

Jane B. Reece Berkeley, California

Lisa A. UrryMills College, Oakland, California

Michael L. Cain Bowdoin College, Brunswick, Maine Steven A. Wasserman University of California, San Diego

Peter V. Minorsky Mercy College, Dobbs Ferry, New York

Robert B. Jackson Stanford University, Stanford, California

PEARSON

Boston Columbus Indianapolis New York San Francisco Upper Saddle River Amsterdam Cape Town Dubai London Madrid Milan Munich Paris Montréal Toronto Delhi Mexico City São Paulo Sydney Hong Kong Seoul Singapore Taipei Tokyo

Brief Contents

1 Evolution, the Themes of Biology, and Scientific Inquiry 1



THE CHEMISTRY OF LIFE 27

- 2 The Chemical Context of Life 28
- 3 Water and Life 44
- **4** Carbon and the Molecular Diversity of Life 56
- 5 The Structure and Function of Large Biological Molecules 66



THE CELL 92

- **6** A Tour of the Cell 93
- 7 Membrane Structure and Function 124
- 8 An Introduction to Metabolism 141
- **9** Cellular Respiration and Fermentation 162
- 10 Photosynthesis 185
- 11 Cell Communication 210
- 12 The Cell Cycle 232



GENETICS 251

- 13 Meiosis and Sexual Life Cycles 252
- 14 Mendel and the Gene Idea 267
- 15 The Chromosomal Basis of Inheritance 292
- 16 The Molecular Basis of Inheritance 312
- 17 Gene Expression: From Gene to Protein 333
- 18 Regulation of Gene Expression 360
- **19** Viruses 392
- **20** DNA Tools and Biotechnology 408
- 21 Genomes and Their Evolution 436



MECHANISMS OF EVOLUTION 461

- **22** Descent with Modification: A Darwinian View of Life 462
- 23 The Evolution of Populations 480
- 24 The Origin of Species 500
- **25** The History of Life on Earth 519



THE EVOLUTIONARY HISTORY OF BIOLOGICAL DIVERSITY 546

- 26 Phylogeny and the Tree of Life 547
- 27 Bacteria and Archaea 567
- 28 Protists 587
- 29 Plant Diversity I: How Plants Colonized Land 612

- **30** Plant Diversity II: The Evolution of Seed Plants 630
- **31** Fungi 648
- **32** An Overview of Animal Diversity 667
- **33** An Introduction to Invertebrates 680
- **34** The Origin and Evolution of Vertebrates 712



PLANT FORM AND FUNCTION 751

- 35 Plant Structure, Growth, and Development 752
- **36** Resource Acquisition and Transport in Vascular Plants 778
- **37** Soil and Plant Nutrition 799
- 38 Angiosperm Reproduction and Biotechnology 815
- 39 Plant Responses to Internal and External Signals 836



ANIMAL FORM AND FUNCTION 866

- **40** Basic Principles of Animal Form and Function 867
- 41 Animal Nutrition 892
- 42 Circulation and Gas Exchange 915
- 43 The Immune System 946
- 44 Osmoregulation and Excretion 971
- 45 Hormones and the Endocrine System 993
- 46 Animal Reproduction 1013
- **47** Animal Development 1037
- 48 Neurons, Synapses, and Signaling 1061
- 49 Nervous Systems 1079
- 50 Sensory and Motor Mechanisms 1101
- 51 Animal Behavior 1133



ECOLOGY 1157

- **52** An Introduction to Ecology and the Biosphere 1158
- **53** Population Ecology 1184
- **54** Community Ecology 1208
- 55 Ecosystems and Restoration Ecology 1232
- 56 Conservation Biology and Global Change 1254

Detailed Contents

Evolution, the Themes of Biology, and Scientific Inquiry 1

Inquiring About Life 1

CONCEPT 1.1 The study of life reveals common themes 2

Theme: New Properties Emerge at Successive Levels of Biological Organization 3

Theme: Life's Processes Involve the Expression and Transmission of Genetic Information 5

Theme: Life Requires the Transfer and Transformation of Energy and Matter 7

Theme: From Ecosystems to Molecules, Interactions Are Important in Biological Systems 8

Evolution, the Core Theme of Biology 9

CONCEPT 1.2 The Core Theme: Evolution accounts for the unity and diversity of life 10

Classifying the Diversity of Life 10

Charles Darwin and the Theory of Natural Selection 12

The Tree of Life 14

CONCEPT 1.3 In studying nature, scientists make observations and form and test hypotheses 16

Making Observations 16

Forming and Testing Hypotheses 16

The Flexibility of the Scientific Process 18

A Case Study in Scientific Inquiry: Investigating Coat

Coloration in Mouse Populations 19

Experimental Variables and Controls 20

Theories in Science 21

CONCEPT 1.4 Science benefits from a cooperative approach and diverse viewpoints 21

Building on the Work of Others 21

Science, Technology, and Society 23

The Value of Diverse Viewpoints in Science 23



THE CHEMISTRY OF LIFE 27

2 The Chemical Context of Life 28

A Chemical Connection to Biology 28

CONCEPT 2.1 Matter consists of chemical elements in pure form and in combinations called compounds 29

Elements and Compounds 29

The Elements of Life 29

Case Study: Evolution of Tolerance

to Toxic Elements 30



CONCEPT 2.2 An element's properties depend on the structure of its atoms 30

Subatomic Particles 30

Atomic Number and Atomic Mass 31

Isotopes 31

The Energy Levels of Electrons 32

Electron Distribution and Chemical Properties 34

Electron Orbitals 35

CONCEPT 2.3 The formation and function of molecules depend on

chemical bonding between atoms 36

Covalent Bonds 36

Ionic Bonds 37

Weak Chemical Bonds 38

Molecular Shape and Function 39

CONCEPT 2.4 Chemical reactions make

and break chemical bonds 40

3 Water and Life 44

The Molecule That Supports All of Life 44

CONCEPT 3.1 Polar covalent bonds in water molecules result in hydrogen bonding 45

CONCEPT 3.2 Four emergent properties of water contribute to Earth's suitability for life 45

Cohesion of Water Molecules 45

Moderation of Temperature by Water 46

Floating of Ice on Liquid Water 48

Water: The Solvent of Life 48

Possible Evolution of Life on Other Planets 50

CONCEPT 3.3 Acidic and basic conditions affect living organisms 51

Acids and Bases 51

The pH Scale 51

Buffers 52

Acidification: A Threat to Water Quality 53

Carbon and the Molecular Diversity of Life 56

Carbon: The Backbone of Life 56

CONCEPT 4.1 Organic chemistry is the study of carbon compounds 57

Organic Molecules and the Origin of Life on Earth 57

CONCEPT 4.2 Carbon atoms can form diverse molecules by bonding to four other atoms 58

The Formation of Bonds with Carbon 59

Molecular Diversity Arising from Variation in Carbon

CONCEPT 4.3 A few chemical groups are key to molecular function 62

The Chemical Groups Most Important in the Processes of

ATP: An Important Source of Energy for Cellular Processes 64 The Chemical Elements of Life: *A Review* 64

The Structure and Function of Large Biological Molecules 66

The Molecules of Life 66

CONCEPT 5.1 Macromolecules are polymers, built from monomers 67

The Synthesis and Breakdown of Polymers 67

The Diversity of Polymers 67

CONCEPT 5.2 Carbohydrates serve as fuel and building material 68

Sugars 68

Polysaccharides 70

CONCEPT 5.3 Lipids are a diverse group of hydrophobic molecules 72

Fats 72

Phospholipids 74

Steroids 75

CONCEPT 5.4 Proteins include a diversity of structures, resulting in a wide range of functions 75

Amino Acid Monomers 75

Polypeptides (Amino Acid Polymers) 78

Protein Structure and Function 78

CONCEPT 5.5 Nucleic acids store, transmit, and help express hereditary information 84

The Roles of Nucleic Acids 84

The Components of Nucleic Acids 85

Nucleotide Polymers 86

The Structures of DNA and RNA Molecules 86

CONCEPT 5.6 Genomics and proteomics have transformed biological inquiry and applications 87

