





---

# BIOLOGY

## SECOND EDITION

Donald D. Ritchie

BARNARD COLLEGE OF COLUMBIA UNIVERSITY

Robert Carola

**ADDISON-WESLEY PUBLISHING COMPANY**

Reading, Massachusetts  
Menlo Park, California  
London  
Amsterdam  
Don Mills, Ontario  
Sydney

---

**This book is in the Addison-Wesley Series in Life Science**

Sponsoring Editor: Nancy J. Kralowetz

Production Editor: Laura R. Skinger

Copy Editor: Nancy Shapiro

Text and Cover Designer: Catherine L. Dorin

Illustrators: Oxford Illustrators

Phil Carver and Friends

Donald D. Ritchie

Photo Researchers: Diann Korta

Mary Dyer

Cover Photographer: Charles Steinhacker

Production Manager: Herbert Nolan

The text of this book was composed in Palatino by York Graphic Services, Inc.

**Library of Congress Cataloging in Publication Data**

Ritchie, Donald D.

Biology.

Bibliography: p.

Includes index.

1. Biology. I. Carola, Robert. II. Title.

QH308.2.R57 1983 574 82-11318

ISBN 0-201-06356-5

*Reprinted with corrections, June 1983*

Copyright © 1983, 1979 by Addison-Wesley Publishing Company, Inc.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the publisher.

Printed in the United States of America. Published simultaneously in Canada.

ISBN 0-201-06356-5

CDEFGHIJ-DO-89876543

# BIOLOGY

**This book is dedicated to Ann Carola**

A great man of science . . . knows  
everything about everything, except why  
a hen's egg don't turn into a crocodile,  
and two or three other things.

Charles Kingsley  
*The Water Babies*

# Preface

COMPLEX PROCESSES HAVE BEEN  
EXPLAINED STEP-BY-STEP

"TO SUM UP" SECTIONS HAVE BEEN  
ADDED

TECHNICAL TERMINOLOGY HAS BEEN  
REDUCED

CHAPTERS HAVE BEEN REWRITTEN

KEY POINTS HAVE BEEN OUTLINED

CHAPTER SUMMARIES HAVE BEEN  
RETAINED

This second edition of *Biology* has been written for introductory biology courses. Our most important considerations were to give the student the information needed to have a comprehensive view of modern biology, while at the same time making the material *understandable*. If it took two paragraphs instead of one to explain a concept properly, we used two. If four pictures provided a better explanation than one, we used four. Whenever it was possible to take a difficult process and break it down into its sequential steps, we did it, and we placed a picture at each step. (See "How Are Proteins Synthesized?" starting on page 116, "Mitosis" on page 131, "Meiosis" on page 137, "The Mechanism of Nerve Action" on page 398, and "The Mechanics of Heart Action" on page 488, for example; there are several other similar sections.)

Whenever a section contained a particularly complex idea, we added an itemized summary, "To Sum Up," at the end of it. We tried in every way possible to anticipate the students' questions and to answer them simply and clearly.

Many so-called technical terms have been omitted, and the overall word count of the book has been decreased substantially. More pictures have been added, and they have been made larger.

Many chapters have been redone completely. The ecology chapters, for instance, have been rewritten after discussion with biology teachers all over the country, and the pictures, especially the photographs, were carefully chosen to complement the text and improve the discussion. Large, full-color photographs help improve the ecology chapters. The Chemistry of Life, Cellular Respiration, The Genetic Code and Protein Synthesis, and other chapters have been modified to make them more accessible to the student. The final part, "Evolution, Ecology, and Animal Behavior" has been reorganized to integrate the chapters within.

Each chapter begins with an itemized list entitled "Some Key Points." Written without using any technical terms, these sections are meant to introduce the student to the important points of the chapter. At the same time, itemized, detailed Chapter Summaries have been placed at the end of each chapter. These summaries were especially well received in the first edition.

CHAPTER-END QUESTIONS HAVE BEEN ADDED

As many as 15 questions have been added at the end of each chapter. These questions, entitled Ask Yourself, have been written to help the student review and understand the text. For the convenience of the instructor, answers to all questions appear in the Instructor's Manual. An exception to the general format occurs in the two chapters dealing specifically with genetics, where Genetics Problems and Answers of a more quantitative nature appear. Additional questions and answers dealing with genetics are found in the Instructor's Manual.

RECOMMENDED READINGS HAVE BEEN UPDATED

An updated list of Recommended Reading, again chosen for the student who would like to do some follow-up reading of relatively non-technical material, has been placed in the students' Study Guide and in the Instructor's Manual.

THE INDEX HAS BEEN EXPANDED AND THE GLOSSARY HAS BEEN UPDATED

The Index in the second edition contains about twice as many entries as the previous one. Its approximately 6000 entries make it the most comprehensive and useful index available for a book of this type. Also, the already comprehensive Glossary has been updated and made more complete.

