



# THE STUDY OF BIOLOGY

Third Edition

Jeffrey J. W. Baker • Garland E. Allen

**Jeffrey J. W. Baker** Wesleyan University

**Garland E. Allen** Washington University

**THE  
STUDY  
OF  
THIRD EDITION  
BIOLOGY**



**Addison-Wesley Publishing Company**

Reading, Massachusetts

Menlo Park, California • London • Amsterdam

Don Mills, Ontario • Sydney

The front and back covers show scanning electron microscope pictures of an egg laid by the silk moth *Antheraea polyphemus*. **Front cover:** High-magnification view of a cross section of a portion of the egg's surface. The structures protruding from the surface are called aeropyles. When submerged in water, these structures trap a layer, the equivalent of a large bubble, next to the egg's surface. Oxygen diffuses from the surrounding water into the bubble; from the bubble it diffuses into the egg to support respiration. Carbon dioxide, a waste product of respiration, passes from egg to bubble to water. **Insert on back cover;** Low-magnification view of a whole egg. The surface is differentiated into three areas: a central smooth area containing the micropyle (a pore through which sperm enters), a surrounding rough layer exhibiting the aeropyles, and smooth sides. (Courtesy Gretchen Dane Mazur, Harvard University Biological Laboratories, and Ed Seling, Museum of Comparative Zoology, Scanning Electron Microscope Laboratory, Harvard University.)

The cell shown opposite the title page was infected with a tumor virus called polyoma. The virus caused the cell to undergo changes in both morphology and growth properties (a process called transformation) so that now it is more like a cancer cell than a normal cell. This particular cell is enormous relative to the surrounding cells. Such cells occur fairly frequently in this type of cell culture. The cell shown has rounded up in the early stages of cell division (mitosis). Originally the cell was spread out and covered the entire area. Then, as mitosis began, the cell cytoplasm withdrew, forming the rounded central ball and leaving behind the many fine "arms" seen in the picture. After dividing, the cell will respread as the cytoplasm flows back out into the "arms," again assuming a large, flat form. The other cells pictured are also polyoma-transformed 3T3 cells. The original line was derived from mouse embryos by Howard Green and George Todero. (Photo by Dr. Paul B. Bell, Jr., and Dr. Jean-Paul Revel, California Institute of Technology.)

---

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

Also by Baker and Allen:

*A Course in Biology*, Third Edition (1979)  
*Hypothesis, Prediction and Implication in Biology*  
(1968)

*Matter, Energy and Life:*

*An Introduction for Biology Students*, Third Edition  
(1974)

*The Process of Biology, Primary Sources* (1970)

*The Study of Botany* (coauthored with Preston Adams)  
(1970)

*The Study of Biology* foreign-language editions

Spanish: *Biología e Investigación Científica*  
First Edition

Portuguese: *Estudo da Biologia*  
Second Edition

---

*Third printing, May 1978*

Copyright © 1977, 1971, 1967 by Addison-Wesley  
Publishing Company, Inc. Philippines copyright 1977,  
1971, 1967 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. Library of Congress Catalog Card No. 76-15460.

ISBN 0-201-00349-X  
ABCDEFGHIJK-RN-798

## Preface

In preparing the third edition of *The Study of Biology* we have incorporated many suggestions from both instructors and students at a variety of colleges and universities. This has resulted in extensive rewriting, the addition of new material to virtually every chapter, reorganization of previously existing material, and the addition of new chapters. We have made the third edition of *The Study of Biology* more comprehensive as well as more up-to-date than the previous versions.