DNA and Proteins as Tape Measures of Evolution 89



THE CELL 92

6 A Tour of the Cell 93

The Fundamental Units of Life 93

CONCEPT 6.1 Biologists use microscopes and the tools of biochemistry to study cells 94

Microscopy 94

Cell Fractionation 96

CONCEPT 6.2 Eukaryotic cells have internal membranes that compartmentalize their functions 97

Comparing Prokaryotic and Eukaryotic Cells 97

A Panoramic View of the Eukaryotic Cell 99

CONCEPT 6.3 The eukaryotic cell's genetic instructions are housed in the nucleus and carried out by the ribosomes 102

The Nucleus: Information Central 102

Ribosomes: Protein Factories 102

CONCEPT 6.4 The endomembrane system regulates protein traffic and performs metabolic functions in the cell 104

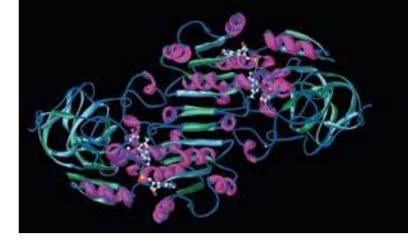
The Endoplasmic Reticulum: Biosynthetic Factory 104

The Golgi Apparatus: Shipping and Receiving Center 105

Lysosomes: Digestive Compartments 107

Vacuoles: Diverse Maintenance Compartments 108

The Endomembrane System: A Review 108



CONCEPT 6.5 Mitochondria and chloroplasts change energy from one form to another 109

The Evolutionary Origins of Mitochondria and

Chloroplasts 109 Mitochondria: Chemical Energy Conversion 110

Chloroplasts: Capture of Light Energy 110

Peroxisomes: Oxidation 112

CONCEPT 6.6 The cytoskeleton is a network of fibers that organizes structures and activities in the cell 112

Roles of the Cytoskeleton: Support and Motility 112

Components of the Cytoskeleton 113

CONCEPT 6.7 Extracellular components and connections between cells help coordinate cellular activities 118

Cell Walls of Plants 118

The Extracellular Matrix (ECM) of Animal Cells 118

Cell Junctions 119

The Cell: A Living Unit Greater Than the Sum of Its Parts 121

Membrane Structure and Function 124

Life at the Edge 124

CONCEPT 7.1 Cellular membranes are fluid mosaics of lipids and proteins 125

The Fluidity of Membranes 126

Evolution of Differences in Membrane Lipid Composition 127

Membrane Proteins and Their Functions 127

The Role of Membrane Carbohydrates in Cell-Cell

Recognition 128

Synthesis and Sidedness of Membranes 129

CONCEPT 7.2 Membrane structure results in selective permeability 129

The Permeability of the Lipid Bilayer 130

Transport Proteins 130

CONCEPT 7.3 Passive transport is diffusion of a substance across a membrane with no energy investment 130

Effects of Osmosis on Water Balance 131

Facilitated Diffusion: Passive Transport Aided by Proteins 133

CONCEPT 7.4 Active transport uses energy to move solutes against their gradients 134

The Need for Energy in Active Transport 134

How Ion Pumps Maintain Membrane Potential 135

Cotransport: Coupled Transport by a Membrane Protein 136

CONCEPT 7.5 Bulk transport across the plasma membrane occurs by exocytosis and endocytosis 137

Exocytosis 137

Endocytosis 137



8 An Introduction to Metabolism 141

The Energy of Life 141

CONCEPT 8.1 An organism's metabolism transforms matter and energy, subject to the laws of thermodynamics 142

Organization of the Chemistry of Life into Metabolic Pathways 142

Forms of Energy 142

The Laws of Energy Transformation 143

CONCEPT 8.2 The free-energy change of a reaction tells us whether or not the reaction occurs spontaneously 145

Free-Energy Change, ΔG 145

Free Energy, Stability, and Equilibrium 145

Free Energy and Metabolism 146

CONCEPT 8.3 ATP powers cellular work by coupling exergonic reactions to endergonic reactions 148

The Structure and Hydrolysis of ATP 149

How the Hydrolysis of ATP Performs Work 149

The Regeneration of ATP 151

CONCEPT 8.4 Enzymes speed up metabolic reactions by lowering energy barriers 151

The Activation Energy Barrier 151

How Enzymes Speed Up Reactions 152

Substrate Specificity of Enzymes 153

Catalysis in the Enzyme's Active Site 154

Effects of Local Conditions on Enzyme Activity 155

The Evolution of Enzymes 157

CONCEPT 8.5 Regulation of enzyme activity helps control metabolism 157

Allosteric Regulation of Enzymes 157 Localization of Enzymes Within the Cell 159

Cellular Respiration and Fermentation 162

Life Is Work 162

CONCEPT 9.1 Catabolic pathways yield energy by oxidizing organic fuels 163

Catabolic Pathways and Production of ATP 163

Redox Reactions: Oxidation and Reduction 163

The Stages of Cellular Respiration: A Preview 166

CONCEPT 9.2 Glycolysis harvests chemical energy by oxidizing glucose to pyruvate 168

CONCEPT 9.3 After pyruvate is oxidized, the citric acid cycle completes the energy-yielding oxidation of organic molecules 169

Oxidation of Pyruvate to Acetyl CoA 169

The Citric Acid Cycle 170

CONCEPT 9.4 During oxidative phosphorylation, chemiosmosis couples electron transport to ATP synthesis 172

The Pathway of Electron Transport 172

Chemiosmosis: The Energy-Coupling Mechanism 173

An Accounting of ATP Production by Cellular Respiration 175 CONCEPT 9.5 Fermentation and anaerobic respiration enable cells to produce ATP without the use of oxygen 177

Types of Fermentation 178

Comparing Fermentation with Anaerobic and Aerobic Respiration 179

The Evolutionary Significance of Glycolysis 179

CONCEPT 9.6 Glycolysis and the citric acid cycle connect to many other metabolic pathways 180

The Versatility of Catabolism 180 Biosynthesis (Anabolic Pathways) 181 Regulation of Cellular Respiration via Feedback Mechanisms 181

10 Photosynthesis 185

The Process That Feeds the Biosphere 185

CONCEPT 10.1 Photosynthesis converts light energy to the chemical energy of food 187

Chloroplasts: The Sites of Photosynthesis in Plants 187 Tracking Atoms Through Photosynthesis: *Scientific*

The Two Stages of Photosynthesis: A Preview 189

CONCEPT 10.2 The light reactions convert solar energy to the chemical energy of ATP and NADPH 190

The Nature of Sunlight 190

Photosynthetic Pigments: The Light Receptors 191

Excitation of Chlorophyll by Light 193

A Photosystem: A Reaction-Center Complex Associated with Light-Harvesting Complexes 193

Linear Electron Flow 195

Cyclic Electron Flow 196

A Comparison of Chemiosmosis in Chloroplasts and Mitochondria 197

CONCEPT 10.3 The Calvin cycle uses the chemical energy of ATP and NADPH to reduce CO₂ to sugar 199

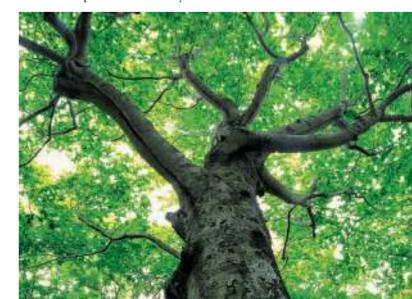
CONCEPT 10.4 Alternative mechanisms of carbon fixation have evolved in hot, arid climates 201

Photorespiration: An Evolutionary Relic? 201

C₄ Plants 201

CAM Plants 203

The Importance of Photosynthesis: A Review 204



11 Cell Communication 210

Cellular Messaging 210

CONCEPT 11.1 External signals are converted to responses within the cell 211

Evolution of Cell Signaling 211

Local and Long-Distance Signaling 212

The Three Stages of Cell Signaling: A Preview 212

CONCEPT 11.2 Reception: A signaling molecule binds to a receptor protein, causing it to change shape 214

Receptors in the Plasma Membrane 214

Intracellular Receptors 217

CONCEPT 11.3 Transduction: Cascades of molecular interactions relay signals from receptors to target molecules in the cell 218