COLOR PORTFOLIOS EXPAND BASIC INFORMATION

Like the first edition, the second edition contains several full-color portfolios that expand on themes introduced within the text. These color portfolios (such as "How Animals Move," following page 430, and "What Animals See," following page 414) were one of the favorite features of both teachers and students. We are gratified that the portfolios have proved to be entertaining, but perhaps even more important, they are also instructive and supportive.

BOXED ESSAYS HAVE BEEN UPDATED

Users of the first edition told us that they enjoyed the boxed essays. The reviewers of the present edition urged us to include the essays in the new edition. So we did, updating, adding, shortening, and generally trying to make them even more useful and interesting.

CAPTIONS ARE SHORTER AND LABELS HAVE BEEN ADDED

The length of the captions has been reduced, so that the student receives the necessary information quickly and clearly. To supplement this change, many labels have been added to photographs to increase their usefulness. On the other hand, if a label on a drawing seemed unnecessary or overly technical, it was deleted.

MANY PICTURES HAVE BEEN ADDED

Finally, the number of pictures has been increased markedly. Many new scanning electron micrographs are included, full-color photographs are used when they enhance the discussion, and several simplified drawings have been inserted in place of (or in addition to) single, comprehensive ones. In general, the pictures are larger, clearer, and more instructive. Photographs have been grouped into compact picture essays when several photographs did the job better than one (see Chapter 26, The Mechanisms of Evolution, for example, especially pages 526, 527, and 537). All in all, we tried to be consistently aware of the power of well-chosen pictures, and did our best to use them in the students' best interests.

Preparing a revision can be terribly boring, but we felt only positive feelings about this revision. Every time we discovered an opportunity to improve the book we were exhilarated by the actual process of finding a better way. We look forward to a third edition, and we ask you to help us make it even better than this one. If you have any suggestions, write to us in care of Addison-Wesley.



**ACKNOWLEDGMENTS**

We were fortunate to have the assistance of many reviewers, all of whom spent a great deal of time reading the manuscript and scrutinizing the pictures in the course of making many intelligent and insightful suggestions. We would like to thank them all:

Teresa Audesirk  
University of Missouri  
Sara Bennett  
Chesterfield, New Hampshire  
Richard Boohar  
University of Nebraska  
William Bowen  
University of Arkansas  
Robert C. Evans  
Rutgers State University  
Kathleen Fields  
Cambridge, Massachusetts  
Paul Hertz  
Barnard College  
Craig Himes  
Bloomsburg State College  
Joseph Hindman  
Washington State University  
Joyce Maxwell  
California State University–Northridge  
Charles R. Noback  
College of Physicians and Surgeons  
Columbia University  
Richard St. John  
Widener College  
John Schmitt  
Ohio State University  
Genevieve Tvrdik  
Slippery Rock State College  
Charles K. Wagner  
Clemson University

We would also like to thank the staff of Addison-Wesley, especially our editors, James Funston and Nancy Kralowetz.

New York  
December 1982

D.D.R.  
R.C.

# Abridged Contents

<b>Prologue</b>	1	<b>16</b> Development of Higher Plants	336
<b>PART ONE</b>		<b>17</b> Nutrition, Growth, and Regulation in Plants	354
<b>THE MECHANICS OF LIFE</b>		<b>PART SIX</b>	
<b>1</b> The Chemistry of Life	15	<b>THE PHYSIOLOGY OF ANIMALS</b>	
<b>2</b> Energy for Life	39	<b>18</b> Animal Hormones and the Endocrine System	375
<b>PART TWO</b>		<b>19</b> The Action of Nerve Cells	394
<b>THE LIFE OF CELLS</b>		<b>20</b> The Nervous System	405
<b>3</b> Cells and Cell Structure	49	<b>21</b> The Skeletal and Muscular Systems	431
<b>4</b> Photosynthesis: Trapping and Storing Energy	73	<b>22</b> Nutrition and the Digestive System	445
<b>5</b> Cellular Respiration: The Release of Energy	85	<b>23</b> The Excretory System and Temperature Regulation	462
<b>6</b> The Importance of DNA	98	<b>24</b> The Respiratory and Circulatory Systems	475
<b>7</b> The Genetic Code and Protein Synthesis	110	<b>PART SEVEN</b>	
<b>8</b> Cellular Growth, Reproduction, and Specialization	129	<b>EVOLUTION, ECOLOGY, AND ANIMAL BEHAVIOR</b>	
<b>PART THREE</b>		<b>25</b> Darwinian Evolution	505
<b>THE DIVERSITY OF LIFE</b>		<b>26</b> The Mechanisms of Evolution	521
<b>9</b> The Living Kingdoms: The Lower Groups and Plants	155	<b>27</b> The Ecology of Populations	540
<b>10</b> The Living Kingdoms: The Animals	186	<b>28</b> The Ecology of Communities	566
<b>PART FOUR</b>		<b>29</b> The Patterns of Animal Behavior	604
<b>GENETICS AND ANIMAL DEVELOPMENT</b>		<b>30</b> Animal Societies	620
<b>11</b> Mendelian Genetics	233	<b>31</b> The Origin and Development of Life on Earth	634
<b>12</b> Genetics and Chromosomes	245	Metric Conversion Factors	645
<b>13</b> Human Reproduction	266	Glossary	G-1
<b>14</b> Human Development	289	Photo Acknowledgments	P-1
<b>PART FIVE</b>		Index	I-1
<b>THE LIFE OF PLANTS</b>			
<b>15</b> Reproduction in Plants	309		

