

# contents

## Part I *The Molecular Basis of Life*

### 1 The Science of Biology 1

- 1.1 The Science of Life 2
- 1.2 The Nature of Science 4
- 1.3 An Example of Scientific Inquiry: Darwin and Evolution 8
- 1.4 Unifying Themes in Biology 12

### 2 The Nature of Molecules 17

- 2.1 The Nature of Atoms 18
- 2.2 Elements Found in Living Systems 21
- 2.3 The Nature of Chemical Bonds 23
- 2.4 Water: A Vital Compound 25
- 2.5 Properties of Water 28
- 2.6 Acids and Bases 29

### 3 The Chemical Building Blocks of Life 33

- 3.1 Carbon: The Framework of Biological Molecules 34
- 3.2 Carbohydrates: Energy Storage and Structural Molecules 37
- 3.3 Nucleic Acids: Information Molecules 41
- 3.4 Proteins: Molecules with Diverse Structures and Functions 43
- 3.5 Lipids: Hydrophobic Molecules 53

## Part II *Biology of the Cell*

### 4 Cell Structure 59

- 4.1 Cell Theory 60
- 4.2 Prokaryotic Cells 63
- 4.3 Eukaryotic Cells 65
- 4.4 The Endomembrane System 70
- 4.5 Mitochondria and Chloroplasts: Cellular Generators 74
- 4.6 The Cytoskeleton 76
- 4.7 Extracellular Structures and Cell Movement 80

### 5 Membranes 85

- 5.1 The Structure of Membranes 86
- 5.2 Phospholipids: The Membrane's Foundation 89
- 5.3 Proteins: Multifunctional Components 91
- 5.4 Passive Transport Across Membranes 93
- 5.5 Active Transport Across Membranes 97
- 5.6 Bulk Transport by Exocytosis and Endocytosis 100

### 6 Energy and Metabolism 105

- 6.1 The Flow of Energy in Living Systems 106
- 6.2 The Laws of Thermodynamics and Free Energy 107
- 6.3 ATP: The Energy Currency of Cells 110
- 6.4 Enzymes: Biological Catalysts 111
- 6.5 Metabolism: The Chemical Description of Cell Function 115

### 7 How Cells Harvest Energy 119

- 7.1 Overview of Respiration 120
- 7.2 The Oxidation of Glucose: A Summary 122
- 7.3 Glycolysis: Splitting Glucose 124
- 7.4 The Oxidation of Pyruvate to Produce Acetyl-CoA 128
- 7.5 The Krebs Cycle 128
- 7.6 The Electron Transport Chain and Chemiosmosis 131
- 7.7 Energy Yield of Aerobic Respiration 134
- 7.8 Regulation of Aerobic Respiration 135
- 7.9 Oxidation Without O<sub>2</sub> 136
- 7.10 Catabolism of Proteins and Fats 138
- 7.11 Evolution of Metabolism 140

### 8 Photosynthesis 143

- 8.1 Overview of Photosynthesis 144
- 8.2 The Discovery of Photosynthetic Processes 146
- 8.3 Pigments 147
- 8.4 Photosystem Organization 150
- 8.5 The Light-Dependent Reactions 152
- 8.6 Carbon Fixation: The Calvin Cycle 157
- 8.7 Photorespiration 160



## 9 Cell Communication 165

- 9.1 Overview of Cell Communication 166
- 9.2 Receptor Types 168
- 9.3 Intracellular Receptors 170
- 9.4 Signal Transduction Through Receptor Kinases 172
- 9.5 Signal Transduction Through G Protein-Coupled Receptors 176
- 9.6 Cell-to-Cell Interactions 180

## 10 How Cells Divide 185

- 10.1 Bacterial Cell Division 186
- 10.2 Eukaryotic Chromosomes 188
- 10.3 Overview of the Eukaryotic Cell Cycle 191
- 10.4 Interphase: Preparation for Mitosis 192
- 10.5 Mitosis: Chromosome Segregation 193
- 10.6 Cytokinesis: The Division of Cytoplasmic Contents 196
- 10.7 Control of the Cell Cycle 197