New information has been added to the chapters on cellular biology and biochemistry, reflecting recent discoveries and new concepts regarding cell structure and function. Chapters on elementary chemistry and biochemistry have been added to assure that the student has review and reference material easily available. The present edition also contains more discussion of human biology, with entirely new chapters on human genetics, reproduction, development, and sexuality. In addition, throughout already existing chapters, new material has been added relating biological issues to medical and social concerns. Since much interest has been voiced in recent years over such biological and social issues as population control, heredity, race and I.Q., the XYY chromosome complement, environmental pollution, and the general social responsibility of scientists, we have included material on these and other controversial topics. Because these issues often have a political as well as a scientific side, the authors recognize that bias could color their presentation. However, since we usually find ourselves on different sides of the political, if not always the scientific, aspects of such issues, our presentations attempt to reflect both sides of these controversies, encouraging readers to come to their own conclusions. The organization has been changed, with the present 25 chapters grouped into six units: Biology and the Scientific Enterprise, The Structure and Function of Cells, The Structure and Function of Whole Organisms, Heredity and Development, Evolutionary Biology, and Population Biology. This unit organization has brought

together in a more cohesive way chapters that deal with related topics.

Organizational changes have also been made *within* chapters. First, the main body of the text has been made to read more smoothly by separating it from supplementary material such as analyses of critical experiments, historical vignettes, and discussions of significant biosocial problems. Such supplementary material appears in tinted boxes. This separation of relevant supplementary material will introduce topics of special interest without interrupting the flow of ideas being developed in the body of the text. Second, throughout each chapter we have set off important principles in prominent headlines, a technique which will ensure that the reader focuses clearly on the biological principles being emphasized. Third, each chapter ends with a summary that can be used for study and review.

Important changes in style have also been made. In keeping with the suggestions of many users, we have abandoned (except in Chapter 1) the device of setting off hypothetico-deductive statements by indentation. Although the older format was useful to some, many felt it became distracting and monotonous when carried through the entire text. To aid the student in reading and information retrieval, we have added numerous subheadings to the text.

Although there have been many alterations, deletions, and additions in this revision, the spirit and intent of the previous two editions has been preserved. Chapters 1 and 2 explain the important role of scientific methodology in devising and testing hypotheses. Throughout the book, experimental design and detail are included (frequently in supplementary boxes) so that the student can examine some of the evidence on which generalizations and explanations are based. One of the most important opportunities an introductory science course affords the student is the opportunity to learn to think critically. To this end we continue to stress "how we know what we know"—the process and method

of scientific investigation. This goal has been maintained even as we have made the book much more comprehensive in its content coverage. To aid the student in acquiring critical attitudes, many of the exercises at the end of the chapters are inquiry-based, challenging the student to interpret scientific data, draw conclusions, and choose between alternative hypotheses.

We have eliminated all vestiges of sexism that inadvertently appeared in previous editions. While such changes are subtle, they reflect evolving social values to which we wish to give full support.

In preparing the present edition we have had the help of a number of individuals. Attila O. Klein of Brandeis University thoroughly reviewed much of the material on chemistry, cell structure and function, plant physiology, and developmental biology. Richard Booher of the University of Nebraska at Lincoln provided informative evaluation of the material on cell structure and function, plant anatomy and physiology, and genetics. Bert K. Whitten of Michigan Technological University and Jonathan C. Hake of the Group Health Hospital in Seattle, Washington, reviewed the chapters on animal structure and function and offered many useful suggestions. M. M. Green of the University of California at Davis was most helpful in his critique of the newly added material on human genetics. Alan Covich of Washington University in St. Louis played a major role in the extensive reviewing, revising, and rewriting of the chapter on ecology. Veda Andrus of Wesleyan University made many specific and helpful suggestions on the chapter dealing with human reproduction and development. Carol Lynch, also of Wesleyan University, thoroughly read the chapters on behavior. Without the help of these subject matter experts, the preparation of much of the new material would have been more difficult and less successful. We have not always followed all the advice of these consultants, however, and the authors assume full responsibility for the content and approach selected.

In addition, a number of people have helped in reviewing older chapters for the rewriting process. Among these are Johns W. Hopkins III, David Polcianski, William H. Mason, Barry Mehler, and Marvin Natowicz. Susan Allen undertook the complex and sometimes frustrating job of organizing the permission materials for new photographs. Mike Veith prepared a number of glossy prints, and Josh Tolin helped track down sources of illustrations and assisted in preparation of the Glossary, as did Ruth Balluff of Virginia. Linda Hassell undertook the detailed and tedious task of preparing the index.

