



SECOND EDITION

# ESSENTIAL BIOLOGY

CAMPBELL | REECE | SIMON

# DETAILED CONTENTS

## 1 Introduction: Biology Today 1

### **The Scope of Biology 2**

*Life at Its Many Levels 2*

*Life in Its Diverse Forms 6*

### **Evolution: Biology's Unifying Theme 8**

*The Darwinian View of Life 9*

*Natural Selection 10*

### **The Process of Science 13**

*Discovery Science 13*

*Hypothesis-Driven Science 14*

*A Case Study in the Process of Science 15*

*The Culture of Science 16*

*Theories in Science 16*

*Science, Technology, and Society 18*

## **Unit One CELLS**

---

## 2 Essential Chemistry for Biology 20

### **Biology and Society: Fluoride in the Water 21**

### **Tracing Life Down to the Chemical Level 21**

### **Some Basic Chemistry 22**

*Matter: Elements and Compounds 22*

*Atoms 23*

*Chemical Bonding and Molecules 25*

*Chemical Reactions 27*

### **Water and Life 28**

*The Structure of Water 28*

*Water's Life-Supporting Properties 29*

*Acids, Bases, and pH 21*

### **Evolution Connection: Earth Before Life 32**

## **3 The Molecules of Life 35**

### **Biology and Society: Got Lactose? 36**

#### **Organic Molecules 36**

*Carbon Chemistry 36*

*Giant Molecules from Smaller Building Blocks 38*

#### **Biological Molecules 39**

*Carbohydrates 39*

*Lipids 42*

*Proteins 44*

*Nucleic Acids 47*

### **Evolution Connection: DNA and Proteins as Evolutionary Tape Measures 49**

## **4 A Tour of the Cell 52**

### **Biology and Society: Drugs That Target Cells 53**

#### **The Microscopic World of Cells 53**

*Microscopes as Windows to Cells 54*

*The Two Major Categories of Cells 55*

*A Panoramic View of Eukaryotic Cells 57*

#### **Membrane Structure and Function 58**

*A Fluid Mosaic of Lipids and Proteins 58*

*Selective Permeability 58*

#### **The Nucleus and Ribosomes: Genetic Control of the Cell 59**

*Structure and Function of the Nucleus 60*

*Ribosomes 60*

*How DNA Controls the Cell 60*



## **The Endomembrane System: Manufacturing and Distributing Cellular Products 61**

*The Endoplasmic Reticulum 61*

*The Golgi Apparatus 62*

*Lysosomes 62*

*Vacuoles 63*

## **Chloroplasts and Mitochondria: Energy Conversion 64**

*Chloroplasts 64*

*Mitochondria 65*

## **The Cytoskeleton: Cell Shape and Movement 65**

*Maintaining Cell Shape 65*

*Cilia and Flagella 66*

## **Cell Surfaces: Protection, Support, and Cell-Cell Interactions 67**

*Plant Cell Walls and Cell Junctions 68*

*Animal Cell Surfaces and Cell Junctions 68*

## **Evolution Connection: The Origin of Membranes 69**

# **5 The Working Cell 72**

## **Biology and Society: Stonewashing Without the Stones 73**

## **Some Basic Energy Concepts 73**

*Conservation of Energy 73*

*Entropy 74*

*Chemical Energy 74*

*Food Calories 75*

## **ATP and Cellular Work 76**

*The Structure of ATP 76*

*Phosphate Transfer 77*

*The ATP Cycle 77*

## **Enzymes 78**

*Activation Energy 78*

*Induced Fit 78*

*Enzyme Inhibitors 78*

## **Membrane Transport 80**

*Passive Transport: Diffusion Across Membranes 80*

*Osmosis and Water Balance in Cells 81*

*Active Transport: The Pumping of Molecules  
Across Membranes 82*

*Exocytosis and Endocytosis: Traffic of Large Molecules 82*

*The Role of Membranes in Cell Signaling 83*

## **Evolution Connection: Evolving Enzymes 84**

# **6 Cellular Respiration: Harvesting Chemical Energy 87**

## **Biology and Society: Feeling the “Burn” 88**

## **Energy Flow and Chemical Cycling in the Biosphere 88**

*Producers and Consumers 89*

*Chemical Cycling Between Photosynthesis and  
Cellular Respiration 89*

## **Cellular Respiration: Aerobic Harvest of Food Energy 90**

*The Relationship Between Cellular Respiration and  
Breathing 90*

*The Overall Equation for Cellular Respiration 91*

*The Role of Oxygen in Cellular Respiration 91*

*The Metabolic Pathway of Cellular Respiration 93*

## **Fermentation: Anaerobic Harvest of Food Energy 98**

*Fermentation in Human Muscle Cells 98*

*Fermentation in Microorganisms 99*