Signal Transduction Pathways 218

Protein Phosphorylation and Dephosphorylation 219 Small Molecules and Ions as Second Messengers 220

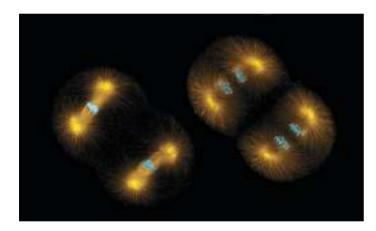
CONCEPT 11.4 Response: Cell signaling leads to regulation of transcription or cytoplasmic activities 223

Nuclear and Cytoplasmic Responses 223

Regulation of the Response 223

CONCEPT 11.5 Apoptosis integrates multiple cell-signaling pathways 227

Apoptosis in the Soil Worm *Caenorhabditis elegans* 228 Apoptotic Pathways and the Signals That Trigger Them 228



12 The Cell Cycle 232

The Key Roles of Cell Division 232

CONCEPT 12.1 Most cell division results in genetically identical daughter cells 233

Cellular Organization of the Genetic Material 233 Distribution of Chromosomes During Eukaryotic Cell Division 234

CONCEPT 12.2 The mitotic phase alternates with interphase in the cell cycle 235

Phases of the Cell Cycle 235

The Mitotic Spindle: A Closer Look 235

Cytokinesis: A Closer Look 239

Binary Fission in Bacteria 240

The Evolution of Mitosis 241

CONCEPT 12.3 The eukaryotic cell cycle is regulated by a molecular control system 242

The Cell Cycle Control System 242 Loss of Cell Cycle Controls in Cancer Cells 246



GENETICS 251

Meiosis and Sexual Life Cycles 252

Variations on a Theme 252

CONCEPT 13.1 Offspring acquire genes from parents by inheriting chromosomes 253

Inheritance of Genes 253

Comparison of Asexual and Sexual Reproduction 253

CONCEPT 13.2 Fertilization and meiosis alternate in sexual life cycles 254

Sets of Chromosomes in Human Cells 254

Behavior of Chromosome Sets in the Human Life Cycle 255 The Variety of Sexual Life Cycles 256

CONCEPT 13.3 Meiosis reduces the number of chromosome sets

from diploid to haploid 257
The Stages of Meiosis 257

Crossing Over and Synapsis During Prophase I 260

A Comparison of Mitosis and Meiosis 260

CONCEPT 13.4 Genetic variation produced in sexual life cycles contributes to evolution 263

Origins of Genetic Variation Among Offspring 263 The Evolutionary Significance of Genetic Variation Within Populations 264

14 Mendel and the Gene Idea 267

Drawing from the Deck of Genes 267

CONCEPT 14.1 Mendel used the scientific approach to identify two laws of inheritance 268

Mendel's Experimental, Quantitative Approach 268

The Law of Segregation 269

The Law of Independent Assortment 272

CONCEPT 14.2 Probability laws govern Mendelian inheritance 274
The Multiplication and Addition Rules Applied to Monohybrid
Crosses 275

Solving Complex Genetics Problems with the Rules of Probability 275

CONCEPT 14.3 Inheritance patterns are often more complex than predicted by simple Mendelian genetics 276

Extending Mendelian Genetics for a Single Gene 277

Extending Mendelian Genetics for Two or More Genes 279

Nature and Nurture: The Environmental Impact on Phenotype 280

A Mendelian View of Heredity and Variation 280

CONCEPT 14.4 Many human traits follow
Mendelian patterns of inheritance 282
Pedigree Analysis 282
Recessively Inherited
Disorders 283
Dominantly Inherited
Disorders 285
Multifactorial
Disorders 285

Genetic Testing and

Counseling 285



The Chromosomal Basis of Inheritance 292

Locating Genes Along Chromosomes 292

CONCEPT 15.1 Morgan showed that Mendelian inheritance has its physical basis in the behavior of chromosomes: Scientific inquiry 294

Morgan's Choice of Experimental Organism 294

Correlating Behavior of a Gene's Alleles with Behavior of a Chromosome Pair 295

CONCEPT 15.2 Sex-linked genes exhibit unique patterns of inheritance 296

The Chromosomal Basis of Sex 296

Inheritance of X-Linked Genes 297

X Inactivation in Female Mammals 298

CONCEPT 15.3 Linked genes tend to be inherited together because they are located near each other on the same chromosome 299

How Linkage Affects Inheritance 299

Genetic Recombination and Linkage 300

Mapping the Distance Between Genes Using Recombination Data: *Scientific Inquiry* 303

CONCEPT 15.4 Alterations of chromosome number or structure cause some genetic disorders 304

Abnormal Chromosome Number 305

Alterations of Chromosome Structure 305

Human Disorders Due to Chromosomal Alterations 306

CONCEPT 15.5 Some inheritance patterns are exceptions to standard Mendelian inheritance 308

Genomic Imprinting 308

Inheritance of Organelle Genes 309

The Molecular Basis of Inheritance 312

Life's Operating Instructions 312

CONCEPT 16.1 DNA is the genetic material 313

The Search for the Genetic Material: *Scientific Inquiry* 313 Building a Structural Model of DNA: *Scientific Inquiry* 316

CONCEPT 16.2 Many proteins work together in DNA replication and repair 318

The Basic Principle: Base Pairing to a Template Strand 318

DNA Replication: A Closer Look 320

Proofreading and Repairing DNA 325

Evolutionary Significance of Altered DNA Nucleotides 326

Replicating the Ends of DNA Molecules $\,$ 326

CONCEPT 16.3 A chromosome consists of a DNA molecule packed together with proteins 328



Gene Expression: From Gene to Protein 333

The Flow of Genetic Information 333

CONCEPT 17.1 Genes specify proteins via transcription and translation 334

Evidence from the Study of Metabolic Defects 334 Basic Principles of Transcription and Translation 336 The Genetic Code 337

CONCEPT 17.2 Transcription is the DNA-directed synthesis of RNA: A closer look 340

Molecular Components of Transcription 340 Synthesis of an RNA Transcript 341

CONCEPT 17.3 Eukaryotic cells modify RNA after transcription 342
Alteration of mRNA Ends 342

Split Genes and RNA Splicing 343

CONCEPT 17.4 Translation is the RNA-directed synthesis of a

polypeptide: A closer look 345

Molecular Components of Translation 345 Building a Polypeptide 348 Completing and Targeting the Functional Protein 351 Making Multiple Polypeptides in Bacteria and Eukaryotes 352

CONCEPT 17.5 Mutations of one or a few nucleotides can affect protein structure and function 355

> Types of Small-Scale Mutations 355 New Mutations and Mutagens 357 What Is a Gene? *Revisiting the Question* 357

Regulation of Gene Expression 360

Differential Expression of Genes 360

CONCEPT 18.1 Bacteria often respond to environmental change by regulating transcription 361

Operons: The Basic Concept 361

Repressible and Inducible Operons: Two Types of Negative Gene Regulation 363

Positive Gene Regulation 364

CONCEPT 18.2 Eukaryotic gene expression is regulated at many stages 365

Differential Gene Expression 365

Regulation of Chromatin Structure 366

Regulation of Transcription Initiation 367

Mechanisms of Post-Transcriptional Regulation 372

CONCEPT 18.3 Noncoding RNAs play multiple roles in controlling gene expression 374

Effects on mRNAs by MicroRNAs and Small Interfering RNAs 374

Chromatin Remodeling by ncRNAs 375

The Evolutionary Significance of Small ncRNAs 376

CONCEPT 18.4 A program of differential gene expression leads to the different cell types in a multicellular organism 376

A Genetic Program for Embryonic Development 376 Cytoplasmic Determinants and Inductive Signals 377 Sequential Regulation of Gene Expression During Cellular Differentiation 378

Pattern Formation: Setting Up the Body Plan 379

CONCEPT 18.5 Cancer results from genetic changes that affect cell cycle control 383

Types of Genes Associated with Cancer 383
Interference with Normal Cell-Signaling Pathways 384
The Multistep Model of Cancer Development 386
Inherited Predisposition and Environmental Factors
Contributing to Cancer 388
The Role of Viruses in Cancer 388