*Middletown, Connecticut*  
*St. Louis, Missouri*  
*January, 1977*

J.J.W.B.  
G.E.A.

## Contents In Brief

### **Dart 1 Biology and the Scientific Enterprise 2**

- Chapter 1 The Nature and Logic of Science 5  
Chapter 2 Testing Hypotheses and Predictions 31

### **Dart 2 The Structure and Function of Cells 46**

- Chapter 3 Matter, Energy, and Chemical  
Change 49  
Chapter 4 Chemistry and Life 83  
Chapter 5 Cell Structure and Function 123  
Chapter 6 Cell Metabolism I: Energy  
Release and Metabolic Pathways 195  
Chapter 7 Cell Metabolism II: The Uphill  
Energy Pathway—Photosynthesis 243

### **Dart 3 The Structure and Function of Whole Organisms 288**

- Chapter 8 Plant Structure and Function I:  
The Movement of Materials  
through Plants 291  
Chapter 9 Plant Structure and Function II:  
Growth and Integration 347  
Chapter 10 Animal Structure and Function I:  
Homeostatic Processes in Nutrition 383  
Chapter 11 Animal Structure and Function II:  
Movement and Coordination 455

### **Dart 4 Heredity and Development 524**

- Chapter 12 Cell Reproduction 527

- Chapter 13 Genetics I: From Math to Mendel 555
- Chapter 14 Genetics II: Genes and Chromosomes 583
- Chapter 15 Genetics III: The Molecular Biology of the Gene 609
- Chapter 16 Human Heredity 661
- Chapter 17 Developmental Biology 693
- Chapter 18 Human Reproduction, Development, and Sexuality 755

## **Part 5**

### **Evolutionary Biology 816**

- Chapter 19 Taxonomy: The Classification of Living Organisms 819
- Chapter 20 The Process of Evolution 841
- Chapter 21 The Origin of Life 887
- Chapter 22 The Evolution of Plants 911
- Chapter 23 The Evolution of Animals 963

## **Part 6**

### **Population Biology 1022**

- Chapter 24 Ecological Relationships: Competition for Energy 1025
- Chapter 25 Animal Behavior 1075

---

Appendix 1 Chief Units of the Metric System A-1

Appendix 2 Conversion of Temperature Scales A-2

Appendix 3 Table of Amino Acids A-4

Appendix 4 Taxonomic Charts A-6

Glossary G-1

Index I-1



# Contents

## **Dart 1 Biology and the Scientific Enterprise 2**

### **Chapter 1 The Nature and Logic of Science 5**

- 1.1 Introduction 5
- 1.2 Biology as a Science 6
- 1.3 Observation and Scientific "Facts" 8
- Supplement 1.1: Fixing and Staining* 11
- 1.4 The "Scientific Method" 13
- 1.5 Explanations in Science 18
- 1.6 The Philosophical Side of Biology 21
- 1.7 The Limitations of Science 25
- Summary 27
- Exercises 28
- Suggested Readings 29

### **Chapter 2 Testing Hypotheses and Predictions 31**

- 2.1 Introduction 31
- 2.2 The Mystery of Homing in Salmon 31
- 2.3 Analysis and Interpretation of Data 37
- Supplement 2.1: It's All in What You Want  
To Show* 40
- Summary 42
- Exercises 42
- Suggested Readings 45

## **Dart 2 The Structure and Function of Cells 46**

### **Chapter 3 Matter, Energy, and Chemical Change 49**

- 3.1 Introduction 49
- 3.2 Matter and Energy 50
- 3.3 Atomic Structure 52
- 3.4 The Polarity of Molecules 60
- Supplement 3.1: Water and Life* 63