# Contents

## Prologue

1

*Essay: THE ROLE OF ENZYMES 28*  
*Essay: PROTEIN AND PERMANENT WAVES 36*

## PART ONE THE MECHANICS OF LIFE

### 1

#### The Chemistry of Life

15

SOME KEY POINTS	15
BIOLOGICALLY USEFUL CHEMICAL ELEMENTS	15
THE STRUCTURE OF ATOMS	16
Atomic Number and Atomic Weight 17	
Energy-Level Shells 18	
THE UNION OF ATOMS: CHEMICAL BONDS	20
Covalent Bonds 20	
Ionic Bonds 20	
Hydrogen Bonds 21	
CHEMICAL REACTIONS	22
Some Important Chemical Reactions 22	
Oxidation-reduction 22   Hydrolysis 23	
Condensation 23	
IONS, ACIDS, AND BASES	23
Measurement and Effects of Acidity 23	
SOME IMPORTANT BIOLOGICAL MOLECULES	25
Water 25	
Carbohydrates 27	
Lipids 31	
Fats 31   Phospholipids 32   Steroids 33	
Proteins 34	
Amino acids 34   The levels of protein structure 35	
Nucleic Acids 37	
BIOLOGICAL LEVELS OF ORGANIZATION	37
SUMMARY	38
ASK YOURSELF	38
<i>Essay: ISOTOPES AS AIDS TO BIOLOGISTS 16</i>	

### 2

#### Energy for Life

39

SOME KEY POINTS	39
SOME PRINCIPLES OF ENERGY CONVERSION	40
HOW IS ENERGY MEASURED?	41
THE RELEASE OF BIOLOGICAL ENERGY IS USUALLY SLOW AND STEADY	41
THE PHYSICAL TRANSFER OF ENERGY REQUIRES A TRANSFER OF ELECTRONS	44
SUMMARY	45
ASK YOURSELF	45
<i>Essay: BIOLOGICAL LUMINESCENCE 42</i>	

## PART TWO THE LIFE OF CELLS

### 3

#### Cells and Cell Structure

49

SOME KEY POINTS	49
WHAT ARE CELLS?	49
PLANT CELL WALLS AND ANIMAL CELL COATS	52
Plant Cell Walls 52	
Animal Cell Coats 53	
CYTOPLASM	53
Cell Membranes 53	
Cell membrane structure 54   The fluid mosaic model 54   Membrane permeability and osmosis 56   Transport across membranes 58	
Particle transport 59	
Endoplasmic Reticulum 60	
Ribosomes 61	

Golgi Bodies and Lysosomes	61
Plastids	63
Mitochondria	63
<i>Plastids and mitochondria as symbiotic organelles</i>	63
Microtrabeculae	64
Microtubules	64
Centrioles	65
THE NUCLEUS AND NUCLEAR MEMBRANES	66
Chromosomes	66
Nucleoli	70
PROKARYOTES AND EUKARYOTES	70
SUMMARY	70
ASK YOURSELF	72
<i>Essay: TAKING CELLS APART TO PUT THEM BACK TOGETHER</i>	64
<i>Essay: CILIA AND FLAGELLA: MICROSCOPIC MOVEMENT</i>	68

## 4

### Photosynthesis: Trapping and Storing Energy 73

SOME KEY POINTS	73
WHAT IS PHOTOSYNTHESIS?	73
PRODUCERS AND CONSUMERS: AUTOTROPHS AND HETEROTROPHS	74
WHAT ARE THE REQUIREMENTS FOR PHOTOSYNTHESIS?	74
Light	74
Chlorophyll, the Photosynthetic Pigment	75
Plastid Organization	76
Carbon Dioxide	77
Water	77
Other Photosynthetic Requirements	78
UNDERSTANDING THE TWO PHASES OF PHOTOSYNTHESIS	79
THE LIGHT REACTIONS OF PHOTOSYNTHESIS	79
THE DARK REACTIONS OF PHOTOSYNTHESIS	80
THE FATE OF WATER IN PHOTOSYNTHESIS	82
ALTERNATIVE PHOTOSYNTHETIC SCHEMES	82
SUMMARY	83
ASK YOURSELF	83