# Part III *Genetic and Molecular Biology*

## 11 Sexual Reproduction and Meiosis 205

- 11.1 Sexual Reproduction Requires Meiosis 206
- 11.2 Features of Meiosis 208
- 11.3 The Process of Meiosis 209
- 11.4 Summing up: Meiosis Versus Mitosis 214

## 12 Patterns of Inheritance 219

- 12.1 The Mystery of Heredity 220
- 12.2 Monohybrid Crosses: The Principle of Segregation 222
- 12.3 Dihybrid Crosses: The Principle of Independent Assortment 227
- 12.4 Probability: Predicting the Results of Crosses 228
- 12.5 The Testcross: Revealing Unknown Genotypes 229
- 12.6 Extensions to Mendel 230

## 13 Chromosomes, Mapping, and the Meiosis–Inheritance Connection 237

- 13.1 Sex Linkage and the Chromosomal Theory of Inheritance 238
- 13.2 Sex Chromosomes and Sex Determination 239
- 13.3 Exceptions to the Chromosomal Theory of Inheritance 242
- 13.4 Genetic Mapping 242
- 13.5 Selected Human Genetic Disorders 247

## 14 DNA: The Genetic Material 255

- 14.1 The Nature of the Genetic Material 256
- 14.2 DNA Structure 258
- 14.3 Basic Characteristics of DNA Replication 262
- 14.4 Prokaryotic Replication 265
- 14.5 Eukaryotic Replication 270
- 14.6 DNA Repair 272

## 15 Genes and How They Work 277

- 15.1 The Nature of Genes 278
- 15.2 The Genetic Code 280
- 15.3 Overview of Gene Expression 282
- 15.4 Prokaryotic Transcription 284
- 15.5 Eukaryotic Transcription 286
- 15.6 Eukaryotic pre-mRNA Splicing 288
- 15.7 The Structure of tRNA and Ribosomes 290
- 15.8 The Process of Translation 293
- 15.9 Summarizing Gene Expression 296
- 15.10 Mutation: Altered Genes 298

## 16 Control of Gene Expression 303

- 16.1 Control of Gene Expression 304
- 16.2 Regulatory Proteins 305
- 16.3 Prokaryotic Regulation 307
- 16.4 Eukaryotic Regulation 312
- 16.5 Eukaryotic Chromatin Structure 315
- 16.6 Eukaryotic Posttranscriptional Regulation 317
- 16.7 Protein Degradation 321

## 17 Biotechnology 325

- 17.1 DNA Manipulation 326
- 17.2 Molecular Cloning 328
- 17.3 DNA Analysis 332
- 17.4 Genetic Engineering 339
- 17.5 Medical Applications 340
- 17.6 Agricultural Applications 343

## 18 Genomics 349

- 18.1 Mapping Genomes 350
- 18.2 Whole-Genome Sequencing 353
- 18.3 Characterizing Genomes 355
- 18.4 Genomics and Proteomics 359
- 18.5 Applications of Genomics 365

## 19 Cellular Mechanisms of Development 369

- 19.1 Overview of Development 370
- 19.2 Cell Division 370
- 19.3 Cell Differentiation 373
- 19.4 Pattern Formation 380
- 19.5 Morphogenesis 387
- 19.6 Environmental Effects on Development 391





## Part IV Evolution

### 20 Genes Within Populations 395

- 20.1 Genetic Variation and Evolution 396
- 20.2 Changes in Allele Frequency 398
- 20.3 Five Agents of Evolutionary Change 400
- 20.4 Fitness and Its Measurement 404
- 20.5 Interactions Among Evolutionary Forces 405
- 20.6 Maintenance of Variation 406
- 20.7 Selection Acting on Traits Affected by Multiple Genes 408
- 20.8 Experimental Studies of Natural Selection 410
- 20.9 The Limits of Selection 412