3.5	Ions and Radicals	64
3.6	Oxidation and Reduction: Redox Reactions	66
3.7	The Collision Theory and Activation Energy	67
3.8	Free-Energy Exchange and Chemical Reactions	69
3.9	Rates of Reaction	72
3.10	Reversible and Irreversible Reactions	74
3.11	Chemical Equilibrium	75
3.12	Acids, Bases, and the pH Scale	77
	Summary	80
	Exercises	81
	Suggested Readings	81

## Chapter 4 Chemistry and Life 83

4.1	Introduction	83
4.2	Classes of Molecules in Living Systems	84
	<i>Supplement 4.1: Structural Representations of Molecules: Glucose</i>	86
4.3	Enzymes	93
	<i>Supplement 4.2: The Efficiency of Enzyme Catalysis</i>	96
	<i>Supplement 4.3: Commercial Use of Enzymes</i>	99
4.4	Theories of Enzyme Activity	100
	<i>Supplement 4.4: How an Enzyme Works</i>	102
4.5	Enzymes and the Control of Biochemical Reactions	110
	<i>Supplement 4.5: Characteristics of Regulatory Enzymes</i>	112
	<i>Supplement 4.6: Determination of Protein Structure</i>	113
	Summary	117
	Exercises	118
	Suggested Readings	120

## Chapter 5 Cell Structure and Function 123

5.1	Introduction	123
5.2	The Cell Concept	123
5.3	Tools and Techniques for Studying Cells	126
	<i>Supplement 5.1: Upper Limit on Cell Size: A Matter of Geometry</i>	132

5.4	The Eucaryotic Cell	134
	<i>Supplement 5.2: Biological Self-Assembly</i>	149
	<i>Supplement 5.3: The Golgi Complex: A History</i>	155
	<i>Supplement 5.4: Lysosomes and Disease</i>	158
	<i>Supplement 5.5: The Function of Cell Parts: How Do We Know?</i>	160
5.5	The Procaryotic Cell	162
	<i>Supplement 5.6: Lower Limit on Cell Size: A Matter of Space</i>	169
5.6	Viruses	170
5.7	A Case Study in Structure and Function: The Cell Membrane	172
	<i>Supplement 5.7: Models in Science</i>	178
	Summary	184
	Exercises	188
	Suggested Readings	193

## Chapter 6 Cell Metabolism I: Energy Release and Metabolic Pathways 195

6.1	Introduction	195
6.2	ATP: The Energy Currency in Cells	197
6.3	Electron Transport and Energy Release: The Generation of ATP	200
	<i>Supplement 6.1: Cytochromes: How Do We Know about Them?</i>	203
	<i>Supplement 6.2: Electron Flow: A One-Way Street</i>	206
6.4	The Release of Electrons: Pathways for the Breakdown of Sugars	206
	<i>Supplement 6.3: Back-Up Enzyme Systems</i>	208
	<i>Supplement 6.4: The Economic Value of Fermentations</i>	210
6.5	Life without Air: Anaerobic Oxidation	217
6.6	Characteristics of Metabolic Pathways as Illustrated by the Oxidation of Sugars	220
	<i>Supplement 6.5: Localization within Mitochondria: The Basis for Our Knowledge</i>	224
	<i>Supplement 6.6: How the Steps in Complex Biochemical Pathways Are Investigated</i>	230
	Summary	232
	Exercises	235
	Suggested Readings	242

**Chapter 7****Cell Metabolism II: The Uphill Energy Pathway—Photosynthesis 243**

- 7.1 Introduction 243
- 7.2 Reading Case Histories 244
- 7.3 Some Early Hypotheses and Experiments 245
- 7.4 Photosynthesis: The Modern View 256
- Supplement 7.1: Chlorophyll as the Energy Absorber in Photosynthesis* 260
- Supplement 7.2: The Light Reaction: How Do We Know?* 263
- Supplement 7.3: The Dark Reaction: How Do We Know?* 268
- 7.5 Localization of Photosynthetic Components 278
- 7.6 The Efficiency of Photosynthesis 279
- Summary 281
- Exercises 284
- Suggested Readings 286