## 5

### Cellular Respiration: The Release of Energy 85

SOME KEY POINTS	85
THE STAGES OF RESPIRATION	86
Glycolysis: The Initial Breakdown of Glucose	86
Fermentation: One Possible Fate of Pyruvic Acid	89
The Krebs Cycle: A Second Possible Fate of Pyruvic Acid	89
The Electron Transport System is the Main Producer of ATP	93
THE CHEMIOSMOTIC EXPLANATION OF MITOCHONDRIAL ATP PRODUCTION	95
RESPIRATION OF OTHER FOODS	95
SUMMARY	96

ASK YOURSELF	97
--------------	----

*Essay: BEER, WINE, AND YOGURT* 88  
*Essay: CYANIDE, MUSHROOMS, AND OTHER FOES OF RESPIRATION* 92

## 6

### The Importance of DNA 98

SOME KEY POINTS	98
NUCLEIC ACIDS	99
PROOF OF THE GENETIC IMPORTANCE OF DNA	100
THE RACE FOR THE DOUBLE HELIX	103
HOW DNA REPRODUCES ITSELF	107
SUMMARY	108
ASK YOURSELF	109

## 7

### The Genetic Code and Protein Synthesis 110

SOME KEY POINTS	110
WHAT IS A GENE?	110
THE ONE GENE-ONE ENZYME HYPOTHESIS	111
THE TRIPLET CODE	111
THE GENETIC CODE	112
THE TRANSCRIPTION OF RNA FROM DNA	112
Ribosomal RNA	115
Messenger RNA	115
Transfer RNA	115
HOW ARE PROTEINS SYNTHESIZED?	116
GENE REGULATION: THE JACOB-MONOD MODEL	119
SPLIT GENES	125
SUMMARY	128
ASK YOURSELF	128
<i>Essay: HOW THE GENETIC CODE WAS DECIPHERED</i>	113
<i>Essay: TURNING GENES ON AND OFF</i>	120
<i>Essay: HOW TO MAKE A GENE</i>	126

## 8

### Cellular Growth, Reproduction, and Specialization 129

SOME KEY POINTS	129
THE MECHANICS OF CELL DIVISION	130
Mitosis Distributes Equal DNA to Each New Cell	131
Meiosis Reduces the Chromosome Number to Half	137
COMMON TYPES OF CELLULAR SPECIALIZATION	142
BIOLOGICAL FEEDBACK PROVIDES HOMEOSTASIS FOR THE SYSTEM	142
Feedback Systems Affect Stability	143
TOTIPOTENCY: EVEN MATURE CELLS CONTAIN ALL THE GENETIC CONTENT OF THE ORGANISM	145
CANCER OCCURS WHEN FEEDBACK CONTROL IS MISSING	146

SUMMARY	152
ASK YOURSELF	152
<i>Essay: NUCLEAR TRANSPLANTS, EMBRYOS, AND CLONES</i>	144
<i>Essay: ENVIRONMENTAL CAUSES OF CANCER</i>	148
<i>Essay: AGING AND DEATH</i>	150

## PART THREE THE DIVERSITY OF LIFE

# 9

## The Living Kingdoms: The Lower Groups and Plants 155

SOME KEY POINTS	155
SCHEMES OF CLASSIFICATION	156
THE LIVING KINGDOMS	157
THE KINGDOM OF THE MONERA	157
Viruses	157
Bacteria	159
Distribution of bacteria	159
Activities of bacteria	160
Identification of bacteria	160
Structure of bacteria	161
Reproduction of bacteria	161
Destructive action of bacteria	162
Protection against bacteria	162
Usefulness of bacteria	163
Actinomycetes	163
Blue-green Algae	164
THE KINGDOM OF THE PROTISTA	165
Phylum Protozoa	165
Phylum Chrysophyta	168
Phylum Pyrrophyta	169
THE KINGDOM OF THE FUNGI	170
The Phycomycetes	170
The Ascomycetes	171
The Basidiomycetes	173
Lichens	174
THE KINGDOM OF THE PLANTS	175
Phylum Rhodophyta, the Red Algae	176
Phylum Phaeophyta, the Brown Algae	176
Phylum Chlorophyta, the Green Algae	177
Phylum Bryophyta, the Moss Plants	177
Phylum Tracheophyta, the Vascular Plants	178
Primitive tracheophytes	179
Subphylum Pteropsida	180
Class Filicineae, the ferns	180
Class Coniferae, the conifers	181
Class Angiospermae, the flowering plants	182
ASK YOURSELF	185

# 10

## The Living Kingdoms: The Animals 186

SOME KEY POINTS	186
BASES OF ANIMAL CLASSIFICATION	187
<b>Section 1</b>	
<b>Sponges through Insects</b>	189
PHYLUM PORIFERA, THE SPONGES	189
PHYLUM COELENTERATA	190