19 Viruses 392

A Borrowed Life 392

CONCEPT 19.1 A virus consists of a nucleic acid surrounded by a protein coat 393

The Discovery of Viruses: *Scientific Inquiry* 393 Structure of Viruses 394

CONCEPT 19.2 Viruses replicate only in host cells 395

General Features of Viral Replicative Cycles 395

Replicative Cycles of Phages 396

Replicative Cycles of Animal Viruses 398

Evolution of Viruses 400

CONCEPT 19.3 Viruses, viroids, and prions are formidable pathogens in animals and plants 402

Viral Diseases in Animals 402

Emerging Viruses 402

Viral Diseases in Plants 405

Viroids and Prions: The Simplest Infectious Agents 405



20 DNA Tools and Biotechnology 408

The DNA Toolbox 408

CONCEPT 20.1 DNA sequencing and DNA cloning are valuable tools for genetic engineering and biological inquiry 409

DNA Sequencing 409

Making Multiple Copies of a Gene or Other DNA Segment 412 Using Restriction Enzymes to Make a Recombinant DNA Plasmid 413

Amplifying DNA: The Polymerase Chain Reaction (PCR) and Its Use in Cloning 414

Expressing Cloned Eukaryotic Genes 416

CONCEPT 20.2 Biologists use DNA technology to study gene expression and function 417

Analyzing Gene Expression 417 Determining Gene Function 421



CONCEPT 20.3 Cloned organisms and stem cells are useful for basic research and other applications 422

Cloning Plants: Single-Cell Cultures 423

Cloning Animals: Nuclear Transplantation 423

Stem Cells of Animals 425

CONCEPT 20.4 The practical applications of DNA-based biotechnology affect our lives in many ways 428

Medical Applications 428

Forensic Evidence and Genetic Profiles 430

Environmental Cleanup 432

Agricultural Applications 432

Safety and Ethical Questions Raised by DNA Technology 432

21 Genomes and Their Evolution 436

Reading the Leaves from the Tree of Life 436

CONCEPT 21.1 The Human Genome Project fostered development of faster, less expensive sequencing techniques 437

CONCEPT 21.2 Scientists use bioinformatics to analyze genomes and their functions 438

Centralized Resources for Analyzing Genome Sequences 438 Identifying Protein-Coding Genes and Understanding Their Functions 439

Understanding Genes and Gene Expression at the Systems Level 440

CONCEPT 21.3 Genomes vary in size, number of genes, and gene density 442

Genome Size 442

Number of Genes 443

Gene Density and Noncoding DNA 443

CONCEPT 21.4 Multicellular eukaryotes have much noncoding DNA and many multigene families 444

Transposable Elements and Related Sequences 444

Other Repetitive DNA, Including Simple Sequence DNA 446 Genes and Multigene Families 446

CONCEPT 21.5 Duplication, rearrangement, and mutation of DNA contribute to genome evolution 448

Duplication of Entire Chromosome Sets 448

Alterations of Chromosome Structure 448

Duplication and Divergence of Gene-Sized Regions of DNA 449

Rearrangements of Parts of Genes: Exon Duplication and Exon Shuffling 450

How Transposable Elements Contribute to Genome Evolution 453

CONCEPT 21.6 Comparing genome sequences provides clues to evolution and development 453

Comparing Genomes 453

Widespread Conservation of Developmental Genes Among Animals 457





MECHANISMS OF EVOLUTION 461

Descent with Modification: A Darwinian View of Life 462

Endless Forms Most Beautiful 462

CONCEPT 22.1 The Darwinian revolution challenged traditional views of a young Earth inhabited by unchanging species 463

Scala Naturae and Classification of Species 464

Ideas About Change over Time 464

Lamarck's Hypothesis of Evolution 465

CONCEPT 22.2 Descent with modification by natural selection explains the adaptations of organisms and the unity and diversity of life 465

Darwin's Research 465

The Origin of Species 467

CONCEPT 22.3 Evolution is supported by an overwhelming amount of scientific evidence 471

Direct Observations of Evolutionary Change 471

Homology 473

The Fossil Record 475

Biogeography 476

What Is Theoretical About Darwin's View of Life? 477

The Evolution of Populations 480

The Smallest Unit of Evolution 480

CONCEPT 23.1 Genetic variation makes evolution possible 481

Genetic Variation 481

Sources of Genetic Variation 482

CONCEPT 23.2 The Hardy-Weinberg equation can be used to test whether a population is evolving 483

Gene Pools and Allele Frequencies 484

The Hardy-Weinberg Equation 484

CONCEPT 23.3 Natural selection, genetic drift, and gene flow can alter allele frequencies in a population 487

Natural Selection 488

Genetic Drift 488

Gene Flow 490

CONCEPT 23.4 Natural selection is the only mechanism that consistently causes adaptive evolution 491

Natural Selection: A Closer Look 491

The Key Role of Natural Selection in Adaptive Evolution 493

Sexual Selection 493

Balancing Selection 494

Why Natural Selection Cannot Fashion Perfect Organisms 495

24 The Origin of Species 500

That "Mystery of Mysteries" 500

CONCEPT 24.1 The biological species concept emphasizes reproductive isolation 501

The Biological Species Concept 501

Other Definitions of Species 504

CONCEPT 24.2 Speciation can take place with or without geographic separation 505

Allopatric ("Other Country") Speciation 505

Sympatric ("Same Country") Speciation 507

Allopatric and Sympatric Speciation: A Review 510

CONCEPT 24.3 Hybrid zones reveal factors that cause reproductive isolation 510

Patterns Within Hybrid Zones 510

Hybrid Zones over Time 511

CONCEPT 24.4 Speciation can occur rapidly or slowly and can result from changes in few or many genes 513

The Time Course of Speciation 514

Studying the Genetics of Speciation 515

From Speciation to Macroevolution 516

The History of Life on Earth 519

Lost Worlds 519

CONCEPT 25.1 Conditions on early Earth made the origin of life possible 520

Synthesis of Organic Compounds on Early Earth 520

Abiotic Synthesis of Macromolecules 521

Protocells 521

Self-Replicating RNA 522

CONCEPT 25.2 The fossil record documents the history of life 522

The Fossil Record 522

How Rocks and Fossils Are Dated 524

The Origin of New Groups of Organisms 524

CONCEPT 25.3 Key events in life's history include the origins of unicellular and multicellular organisms and the colonization of land 526

The First Single-Celled Organisms 526

The Origin of Multicellularity 529

The Colonization of Land 530

CONCEPT 25.4 The rise and fall of groups of organisms reflect differences in speciation and extinction rates 531

Plate Tectonics 532

Mass Extinctions 534

Adaptive Radiations 536

CONCEPT 25.5 Major changes in body form can result from changes in the sequences and regulation of developmental genes 538

Effects of Developmental Genes 538

The Evolution of Development 539

CONCEPT 25.6 Evolution is not goal oriented 541

Evolutionary Novelties 541





THE EVOLUTIONARY HISTORY OF BIOLOGICAL DIVERSITY 546

Phylogeny and the Tree 26 of Life 547

Investigating the Tree of Life 547

CONCEPT 26.1 Phylogenies show evolutionary relationships 548

Binomial Nomenclature 548

Hierarchical Classification 548

Linking Classification and Phylogeny 549

What We Can and Cannot Learn from Phylogenetic Trees 550 Applying Phylogenies 550

CONCEPT 26.2 Phylogenies are inferred from morphological and molecular data 551

Morphological and Molecular Homologies 551

Sorting Homology from Analogy 551

Evaluating Molecular Homologies 552

CONCEPT 26.3 Shared characters are used to construct phylogenetic trees 553

Cladistics 553

Phylogenetic Trees with Proportional Branch Lengths 555

Maximum Parsimony and Maximum Likelihood 556

Phylogenetic Trees as Hypotheses 558

CONCEPT 26.4 An organism's evolutionary history is documented in its genome 559

Gene Duplications and Gene Families 559

Genome Evolution 560

CONCEPT 26.5 Molecular clocks help track evolutionary time 560

Molecular Clocks 560

Applying a Molecular Clock: Dating the Origin of HIV 561

CONCEPT 26.6 Our understanding of the tree of life continues to change based on new data 562

