

# CONTENTS

## PART ONE

### THE ORIGIN OF LIVING THINGS

#### 1 THE SCIENCE OF BIOLOGY 3

- What is a Biologist? 3
- Why is Biology Important to You? 7
  - The Battle Against Disease 7
  - Preserving Our Heritage 8
  - An Overcrowded World 11
- Your Study of Biology 14
- Boxed Essay: How Biologists Do Their Work* 10

#### 2 THE NATURE OF MOLECULES 15

- Atoms 16
  - Energy in the Atom: Electron Orbitals 17
  - The Periodic Table 18
- Molecules 19
- Nature of the Chemical Bond 19
  - Ionic Bonds 20
  - Covalent Bonds 22
- Atoms in Living Organisms 24
- The Cradle of Life: Water 25
  - Water Clings to Itself 27
  - Water Stores Heat 28
  - Water is a Powerful Solvent 29
  - Water Organizes Nonpolar Molecules 30
  - Water Ionizes 31
- The Chemicals of Life 32
  - Carbon Dioxide 32
  - Nitrogen Gas 33
  - Ammonia 33
  - Methane 34
- Boxed Essay: The Origin of Molecules* 28

#### 3 THE ORIGIN AND EARLY HISTORY OF LIFE 37

- The Origin of Organic Molecules: Carbon Polymers 38
- Nature of Life Processes 41
- Origin of the First Cells 44

- History of Early Life 45
  - The Puzzle of Precambrian Life 46
  - The First Autotrophs 47
  - The Advent of Atmospheric Oxygen 48
  - The Dawn of the Eukaryotes 49
- Is There Life on Other Worlds? 50
  - Boxed Essay: The Puzzle of Complex Molecules* 44
  - Boxed Essay: Other Worlds Where Life Might Exist* 50

#### 4 THE CHEMICAL BUILDING BLOCKS OF LIFE 55

- The Building Blocks of Organisms 56
- Energy-Storing Molecules 57
  - Sugars 57
  - Transport Disaccharides 58
  - Starches 60
  - Cellulose 61
  - Fats 62
- Phospholipids and Biological Membranes 64
  - Transport Across Membranes 67
- Proteins 68
  - Amino Acids 68
  - Polypeptides 70
- The Energy Currency of Organisms: ATP 72
- Nucleic Acids 73
  - DNA 75
  - RNA 76
  - An Evolutionary Perspective: DNA 77
- Boxed Essay: Amino Acid Sequence Determines Protein Shape* 72



PART TWO

BIOLOGY OF THE CELL

5 EVOLUTION OF CELL ARCHITECTURE 83

- Cells 84
- Primitive Prokaryotes 85
- Structure of the Prokaryotic Cell 86
  - Exterior Cell Walls 86
  - Lack of Interior Organization 88
- Origin of Eukaryotic Cells 89
  - Changes in Cell Morphology 90
  - Pooling of Genetic Resources 90
  - Development of Genetic Recombination 92
  - Gene Fragmentation 92
- Evolutionary Divergence of the Eukaryotes 93
  - Differences between Plant and Animal Cells 95
  - Vacuoles 95
  - Why Plants Have Cell Walls 96
  - Plasma Membranes 98

6 THE STRUCTURE OF EUKARYOTIC CELLS 101

- The Cytoskeleton 102
  - Microfilaments 102
  - Microtubules 102
- Internal Compartmentalization:
  - The Endoplasmic Reticulum 103
  - Interior Channels 105
  - Enzyme Sites 105
  - Subcompartments 105
- The Nucleus 106
  - The Nuclear Envelope 106
  - The Nucleoplasm 108
  - Chromosomes 108
  - The Nucleolus 108
- The Golgi Complex 109
- Microbodies 110
  - Lysosomes 110
  - Peroxisomes 112
  - Glyoxysomes 112

- Relict Symbionts 112
  - Mitochondria 112
  - Chloroplasts 114
  - Minor Relict Symbionts 115
- An Overview of Cell Structure 116

7 CELL DYNAMICS 121

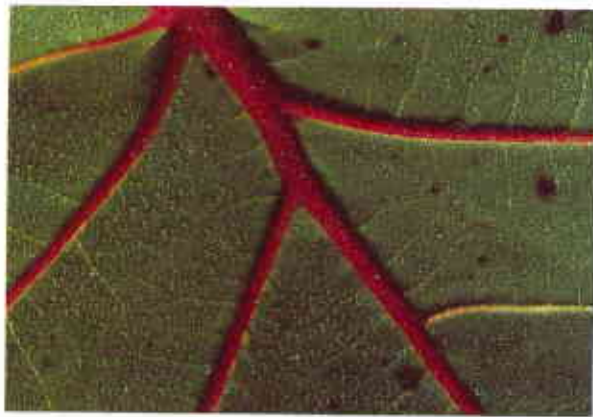
- Flagellar Rotation 122
- Microtubular Movement 124
  - The Structure of Microtubules 125
  - The Basis of Microtubular Movement 126
  - The 9 + 2 Flagellum 127
- Microfilament Contraction 130
  - The Structure of Microfilaments 131
  - How Microfilaments Contract 132
  - Muscles 134
  - Movements Within the Cytoplasm 134
- Movement is a Basic Property of Cells 135

8 THE CELL CYCLE 138

- Cell Division in Bacteria 139
  - The Cell Cycle 139
- The Cell Cycle of Eukaryotes 141
- Mitosis 142
  - Preparing the Scene: Interphase 142
  - Formation of the Mitotic Apparatus:
    - Prophase 143
    - Division of the Centromeres:
      - Metaphase 144
    - Separation of the Chromatids: Anaphase 146
    - Re-formation of Nuclei: Telophase 147
- Cytokinesis 148
  - Cytoplasmic Cleavage in Animal Cells 148
  - Cytoplasmic Cleavage in Plants 148
- Comparing Cell Division in Eukaryotes and Prokaryotes 150
- Boxed Essay: The Evolution of Cell Division in Eukaryotes 146*