PHYLUM PLATYHELMINTHES, THE FLATWORMS	192
PHYLUM ASCHELMINTHES, THE ROUNDWORMS	193
PHYLUM MOLLUSCA, THE MOLLUSCS	193
Classes of Mollusca	194
PHYLUM ANNELIDA, THE SEGMENTED WORMS	196
PHYLUM ARTHROPODA	198
Subphylum Trilobita	198
Subphylum Chelicerata	199
Subphylum Mandibulata	201
Class Crustacea	201
Classes Chilopoda and Diplopoda	203
Class Insecta	204

## Section 2 Echinoderms through Mammals 210

PHYLUM ECHINODERMATA	210
Classes of Echinoderms	210
PHYLUM HEMICHORDATA	211
PHYLUM CHORDATA	211
Subphylum Urochordata	212
Subphylum Cephalochordata	212
Subphylum Vertebrata	213
Class Agnatha	214
Class Chondrichthyes	214
Class Osteichthyes	214
Class Amphibia	217
Class Reptilia	217
Class Aves	220
Class Mammalia	221
THE EVOLUTION OF HUMAN BEINGS	226
ASK YOURSELF	229

## PART FOUR GENETICS AND ANIMAL DEVELOPMENT

# 11

## Mendelian Genetics 233

SOME KEY POINTS	233
MENDEL AND THE BEGINNING OF STATISTICAL GENETICS	233
THE MENDELIAN LAW OF SEGREGATION	236
Genotypes and Phenotypes	238
The Test Cross	239
Incomplete Dominance	239
MENDEL'S LAW OF INDEPENDENT ASSORTMENT	240
HOW IS MEIOSIS RELATED TO MENDELIAN PRINCIPLES?	241
GENETICS PROBLEMS	243
ANSWERS TO GENETICS PROBLEMS	243
SUMMARY	244
<i>Essay: PROBABILITY AND CHANCE IN MENDELIAN GENETICS</i>	241

# 12

## Genetics and Chromosomes 245

SOME KEY POINTS	245
MUTATIONS MUST BE EXPRESSED VISIBLY	245
The Frequency of Mutations	247
Causes and Effects of Mutations	247
Artificially induced mutations	248
The Fate of Mutations	248



SEX-LINKED TRAITS IN DROSOPHILA	248
Chromosomal Sex Determination in <i>Drosophila</i>	249
NONDISJUNCTION IN DROSOPHILA	250
Nondisjunction and Sex Determination	252
GENE LINKAGE AND CROSSING OVER	252
Gene Linkage	254
Crossing Over	254
Chromosome Mapping	255
CHROMOSOMAL ABERRATIONS SOMETIMES OCCUR	256
MULTIPLE ALLELES AND BLOOD GROUPS	257
Multiple Alleles and Blood Grouping	257
SEX-LINKED GENES IN HUMAN BEINGS	260
SOME EFFECTS OF HUMAN CHROMOSOMAL ABERRATIONS	261
Nondisjunction in Human Chromosomes	262
Aberrations in Human Sex Chromosomes	262
MULTIPLE FACTOR INHERITANCE	263
GENETICS PROBLEMS	264
ANSWERS TO GENETICS PROBLEMS	264
SUMMARY	265
<i>Essay: RECOMBINANT DNA</i> 250	
<i>Essay: MARY LYON AND CALICO CAT</i> 259	

# 13

## Human Reproduction 266

SOME KEY POINTS	266
ASEXUAL REPRODUCTION IS USUALLY LIMITED TO THE SIMPLER ANIMALS	266
VARIATIONS IN ANIMAL REPRODUCTIVE PROCESSES	266
HUMAN SEXUAL ANATOMY AND FUNCTION: MALE	269
The Testes	269
Hormonal Regulation in the Male	270
Puberty and "Menopause"	271
Spermatogenesis	271
Accessory Ducts and Glands	272
The Penis	272
SOME CLINICAL CONSIDERATIONS	273
HUMAN SEXUAL ANATOMY AND FUNCTION: FEMALE	273
The Ovaries and Oviducts	273
Oogenesis	274
The Uterus, Vagina, and External Genitalia	276
The Mammary Glands	277
Hormonal Regulation in the Nonpregnant Female	277
Hormonal Regulation in the Pregnant Female	280
Puberty and Menopause	280
HUMAN MATING	280
CONCEPTION	281
CONTRACEPTION	284
VENEREAL DISEASES	285
SUMMARY	287
ASK YOURSELF	288
<i>Essay: HUMAN SEX DETERMINATION</i> 286	

# 14

## Human Development 289

SOME KEY POINTS	289
A REVIEW OF MITOSIS AND MEIOSIS	290
PRINCIPLES OF EARLY EMBRYONIC DEVELOPMENT	291
Early Cleavage in Vertebrates	292
Gastrulation	292
Early Human Development	292
DEVELOPMENT OF HUMAN EMBRYOS	293
Implantation in the Uterus	293
The Fetal Membranes and the Placenta	296
LATE EMBRYONIC DEVELOPMENT AND BIRTH	299
The Process of Childbirth	301
The Breathing Process of the Newborn	303
Lactation	304
SUMMARY	304
ASK YOURSELF	305
<i>Essay: THE DEVELOPMENT OF THE SPINAL CORD AND EYE</i> 294	
<i>Essay: MULTIPLE BIRTHS IN HUMAN BEINGS</i> 298	
<i>Essay: AMNIOCENTESIS: "VISITING" THE BABY BEFORE BIRTH</i> 300	