**Dart 3****The Structure and Function of Whole Organisms 288****Chapter 8****Plant Structure and Function I: The Movement of Materials through Plants 291**

- 8.1 Introduction 291
- 8.2 General Organization of a Vascular Plant 292
- 8.3 Plant Tissues 294
- 8.4 The Root System 305
- 8.5 Movement of Water and Materials into the Plant 308
- Supplement 8.1: Minerals and Plant Metabolism* 312
- 8.6 Organization of the Shoot System 313
- 8.7 Translocation through the Shoot System 316
- 8.8 Upward Movement through the Xylem 319
- 8.9 Downward Movement through the Phloem 325
- 8.10 Leaves and Translocation: Leaf Structure 328
- Supplement 8.2: Two Schools of Thought on Translocation through Phloem* 330

- 8.11 Leaves and Translocation: Gas Exchange and Transpiration 334
- 8.12 Movement of Liquid and Metabolic Waste Out of the Plant 340
- Summary 342
- Exercises 344
- Suggested Readings 345

**Chapter 9****Plant Structure and Function II: Growth and Integration 347**

- 9.1 Introduction 347
- 9.2 Increase in Size of the Plant Body 347
- 9.3 Plant Hormones 352
- 9.4 Photoperiodism 360
- Supplement 9.1: Autumn Leaves* 361
- Supplement 9.2: The Causes of Flowering: Some Early Hypotheses* 364
- 9.5 Tropisms 369
- 9.6 Apical Dominance and the Control of Plant Form 373
- Summary 377
- Exercises 379
- Suggested Readings 381

**Chapter 10****Animal Structure and Function I: Homeostatic Processes in Nutrition 383**

- 10.1 Introduction 383
- 10.2 The Principle of Homeostatic Control 384
- 10.3 Animal Tissues 387
- 10.4 Digestion 392
- Supplement 10.1: How Digestion Is Initiated* 396
- 10.5 Absorption 400
- Supplement 10.2: What Are Hunger Pangs?* 401
- 10.6 Elimination 403
- 10.7 Circulation: The Heart 404
- 10.8 Circulation: The Heartbeat 407
- 10.9 Circulation: Blood and Blood Vessels 409
- Supplement 10.3: The Clotting of Blood* 413
- 10.10 The Exchange of Materials across Capillary Walls 417
- 10.11 The Lymphatic System 418
- Supplement 10.4: Measuring Blood Pressure* 420

10.12 The Regulation of Blood Pressure 422  
*Supplement 10.5: William Harvey and the Circulation of the Blood* 424  
 10.13 Respiratory Exchange 428  
 10.14 Hemoglobin and Respiratory Gas Exchange 430  
 10.15 The Control of Breathing 433  
 10.16 Excretion 435  
 10.17 Filtration and Reabsorption 439  
 10.18 Hypertension: A Control System Gone Awry 441  
 Summary 444  
 Exercises 447  
 Suggested Readings 453

**Chapter 11**  
**Animal Structure and Function II: Movement and Coordination 455**

11.1 Introduction 455  
 11.2 Nerves and Muscles: Electrochemical Potential 455  
 11.3 The Structure of Muscle Tissue 456  
 11.4 Muscle Contraction: The Biochemical Approach 459  
 11.5 Muscle Contraction: The Biophysical Approach 462  
 11.6 Vertebrate Movement: The Relation of Muscle to Bone 466  
 11.7 Neurons and the Nature of the Nerve Impulse 468  
*Supplement 11.1: Nerves and Electricity* 469  
 11.8 Neuron-to-Neuron Connections 481  
 11.9 Neuron-to-Muscle Connections 484  
 11.10 Simple Integration in the Nervous System: The Reflex Arc 484  
 11.11 Complex Integration in the Nervous System 486  
 11.12 The Central Nervous System 488  
*Supplement 11.2: Are the Right and Left Cerebral Hemispheres Very Different?* 493  
 11.13 The Autonomic Nervous System 496  
*Supplement 11.3: Psychosurgery* 498  
 11.14 The Sense Organs 500  
 11.15 The System of Chemical Control 507