9	MEMBRANE TRANSPORT 153	The Evolution of Metabolism 178
	The Osmotic Dilemma: Keeping Water out of Cells 154	Abiotic Synthesis 178
	Bacterial Cell Walls 155	Degradation 179
	Avoiding Osmotic Pressure 155	Fermentation 179
	Water Removal 156	Anaerobic Photosynthesis 180
	Plant Cell Walls 156	Nitrogen Fixation 181
	The Metabolic Dilemma: Letting Metabolites in 157	Oxygen-Forming Photosynthesis 182
	Bulk Passage by the Membrane Fusion 157	Using Oxygen to Drive Redox Processes 182
	Channels Through the Membrane 158	Chemoautotrophs 183
	The Importance of Selective Permeability 158	Aerobic Respiration 185
	Open Channels 159	The Metabolic Journey 186
	Mechanisms of Selective Transport 159	<i>Boxed Essay: The Evolution of Specificity 176</i>
	Passive Two-Way Channels: Facilitated Diffusion 161	
	Passive One-Way Channels: Group Translocation 162	11 THE METABOLIC LIFE OF A CELL 190
	Active Channels 163	Using Chemical Energy to Drive Metabolism 191
	Coupled Channels 165	Coupled Reactions 192
	Secretory Channels 166	Harvesting Energy from Chemical Bonds: ATP 192
	The Importance of Transport Channels 166	Catabolic Metabolism 193
	<i>Boxed Essay: Chloride Channels and Cystic Fibrosis 164</i>	Glycolysis 193
10	METABOLISM 170	An Overview of Glycolysis 193
	The Energy of Chemical Bonds 171	The Universality of the Glycolytic Sequence 195
	Enthalpy 171	The Need to Close the Metabolic Circle:
	Entropy 171	Fermentation and NAD 196
	Free Energy 172	Oxidative Respiration 198
	Catalysis 173	The Oxidation of Glucose: An Overview 198
	Activation Energy 173	The Decarboxylation of Pyruvate 198
	Enzymes 173	The Oxidation of Acetyl-CoA 199
	The Mechanism of Enzyme Catalysis 174	The Reactions of the Citric Acid Cycle 199
	Why Enzymes Are Specific 174	How the Citric Acid Cycle Works 202
	How Enzymes Bind their Substrates 175	Using the Electrons Generated by the Citric Acid Cycle to Make ATP 204
	How Catalysis Occurs 175	Chemiosmotic Synthesis of ATP 204
	Biochemical Pathways 175	An Overview of Glucose Catabolism:
	How Biochemical Pathways Evolved 176	The Balance Sheet 206
	How Biochemical Pathways Are Regulated 177	Mitochondria and ATP Generation 208
		An Overview of Heterotrophic Metabolism 209



## 12 PHOTOSYNTHESIS 212

- The Biophysics of Light 213
- Capturing Light Energy in Chemical Bonds 214
- An Overview of Photosynthesis 217
  - Absorbing Light Energy 217
  - Fixing Carbon 217
  - Replenishing the Pigment 217
- The Chemical Consequences of Photosynthesis 218
- How Light Drives Chemistry:
  - The Light Reactions 219
    - A Primitive Form of the Light Reaction 219
    - Evolution of the Photo-center 219
    - Cyclic Photophosphorylation 220
- Light Reactions of Plants 221
  - The Advent of Photosystem II 221
  - How Photosystems I and II Work Together 221
  - The Generation of Reducing Power 223
  - The Formation of Oxygen Gas 223
  - Comparing Plant and Bacterial Light Reactions 224
  - Accessory Pigments 225
- The Dark Reactions of Photosynthesis:
  - The Calvin Cycle 225
    - Phase 1: Carboxylation 225
    - Phase 2: Glycolytic Reversal 225
    - Phase 3: Regeneration of RuBP 226
- The Chloroplast as a Photosynthetic Machine 227
- The Limit Imposed by Photorespiration 228
- A Look Back 231

## PART THREE

## GENETICS AND HEREDITY

### 13 PATTERNS OF INHERITANCE 237

- The Faces of Variation 237
- Early Ideas About Heredity: the Road to Mendel 239
- Mendel and the Garden Pea 240
- Mendel's Experimental Design 241
- What Mendel Found 242
- How Mendel Interpreted His Results 244
  - The F<sub>1</sub> Generation 246
  - The F<sub>2</sub> Generation 246
  - Further Generations 246
- The Testcross 247
- Probability and Allele Distribution 248
- Independent Assortment 250
- The Gene Concept 252
- Modified Mendelian Ratios 254
- Summary 255
- Boxed Essay: Did Mendel Cheat?* 248

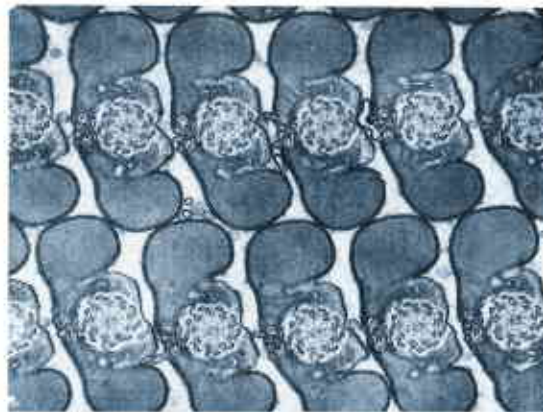
### 14 MEIOSIS AND CHROMOSOMES 259

- The Stages of Meiosis 261
  - The First Meiotic Division 262
  - The Second Meiotic Division 264
- Chromosomes: the Vehicles of Mendelian Inheritance 265
- Crossing-Over 268
  - Genetic Maps 268
- The Importance of Meiotic Recombination 270
- The Structure of Eukaryotic Chromosomes 271
  - Karyotypes 273
- The Significance of Meiosis 276
- Summary 277
- Boxed Essay: Constructing a Genetic Map* 276