From Two Kingdoms to Three Domains 562

The Important Role of Horizontal Gene Transfer 562

Bacteria and Archaea 567

Masters of Adaptation 567

CONCEPT 27.1 Structural and functional adaptations contribute to prokaryotic success 568

Cell-Surface Structures 568

Motility 570

Internal Organization and DNA 571

Reproduction 571

CONCEPT 27.2 Rapid reproduction, mutation, and genetic recombination promote genetic diversity in prokaryotes 572

Rapid Reproduction and Mutation 572

Genetic Recombination 573

CONCEPT 27.3 Diverse nutritional and metabolic adaptations have evolved in prokaryotes 575

The Role of Oxygen in Metabolism 575

Nitrogen Metabolism 576

Metabolic Cooperation 576

CONCEPT 27.4 Prokaryotes have radiated into a diverse set of lineages 577

An Overview of Prokaryotic Diversity 577

Bacteria 577

Archaea 580



CONCEPT 27.5 Prokarvotes play crucial roles in the biosphere 581

Chemical Recycling 581

Ecological Interactions 582

CONCEPT 27.6 Prokaryotes have both beneficial and harmful impacts on humans 582

Mutualistic Bacteria 582

Pathogenic Bacteria 583

Prokaryotes in Research and Technology 583

Protists 587

Living Small 587

CONCEPT 28.1 Most eukaryotes are single-celled organisms 588

Structural and Functional Diversity in Protists 588

Four Supergroups of Eukaryotes 588

Endosymbiosis in Eukaryotic Evolution 589

CONCEPT 28.2 Excavates include protists with modified mitochondria and protists with unique flagella 593

Diplomonads and Parabasalids 593

Euglenozoans 594

CONCEPT 28.3 The "SAR" clade is a highly diverse group of protists defined by DNA similarities 595

Stramenopiles 595

Alveolates 598

Rhizarians 601

CONCEPT 28.4 Red algae and green algae are the closest relatives of land plants 602

Red Algae 602

Green Algae 603

CONCEPT 28.5 Unikonts include protists that are closely related to fungi and animals 604

Amoebozoans 605

Opisthokonts 607

CONCEPT 28.6 Protists play key roles in ecological communities 608

Symbiotic Protists 608

Photosynthetic Protists 608





Plant Diversity I: How Plants Colonized Land 612

The Greening of Earth 612

CONCEPT 29.1 Land plants evolved from green algae 613

Morphological and Molecular Evidence 613

Adaptations Enabling the Move to Land 613

Derived Traits of Plants 613

The Origin and Diversification of Plants 616

CONCEPT 29.2 Mosses and other nonvascular plants have life cycles dominated by gametophytes 618

Bryophyte Gametophytes 618

Bryophyte Sporophytes 621

The Ecological and Economic Importance of Mosses 621

CONCEPT 29.3 Ferns and other seedless vascular plants were the first plants to grow tall 622

Origins and Traits of Vascular Plants 622

Classification of Seedless Vascular Plants 625

The Significance of Seedless Vascular Plants 627

Plant Diversity II: The Evolution of Seed Plants 630

Transforming the World 630

30

CONCEPT 30.1 Seeds and pollen grains are key adaptations for life on land 631

Advantages of Reduced Gametophytes 631

Heterospory: The Rule Among Seed Plants 632

Ovules and Production of Eggs 632

Pollen and Production of Sperm 632

The Evolutionary Advantage of Seeds 632

CONCEPT 30.2 Gymnosperms bear "naked" seeds, typically on cones 633

The Life Cycle of a Pine 634

Early Seed Plants and the Rise of Gymnosperms 635

Gymnosperm Diversity 635

CONCEPT 30.3 The reproductive adaptations of angiosperms include flowers and fruits 638

Characteristics of Angiosperms 638

Angiosperm Evolution 641

Angiosperm Diversity 643

CONCEPT 30.4 Human welfare depends on seed plants 645

Products from Seed Plants 645

Threats to Plant Diversity 645



31 Fungi 648

Mighty Mushrooms 648

CONCEPT 31.1 Fungi are heterotrophs that feed by absorption 649

Nutrition and Ecology 649

Body Structure 649

Specialized Hyphae in Mycorrhizal Fungi 650

CONCEPT 31.2 Fungi produce spores through sexual or asexual life cycles 651

Sexual Reproduction 652

Asexual Reproduction 652

CONCEPT 31.3 The ancestor of fungi was an aquatic, single-celled, flagellated protist 653

The Origin of Fungi 653

Early-Diverging Fungal Groups 654

The Move to Land 654

CONCEPT 31.4 Fungi have radiated into a diverse set of lineages 654

Chytrids 654

Zygomycetes 656

Glomeromycetes 657

Ascomycetes 657

Basidiomycetes 659

CONCEPT 31.5 Fungi play key roles in nutrient cycling, ecological interactions, and human welfare 661

Fungi as Decomposers 661

Fungi as Mutualists 661

Fungi as Parasites 663



A Kingdom of Consumers 667

CONCEPT 32.1 Animals are multicellular, heterotrophic eukaryotes with tissues that develop from embryonic layers 668

Nutritional Mode 668

Cell Structure and Specialization 668

Reproduction and Development 668

CONCEPT 32.2 The history of animals spans more than half a billion years 669

Steps in the Origin of Multicellular Animals 669

Neoproterozoic Era (1 Billion-542 Million Years Ago) 670

Paleozoic Era (542-251 Million Years Ago) 671

Mesozoic Era (251-65.5 Million Years Ago) 673

Cenozoic Era (65.5 Million Years Ago to the Present) 673

CONCEPT 32.3 Animals can be characterized by "body plans" 673

Symmetry 673

Tissues 674

Body Cavities 674

Protostome and Deuterostome Development 675

CONCEPT 32.4 Views of animal phylogeny continue to be shaped by new molecular and morphological data 676

The Diversification of Animals 676

Future Directions in Animal Systematics 677

An Introduction to Invertebrates 680

Life Without a Backbone 680

CONCEPT 33.1 Sponges are basal animals that lack true tissues 684

CONCEPT 33.2 Cnidarians are an ancient phylum of eumetazoans 685

Medusozoans 686

Anthozoans 687

CONCEPT 33.3 Lophotrochozoans, a clade identified by molecular data, have the widest range of animal body forms 688

Flatworms 688

Rotifers 691

Lophophorates: Ectoprocts and Brachiopods 692

Molluscs 692 Annelids 696

CONCEPT 33.4 Ecdysozoans are the most species-rich animal group 699

Nematodes 699

Arthropods 700

CONCEPT 33.5 Echinoderms and chordates are deuterostomes 707

Echinoderms 707 Chordates 709

The Origin and Evolution of Vertebrates 712

Half a Billion Years of Backbones 712

CONCEPT 34.1 Chordates have a notochord and a dorsal, hollow nerve cord 713

Derived Characters of Chordates 713

Lancelets 714

Tunicates 715

Early Chordate Evolution 716

CONCEPT 34.2 Vertebrates are chordates that have a backbone 716

Derived Characters of Vertebrates 716

Hagfishes and Lampreys 717

Early Vertebrate Evolution 718

Origins of Bone and Teeth 719

CONCEPT 34.3 Gnathostomes are vertebrates that have jaws 719

Derived Characters of Gnathostomes 719

Fossil Gnathostomes 720

Chondrichthyans (Sharks, Rays, and Their Relatives) 720

Ray-Finned Fishes and Lobe-Fins 722

CONCEPT 34.4 Tetrapods are gnathostomes that have limbs 724

Derived Characters of Tetrapods 724

The Origin of Tetrapods 725

Amphibians 726

CONCEPT 34.5 Amniotes are tetrapods that have a terrestrially adapted egg 727

Derived Characters of Amniotes 728

Early Amniotes 729

Reptiles 729

CONCEPT 34.6 Mammals are amniotes that have hair and produce

Derived Characters of Mammals 735

Early Evolution of Mammals 735

Monotremes 736



Marsupials 736

Eutherians (Placental Mammals) 737

CONCEPT 34.7 Humans are mammals that have a large brain and bipedal locomotion 742