*Color Portfolio: HOW A HUMAN EMBRYO DEVELOPS* 302

## PART FIVE THE LIFE OF PLANTS

# 15

## Reproduction in Plants 309

SOME KEY POINTS	309
ASEXUAL REPRODUCTION IS USED BY SOME SPECIES OF PLANTS	310
Fission and Fragmentation	310
Spores	310
Vegetative Reproduction	310
THE ORIGIN OF COMPLEX SEXUALITY	312
SEXUAL REPRODUCTION IN LOWER PLANTS	313
Algae	313
Fungi	314
Mosses and Ferns	316
SPORE AND SEED PRODUCTION	319
Heterospory	319
Conifers	319
FLOWERING PLANTS	323
Flowers: Structure and Variation	323
Spore Production in Flowers	325
Pollination	326
Seed and Fruit Formation	328
SUMMARY	334
ASK YOURSELF	335
<i>Essay: SEEDS AND CIVILIZATION</i> 320	
<i>Essay: FRUITS WITHOUT SEEDS</i> 330	

# 16

## Development of Higher Plants 336

SOME KEY POINTS	336
GERMINATION IS THE RECOMMENCEMENT OF THE LIFE OF A SEED	338
ROOTS ARE THE ANCHORING AND ABSORBING ORGANS OF A PLANT	338
STEMS SERVE MAINLY FOR SUPPORT AND CONDUCTION	341
LEAVES ARE THE MAIN PHOTOSYNTHETIC ORGANS OF PLANTS	348
SUMMARY	352
ASK YOURSELF	353

# 17

## Nutrition, Growth, and Regulation in Plants 354

SOME KEY POINTS	354
MINERAL NUTRITION OF PLANTS	354
Soils 354	
Mineral Requirements of Plants 356	
TRANSLOCATION IN PLANTS	357
Rise of Water 357	
Phloem Transport 358	
GROWTH REGULATION IN PLANTS	359
Tropisms and Auxin 359	
Other Actions of Auxin 362	
Phytochrome and Photoperiodism 365	
"Florigen" 366	
Other Growth-Regulating Substances 366	
Growth Retardants 369	
SUMMARY	370
ASK YOURSELF	371
<i>Essay: MANY FROM ONE OR TWO</i> 363	
<i>Essay: WITCHWEED</i> 368	

## PART SIX THE PHYSIOLOGY OF ANIMALS

# 18

## Animal Hormones and the Endocrine System 375

SOME KEY POINTS	375
THE ENDOCRINE SYSTEM DEPENDS ON A FEEDBACK SYSTEM	376
THE VERTEBRATE PITUITARY GLAND AND ITS RELATIONSHIP TO THE HYPOTHALAMUS	377
Some Disorders of the Pituitary 382	
THE THYROID GLAND REGULATES METABOLIC FUNCTIONS	383
Some Disorders of the Thyroid 383	
THE PARATHYROID GLANDS	384

THE ADRENAL GLANDS	384
Some Disorders of the Adrenal Glands 387	
THE PANCREAS	388
Some Disorders of the Pancreas 388	
THE GONADS	389
OTHER SOURCES OF HORMONES	389
The Pineal Gland 389	
The Thymus Gland 389	
The Digestive System 390	
Prostaglandins 390	
WHAT MECHANISM CONTROLS THE ENDOCRINE SYSTEM?	391
SUMMARY	392
ASK YOURSELF	393
<i>Essay: INVERTEBRATE HORMONES</i> 380	
<i>Essay: NEW IDEAS IN BIOLOGICAL CONTROL: RADIOIMMUNOASSAY (RIA)</i> 381	
<i>Essay: JFK'S "SUNTAN" AND NAPOLEON'S NAPS</i> 386	

# 19

## The Action of Nerve Cells 394

SOME KEY POINTS	394
NEURONS ARE THE FUNCTIONAL UNITS OF THE NERVOUS SYSTEM	394
Parts of the Neuron 395	
Types of Neurons 396	
HOW IS A NERVE IMPULSE TRANSMITTED?	397
The Reflex Arc 398	
The Mechanism of Nerve Action 398	
The sodium-potassium pump and ion channels 400	
How Fast Does a Nerve Impulse Travel? 400	
The Synapse 401	
SUMMARY	404
ASK YOURSELF	404
<i>Essay: THE GIANT AXONS OF SQUIDS</i> 400	