### 15 INVESTIGATING THE MECHANISM OF HEREDITY: An Experimental Journey 281

- The Scientific Method 282
- Where Do Cells Store Hereditary Information? 284
- What Component of the Chromosomes Contains the Heredity Information? 286





- The Griffith-Avery Experiments 286  
 The Hershey-Chase Experiment 287  
 The Fraenkel-Conrat Experiment 289  
 How is the Information in DNA Reproduced So Accurately? 290  
 What is the Unit of Hereditary Information? 291  
 How Are Genes Encoded? 294  
 How Does DNA Sequence Dictate Protein Structure? 297  
 An Overview of the Hereditary Mechanism 298  
 Summary 298
- 16 GENES AND HOW THEY WORK 301**  
 An Overview of Gene Expression 302  
 Transcription 302  
 Translation 302  
 Regulating Gene Expression 302  
 The Components of a Gene 304  
 A Coding Sequence 304  
 Translation Signals 305  
 Ribosome Recognition Site 305  
 Transcription Signals 305  
 Polymerase Binding Site 305  
 Regulatory Sites 305  
 The Architecture of a Real Gene 306  
 The Genetic Code 307  
 Processing the mRNA Transcript 311  
 Translating mRNA into Protein 311  
 How DNA Replicates 315  
 How Bacteria Replicate Their DNA 317  
 How a Eukaryote Replicates Its Chromosome 318  
 The Gene Machine 319  
 Summary 319  
*Boxed Essay: The Control of Transcription 308*  
*Boxed Essay: Intervening Sequences: the Discovery of Introns 314*  
*Boxed Essay: Not All Organisms Use the Same Genetic Code 316*
- 17 GENETIC CHANGE 323**  
 Mutation 324  
 DNA Damage 324  
 Spontaneous Mismatching 236  
 An Overview of Recombination 328  
 Gene Transfer 328  
 Plasmids 329  
 Gene Transfer Among Bacteria 329  
 Transposition 331  
 Retroviruses 332  
 The Impact of Transposition 332  
 Chromosomal Rearrangement 333  
 Reciprocal Recombination 335  
 Crossing-Over 335  
 Gene Conversion 338  
 Unequal Crossing-Over 338  
 The Evolution of Gene Organization 340  
 Satellite DNA 340  
 Transposon Elements 340  
 Tandem Clusters 341  
 Multigene Families 342  
 Dispersed Pseudogenes 342  
 Single-Copy Genes 342  
 The Importance of Genetic Change 343  
 Summary 343  
*Boxed Essay: Chromosomal Rearrangement: The Source of Antibody Diversity 334*  
*Boxed Essay: The Molecular Mechanism of Crossing-Over 336*
- 18 GENE TECHNOLOGY 347**  
 Plasmids and the New Genetics 348  
 Restriction Enzymes 348  
 Constructing Chimeric Genomes 350  
 Genetic Engineering 352  
 The Riddle of Cancer 354  
 The Story of Chicken Sarcoma 356  
 The Molecular Basis of Cancer 357  
 Smoking and Cancer 359  
 Summary 360  
*Boxed Essay: How to Catch Cancer 360*