Derived Characters of Humans 742

The Earliest Hominins 742

Australopiths 743

Bipedalism 744 Tool Use 745

Early Homo 746

Neanderthals 746

Homo sapiens 746



PLANT FORM AND **FUNCTION 751**

Plant Structure, Growth, and Development 752

Are Plants Computers? 752

CONCEPT 35.1 Plants have a hierarchical organization consisting of organs, tissues, and cells 753

The Three Basic Plant Organs: Roots, Stems, and Leaves 753 Dermal, Vascular, and Ground Tissue Systems 756

Common Types of Plant Cells 757

CONCEPT 35.2 Different meristems generate new cells for primary and secondary growth 760

CONCEPT 35.3 Primary growth lengthens roots and shoots 761

Primary Growth of Roots 761

Primary Growth of Shoots 763

CONCEPT 35.4 Secondary growth increases the diameter of stems and roots in woody plants 765

The Vascular Cambium and Secondary Vascular Tissue 765 The Cork Cambium and the Production of Periderm 768 Evolution of Secondary Growth 768

CONCEPT 35.5 Growth, morphogenesis, and cell differentiation produce the plant body 769

Model Organisms: Revolutionizing the Study of Plants 769 Growth: Cell Division and Cell Expansion 770

Morphogenesis and Pattern Formation 772

Gene Expression and the Control of Cell Differentiation 773

Shifts in Development: Phase Changes 773

Genetic Control of Flowering 774

Resource Acquisition and Transport in Vascular Plants 778

A Whole Lot of Shaking Going On 778

CONCEPT 36.1 Adaptations for acquiring resources were key steps in the evolution of vascular plants 779

Shoot Architecture and Light Capture 780

Root Architecture and Acquisition of Water and Minerals 781

CONCEPT 36.2 Different mechanisms transport substances over short or long distances 781

The Apoplast and Symplast: Transport Continuums 781 Short-Distance Transport of Solutes Across Plasma

Membranes 782

Short-Distance Transport of Water Across Plasma Membranes 782

Long-Distance Transport: The Role of Bulk Flow 785 CONCEPT 36.3 Transpiration drives the transport of water and minerals from roots to shoots via the xylem 786

Absorption of Water and Minerals by Root Cells 786

Transport of Water and Minerals into the Xylem 786

Bulk Flow Transport via the Xylem 786

Xylem Sap Ascent by Bulk Flow: A Review 790

CONCEPT 36.4 The rate of transpiration is regulated by stomata 790

Stomata: Major Pathways for Water Loss 790 Mechanisms of Stomatal Opening and Closing 791

Stimuli for Stomatal Opening and Closing 792 Effects of Transpiration on Wilting and

Leaf Temperature 792

Adaptations That Reduce Evaporative Water Loss 792

CONCEPT 36.5 Sugars are transported from sources to sinks via the phloem 793

Movement from Sugar Sources to Sugar Sinks 793 Bulk Flow by Positive Pressure: The Mechanism of Translocation in Angiosperms 794

CONCEPT 36.6 The symplast is highly dynamic 795

Changes in Plasmodesmatal Number and Pore Size 796 Phloem: An Information Superhighway 796 Electrical Signaling in the Phloem 796

Soil and Plant Nutrition 799

The Corkscrew Carnivore 799

CONCEPT 37.1 Soil contains a living, complex ecosystem 800

Soil Texture 800

Topsoil Composition 800

Soil Conservation and Sustainable Agriculture 801

CONCEPT 37.2 Plants require essential elements to complete their life cycle 803

Essential Elements 803

Symptoms of Mineral Deficiency 804

Improving Plant Nutrition by Genetic Modification 805

CONCEPT 37.3 Plant nutrition often involves relationships with other organisms 806

Bacteria and Plant Nutrition 807 Fungi and Plant Nutrition 810

Epiphytes, Parasitic Plants, and Carnivorous Plants 813

Angiosperm Reproduction and Biotechnology 815

Flowers of Deceit 815

CONCEPT 38.1 Flowers, double fertilization, and fruits are key features of the angiosperm life cycle 816

Flower Structure and Function 816

The Angiosperm Life Cycle: An Overview 818

Methods of Pollination 820

From Seed to Flowering Plant: A Closer Look 822

Fruit Structure and Function 824

CONCEPT 38.2 Flowering plants reproduce sexually, asexually, or both 827

Mechanisms of Asexual Reproduction 827

Advantages and Disadvantages of Asexual and Sexual Reproduction 827

Mechanisms That Prevent Self-Fertilization 828 Totipotency, Vegetative Reproduction, and

Tissue Culture 829

CONCEPT 38.3 People modify crops by breeding and genetic engineering 830

Plant Breeding 831

Plant Biotechnology and Genetic Engineering 831 The Debate over Plant

Biotechnology 832

Plant Responses to Internal and External Signals 836

Stimuli and a Stationary Life 836

CONCEPT 39.1 Signal transduction pathways link signal reception to response 837

Reception 838

Transduction 838

Response 839

CONCEPT 39.2 Plant hormones help coordinate growth, development, and responses to stimuli 840

A Survey of Plant Hormones 841

CONCEPT 39.3 Responses to light are critical for plant success 849

Blue-Light Photoreceptors 849

Phytochrome Photoreceptors 850

Biological Clocks and Circadian Rhythms 851

The Effect of Light on the Biological Clock 852

Photoperiodism and Responses to Seasons 853

CONCEPT 39.4 Plants respond to a wide variety of stimuli other than light 855

Gravity 855

Mechanical Stimuli 855

Environmental Stresses 856

CONCEPT 39.5 Plants respond to attacks by pathogens and herbivores 859

> Defenses Against Pathogens 859 Defenses Against Herbivores 861





ANIMAL FORM AND **FUNCTION 866**

Basic Principles of Animal Form 40 and Function 867

Diverse Forms, Common Challenges 867

CONCEPT 40.1 Animal form and function are correlated at all levels of organization 868

Evolution of Animal Size and Shape 868

Exchange with the Environment 868

Hierarchical Organization of Body Plans 870

Coordination and Control 874

CONCEPT 40.2 Feedback control maintains the internal environment in many animals 875

Regulating and Conforming 875

Homeostasis 875

CONCEPT 40.3 Homeostatic processes for thermoregulation involve form, function, and behavior 878

Endothermy and Ectothermy 878

Variation in Body Temperature 878

Balancing Heat Loss and Gain 879

Acclimatization in Thermoregulation 882

Physiological Thermostats and Fever 882

CONCEPT 40.4 Energy requirements are related to animal size, activity, and environment 883

Energy Allocation and Use 883

Quantifying Energy Use 884

Minimum Metabolic Rate and Thermoregulation 884

Influences on Metabolic Rate 885

Torpor and Energy Conservation 886

Animal Nutrition 892

The Need to Feed 892

CONCEPT 41.1 An animal's diet must supply chemical energy, organic molecules, and essential nutrients 893

Essential Nutrients 893

Dietary Deficiencies 895

Assessing Nutritional Needs 896

CONCEPT 41.2 The main stages of food processing are ingestion, digestion, absorption, and elimination 897

Digestive Compartments 897

CONCEPT 41.3 Organs specialized for sequential stages of food processing form the mammalian digestive system 900

The Oral Cavity, Pharynx, and Esophagus 900

Digestion in the Stomach 901

Digestion in the Small Intestine 902

Absorption in the Small Intestine 904

Processing in the Large Intestine 905

CONCEPT 41.4 Evolutionary adaptations of vertebrate digestive systems correlate with diet 906

Dental Adaptations 906

Stomach and Intestinal Adaptations 906

Mutualistic Adaptations 907

CONCEPT 41.5 Feedback circuits regulate digestion, energy storage, and appetite 908

Regulation of Digestion 908

Regulation of Energy Storage 909

Regulation of Appetite and Consumption 911



Circulation and Gas Exchange 915

Tradina Places 915

CONCEPT 42.1 Circulatory systems link exchange surfaces with cells throughout the body 916

Gastrovascular Cavities 916

Open and Closed Circulatory Systems 917

Organization of Vertebrate Circulatory Systems 918

CONCEPT 42.2 Coordinated cycles of heart contraction drive double circulation in mammals 920