*Supplement 11.4: The Discovery of Insulin* 512  
 Summary 515  
 Exercises 518  
 Suggested Readings 522

**Part 4**  
**Heredity and Development 524**

**Chapter 12**  
**Cell Reproduction 527**

12.1 Introduction 527  
 12.2 Cell Division: Some Problems of Study 527  
 12.3 Mitosis 528  
*Supplement 12.1: Mitosis—Some Problems* 537  
 12.4 Meiosis 539  
*Supplement 12.2: Is There a "Criminal Chromosome"?* 545  
 Summary 550  
 Exercises 552  
 Suggested Readings 553

**Chapter 13**  
**Genetics I: From Math to Mendel 555**

13.1 Introduction 555  
 13.2 A Mathematical Basis 555  
 13.3 Binomial Expansions 557  
 13.4 Experimental Genetics: Mendel's Work 562  
 13.5 Application of Mendel's Hypothesis to Animals 565  
*Supplement 13.1: Were Mendel's Results Too Good?* 570  
 13.6 Two Pairs of Genes 572  
 13.7 Binomial Expansions and Mendelian Genetics 576  
*Supplement 13.2: Some Hints about Solving Genetics Problems* 578  
 Summary 580  
 Exercises 581  
 Suggested Readings 582

## Chapter 14 Genetics II: Genes and Chromosomes 583

- 14.1 Introduction 583
- 14.2 Linkage 583
- 14.3 The Fruit Fly Era 585
- 14.4 Broken Links and the Gene–Chromosome Theory 588
- 14.5 Chromosome Mapping in Eucaryotes 589
- Supplement 14.1: Chromosomes: The Material Basis of Mendel's Genes* 592
- 14.6 Chromosome Mapping in Procaryotes (Bacteria and Viruses) 595
- 14.7 Epistasis and Multiple Alleles 600
- 14.8 Extrachromosomal Inheritance 602
- Summary 603
- Exercises 604
- Suggested Readings 607

## Chapter 15 Genetics III: The Molecular Biology of the Gene 609

- 15.1 Introduction 609
- 15.2 In Search of the Gene 609
- 15.3 Gene Structure 612
- 15.4 DNA Replication: The Modern Picture 619
- Supplement 15.1: DNA Replication: How Do We Know?* 620
- 15.5 Protein Synthesis 625
- Supplement 15.2: Genes Produce Proteins: How Do We Know?* 626
- 15.6 The Genetic Code 637
- Supplement 15.3: DNA and Protein Synthesis in Eucaryotic Organisms* 638
- 15.7 Genes, Cistrons, and Operons 645
- Supplement 15.4: Are Mutations Random? How Do We Know?* 646
- Supplement 15.5: The Mating Habits of DNA* 649
- Supplement 15.6: Genes, Cistrons, and Chromosome Bands* 653
- Summary 655
- Exercises 657
- Suggested Readings 659

## Chapter 16 Human Heredity 661

- 16.1 Introduction 661
- 16.2 Detecting and Studying Human Genetic Traits 663
- 16.3 Simple Mendelian Inheritance in Human Beings 666
- Supplement 16.1: Blood Group Differences and Blood Transfusion* 667
- 16.4 Variations in Autosome Number: Effects on Heredity 674
- 16.5 Sex Determination 677
- 16.6 Human Biochemical Genetics 681
- Supplement 16.2: Gene Therapy* 682
- 16.7 Human Genetics and Eugenics 684
- Summary 688
- Exercises 689
- Suggested Readings 691