PART FOUR

EVOLUTION

19 DEVELOPMENT OF EVOLUTIONARY THEORY 367

From Special Creation to Evolution 368

Charles Darwin and Modern Evolutionary Thought 369

Darwin's Evidence 370

What Darwin Saw 370

Darwin and Malthus 371

Natural Selection 372

Publication of Darwin's Theory 372

Evolution After Darwin 375

Paleontology 375

Genetics 375

Biochemistry 376

Ecology 376

Contemporary Issues in Evolution 377

Levels of Variation and Their Significance 377

Evolutionary Rates 378

Does Evolution Occur In spurts? 379

Scientific Creationism 380

Summary 381

*Boxed Essay: Gel Electrophoresis* 376

20 ADAPTATION 384

The Nature of Adaptation 385

Two Kinds of Adaptation 386

Gene Frequencies in Nature 386

Human Blood Groups 386

Why is the Human ABO System Maintained? 387

Genetic Polymorphism 388

Population Genetics 389

Hardy-Weinberg Equilibrium 389

Reasons for Change in Populations 391

Mutation 391

Migration 391

Sampling Error 392

Nonrandom Mating 393

Selection 394

Maintaining Polymorphisms 395

Changes in Natural Populations 396

Sickle Cell Anemia 396

Peppered Moths and Industrial Melanism 397

Welsh Grasses 398

The Shifting-Balance Theory of Evolution 399

Summary 401

21 THE ORIGIN OF SPECIES 404

Adaptive Change 404

The Nature of Species 405

The Divergence of Populations 407

Barriers to Hybridization 409

Prezygotic Mechanisms 409

Postzygotic Mechanisms 413

Reproductive Isolation: A Summary 414

Ecological Races 415

Ecotypes in Plants 416

Ecological Races in Animals 417

Cluster of Species 418

Darwin's Finches 418

Hawaiian *Drosophila* 420

Rapid Evolution 421

The Role of Hybridization in Evolution 421

Summary 423

*Boxed Essay: Facing Extinction* 412

*Boxed Essay: Experimental Studies of Plant Ecotypes in California* 416

*Boxed Essay: Human Races* 420



- 22 CLASSIFYING THE PRODUCTS OF EVOLUTION 426
- The History of Classification of Organisms 427
    - The Polynomial System 427
    - The Binomial System 428
    - The Type Method 429
  - What is a Species? 430
  - How Many Species are There? 430
  - The Taxonomic Hierarchy 432
    - The Form of Scientific Names 433
  - Classification and Evolution 434
  - Cladistics 436
  - The Major Groups of Organisms 436
    - Problems with Traditional Groupings 436
    - The Five Kingdoms of Organisms 437
  - Summary 440
- 23 EVOLUTIONARY HISTORY OF THE EARTH 443
- The Fossil Record 444
    - Mechanical Problems in Preservation 444
    - Theoretical Problems in Interpretation 445
    - Dating Fossils 446
  - The Formation and Movement of Continents 447
    - History of Continental Movements 448
  - The Early History of Life on Earth 449
  - The Paleozoic Era 452
    - Origins of Phyla and Divisions 453
    - The Invasion of the Land 454
    - Mass Extinctions 455
  - The Mesozoic Era 456
    - The History of the Vertebrates 457
    - The History of Plants 458
    - The Extinction of the Dinosaurs 460
  - The Cenozoic Era: The World We Know 461
  - The Evolution of Life on Earth 462
  - Summary 462
  - Boxed Essay: Homology and the Evolution of the Eye* 450
- 24 EVOLUTION OF HUMAN BEINGS 466
- Earlier Views of Human Origins 467
  - The Evolution of Mammals 467
  - The Evolution of Primates 468
    - Early History of the Primates 468
    - Monkeys, Apes, and Human Beings 470
  - The Evolution of Hominoids 475
    - Fossil Evidence 475
    - Biochemical Evidence 475
    - The Pattern of Evolution 479
  - The Appearance of Hominoids 481
    - The Australopithecines 481
    - The Use of Tools: *Homo habilis* 482
    - Modern Human Beings: *Homo sapiens* 485
  - The Domestication of Animals and Plants 486
  - Summary 487
  - Boxed Essay: The Threat to Primates* 476
  - Boxed Essay: Allometry in Human Evolution* 480



PART FIVE

BIOLOGY OF SIMPLE ORGANISMS

25 VIRUSES 493

- The Discovery of Viruses 494
- The Nature of Viruses 496
- The Structure of Viruses 496
- Virus Replication 497
- Diversity Among the Viruses 499
  - Unenveloped Plus-Strand RNA Viruses 499
  - Enveloped Plus-Strand RNA Viruses 500
  - Minus-Strand RNA Viruses 501
  - Viroids 502
  - Double-Stranded RNA Viruses 504
  - Small-Genome DNA Viruses 504
  - Medium-Genome and Large-Genome DNA Viruses 505
  - Bacteriophages 506
- Viruses: Particles of Genomes 508
- Summary 508
- Boxed Essay: Prions* 502
- Boxed Essay: The Evolution of Smallpox* 506

26 BACTERIA 511

- Prokaryotes versus Eukaryotes 514
- Bacterial Structure 515
- Bacterial Reproduction 515
- Bacterial Variation 516
  - Mutation 516
  - Genetic Recombination 517
- Bacterial Ecology and Metabolic Diversity 518
  - Autotrophic Bacteria 519
  - Heterotrophic Bacteria 519
  - Nitrogen-Fixing Bacteria 520
- Bacteria as Pathogens 520
- Bacterial Diversity 523
  - The Methane-Producing Bacteria 523
  - The Omnibacteria 525
  - Cyanobacteria 525
  - Chloroxybacteria 527

- Mycoplasmas and Spiroplasmas 528
- Spirochetes 529
- Pseudomonads 529
- Actinomyceetes 529
- Mycobacteria 530
- Nitrogen-Fixing Aerobic Bacteria 531
- Chemoautotrophic Bacteria 531
- Simple But Versatile Organisms 532
- Summary 532

- Boxed Essay: Bacterial Magnetic Navigation* 516
- Boxed Essay: Traveler's Diarrhea* 518
- Boxed Essay: A Living Relic* 526
- Boxed Essay: Bacteria and Fruit Damage in Plants* 531

27 PROTISTS 535

- Evolutionary Relationships of Protists 535
- Symbiosis and the Origin of Eukaryotes 537
  - Mitochondria 537
  - Chloroplasts 537
  - Flagella and Centrioles 538
- Evolution of Multicellularity and Sexuality 538
  - Multicellularity 538
  - Sexuality 539
- Major Groups of Protists 540
  - Dinoflagellates 540
  - Amoebas 542
  - Forams 542
  - Sporozoans 543
  - Cellular Slime Molds 544
  - Plasmodial Slime Molds 546
  - Zoostigotes 547
  - Euglenoids 548
  - Brown Algae 549





## PART SIX

### BIOLOGY OF PLANTS

- Diatoms 550  
 Green Algae 551  
 Ciliates 553  
 Oomycetes 555  
 Red Algae 555  
 The Most Diverse Kingdom of Eukaryotes 556  
 Summary 557  
*Boxed Essay: Malaria* 544
- 28 FUNGI 560**  
 Fungal Ecology 561  
 Fungal Structure 562  
 Fungal Reproduction 564  
 Fungal Divisions 564  
   Zygomycetes 565  
   Ascomycetes 566  
   Basidiomycetes 568  
 A Comparison of the Fungal Divisions 570  
 Fungi Imperfecti 571  
 Lichens 572  
   Lichens and Pollution 575  
   Mycorrhizae 575  
   Summary 577  
*Boxed Essay: Cyclosporine—A Modern  
 Wonder Drug* 562  
*Boxed Essay: Cultivating Mushrooms* 573  
*Boxed Essay: Fungi as Carnivores* 574
- 29 DIVERSITY OF PLANTS 583**  
 The Evolutionary Origins of Plants 584  
 The Green Invasion of the Land 585  
 The Plant Life Cycle 587  
   Alternation of Generations 587  
   The Specialization of Gametophytes 588  
 Mosses and Other Bryophytes 590  
   The Classes of Bryophytes 591  
   Bryophyte Life Cycles 592  
 Vascular Plants 595  
   Conducting Systems of the Vascular Plants 595  
   The Divisions of Living Vascular Plants 596  
   Seeds 597  
   Evolution of the Seed Plants 598  
   Gymnosperms 599  
   Angiosperms 599  
 Vascular Plant Life Cycles 600  
   The Fern Life Cycle 600  
   The Pine Life Cycle 602  
   The Flowering Plant Life Cycle 603  
   A Very Successful Group 606  
 Summary 606  
*Boxed Essay: The Versatility of Mosses* 592
- 30 FLOWERING PLANTS 609**  
 History of the Flowering Plants 610  
   Ancestors 610  
   Age 611  
   Monocots and Dicots 613  
   Why Were the Angiosperms Successful? 613  
   The Rise to Dominance 614  
 Evolution of the Flower 615  
   Analyzing Relationships Among the  
   Angiosperms 615  
   General Characteristics of Floral Evolution 616  
   Calyx 616  
   Corolla 616  
   Androecium 617  
   Gynoecium 618