### 21 The Evidence for Evolution 415

- 21.1 The Beaks of Darwin's Finches: Evidence of Natural Selection 416
- 21.2 Peppered Moths and Industrial Melanism: More Evidence of Selection 418
- 21.3 Artificial Selection: Human-Initiated Change 419
- 21.4 Fossil Evidence of Evolution 421
- 21.5 Anatomical Evidence for Evolution 426
- 21.6 Convergent Evolution and the Biogeographical Record 428
- 21.7 Darwin's Critics 428

### 22 The Origin of Species 433

- 22.1 The Nature of Species 434
- 22.2 The Biological Species Concept 434
- 22.3 The Evolution of Reproductive Isolation 438
- 22.4 The Role of Genetic Drift and Natural Selection in Speciation 439
- 22.5 The Geography of Speciation 440
- 22.6 Species Clusters: Evidence of Rapid Evolution 443
- 22.7 The Pace of Evolution 447
- 22.8 Speciation and Extinction Through Time 448
- 22.9 The Future of Evolution 450

### 23 Systematics and the Phylogenetic Revolution 453

- 23.1 Systematics 454
- 23.2 Cladistics 455
- 23.3 Systematics and Classification 458
- 23.4 Phylogenetics and Comparative Biology 461
- 23.5 Phylogenetics and Disease Evolution 467

### 24 Genome Evolution 471

- 24.1 Comparative Genomics 473
- 24.2 Evolution of Whole Genomes 475
- 24.3 Evolution Within Genomes 479
- 24.4 Gene Function and Expression Patterns 482

- 24.5 Nonprotein-Coding DNA and Regulatory Function 484
- 24.6 Genome Size and Gene Number 484
- 24.7 Genome Analysis and Disease Prevention and Treatment 485
- 24.8 Crop Improvement Through Genome Analysis 486

### 25 Evolution of Development 489

- 25.1 The Evolutionary Paradox of Development 490
- 25.2 One or Two Gene Mutations, New Form 492
- 25.3 Same Gene, New Function 493
- 25.4 Different Genes, Convergent Function 495
- 25.5 Gene Duplication and Divergence 496
- 25.6 Functional Analysis of Genes Across Species 497
- 25.7 Diversity of Eyes in the Natural World: A Case Study 498

## Part V Diversity of Life on Earth

### 26 The Tree of Life 503

- 26.1 Origins of Life 504
- 26.2 Classification of Organisms 507
- 26.3 Grouping of Organisms 509
- 26.4 Making Sense of the Protists 515
- 26.5 Origin of Plants 516
- 26.6 Sorting out the Animals 518

### 27 Viruses 523

- 27.1 The Nature of Viruses 524
- 27.2 Bacteriophage: Bacterial Viruses 526
- 27.3 Human Immunodeficiency Virus (HIV) 528
- 27.4 Other Viral Diseases 534
- 27.5 Prions and Viroids: Subviral Particles 536

### 28 Prokaryotes 539

- 28.1 The First Cells 540
- 28.2 Prokaryotic Diversity 541
- 28.3 Prokaryotic Cell Structure 546
- 28.4 Prokaryotic Genetics 548
- 28.5 Prokaryotic Metabolism 553
- 28.6 Human Bacterial Disease 554
- 28.7 Beneficial Prokaryotes 557

### 29 Protists 561

- 29.1 Defining Protists 562
- 29.2 Eukaryotic Origins and Endosymbiosis 563
- 29.3 General Biology of the Protists 565
- 29.4 Diplomonads and Parabasalids: Flagellated Protists Lacking Mitochondria 566



- 29.5 Euglenozoa: A Diverse Group in Which Some Members Have Chloroplasts 567
- 29.6 Alveolata: Protists With Submembrane Vesicles 569
- 29.7 Stramenopila: Protists With Fine Hairs 573
- 29.8 Rhodophyta: Red Algae 575
- 29.9 Choanoflagellida: Possible Animal Ancestors 576
- 29.10 Protists Without a Clade 576