# 20

## The Nervous System 405

SOME KEY POINTS	405
THE CENTRAL NERVOUS SYSTEM	405
The Spinal Cord 406	
The Brain 407	
THE PERIPHERAL NERVOUS SYSTEM	411
The Somatic Nervous System 411	
The Autonomic Nervous System 412	
THE SENSES: PERCEPTION OF STIMULI	414
The Eye and Vision 414	
The Touch Receptors 420	
Taste and Smell 421	
Hearing and Balance 422	
CONSCIOUSNESS AND BEHAVIOR	425
Learning and Memory 425	
Sleep and Dreams 426	
Drugs and the Nervous System 427	
Curare 428	
Pesticides and "nerve gases" 428	
Botulinus toxin 428	

SUMMARY	428
ASK YOURSELF	430
<i>Essay: THE SPLIT BRAIN IN HUMAN BEINGS</i>	410
<i>Essay: BIOFEEDBACK: THE BRAIN CONTROLS THE BODY</i>	412
<i>Color Portfolio: WHAT ANIMALS SEE</i>	414

## 21

### The Skeletal and Muscular Systems 431

SOME KEY POINTS	431
BONES DO MORE THAN SUPPORT THE BODY	431
The Structure of Bone	432
The Classification of Bone	433
THE VERTEBRATE SKELETON IS ESSENTIAL FOR SUPPORT, MOVEMENT, AND PROTECTION	434
The Organization of the Vertebrate Skeleton	434
Joints	436
THE INTEGRATION OF BONES AND MUSCLES	437
The Lever Action of Bones and Muscles	437
SKELETAL MUSCLE	438
The Cellular Structure of Skeletal Muscle	439
The Molecular Mechanism of Muscle Contraction	440
The Nervous Control of Muscle Contraction	442
Energy for Contraction	442
SMOOTH MUSCLE	443
CARDIAC MUSCLE	443
SUMMARY	444
ASK YOURSELF	444
<i>Essay: SUNLIGHT AND SKELETON BUILDING</i>	435
<i>Essay: SPRAINS, STRAINS, DISLOCATIONS, AND FRACTURES</i>	439
<i>Color Portfolio: HOW ANIMALS MOVE</i>	430

## 22

### Nutrition and the Digestive System 445

SOME KEY POINTS	445
WHAT ARE THE ESSENTIAL NUTRIENTS?	445
Carbohydrates	446
Fats	446
Proteins	448
Vitamins	448
Minerals	451
THE DIGESTIVE PROCESS REDUCES LARGE INSOLUBLE MOLECULES TO SMALL, SOLUBLE ONES	451
ADAPTATIONS IN DIGESTIVE SYSTEMS	451
THE HUMAN DIGESTIVE SYSTEM IS COMPARTMENTALIZED	451
Digestion in the Oral Cavity	454
Digestion in the Stomach	455
Digestion in the Small Intestine	456
Enzymes for Digestion in the Small Intestine	457
The Liver as a Digestive Organ	458
The Pancreas as a Digestive Organ	459
Action of the Large Intestine	460

SUMMARY	460
ASK YOURSELF	461
<i>Essay: HUNGER AND STARVATION</i>	446
<i>Color Portfolio: HOW ANIMALS EAT</i>	446

## 23

### The Excretory System and Temperature Regulation 462

SOME KEY POINTS	462
SALT AND WATER BALANCE IN ANIMALS	462
INVERTEBRATE EXCRETORY MECHANISMS	463
THE VERTEBRATE KIDNEYS AND EXCRETORY SYSTEM	464
THE MECHANISM OF URINE COLLECTION	467
Glomerular Filtration, Tubular Secretion, and Tubular Reabsorption	467
Urine and Urination	468
THE LIVER AS AN EXCRETORY ORGAN	469
THE SKIN	469
REGULATION OF BODY TEMPERATURE	471
Adaptations to Cold	472
Adaptations to Heat	473
SUMMARY	474
ASK YOURSELF	474
<i>Essay: ARTIFICIAL KIDNEYS</i>	466
<i>Essay: DESERT RATS, CAMELS, AND "WARM-BLOODED" FISHES</i>	470

## 24

### The Respiratory and Circulatory Systems 475

SOME KEY POINTS	475
THE EVOLUTION OF GAS EXCHANGE IN ANIMALS	475
Respiration by Surface Diffusion	475
Gills	476
Lungs	476
Tracheae	477
RESPIRATION IN HUMAN BEINGS	478
The Organization of the Respiratory System	478
The Mechanics of Breathing	479
The Control of Breathing Rate	481
Gas Exchange in the Lungs	481
THE GAS-CARRYING ABILITY OF BLOOD	482
The Transport of Oxygen in Blood	482
The Transport of Carbon Dioxide in Blood	482
BLOOD SERVES MANY FUNCTIONS IN THE HUMAN BODY	482
Composition of Blood	483
How Blood Clots	485
THE HEART IS A DOUBLE PUMP	485
The Quantity of Blood Circulated	486
The Mechanics of Heart Action	486
The Control of Heart Muscle Activity	489
THE CIRCULATORY SYSTEM HELPS TO MAINTAIN HOMEOSTASIS	491
Arteries, Capillaries, and Veins	491