Mammalian Circulation 920

The Mammalian Heart: A Closer Look 920

Maintaining the Heart's Rhythmic Beat 922

CONCEPT 42.3 Patterns of blood pressure and flow reflect the structure and arrangement of blood vessels 923

Blood Vessel Structure and Function 923

Blood Flow Velocity 924

Blood Pressure 924

Capillary Function 926

Fluid Return by the Lymphatic System 927

CONCEPT 42.4 Blood components function in exchange, transport, and defense 928

Blood Composition and Function 928

Cardiovascular Disease 931

CONCEPT 42.5 Gas exchange occurs across specialized respiratory surfaces 933

Partial Pressure Gradients in Gas Exchange 933

Respiratory Media 933

Respiratory Surfaces 933

Gills in Aquatic Animals 934

Tracheal Systems in Insects 935

Lungs 936

CONCEPT 42.6 Breathing ventilates the lungs 938

How an Amphibian Breathes 938

How a Bird Breathes 938

How a Mammal Breathes 939

Control of Breathing in Humans 940

CONCEPT 42.7 Adaptations for gas exchange include pigments that bind and transport gases 941

Coordination of Circulation and Gas Exchange 941

Respiratory Pigments 941

Respiratory Adaptations of Diving Mammals 943



43 The Immune System 946

Recognition and Response 946

CONCEPT 43.1 In innate immunity, recognition and response rely on traits common to groups of pathogens 947

Innate Immunity of Invertebrates 947

Innate Immunity of Vertebrates 948

Evasion of Innate Immunity by Pathogens 952

CONCEPT 43.2 In adaptive immunity, receptors provide pathogen-specific recognition 952

Antigen Recognition by B Cells and Antibodies 953 Antigen Recognition by T Cells 954

B Cell and T Cell Development 954

CONCEPT 43.3 Adaptive immunity defends against infection of body fluids and body cells 958

Helper T Cells: A Response to Nearly All Antigens 958 Cytotoxic T Cells: A Response to Infected Cells 959

B Cells and Antibodies: A Response to Extracellular Pathogens 960

Summary of the Humoral and Cell-Mediated Immune Responses 961

Active and Passive Immunity 962

Antibodies as Tools 963

Immune Rejection 963

CONCEPT 43.4 Disruptions in immune system function can elicit or exacerbate disease 964

Exaggerated, Self-Directed, and Diminished Immune Responses 964

Evolutionary Adaptations of Pathogens That Underlie Immune System Avoidance 966

Cancer and Immunity 968

Osmoregulation 44 and Excretion 971

A Balancing Act 971

CONCEPT 44.1 Osmoregulation balances the uptake and loss of water and solutes 972

Osmosis and Osmolarity 972

Osmoregulatory Challenges and Mechanisms 972

Energetics of Osmoregulation 974

Transport Epithelia in Osmoregulation 975

CONCEPT 44.2 An animal's nitrogenous wastes reflect its phylogeny and habitat 976

Forms of Nitrogenous Waste 976

The Influence of Evolution and Environment on Nitrogenous Wastes 977

CONCEPT 44.3 Diverse excretory systems are variations on a tubular theme 978

Excretory Processes 978

Survey of Excretory Systems 978

CONCEPT 44.4 The nephron is organized for stepwise processing of blood filtrate 981

From Blood Filtrate to Urine: A Closer Look 982

Solute Gradients and Water Conservation 983

Adaptations of the Vertebrate Kidney to Diverse Environments 985

CONCEPT 44.5 Hormonal circuits link kidney function, water balance, and blood pressure 988

Homeostatic Regulation of the Kidney 988

Hormones and the Endocrine System 993

The Body's Long-Distance Regulators 993

CONCEPT 45.1 Hormones and other signaling molecules bind to target receptors, triggering specific response pathways 994

Intercellular Communication 994

Chemical Classes of Local Regulators and Hormones 995

Cellular Response Pathways 996

Multiple Effects of Hormones 998

Endocrine Tissues and Organs 998

CONCEPT 45.2 Feedback regulation and coordination with the nervous system are common in endocrine signaling 1000

Simple Hormone Pathways 1000

Feedback Regulation 1001

Coordination of Endocrine and Nervous Systems 1001

Thyroid Regulation: A Hormone Cascade Pathway 1004 Hormonal Regulation of Growth 1005

CONCEPT 45.3 Endocrine glands respond to diverse stimuli in regulating homeostasis, development, and behavior 1006

Parathyroid Hormone and Vitamin D: Control of Blood Calcium 1006

Adrenal Hormones: Response to Stress 1006

Sex Hormones 1008

Hormones and Biological Rhythms 1009

Evolution of Hormone Function 1010



46 Animal Reproduction 1013

Pairing Up for Sexual Reproduction 1013

CONCEPT 46.1 Both asexual and sexual reproduction occur in the animal kingdom 1014

Mechanisms of Asexual Reproduction 1014

Sexual Reproduction: An Evolutionary Enigma 1014

Reproductive Cycles 1015

Variation in Patterns of Sexual Reproduction 1016

CONCEPT 46.2 Fertilization depends on mechanisms that bring together sperm and eggs of the same species 1016

Ensuring the Survival of Offspring 1017

Gamete Production and Delivery 1017

CONCEPT 46.3 Reproductive organs produce and transport gametes 1019

Human Male Reproductive Anatomy 1019

Human Female Reproductive Anatomy 1020

Gametogenesis 1021

CONCEPT 46.4 The interplay of tropic and sex hormones regulates mammalian reproduction 1024

Hormonal Control of the Male Reproductive System $\,1024$

Hormonal Control of Female Reproductive Cycles 1025

Human Sexual Response 1027

CONCEPT 46.5 In placental mammals, an embryo develops fully within the mother's uterus 1028

Conception, Embryonic Development, and Birth 1028 Maternal Immune Tolerance of the Embryo and Fetus 1031

Contraception and Abortion 1032

Modern Reproductive Technologies 1033



47 Animal Development 1037

A Body-Building Plan 1037

CONCEPT 47.1 Fertilization and cleavage initiate embryonic development 1038

Fertilization 1038

Cleavage 1041

CONCEPT 47.2 Morphogenesis in animals involves specific changes in cell shape, position, and survival 1044

Gastrulation 1044

Developmental Adaptations of Amniotes 1047

Organogenesis 1048

Mechanisms of Morphogenesis 1050

CONCEPT 47.3 Cytoplasmic determinants and inductive signals contribute to cell fate specification 1051

Fate Mapping 1051

Cell Fate Determination and Pattern Formation by Inductive Signals 1055

Cilia and Cell Fate 1058

Neurons, Synapses, and Signaling 1061

Lines of Communication 1061

CONCEPT 48.1 Neuron structure and organization reflect function in information transfer 1062

Neuron Structure and Function 1062

Introduction to Information Processing 1063

CONCEPT 48.2 lon pumps and ion channels establish the resting potential of a neuron 1064

Formation of the Resting Potential 1064

Modeling the Resting Potential 1065

CONCEPT 48.3 Action potentials are the signals conducted by axons 1066

Hyperpolarization and Depolarization 1066

Graded Potentials and Action Potentials 1067

Generation of Action Potentials: A Closer Look 1068

Conduction of Action Potentials 1069

CONCEPT 48.4 Neurons communicate with other cells at synapses 1071

Generation of Postsynaptic Potentials 1072

Summation of Postsynaptic Potentials 1073

Modulated Signaling at Synapses 1073 Neurotransmitters 1074

49 Nervous Systems 1079

Command and Control Center 1079

CONCEPT 49.1 Nervous systems consist of circuits of neurons and supporting cells 1080

Glia 1081

Organization of the Vertebrate Nervous System 1082

The Peripheral Nervous System 1083

CONCEPT 49.2 The vertebrate brain is regionally specialized 1085

Arousal and Sleep 1088

Biological Clock Regulation 1088

Emotions 1089

Functional Imaging of the Brain 1090

CONCEPT 49.3 The cerebral cortex controls voluntary movement and cognitive functions 1090