### 30 Overview of Green Plants 581

- 30.1 Defining Plants 582
- 30.2 Plant Life Cycles 583
- 30.3 Chlorophytes: Aquatic Green Algae 584
- 30.4 Charophytes: Green Algae Related to Land 585
- 30.5 Bryophytes: Nontracheophyte Green Plants 586
- 30.6 Features of Tracheophyte Plants 588
- 30.7 Lycophytes: Club Mosses 590
- 30.8 Pterophytes: Ferns and Their Relatives 590
- 30.9 The Evolution of Seed Plants 593
- 30.10 Gymnosperms: Plants with “Naked” Seeds 593
- 30.11 Angiosperms: Flowering Plants 596

### 31 Fungi 603

- 31.1 Defining Fungi 604
- 31.2 General Biology of the Fungi 605
- 31.3 Phylogenetic Relationships 607
- 31.4 Chytridiomycetes: Aquatic Fungi with Flagellated Zoospores 608
- 31.5 Zygomycetes: Fungi That Produce Zygotes 609
- 31.6 Glomeromycetes: Asexual Plant Symbionts 610
- 31.7 Ascomycetes: Sac (Ascus) Fungi 610
- 31.8 Basidiomycetes: Club (Basidium) Fungi 612
- 31.9 Deuteromycetes: A Polyphyletic Group That Includes Most Molds 613
- 31.10 Ecology of Fungi 614
- 31.11 Fungal Parasites and Pathogens 617

### 32 Overview of Animal Diversity 621

- 32.1 Some General Features of Animals 622
- 32.2 Evolution of the Animal Body Plan 624
- 32.3 The Traditional Classification of Animals 628
- 32.4 A New Look at the Metazoan Tree of Life 628
- 32.5 Evolutionary Development Biology and the Roots of the Animal Tree of Life 632

### 33 Noncoelomate Invertebrates 635

- 33.1 A Revolution in Invertebrate Phylogeny 636
- 33.2 Parazoa: Animals That Lack Specialized Tissues 640
- 33.3 Eumetazoa: Animals with True Tissues 640
- 33.4 The Bilaterian Acoelomates 644
- 33.5 The Pseudocoelomates 648

### 34 Coelomate Invertebrates 653

- 34.1 Phylum Mollusca: The Mollusks 654
- 34.2 Phylum Annelida: The Annelids 660
- 34.3 The Lophophorates: Bryozoa and Brachiopoda 664
- 34.4 Phylum Arthropoda: The Arthropods 666
- 34.5 Phylum Echinodermata: The Echinoderms 676

### 35 Vertebrates 681

- 35.1 The Chordates 682
- 35.2 The Nonvertebrate Chordates 683
- 35.3 The Vertebrate Chordates 684
- 35.4 Fishes 686
- 35.5 Amphibians 691
- 35.6 Reptiles 694
- 35.7 Birds 700
- 35.8 Mammals 704
- 35.9 Evolution of the Primates 709

## Part VI *Plant Form and Function*

### 36 Plant Form 717

- 36.1 Organization of the Plant Body: An Overview 718
- 36.2 Plant Tissues 721
- 36.3 Roots: Anchoring and Absorption Structures 727
- 36.4 Stems: Support for Above-Ground Organs 732
- 36.5 Leaves: Photosynthetic Organs 736

### 37 Vegetative Plant Development 741

- 37.1 Embryo Development 742
- 37.2 Seeds 748
- 37.3 Fruits 750
- 37.4 Germination 752

### 38 Transport in Plants 757

- 38.1 Transport Mechanisms 758
- 38.2 Water and Mineral Absorption 763
- 38.3 Xylem Transport 764
- 38.4 The Rate of Transpiration 765
- 38.5 Water-Stress Responses 767
- 38.6 Phloem Transport 769

### 39 Plant Nutrition and Soils 773

- 39.1 Soils: The Substrates on Which Plants Depend 774
- 39.2 Plant Nutrients 776
- 39.3 Special Nutritional Strategies 779
- 39.4 Carbon–Nitrogen Balance and Global Change 782
- 39.5 Phytoremediation 784



## 40 Plant Defense Responses 789

- 40.1 Physical Defenses 790
- 40.2 Toxin Defenses 792
- 40.3 Animals That Protect Plants 795
- 40.4 Systemic Responses to Invaders 796