## Chapter 17 Developmental Biology 693

- 17.1 Introduction 693
- 17.2 Embryonic Development: An Overview 693
- Supplement 17.1: The Biogenetic Law: An Outmoded Biological Idea* 695
- 17.3 Fertilization 697
- Supplement 17.2: Prevention of Polyspermy* 700
- 17.4 Early Embryonic Development 704
- 17.5 Later Embryonic Development: Tissues into Organs 710
- 17.6 Causes of Differentiation: Embryonic Induction 714
- Supplement 17.3: Epigenesis and Preformation* 715
- 17.7 Regeneration 723
- 17.8 Genes, Regulation, and Development 734
- 17.9 Evidence for Gene Regulation in Growth and Development 739
- Supplement 17.4: The Cellular Basis of Aging* 742
- Summary 747
- Exercises 750
- Suggested Readings 754

## Chapter 18 Human Reproduction, Development, and Sexuality 755

- 18.1 Introduction 755
- 18.2 The Male Reproductive System 755
- 18.3 The Female Reproductive System 761
- 18.4 Sexual Intercourse 765
- 18.5 The Female Reproductive Cycle 767
- Supplement 18.1: Pregnancy Tests* 773
- 18.6 From Conception to Birth 776
- Supplement 18.2: Time Lag and the Menstrual Cycle* 777
- Supplement 18.3: The Switch from Fetal to Adult Circulation* 786
- 18.7 Controlling Human Fertility 788
- 18.8 Development of Sex Organs 795
- 18.9 Development of Sex Roles and Behavior 797
- Supplement 18.4: Biological Determinism versus Environmentalism: A Controversy and the Issues* 804
- Summary 810
- Exercises 813
- Suggested Readings 815

## Dart 5 Evolutionary Biology 816

### Chapter 19 Taxonomy: The Classification of Living Organisms 819

- 19.1 Introduction 819
- 19.2 Development of Taxonomic Schemes 819
- 19.3 Binomial Nomenclature 823
- 19.4 The Problem of Species Definition 826
- 19.5 Some Modern Taxonomic Approaches 829
- 19.6 Taxonomic Charts 832
- Supplement 19.1: Splitters and Lumpers* 833
- 19.7 Taxonomy and the Process of Science 835
- Summary 835
- Exercises 837
- Suggested Readings 839

### Chapter 20 The Process of Evolution 841

- 20.1 Introduction 841
- 20.2 The Evidence for Evolution 841
- Supplement 20.1: Evolution as an Hypothesis* 845
- 20.3 Darwinian Natural Selection 850
- 20.4 Direction of Natural Selection 855
- 20.5 The Population Concept of Evolution 857
- 20.6 Natural Selection and Changes in Gene Frequency 861
- 20.7 Sexual Selection 864
- 20.8 Speciation 865
- Supplement 20.2: The Irish Elk: An Evolutionary Case Study* 868
- 20.9 Migration and Genetic Drift 873
- 20.10 Adaptive Radiation 874
- 20.11 Adaptation and Survival 878
- Summary 879
- Exercises 882
- Suggested Readings 885

### Chapter 21 The Origin of Life 887

- 21.1 Introduction 887
- 21.2 Spontaneous Generation 887
- 21.3 The Origin of Life by Chemosynthesis 889
- 21.4 Viruses and the Origin of Life 896
- 21.5 The Geological Time Scale 899
- Supplement 21.1: Viruses and the "Chicken-and-Egg" Problem in the Origin of Life* 900
- Supplement 21.2: Oxygen and Evolution* 904
- Summary 905
- Exercises 907
- Suggested Readings 909

### Chapter 22 The Evolution of Plants 911

- 22.1 Introduction 911
- 22.2 Evolution of the Prokaryotes 911
- 22.3 Origin of Eucaryotic Organisms 916
- 22.4 Origin and Adaptive Significance of Multicellularity 919