Information Processing 1090

Language and Speech 1092

Lateralization of Cortical Function 1092

Frontal Lobe Function 1092

Evolution of Cognition in Vertebrates 1093

CONCEPT 49.4 Changes in synaptic connections underlie memory and learning 1093

Neuronal Plasticity 1094

Memory and Learning 1094

Long-Term Potentiation 1095

CONCEPT 49.5 Many nervous system disorders can be explained in molecular terms 1096

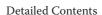
Schizophrenia 1096

Depression 1097

The Brain's Reward System and Drug Addiction 1097

Alzheimer's Disease 1097

Parkinson's Disease 1098



Sensory and Motor Mechanisms 1101

Sense and Sensibility 1101

CONCEPT 50.1 Sensory receptors transduce stimulus energy and transmit signals to the central nervous system 1102

Sensory Reception and Transduction 1102

Transmission 1103

Perception 1103

Amplification and Adaptation 1103

Types of Sensory Receptors 1104

CONCEPT 50.2 The mechanoreceptors responsible for hearing and equilibrium detect moving fluid or settling particles 1106

Sensing of Gravity and Sound in Invertebrates 1106

Hearing and Equilibrium in Mammals 1106

Hearing and Equilibrium in Other Vertebrates 1110

CONCEPT 50.3 The diverse visual receptors of animals depend on light-absorbing pigments 1111

Evolution of Visual Perception 1111

The Vertebrate Visual System 1113

CONCEPT 50.4 The senses of taste and smell rely on similar sets of sensory receptors 1117

Taste in Mammals 1117

Smell in Humans 1118

CONCEPT 50.5 The physical interaction of protein filaments is required for muscle function 1119

Vertebrate Skeletal Muscle 1120

Other Types of Muscle 1125

CONCEPT 50.6 Skeletal systems transform muscle contraction into locomotion 1126

Types of Skeletal Systems 1126

Types of Locomotion 1129

Animal Behavior 1133

The How and Why of Animal Activity 1133

CONCEPT 51.1 Discrete sensory inputs can stimulate both simple and complex behaviors 1134

Fixed Action Patterns 1134

Migration 1135

Behavioral Rhythms 1135

Animal Signals and Communication 1136

CONCEPT 51.2 Learning establishes specific links between experience and behavior 1138

Experience and Behavior 1138

Learning 1138

CONCEPT 51.3 Selection for individual survival and reproductive success can explain diverse behaviors 1143

Evolution of Foraging Behavior 1143

Mating Behavior and Mate Choice 1145

CONCEPT 51.4 Genetic analyses and the concept of inclusive fitness provide a basis for studying the evolution of behavior 1149

Genetic Basis of Behavior 1149

Genetic Variation and the Evolution of Behavior 1150

Altruism 1151

Inclusive Fitness 1152

Evolution and Human Culture 1153



ECOLOGY 1157

An Introduction to Ecology **52** and the Biosphere 1158

Discovering Ecology 1158

CONCEPT 52.1 Earth's climate varies by latitude and season and is changing rapidly 1161

Global Climate Patterns 1161

Regional and Local Effects on Climate 1161

Microclimate 1163

Global Climate Change 1163

CONCEPT 52.2 The structure and distribution of terrestrial biomes are controlled by climate and disturbance 1164

Climate and Terrestrial Biomes 1164

General Features of Terrestrial Biomes 1165

Disturbance and Terrestrial Biomes 1166

CONCEPT 52.3 Aquatic biomes are diverse and dynamic systems that cover most of Earth 1171

Zonation in Aquatic Biomes 1171

CONCEPT 52.4 Interactions between organisms and the environment limit the distribution of species 1172

Dispersal and Distribution 1178

Behavior and Habitat Selection 1178

Biotic Factors 1179

Abiotic Factors 1179

Population Ecology 1184

Turtle Tracks 1184

CONCEPT 53.1 Biological processes influence population density, dispersion, and demographics 1185

Density and Dispersion 1185

Demographics 1186

CONCEPT 53.2 The exponential model describes population growth in an idealized, unlimited environment 1190

Per Capita Rate of Increase 1190

Exponential Growth 1191

CONCEPT 53.3 The logistic model describes how a population grows more slowly as it nears its carrying capacity 1192

The Logistic Growth Model 1192

The Logistic Model and Real Populations 1193

CONCEPT 53.4 Life history traits are products of natural selection 1195

Evolution and Life History Diversity 1195

"Trade-offs" and Life Histories 1195

CONCEPT 53.5 Many factors that regulate population growth are density dependent 1197

Population Change and Population Density 1197

Mechanisms of Density-Dependent Population

Regulation 1198

Population Dynamics 1198

CONCEPT 53.6 The human population is no longer growing exponentially but is still increasing rapidly 1201

> The Global Human Population 1201 Global Carrying Capacity 1204



54 Community Ecology 1208

Communities in Motion 1208

CONCEPT 54.1 Community interactions are classified by whether they help, harm, or have no effect on the species involved 1209

Competition 1209 Predation 1211 Herbivory 1213 Symbiosis 1214

Facilitation 1215

CONCEPT 54.2 Diversity and trophic structure characterize biological communities 1216

Species Diversity 1216

Diversity and Community Stability 1217

Trophic Structure 1217

Species with a Large Impact 1219

Bottom-Up and Top-Down Controls 1221

CONCEPT 54.3 Disturbance influences species diversity and composition 1222

Characterizing Disturbance 1222 Ecological Succession 1223

Human Disturbance 1225

CONCEPT 54.4 Biogeographic factors affect community diversity 1225

Latitudinal Gradients 1226

Area Effects 1226

Island Equilibrium Model 1226

CONCEPT 54.5 Pathogens alter community structure locally and globally 1228

Pathogens and Community Structure 1228 Community Ecology and Zoonotic Diseases 1228

Ecosystems and Restoration Ecology 1232

Transformed to Tundra 1232

CONCEPT 55.1 Physical laws govern energy flow and chemical cycling in ecosystems 1233

Conservation of Energy 1233

Conservation of Mass 1234

Energy, Mass, and Trophic Levels 1234

CONCEPT 55.2 Energy and other limiting factors control primary production in ecosystems 1235

Ecosystem Energy Budgets 1235

Primary Production in Aquatic Ecosystems 1237

Primary Production in Terrestrial Ecosystems 1238

CONCEPT 55.3 Energy transfer between trophic levels is typically only 10% efficient 1239

Production Efficiency 1239

Trophic Efficiency and Ecological Pyramids 1240

CONCEPT 55.4 Biological and geochemical processes cycle nutrients and water in ecosystems 1244

Biogeochemical Cycles 1244

Decomposition and Nutrient Cycling Rates 1246

Case Study: Nutrient Cycling in the Hubbard Brook

Experimental Forest 1247

CONCEPT 55.5 Restoration ecologists return degraded ecosystems to a more natural state 1248

Bioremediation 1249

Biological Augmentation 1249



Conservation Biology and Global Change 1254

Psychedelic Treasure 1254

CONCEPT 56.1 Human activities threaten Earth's biodiversity 1255

Three Levels of Biodiversity 1255

Biodiversity and Human Welfare 1257

Threats to Biodiversity 1258

Can Extinct Species Be Resurrected? 1260

CONCEPT 56.2 Population conservation focuses on population size, genetic diversity, and critical habitat 1261

Small-Population Approach 1261

Declining-Population Approach 1264

Weighing Conflicting Demands 1265

CONCEPT 56.3 Landscape and regional conservation help sustain biodiversity 1265

Landscape Structure and Biodiversity 1265

Establishing Protected Areas 1267

Urban Ecology 1269

CONCEPT 56.4 Earth is changing rapidly as a result of human actions 1269

Nutrient Enrichment 1270

Toxins in the Environment 1271

Greenhouse Gases and Climate Change 1272

Depletion of Atmospheric Ozone 1274

CONCEPT 56.5 Sustainable development can improve human lives while conserving biodiversity 1276

Sustainable Development 1276

The Future of the Biosphere 1277

APPENDIX A Answers A-1

APPENDIX B Periodic Table of the Elements B-1

APPENDIX C The Metric System C-1

APPENDIX D A Comparison of the Light Microscope and the Electron

Microscope D-1

APPENDIX E Classification of Life E-1

APPENDIX F Scientific Skills Review F-1

CREDITS CR-1
GLOSSARY G-1
INDEX I-1