## **Evolution Connection: Life on an Anaerobic Earth 99**

## **7 Photosynthesis: Converting Light Energy to Chemical Energy 102**

**Biology and Society: Plant Power 103**

**The Basics of Photosynthesis 103**

*Chloroplasts: Sites of Photosynthesis 103*

*The Overall Equation for Photosynthesis 105*

*A Photosynthesis Road Map 105*

**The Light Reactions: Converting Solar Energy to Chemical Energy 106**

*The Nature of Sunlight 106*

*Chloroplast Pigments 107*

*How Photosystems Harvest Light Energy 107*

*How the Light Reactions Generate ATP and NADPH 109*

**The Calvin Cycle: Making Sugar from Carbon Dioxide 111**

*Water-Saving Adaptations of  $C_4$  and CAM Plants 112*

**The Environmental Impact of Photosynthesis 113**

*How Photosynthesis Moderates the Greenhouse Effect 112*

**Evolution Connection: The Oxygen Revolution 114**

## **Unit Two GENETICS**

---

## **8 The Cellular Basis of Reproduction and Inheritance 118**

**Biology and Society: A \$50,000 Egg! 119**

**What Cell Reproduction Accomplishes 119**

*Passing On the Genes from Cell to Cell 120*

*The Reproduction of Organisms 120*

**The Cell Cycle and Mitosis 121**

*Eukaryotic Chromosomes 121*

*The Cell Cycle* 122

*Mitosis and Cytokinesis* 124

*Cancer Cells: Growing Out of Control* 126

## **Meiosis, the Basis of Sexual Reproduction 128**

*Homologous Chromosomes* 128

*Gametes and the Life Cycle of a Sexual Organism* 129

*The Process of Meiosis* 130

*Review: Comparing Mitosis and Meiosis* 133

*The Origins of Genetic Variation* 133

*When Meiosis Goes Awry* 134

## **Evolution Connection: New Species from Errors in Cell Division 137**

# **9 Patterns of Inheritance 141**

## **Biology and Society: Testing Your Baby 142**

## **Heritable Variation and Patterns of Inheritance 142**

*In an Abbey Garden* 143

*Mendel's Principle of Segregation* 144

*Mendel's Principle of Independent Assortment* 147

*Using a Testcross to Determine an Unknown Genotype* 149

*The Rules of Probability* 149

*Family Pedigrees* 150

*Human Disorders Controlled by a Single Gene* 151

## **Beyond Mendel 154**

*Incomplete Dominance in Plants and People* 155

*Multiple Alleles and Blood Type* 156

*Pleiotropy and Sickle-Cell Disease* 157

*Polygenic Inheritance* 158

*The Role of Environment* 158

## **The Chromosomal Basis of Inheritance 159**

*Gene Linkage* 160

*Genetic Recombination: Crossing Over and Linkage Maps* 162

**Sex Chromosomes and Sex-Linked Genes 163**

*Sex Determination in Humans and Fruit Flies 163*

*Sex-Linked Genes 163*

*Sex-Linked Disorders in Humans 165*

**Evolution Connection:**

**The Telltale Y Chromosome 166**

**10 Molecular Biology  
of the Gene 170**

**Biology and Society: Sabotaging HIV 171**

**The Structure and Replication of DNA 171**

*DNA and RNA: Polymers of Nucleotides 172*

*Watson and Crick's Discovery of the Double Helix 173*

*DNA Replication 175*

**The Flow of Genetic Information from  
DNA to RNA to Protein 176**

*How an Organism's DNA Genotype Produces  
Its Phenotype 177*

*From Nucleotide Sequence to Amino Acid  
Sequence: An Overview 178*

*The Genetic Code 179*

*Transcription: From DNA to RNA 180*

*The Processing of Eukaryotic RNA 181*

*Translation: The Players 182*

*Translation: The Process 183*

*Review: DNA → RNA → Protein 184*

*Mutations 186*

**Viruses: Genes in Packages 188**

*Bacteriophages 188*

*Plant Viruses 189*

*Animal Viruses 190*

*HIV, the AIDS Virus 190*

**Evolution Connection: Emerging Viruses 192**



## 11 Gene Regulation 196

**Biology and Society:**  
**Baby's First Bank Account 197**

**From Egg to Organism: How and Why Genes Are Regulated 197**

*Patterns of Gene Expression in Differentiated Cells 198*

*DNA Microarrays: Visualizing Gene Expression 198*

*The Genetic Potential of Cells 200*

*Reproductive Cloning of Animals 200*

*Therapeutic Cloning and Stem Cells 201*

**The Regulation of Gene Expression 203**

*Gene Regulation in Bacteria 203*

*Gene Regulation in the Nucleus of Eukaryotic Cells 204*