- Trends of Floral Specialization 618  
 Factors Promoting Outcrossing 619  
 Trends in Floral Symmetry 620  
 Pollination in Flowering Plants 620  
 Pollination by Wind 620  
 Pollination by Animals 621  
 Bees and Flowers 621  
 Insects Other Than Bees 622  
 Pollination by Birds 623  
 Wind-Pollinated Angiosperms 624  
 Self-Pollination 624  
 The Evolution of Fruits 625  
 Summary 627
- 31 VASCULAR PLANT STRUCTURE 630**  
 Early Development 631  
 Organization of the Plant Body 633  
 Tissue Types in Plants 633  
 Types of Meristems 633  
 How Long Do Individual Plants Live? 635  
 Plant Cell Types 637  
 Meristems 637  
 Parenchyma and Collenchyma 638  
 Sclerenchyma 638  
 Xylem 638  
 Phloem 639  
 Epidermis 640  
 Leaves 641  
 General Features 641  
 Structure and Organization 643  
 Modified Leaves 645  
 Shoots 644  
 Primary Growth 644  
 Secondary Growth 646  
 Wood 648  
 Modified Stems 650  
 The Formation of Flowers 650  
 The Root 650  
 Branching in Roots 652  
 Secondary Growth 652  
 Adventitious Roots and Shoots 652  
 Plant Growth and Development 653  
 Summary 654  
*Boxed Essay: The Flowering of Bamboos and the Starvation of Giant Pandas* 634
- 32 PLANT DEVELOPMENT 657**  
 Continuous Development: A Characteristic of Plants 658  
 Differentiation in Plants:  
 Experimental Evidence 659  
 Cell Culture 659  
 Tissue Culture 660  
 Embryo Culture 663  
 Pollen and Anther Culture 664  
 Factors in the Growth Medium 664  
 Experimental Studies 664  
 Regeneration in Nature 665  
 Plant Embryonic Development 666  
 Germination in Plants 668  
 The Role of Seed Dormancy 668  
 Germination 669  
 The Mobilization of Reserves 670  
 The Role of the Apical Meristems 670  
 The Autonomy of Apical Meristems 671  
 Leaf Primordia: Irreversibly Determined? 672  
 The Vascular Cambium:  
 A Differentiated Meristem 672  
 Summary 673  
*Boxed Essay: Cloning in Coconuts* 662
- 33 REGULATION OF PLANT GROWTH 676**  
 Plant Hormones 677  
 Auxins 677  
 Cytokinins 681  
 Gibberellins 681  
 Ethylene 682  
 Abscisic Acid 684  
 The Combined Action of Plant Hormones 684



## PART SEVEN

### BIOLOGY OF INVERTEBRATE ANIMALS

- Tropisms 685  
 Phototropism 685  
 Gravitropism 685  
 Thigmotropism 686  
 Turgor Movements 686  
 Photoperiodism 688  
 Flowering Responses 688  
 The Chemical Basis of the  
 Photoperiodic Response 688  
 The Flowering Hormone: Does it Exist? 690  
 Dormancy 690  
 Summary 692
- 34 NUTRITION AND TRANSPORT  
 IN PLANTS 695**  
 The Soil 696  
 Water Movement 698  
 Transpiration 700  
 The Absorption of Water by Roots 700  
 The Process of Water Movement in Plants 701  
 The Regulation of Transpiration Rate 701  
 Nutrient Movement 703  
 The Movement of Carbohydrates 703  
 Plant Nutrients 706  
 Nutrient Cycles 707  
 The Phosphorus Cycle 708  
 The Nitrogen Cycle 709  
 Carnivorous Plants 712  
 Summary 715  
*Boxed Essay: Plant Responses to Flooding* 704  
*Boxed Essay: Fertilizer* 712  
*Boxed Essay: A Tropical Ant Plant* 714
- 35 THE PRIMITIVE INVERTEBRATES 721**  
 The Animal Kingdom 722  
 The Lower Invertebrates 723  
 The Sponges—Animals Without Tissues 723  
 The Body Plan of Sponges 727  
 The Choanocyte 727  
 Symbiosis in Sponges 726  
 Reproduction in Sponges 726  
 The Evolution of Sponges 727  
 Cnidarians: The Radially Symmetrical  
 Animals 727  
 Embryonic Layers of Eumetazoans 728  
 The Body Plan of Cnidarians 728  
 Nematocysts 729  
 Extracellular Digestion 730  
 Classes of Cnidarians 731  
 Ctenophora: The Comb Jellies 734  
 The Evolution of Bilateral Symmetry 735  
 Body Plans of Bilaterally  
 Symmetrical Animals 736  
 Solid Worms: The Acoelomate Phyla 737  
 Mesozoans 737  
 Flatworms 737  
 Ribbon Worms 742  
 The Evolution of a Body Cavity 743  
 Nematodes 744  
 Other Pseudocoelomates 747  
 Evolutionary Experiments in Body Plan 747  
 Summary 748  
*Boxed Essay: A Newly Discovered Phylum* 748