## 41 Sensory Systems in Plants 801

- 41.1 Responses to Light 802
- 41.2 Responses to Gravity 806
- 41.3 Responses to Mechanical Stimuli 808
- 41.4 Responses to Water and Temperature 810
- 41.5 Hormones and Sensory Systems 812

## 42 Plant Reproduction 827

- 42.1 Reproductive Development 828
- 42.2 Flower Production 830
- 42.3 Structure and Evolution of Flowers 836
- 42.4 Pollination and Fertilization 838
- 42.5 Asexual Reproduction 845
- 42.6 Plant Life Spans 847

# Part VII *Animal Form and Function*

## 43 The Animal Body and Principles of Regulation 851

- 43.1 Organization of the Vertebrate Body 852
- 43.2 Epithelial Tissue 853
- 43.3 Connective Tissues 856
- 43.4 Muscle Tissue 858
- 43.5 Nerve Tissue 860
- 43.6 Overview of Vertebrate Organ Systems 861
- 43.7 Homeostasis 864

## 44 The Nervous System 869

- 44.1 Nervous System Organization 870
- 44.2 The Mechanism of Nerve Impulse Transmission 872
- 44.3 Synapses: Where Neurons Communicate with Other Cells 878
- 44.4 The Central Nervous System: Brain and Spinal Cord 884
- 44.5 The Peripheral Nervous System: Sensory and Motor Neurons 891

## 45 Sensory Systems 897

- 45.1 Overview of Sensory Receptors 898
- 45.2 Mechanoreceptors: Touch and Pressure 900
- 45.3 Hearing, Vibration, and Detection of Body Position 903
- 45.4 Chemoreceptor: Taste, Smell, and pH 908

45.5 Vision 910

45.6 The Diversity of Sensory Experiences 916

## 46 The Endocrine System 919

- 46.1 Regulation of Body Processes by Chemical Messengers 920
- 46.2 Actions of Lipophilic Versus Hydrophilic Hormones 925
- 46.3 The Pituitary and Hypothalamus: The Body's Control Centers 928
- 46.4 The Major Peripheral Endocrine Glands 933
- 46.5 Other Hormones and Their Effects 938

## 47 The Musculoskeletal System 943

- 47.1 Types of Skeletal Systems 944
- 47.2 A Closer Look at Bone 946
- 47.3 Joints and Skeletal Movement 950
- 47.4 Muscle Contraction 952
- 47.5 Modes of Animal Locomotion 958

## 48 The Digestive System 963

- 48.1 Types of Digestive Systems 964
- 48.2 The Mouth and Teeth: Food Capture and Bulk Processing 966
- 48.3 The Esophagus and the Stomach: The Beginning of Digestion 968
- 48.4 The Small Intestine: Breakdown and Absorption 969
- 48.5 The Large Intestine: Elimination of Waste Material 972
- 48.6 Variations in Vertebrate Digestive Systems 973
- 48.7 Neutral and Hormonal Regulation of the Digestive Tract 975
- 48.8 Accessory Organ Function 976
- 48.9 Food Energy, Energy Expenditure, and Essential Nutrients 977

## 49 The Circulatory and Respiratory Systems 983

- 49.1 Invertebrate Circulatory Systems 984
- 49.2 Vertebrate Circulatory Systems 985
- 49.3 The Four-Chambered Heart and the Blood Vessels 988
- 49.4 Characteristics of Blood Vessels 991
- 49.5 Regulation of Blood Flow and Blood Pressure 995
- 49.6 The Components of Blood 997
- 49.7 Gas Exchange Across Respiratory Surfaces 1000
- 49.8 Gills, Cutaneous Respiration, and Tracheal Systems 1002
- 49.9 Lungs 1004
- 49.10 Structures and Mechanisms of Ventilation 1007
- 49.11 Transport of Gases in Body Fluids 1011

## 50 Temperature, Osmotic Regulation, and the Urinary System 1017

- 50.1 Regulating Body Temperature 1018
- 50.2 Osmolarity and Osmotic Balance 1023