*Regulation in the Cytoplasm 206*

*Cell Signaling 207*

**The Genetic Basis of Cancer 208**

*Genes That Cause Cancer 208*

*The Effects of Lifestyle on Cancer Risk 211*

**Evolution Connection: Homeotic Genes 212**

## 12 DNA Technology 216

**Biology and Society: Hunting for Genes 217**

**Recombinant DNA Technology 217**

*From Humulin to Genetically Modified Foods 218*

*Recombinant DNA Techniques 220*

**DNA Fingerprinting and Forensic Science 224**

*Murder, Paternity, and Ancient DNA 225*

*DNA Fingerprinting Techniques 226*

**Genomics 229**

*The Human Genome Project 230*

*Tracking the Anthrax Killer* 231

*Genome-Mapping Techniques* 232

## **Human Gene Therapy 234**

*Treating Severe Combined Immunodeficiency* 2234

## **Safety and Ethical Issues 235**

*The Controversy Over Genetically Modified Foods* 235

*Ethical Questions Raised by DNA Technology* 236

## **Evolution Connection: Genomes Hold Clues to Evolution 237**

# **Unit Three EVOLUTION AND DIVERSITY —**

## **13 How Populations Evolve 242**

### **Biology and Society: Persistent Pests 243**

### **Charles Darwin and *The Origin of Species* 244**

*Darwin's Cultural and Scientific Context* 245

*Descent with Modification* 248

### **Evidence of Evolution 249**

*The Fossil Record* 250

*Biogeography* 251

*Comparative Anatomy* 251

*Comparative Embryology* 252

*Molecular Biology* 253

### **Natural Selection and Adaptive Evolution 254**

*Darwin's Theory of Natural Selection* 254

*Natural Selection in Action* 255

### **The Modern Synthesis: Darwinism Meets Genetics 256**

*Populations as the Units of Evolution* 256

*Genetic Variation in Populations* 257

*Analyzing Gene Pools* 258

*Population Genetics and Health Science* 259

*Microevolution as Change in a Gene Pool* 260

## **Mechanisms of Microevolution 260**

*Genetic Drift* 261

*Gene Flow* 263

*Mutations* 263

*Natural Selection: A Closer Look* 263

## **Evolution Connection: Population Genetics of the Sickle-Cell Allele 266**

# **14 How Biological Diversity Evolves 270**

## **Biology and Society: The Impact of Asteroids 271**

## **Macroevolution and the Diversity of Life 271**

## **The Origin of Species 272**

*What Is a Species?* 272

*Reproductive Barriers Between Species* 274

*Mechanisms of Speciation* 275

*What Is the Tempo of Speciation?* 278

## **The Evolution of Biological Novelty 280**

*Adaptation of Old Structures for New Functions* 280

*"Evo-Devo": Development and Evolutionary Novelty* 281

## **Earth History and Macroevolution 282**

*Geologic Time and the Fossil Record* 282

*Continental Drift and Macroevolution* 285

*Mass Extinctions and Explosive Diversifications of Life* 285

## **Classifying the Diversity of Life 287**

*Some Basics of Taxonomy* 287

*Classification and Phylogeny* 288

*Arranging Life into Kingdoms: A Work in Progress* 290

## **Evolution Connection: Just a Theory? 292**

# **The Evolution of Microbial Life 296**

## **Biology and Society: Bioterrorism 297**

## **Major Episodes in the History of Life 297**

### **The Origin of Life 300**

*Resolving the Biogenesis Paradox 300*

*A Four-Stage Hypothesis for the Origin of Life 300*

*From Chemical Evolution to Darwinian Evolution 302*

### **Prokaryotes 303**

*They're Everywhere! 303*

*The Two Main Branches of Prokaryotic Evolution: Bacteria  
and Archaea 304*

*The Structure, Function, and Reproduction of  
Prokaryotes 304*

*The Nutritional Diversity of Prokaryotes 307*

*The Ecological Impact of Prokaryotes 307*

### **Protists 311**

*The Origin of Eukaryotic Cells 311*

*The Diversity of Protists 312*

### **Evolution Connection:**

### **The Origin of Multicellular Life 317**

## **6 Plants, Fungi, and the Move onto Land 320**

### **Biology and Society: The Balancing Act of Forest Conservation 321**

### **Colonizing Land 321**

*Terrestrial Adaptations of Plants 321*

*The Origin of Plants from Green Algae 323*

### **Plant Diversity 324**

*Highlights of Plant Evolution 324*