- 36 MOLLUSKS AND ANNELIDS 751  
 The Advent of the Coelom 752  
 An Embryonic Revolution 753  
 Mollusks 755  
 Body Plan of the Mollusks 756  
 Reproduction in Mollusks 758  
 The Classes of Mollusks 758  
 The Rise of Segmentation 764  
 Annelids 764  
 Classes of Annelids 766  
 Summary 769  
*Boxed Essay: Giant Tube Worms* 762
- 37 ARTHROPODS 772  
 General Characteristics of Arthropods 773  
 Major Groups of Arthropods 774  
 Evolutionary Relationships of the Major Groups 775  
 External Features 776  
 Exoskeleton 777  
 Compound Eye 778  
 Internal Features 779  
 Circulatory System 779  
 Respiratory System 780  
 Excretory System 780  
 Nervous System 781  
 Evolutionary History of the Arthropods 781  
 The Chelicerates 782  
 Arachnids 782  
 Horseshoe Crabs 788  
 Sea Spiders 788  
 Crustaceans 789  
 Umrania 790  
 Millipedes and Centipedes 790  
 Insects 793  
 Summary 802  
*Boxed Essay: Oxychophora* 774  
*Boxed Essay: Spiders and Their Webs* 784  
*Boxed Essay: Insect Phenomena and Pest Control* 796
- 38 ECHINODERMS AND CHORDATES 805  
 Deuterostomes 805  
 Echinoderms 806  
 Basic Features of Echinodermis 807  
 Diversity of Echinodermis 809  
 Two Minor Phyla: Arrow Worms and Acorn Worms 813  
 Arrow Worms 813  
 Acorn Worms 814  
 Chordates 814  
 Characteristic Features 814  
 Chordate Subphyla 815  
 Summary 820  
*Boxed Essay: Fossil Echinoderms—A Parade of Unsuccessful Experiments* 810





PART EIGHT

BIOLOGY OF VERTEBRATE ANIMALS 823

39 VERTEBRATE DIVERSITY 825

- Jawless Fishes 826
- The Appearance of Jawed Fishes 828
  - The Evolution of Jaws 828
  - The Jawed Fishes 828
- Bony Fishes 829
  - Origin and Evolution 829
  - Subclasses of Osteichthyes 832
- The Invasion of the Land 832
- Amphibians 833
- Reptiles 834
- Temperature Control in Land Animals 836
- Birds 837
- Mammals 840
  - Characteristics of Mammals 840
  - Diversity of Mammals 841
- Summary 847
- Boxed Essay: The Discovery of a Living Coelacanth* 849
- Boxed Essay: What are the Relatives of the Giant Panda? A Molecular Solution* 838
- Boxed Essay: Bats* 844

40 SEX AND REPRODUCTION 850

- Why Sex? 851
- The Evolutionary Consequences of Sex 853
- Sex Evolved in the Sea 854
- Vertebrate Sex and Reproduction: Four Strategies 854
  - Fishes 854
  - Amphibians 855
  - Reptiles and Birds 856
  - Mammals 857
- The Evolution of Life History Traits 857
- Sexual Cycles 859
- Hormones 860
- The Reproductive Cycle of Mammals 861
- The Human Reproductive System 863
  - Males 863
  - Females 866

The Physiology of Human Intercourse 868

- Excitement 869
- Plateau 869
- Orgasm 870
- Resolution 870
- Contraception and Birth Control 870
  - Abstinence 871
  - Sperm Blockage 871
  - Sperm Destruction 871
  - Prevention of Egg Maturation 872
  - Surgical Intervention 872
  - Prevention of Embryo Implantation 872
  - Abortion 873

An Overview of Vertebrate Reproduction 873

- Summary 874
- Boxed Essay: Different Approaches to Sex* 852

41 PATHS OF EMBRYONIC DEVELOPMENT 878

- Initial Stage of Reproduction: Fertilization 879
  - Penetration 879
  - Activation 879
  - Fusion 881
- Setting the Stage for Development: Cell Cleavage 881
  - Cell Cleavage Patterns 881
  - The Blastula 883
- The Onset of Developmental Change: Gastrulation 883
  - Alternative Patterns of Gastrulation 883
- The Determination of Body Architecture: Neurulation 886
- Evolutionary Origin of the Vertebrates: The Neural Crest 886
  - Structures Derived From the Neural Crest 887
  - The Role of the Neural Crest in Vertebrate Evolution 888
- How Cells Communicate During Development 889



