overpopulation	1154
The cyclic use of matter and the flow of energy	1090	When is a nation overpopulated?	1155
The carbon cycle	1090	The future	1155
The water cycle	1091	Recommended Readings	1157
Other elements	1091	Answers	1161
Energy flow	1091	Appendix A: The Classification of Organisms	1166
Food chains and pyramids	1094	Appendix B: Dissecting Terms	1171
Limits and limiting factors	1097	Glossary/Index	1173
Temperature	1097		

part I

THE ORGANIZATION OF LIFE



Microscopic jewels, several species of algae glitter in this photomicrograph by Tom Adams. The globular colonies are *Volvox*, one of which contains several daughter colonies about to be released to start independent life on their own. Filamentous algae, *Spirogyra*, curve in the foreground and background. Strands of such algae consist of numerous cylindrical cells joined end-to-end. Also seen are two small crustaceans, a copepod (left) and *Chydorus* (right). (Magnification $\times 60$ and enlarged photographically.)

1

A View of Life

OUTLINE

- I. What is life?
 - A. Specific organization
 - B. Metabolism
 - C. Homeostasis
 - D. Growth
 - E. Movement
 - F. Responsiveness
 - G. Reproduction
 - H. Adaptation
- II. The organization of life
 - A. Organization of the organism
 - B. Ecological organization
- III. The variety of organisms
 - A. Kingdom Monera
 - B. Kingdom Protista
 - C. Kingdom Fungi
 - D. Kingdom Plantae (plants)
 - E. Kingdom Animalia (animals)
- IV. How biology is studied
 - A. Systematic thought processes
 - B. Designing an experiment
 - C. How a hypothesis becomes a theory
 - D. The ethics of science

LEARNING OBJECTIVES

After you have read this chapter you should be able to:

- 1. Distinguish between living and nonliving things, describing the features that characterize living things.
- 2. Define *metabolism* and *homeostasis*, and give examples of these processes.
- 3. Define *adaptation*, and describe its function in promoting perpetuation of a species.
- 4. List in sequence and briefly describe each of the levels of biological organization.
- 5. Describe the roles and interdependence of producers, consumers, and decomposers.
- 6. Identify the five kingdoms of living organisms, and give examples for each group.
- 7. Design an experiment to test a given hypothesis using the procedure and terminology of the scientific method.
- 8. Outline the ethical dimensions of the scientific method, and give examples of possible ethical problems that may arise in the course of scientific investigation.