*Bryophytes 325*

*Ferns* 327

*Gymnosperms* 328

*Angiosperms* 330

*Plant Diversity as a Nonrenewable Resource* 332

## **Fungi 334**

*Characteristics of Fungi* 336

*The Ecological Impact of Fungi* 337

## **Evolution Connection: Mutual Symbiosis 340**

# **17 The Evolution of Animals 343**

## **Biology and Society: Invasion of the Killer Toads 344**

## **The Origins of Animal Diversity 344**

*What Is an Animal?* 344

*Early Animals and the Cambrian Explosion* 346

*Animal Phylogeny* 347

## **Major Invertebrate Phyla 349**

*Sponges* 350

*Cnidarians* 350

*Flatworms* 351

*Roundworms* 351

*Mollusks* 353

*Annelids* 354

*Arthropods* 356

*Echinoderms* 359

## **The Vertebrate Genealogy 360**

*Characteristics of Chordates* 361

*Fishes* 363

*Amphibians* 364

*Reptiles* 365

*Birds* 366

*Mammals* 367

**The Human Ancestry 368**

*The Evolution of Primates 368*

*The Emergence of Humankind 370*

**Evolution Connection: Earth's New Crisis 376**

**Unit Four ECOLOGY**

---

**18 The Ecology of Organisms and Populations 380**

**Biology and Society: The Human Population Explosion 381**

**An Overview of Ecology 381**

*Ecology as Scientific Study 382*

*A Hierarchy of Interactions 383*

*Ecology and Environmentalism 383*

*Abiotic Factors of the Biosphere 384*

**The Evolutionary Adaptations of Organisms 387**

*Physiological Responses 387*

*Anatomical Responses 388*

*Behavioral Responses 388*

**What Is Population Ecology? 388**

*Population Density 389*

*Patterns of Dispersion 390*

*Population Growth Models 390*

*Regulation of Population Growth 392*

*Human Population Growth 395*

**Life Histories and Their Evolution 398**

*Life Tables and Survivorship Curves 399*

*Life History Traits as Evolutionary Adaptations 400*

**Evolution Connection: Testing a Darwinian Hypothesis 401**



# **19 Communities and Ecosystems 406**

## **Biology and Society: Reefs: Coral and Artificial 407**

### **Key Properties of Communities 407**

*Diversity 408*

*Prevalent Form of Vegetation 408*

*Stability 408*

*Trophic Structure 409*

### **Interspecific Interactions in Communities 409**

*Competition Between Species 409*

*Predation 410*

*Symbiotic Relationships 414*

*The Complexity of Community Networks 415*

### **Disturbance of Communities 415**

*Ecological Succession 416*

*A Dynamic View of Community Structure 417*

### **An Overview of Ecosystem Dynamics 417**

*Trophic Levels and Food Chains 419*

*Food Webs 419*

### **Energy Flow in Ecosystems 421**

*Productivity and the Energy Budgets of Ecosystems 421*

*Energy Pyramids 422*

*Ecosystem Energetics and Human Nutrition 423*

### **Chemical Cycling in Ecosystems 424**

*The General Scheme of Chemical Cycling 424*

*Examples of Biogeochemical Cycles 425*

### **Biomes 428**

*How Climate Affects Biome Distribution 428*

*Terrestrial Biomes 428*

*Freshwater Biomes 434*

*Marine Biomes 435*

### **Evolution Connection: Coevolution in Biological Communities 438**

## **20 Human Impact on the Environment 442**

### **Biology and Society: Aquarium Menaces 443**

### **Human Impact on Biological Communities 443**

*Human Disturbance of Communities 444*

*Introduced Species 444*

### **Human Impact on Ecosystems 446**

*Impact on Chemical Cycles 446*

*Deforestation and Chemical Cycles: A Case Study 447*

*The Release of Toxic Chemicals to Ecosystems 448*

*Human Impact on the Atmosphere and Climate 449*

### **The Biodiversity Crisis 452**

*The Three Levels of Biodiversity 452*

*The Loss of Species 452*

*The Three Main Causes of the Biodiversity Crisis 454*

*Why Biodiversity Matters 455*

### **Conservation Biology 456**

*Biodiversity "Hot Spots" 456*

*Conservation at the Population and Species Levels 457*

*Conservation at the Ecosystem Level 459*

*The Goal of Sustainable Development 461*

### **Evolution Connection: Biophilia and an Environmental Ethic 462**

Appendix A Metric Conversion Table

Appendix B Answers to Self-Quiz Questions

Appendix C Credits

Glossary

Index