- The Nature of Developmental Decisions 891  
 The Evolution of Development 891  
 The Course of Human Development 893  
   First Trimester 893  
   Second Trimester 895  
   Third Trimester 896  
 Postnatal Development 896  
 Summary 898  
*Boxed Essay: Development Gone Wrong: Down Syndrome* 892
- 42 ORGANIZATION OF THE VERTEBRATE BODY 901**  
 Epithelium 902  
   Simple Epithelium 903  
   Stratified Epithelium 903  
   Glands 903  
 Connective Tissue 903  
   Defensive Connective Tissues 904  
   Structural Connective Tissues 906  
   Sequestering Connective Tissues 910  
 Muscle Tissue 910  
   Smooth Muscle 910  
   Striated Muscle 911  
   Cardiac Muscle 913  
 Nerve Tissue 914  
   How Nerves Cause Muscles to Contract 914  
 The Major Organ Systems of Vertebrates 916  
 Summary 917  
*Boxed Essay: The Many Roles of Skin* 906
- 43 FUELING BODY ACTIVITIES: DIGESTION 919**  
 The Nature of Digestion 920  
   Protein Digestion 920  
   Starch and Fat Digestion 921  
 The Evolution of Digestive Systems 922  
 Phagocytosis 922  
 A Digestive Cavity 922  
 Extracellular Digestion 923  
 Organization of Vertebrate Digestive Systems: 924  
 Where it All Begins: The Mouth 924  
 The Journey of Food to the Stomach 926  
 Preliminary Digestion: The Stomach 926  
 Terminal Digestion and Absorption:  
   The Small Intestine 931  
 Concentration of Solids:  
   The Large Intestine 932  
 Symbiosis within the Digestive Systems  
   of Vertebrates 935  
 Nutrition 935  
 Summary 937  
*Boxed Essay: Beaks* 928
- 44 THE CAPTURE OF OXYGEN: RESPIRATION 940**  
 How Gas Enters a Cell 941  
   The Composition of Air 941  
   The Diffusion of Oxygen into Water 943  
   The Passage of Oxygen into Cells 943  
 The Evolution of Respiration 943  
 Simple Diffusion 944  
   Creating a Water Current 944  
   Increasing the Diffusion Surface 944  
   Enclosing the Respiratory Organ 945  
 The Gill as an Aqueous Respiratory Machine 946  
 From Aquatic to Atmospheric Breathing:  
   The Lung 948  
   Amphibians 948  
   Reptiles 949  
   Mammals 949  
   Birds 950  
 The Mechanics of Human Breathing 951  
 How Respiration Works: Gas Transport  
 and Exchange 953  
   Hemoglobin and Gas Transport 953  
   The Exchange Process 954  
 Summary 955



- 45 TRANSPORT WITHIN THE BODY:  
CIRCULATION 958**
- The Evolution of Circulatory Systems 958
  - The Function of Circulatory Systems 960
    - Nutrient and Waste Transport 960
    - Oxygen and Carbon Dioxide Transport 960
    - Temperature Maintenance 961
    - Hormone Circulation 961
  - The Cardiovascular System 962
    - Arteries 963
    - Arterioles 963
    - Capillaries 964
    - Veins 964
    - The Lymphatic System 966
  - The Contents of Vertebrate Circulatory Systems 967
    - Blood Plasma 967
    - Types of Blood Cells 970
  - How the Liver Regulates Blood Glucose Levels 971
  - The Evolution of the Vertebrate Heart 973
    - The Early Chordate Heart: A Peristaltic Pump 973
    - The Fish Heart: A One-Cycle Chamber Pump 973
    - Amphibian and Reptile Hearts:
      - The Advent of Pulmonary Circulation 975
    - Mammal and Bird Hearts: A True Two-Cycle Pump 975
    - The Pacemaker: Preservation of the Sinus Venosus 976
    - Increase in Pumping Capacity 976
  - The Human Heart 977
    - Circulation Through the Heart 977
    - How the Heart Contracts 979
    - Monitoring the Heart's Performance 982
    - Cardiac Output 983
  - The Central Importance of Circulation 983
  - Summary 984
  - Boxed Essay: How Blood Clots 968*
  - Boxed Essay: Diseases of the Heart and Blood Vessels 980*
- 46 REGULATING BODILY ACTIVITIES:  
THE NERVOUS SYSTEM 987**
- Transmitting Information within the Body:
    - An Overview 988
  - Organization of the Vertebrate Nervous System 988
  - The Neuron: Functional Unit of the Nervous System 990
    - The Functional Architecture of Neurons 990
    - Excitable Membranes 992
    - The Nerve Impulse 992
    - Transferring Information from Nerve to Tissue 994
    - Transferring Information from Nerve to Nerve 997
    - An Overview of Neuron Function 998
  - The Evolution of Nervous Systems 998
    - The Simplest Nervous Systems: Reflex Arcs 999
    - The Advent of More Complex Nervous Systems: Associative Activities 999
    - The Evolutionary Path to the Vertebrates 1000
  - Evolution of the Vertebrate Brain 1000
    - Basic Organization of the Vertebrate Brain 1003
    - The Advent of a Dominant Forebrain 1004
    - The Recent Expansion of the Cerebrum 1004
  - Anatomy and Function of the Human Brain 1004
    - The Cerebral Cortex 1004
    - Associative Organization of the Cerebral Cortex 1006
    - Memory and Learning 1006
  - The Importance of the Peripheral Nervous System 1007
  - Summary 1007