- 22.5 Origin and Diversification of Sexual Systems 921  
*Supplement 22.1: The Origin and Diversification of Eucaryotes* 923  
*Supplement 22.2: The Origin of Bacteria, Mitochondria, and Chloroplasts* 929  
 22.6 The Primary Invasion of Land 932  
 22.7 The Early Land Plants 933  
*Supplement 22.3: Invasion of the Land: An Hypothesis* 936  
 22.8 Evolution of Reproductive Systems in the Early Land Plants 939  
 22.9 Secondary Invasions of the Land: The Bryophytes 943  
 22.10 Secondary Invasions of the Land: The Fungi 945  
 22.11 Secondary Invasions of the Land: Lichens 949  
 22.12 The Gymnosperms 951  
 22.13 Evolution of the Angiosperms 953  
 Summary 956  
 Exercises 959  
 Suggested Readings 961

## Chapter 23 The Evolution of Animals 963

- 23.1 Introduction 963  
 23.2 Evolution: A Biological Foundation 963  
*Supplement 23.1: Mass Extinctions in Animal Evolution* 966  
 23.3 Evolution: A Working Hypothesis 970  
 23.4 The Problem of Establishing Phylogenetic Relationships 971  
 23.5 Phylogenetic Relationships: The Invertebrates 974  
*Supplement 23.2: "Reasons for Being"* 980  
 23.6 Phylogenetic Relationships: The Vertebrates 982  
 23.7 The Molecular Level of Investigation 989  
*Supplement 23.3: Hemoglobin and the Rate of Molecular Evolution* 991  
 23.8 Human Evolution 997  
 Summary 1016  
 Exercises 1019  
 Suggested Readings 1021

## Part 6 Population Biology 1022

### Chapter 24 Ecological Relationships: Competition for Energy 1025

- 24.1 Introduction 1025  
 24.2 Interaction between Organisms 1026  
 24.3 Interaction between Organisms and the Physiochemical Environment 1028  
 24.4 The Growth and Regulation of Populations 1032  
*Supplement 24.1: The Kaibab Deer Case: Myth or Reality?* 1035  
 24.5 Ecology and Evolution 1036  
 24.6 Ecological Niches, Habitats, and the Ecosystem 1037  
*Supplement 24.2: Poverty, Hunger, and Overpopulation: A Debate* 1038  
 24.7 Community Structure and Energy Flow 1045  
*Supplement 24.3: Concentration of Toxins in Food Webs* 1049  
 24.8 Productivity as a Measure of Energy Flow 1051  
 24.9 The Cyclic Use of Materials 1051  
 24.10 Succession: Changes in Ecosystems through Time 1055  
 24.11 Human Impact on Rates of Aquatic Succession 1059  
*Supplement 24.4: The Cleaning of Lake Washington* 1060  
 24.12 Ecology, the Environment, and Economics 1062  
 Summary 1066  
 Exercises 1069  
 Suggested Readings 1073

### Chapter 25 Animal Behavior 1075

- 25.1 Introduction 1075  
 25.2 Simple Behavioral Systems: The Rise of Instinct Theory 1077  
 25.3 Animal Behavior as a Combination of Learned and Innate Responses 1083

25.4	Motivation	1085
25.5	Insight and Imprinting	1086
	<i>Supplement 25.1: Models of Behavior</i>	1087
25.6	Communication	1092
25.7	The Development of Behavior	1097
25.8	Genetic and Evolutionary Aspects of Behavior	1101
25.9	Agonistic and Aggressive Behavior	1104
	<i>Supplement 25.2: Sex and the Dominant Male</i>	1111
25.10	Sociobiology: Extrapolating from Animal to Human Behavior	1115
	Summary	1118
	Exercises	1120
	Suggested Readings	1121

---

**Appendix 1**  
**Chief Units of the Metric System A-1**

**Appendix 2**  
**Conversion of Temperature Scales A-2**

**Appendix 3**  
**Table of Amino Acids A-4**

**Appendix 4**  
**Taxonomic Charts A-6**

**Glossary G-1**

**Index I-1**



**THE  
STUDY  
OF  
THIRD EDITION  
BIOLOGY**