- 50.3 Osmoregulatory Organs 1024
- 50.4 Evolution of the Vertebrate Kidney 1026
- 50.5 Nitrogenous Wastes: Ammonia, Urea, and Uric Acid 1028
- 50.6 The Mammalian Kidney 1030
- 50.7 Hormonal Control of Osmoregulatory Functions 1034

## 51 The Immune System 1039

- 51.1 The Integumentary System: The First Line of Defense 1040
- 51.2 Nonspecific Immunity: The Second Line of Defense 1041
- 51.3 The Specific Immune Response: The Third Line of Defense 1044
- 51.4 T Cells: Cell-Mediated Immunity 1049
- 51.5 B Cells: Humoral Immunity and Antibody Production 1051
- 51.6 Autoimmunity and Hypersensitivity 1058
- 51.7 Antibodies in Medical Treatment and Diagnosis 1060
- 51.8 Pathogens That Evade the Immune System 1063

## 52 The Reproductive System 1067

- 52.1 Animal Reproductive Strategies 1068
- 52.2 Vertebrate Fertilization and Development 1069
- 52.3 Structure and Function of the Human Male Reproductive System 1073
- 52.4 Structure and Function of the Human Female Reproductive System 1076
- 52.5 Contraception and Infertility Treatments 1080

## 53 Animal Development 1087

- 53.1 Fertilization 1088
- 53.2 Cleavage and the Blastula Stage 1092
- 53.3 Gastrulation 1094
- 53.4 Organogenesis 1098
- 53.5 Vertebrate Axis Formation 1104
- 53.6 Human Development 1107

# Part VIII Ecology and Behavior

## 54 Behavioral Biology 1115

- 54.1 Approaches to the Study of Behavior 1116
- 54.2 Behavioral Genetics 1117
- 54.3 Learning 1120
- 54.4 The Development of Behavior 1122
- 54.5 Animal Cognition 1124
- 54.6 Orientation and Migratory Behavior 1125
- 54.7 Animal Communication 1127
- 54.8 Behavioral Ecology 1130

- 54.9 Reproductive Strategies and Sexual Selection 1133
- 54.10 Altruism and Group Living 1137
- 54.11 The Evolution of Social Systems 1140

## 55 Population Ecology 1145

- 55.1 The Environmental Challenge 1146
- 55.2 Populations: Groups of a Single Species in One Place 1148
- 55.3 Population Demography and Dynamics 1152
- 55.4 Life History and the Cost of Reproduction 1154
- 55.5 Population Growth and Environmental Limits 1156
- 55.6 Factors That Regulate Populations 1158
- 55.7 Human Population Growth 1161

## 56 Community Ecology 1167

- 56.1 Biological Communities: Species Living Together 1168
- 56.2 The Ecological Niche Concept 1170
- 56.3 Predator–Prey Relationships 1174
- 56.4 The Many Types of Species Interactions 1178
- 56.5 Ecological Succession, Disturbance, and Species Richness 1184

## 57 Dynamics of Ecosystems 1189

- 57.1 Biogeochemical Cycles 1190
- 57.2 The Flow of Energy in Ecosystems 1196
- 57.3 Trophic-Level Interactions 1201
- 57.4 Biodiversity and Ecosystem Stability 1205
- 57.5 Island Biogeography 1208

## 58 The Biosphere 1211

- 58.1 Ecosystem Effects of Sun, Wind, and Water 1212
- 58.2 Earth's Biomes 1216
- 58.3 Freshwater Habitats 1220
- 58.4 Marine Habitats 1223
- 58.5 Human Impacts on the Biosphere: Pollution and Resource Depletion 1227
- 58.6 Human Impacts on the Biosphere: Global Warming 1231

## 59 Conservation Biology 1237

- 59.1 Overview of the Biodiversity Crisis 1238
- 59.2 The Value of Biodiversity 1242
- 59.3 Factors Responsible for Extinction 1245
- 59.4 Approaches for Preserving Endangered Species 1256
- 59.5 Conservation of Ecosystems 1258

**Glossary G-1**

**Credits C-1**

**Index I-1**