47	<p><b>SENSORY SYSTEMS</b> 1010</p> <p>The Nature of Neurosensory Communication 1011</p> <p>Sensing Internal Information 1011</p> <p>    Nerve Endings as Sensory Receptors 1011</p> <p>    Simple Mechanical Receptors 1012</p> <p>Sensing the Body's Position in Space 1014</p> <p>    Gravity 1014</p> <p>    Angular Acceleration 1014</p> <p>    Lateral Line 1016</p> <p>Sensing the External Environment 1016</p> <p>    Taste and Smell 1017</p> <p>    Hearing 1018</p> <p>    Vision 1021</p> <p>    Mechanical Design of the Vertebrate Eye 1025</p> <p>    Other Environmental Senses in Vertebrates 1027</p> <p>An Overview of Sensory Systems 1028</p> <p>Summary 1029</p>
48	<p><b>INTEGRATION AND HOMEOSTASIS</b> 1032</p> <p>How the Central Nervous System Regulates Body Activities 1033</p> <p>Neuromuscular Control 1034</p> <p>    Feedback Loops 1034</p> <p>    Antagonistic Control of Skeletal Muscles 1036</p> <p>Neurovisceral Control 1036</p> <p>    The Autonomic Nervous System 1036</p> <p>    Antagonistic Control of the Autonomic Nervous System 1037</p> <p>    Heartbeat: How a Neurovisceral Control Works 1038</p> <p>Neuroendocrine Control 1039</p> <p>    Hormones Released by the Posterior Pituitary 1040</p> <p>    Hormones Released by the Anterior Pituitary 1040</p> <p>    Non-Pituitary Hormones 1042</p> <p>    How Neuroendocrine Control Works 1042</p>
	<p>The Regulation of Physiological Functions: Water Balance 1044</p> <p>    Osmoconformers 1044</p> <p>    The Problems Faced by Osmoregulators 1045</p> <p>    How Osmoregulation is Achieved 1045</p> <p>The Evolution of Kidneys Among the Vertebrates 1046</p> <p>    Freshwater Fishes 1046</p> <p>    Marine Fishes 1048</p> <p>    Amphibians and Reptiles 1049</p> <p>    Mammals and Birds 1049</p> <p>How the Mammalian Kidney Works 1050</p> <p>    The Countercurrent Multiplier Hypothesis 1050</p> <p>    The Two-Solute Model 1051</p> <p>Integration and Homeostasis 1053</p> <p>Summary 1053</p>
49	<p><b>BEHAVIOR</b> 1056</p> <p>Innate Patterns of Behavior 1058</p> <p>    Recurring Patterns in Behavior 1058</p> <p>    Hierarchical Behaviors 1060</p> <p>    Latent Behaviors 1060</p> <p>Learning 1061</p> <p>    Nonassociative Learning 1061</p> <p>    Associative Learning 1061</p> <p>The Nature of Social Behavior 1063</p> <p>    Aggression 1064</p> <p>    Patterns of Aggressive Behavior 1066</p> <p>    Altruistic Behavior 1068</p> <p>The Evolution of Behavior 1070</p> <p>    Natural Selection and Behavior 1071</p> <p>An Overview of Vertebrate Behavior 1074</p> <p>Summary 1075</p> <p><i>Boxed Essay: Aplysia and the Neurological Basis of Learning</i> 1064</p> <p><i>Boxed Essay: Naked Mole Rats—A Rigidly Organized Vertebrate Society</i> 1068</p> <p><i>Boxed Essay: The Long Journey of the Monarch Butterfly</i> 1072</p>





PART NINE

ECOLOGY 1079

50 ATMOSPHERE, OCEANS, AND BIOMES 1081

- The General Circulation of the Atmosphere 1083
  - The Sun and Atmospheric Circulation 1083
  - Major Circulation Patterns 1083
  - Atmospheric Circulation, Precipitation, and Climate 1084
  - Patterns of Circulation in the Ocean 1086
- The Oceans 1088
  - The Neritic Zone 1089
  - The Surface Zone 1090
  - The Abyssal Zone 1091
- Fresh Water 1091
- Biomes 1093
  - Tropical Rain Forests 1094
  - Savannas 1095
  - Desert 1096
  - Grasslands 1100
  - Temperate Deciduous Forests 1101
  - Taiga 1103
  - Tundra 1105
- Summary 1105
- Boxed Essay: El Niño* 1086
- Boxed Essay: The Dams of the North* 1098

51 DYNAMICS OF ECOSYSTEMS 1109

- Biogeochemical Cycles 1111
  - The Water Cycle 1112
  - The Carbon Cycle 1113
  - The Nitrogen Cycle 1115
  - The Oxygen Cycle 1116
  - The Phosphorus Cycle 1116
- Recycling in a Forested Ecosystem 1117
- The Flow of Energy 1118
  - Trophic Levels 1119

- Ecological Succession 1121
- Pollution 1125
- Summary 1128
- Boxed Essay: Carbon Dioxide and Rising World Temperatures* 1114
- Boxed Essay: Life Develops on Sonora* 1122
- Boxed Essay: Acid Rain* 1126

52 POPULATION DYNAMICS 1131

- Population Size and Dispersion 1132
- Population Growth 1133
  - Biotic Potential 1133
  - Carrying Capacity 1134
  - Density-Dependent and Density-Independent Effects 1134
  - r-Strategists and K-Strategists 1135
  - Human Populations 1136
- Mortality and Survivorship 1136
- Demography 1137
- Interspecific Interactions That Limit Population Size 1137
  - Competition 1138
  - Competition in Nature 1139
  - The Niche 1142
  - Predation 1143
- Summary 1147
- Boxed Essay: Island Biogeography* 1140

53 COMMUNITY ECOLOGY 1150

- The Redwood Forest: An Example 1140
- Factors Limiting Distributions 1153
- Coevolution 1155
- Predator-Prey Interactions 1155
  - Plant-Herbivore Relationships 1155
  - Plant Defenses 1156
  - Producing Defenses When They are Needed 1157



	The Evolution of Herbivores	1158
	Chemical Defenses in Animals	1160
	Aposematic Coloration	1162
	Mimicry	1162
	Predatory Behavior in Animals	1166
	Symbiosis	1167
	Commensalism	1168
	Mutualism	1168
	Parasitism	1170
	What Are Communities?	1170
	Summary	1171
	<i>Boxed Essay: The Community As a Superorganism</i>	1152
	<i>Boxed Essay: Deception in Orchids</i>	1164
54	THE FUTURE OF THE BIOSPHERE	1174
	The Future of Agriculture	1175
	The Population Explosion	1178
	The Present Situation	1179
	Food and Population	1181
	Water, Energy, and Minerals	1182
	Water	1182
	Energy	1184
	Minerals	1186
	The Prospects For More Food	1186
	The Tropics	1189
	Nuclear Winter: The Biological Consequences	1193
	What Biologists Have To Contribute	1194
	Summary	1195
	<i>Boxed Essay: The Potential For New Crops</i>	1176
	<i>Boxed Essay: The Firewood Crisis</i>	1184
	<i>Appendix A: Classification of Organisms</i>	A-1
	<i>Appendix B: Answers to Self-Quiz Questions</i>	B-1
	<i>Glossary</i>	G-1
	<i>Illustration Acknowledgments</i>	IA-1
	<i>Index</i>	I-1