Arteries 494	Capillaries 494	Veins 494
The Lymphatic System 494		
IMMUNOLOGY	496	
SUMMARY	499	
ASK YOURSELF	501	
<i>Essay: THE UNHEALTHY HEART 490</i>		
<i>Essay: BLOOD PRESSURE 493</i>		
<i>Essay: IMMUNITY FROM NAZI SLAVERY 497</i>		
<i>Essay: ALLERGY: WHAT IS IT? 498</i>		

## PART SEVEN EVOLUTION, ECOLOGY, AND ANIMAL BEHAVIOR

# 25

### Darwinian Evolution 505

SOME KEY POINTS	505
THE IDEA OF EVOLUTION	506
Geological Sources 506	
Lamarckian Evolution 506	
CHARLES DARWIN AND THE VOYAGE OF THE BEAGLE	507
The Influence of Malthus 508	
NATURAL SELECTION: THE KEY IS	
VARIATION AND SURVIVAL	509
What Role Does the Environment Play? 509	
DARWIN'S THEORY UPDATED	510
THE EVIDENCE FOR EVOLUTION	512
Comparative Anatomy 512	
Embryological Development of Animals 515	
Variations among Domestic Species 515	
The Geographical Distribution of	
Organisms 515	
Fossil Organisms 516	
EXPERIMENTAL EVOLUTION	518
SUMMARY	519
ASK YOURSELF	520
<i>Essay: THE COCKROACH:</i>	
<i>EVOLUTIONARY PERFECTIONIST 511</i>	
<i>Essay: DARWIN'S FINCHES 517</i>	

# 26

### The Mechanisms of Evolution 521

SOME KEY POINTS	521
VARIATIONS CAN BE INDUCED GENETICALLY	
OR ENVIRONMENTALLY	521
Mutation and Recombinants as the Basis of	
Variation 522	
Great Changes or Small? 522	
ADAPTATION IS CRUCIAL IN A CHANGING	
ENVIRONMENT	522
Industrial melanism 524	
Cryptic	
coloration 525	
Mimicry 526	
Warning	
coloration and adaptive coloration 528	
"SPECIES" IS DIFFICULT TO DEFINE	528
DEMES ARE GROUPS OF INDIVIDUALS ISOLATED	
FROM THEIR SPECIES	529
GENE POOLS	530

THE HARDY-WEINBERG PRINCIPLE IS EFFECTIVE	530
ONLY IF GENETIC STABILITY IS ASSUMED	532
GENETIC DRIFT IS THE RESULT OF CHANCE	532
SPECIATION IS THE PRODUCTION OF NEW	
SPECIES FROM OLD ONES	533
Polyploidy 533	
Adaptive Radiation 534	
Reproductive Isolation 534	
Sympatric and Allopatric Species 534	
CONVERGENT EVOLUTION: CHANGES	
TOWARD SIMILARITY	534
COEVOLUTION	535
INORGANIC EVOLUTION	537
SUMMARY	538
ASK YOURSELF	539
<i>Essay: THE EVOLUTION OF ANIMAL BEHAVIOR 524</i>	
<i>Color Portfolio: HOW ANIMALS AVOID PREDATORS 526</i>	

# 27

### The Ecology of Populations 540

SOME KEY POINTS	540
ECOLOGY AND THE LEVELS OF ORGANIZATION	540
ECOLOGY IS RELATED TO HUMAN AFFAIRS	541
THE METHODS OF ECOLOGY ARE VARIED	542
Recording and Estimating Population	
Changes 543	
HUMAN POPULATION: THE UNITED STATES	544
HUMAN POPULATION: THE WORLD	545
HABITATS AND NICHES	548
ABIOTIC FACTORS AFFECTING DISTRIBUTION	
AND ABUNDANCE	550
Water 550	
Temperature 550	
Light 551	
Mineral Nutrients 552	
Fire 554	
BIOTIC FACTORS AFFECTING DISTRIBUTION	
AND ABUNDANCE	555
Dispersal 555	
Behavior 556	
Competition 557	
Predation 559	
Parasitism 562	
Mutualism 563	
BIOTIC FACTORS USUALLY DEPEND ON DENSITY;	
CLIMATIC FACTORS DO NOT	564
SUMMARY	565
ASK YOURSELF	565
<i>Essay: INNOVATIVE PREDATORY BEHAVIOR IN ANIMALS 560</i>	

# 28

### The Ecology of Communities 566

SOME KEY POINTS	566
ECOSYSTEMS INCLUDE BOTH LIVING AND	
NONLIVING FEATURES	567
PRIMARY PRODUCTIVITY RELIES ON ENERGY	
FROM THE SUN	567