

# Biology

11e

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# Biology<sup>11e</sup>

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To our families, friends, and colleagues who gave  
freely of their love, support, knowledge, and time as  
we prepared this eleventh edition of *Biology*, and in  
appreciation of all who teach and learn.

*Especially to*

My grandchildren and their generation

Margaret, Damian, and Ava

Alan, Jennifer, and Pat

## About the Authors



**Eldra P. Solomon** has written several leading college textbooks in biology and in human anatomy and physiology. Her books have been translated into more than ten languages. She earned an M.S. from the University of Florida and an M.A. and Ph.D. from the University of South Florida. Dr. Solomon taught biology and nursing students for more than 20 years.

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His research on gene regulation of membrane protein enzyme systems in yeast and other fungi illustrates the interdisciplinary nature of the life sciences. He is most proud of the many generations of undergraduate, graduate, and postdoctoral students who contributed to this research and have gone on to productive careers. He continues to be committed to teaching and is grateful for the opportunities to pursue a teaching and research career in what continues to be the most exciting era of the biological sciences.



**Diana W. Martin** is professor emeritus and former director of general biology in the Division of Life Sciences at Rutgers University. Dr. Martin received an M.S. from Florida State University, where she studied the chromosomes of related plant species to understand their evolutionary relationships. She earned a Ph.D. from the University of Texas at Austin, where she studied the genetics of the fruit fly, *Drosophila melanogaster*, and then conducted postdoctoral research at Princeton University.

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During her career as a professional science writer, Dr. Berg has authored or coauthored several leading college science textbooks. Her writing reflects her teaching style and love of science.

# Brief Contents

Preface **xxiii**

To the Student **xxx**

## **PART ONE: The Organization of Life**

- 1 A View of Life **1**
- 2 Atoms and Molecules:  
The Chemical Basis of Life **26**
- 3 The Chemistry of Life: Organic Compounds **46**
- 4 Organization of the Cell **73**
- 5 Biological Membranes **106**
- 6 Cell Communication **131**

## **PART TWO: Energy Transfer through Living Systems**

- 7 Energy and Metabolism **150**
- 8 How Cells Make ATP:  
Energy-Releasing Pathways **167**
- 9 Photosynthesis: Capturing Light Energy **187**

## **PART THREE: The Continuity of Life: Genetics**

- 10 Chromosomes, Mitosis, and Meiosis **206**
- 11 The Basic Principles of Heredity **228**
- 12 DNA: The Carrier of Genetic Information **253**
- 13 Gene Expression **272**
- 14 Gene Regulation **297**
- 15 DNA Technology and Genomics **315**
- 16 Human Genetics and the Human  
Genome **340**
- 17 Developmental Genetics **362**

## **PART FOUR: The Continuity of Life: Evolution**

- 18 Introduction to Darwinian Evolution **385**
- 19 Evolutionary Change in Populations **406**
- 20 Speciation and Macroevolution **421**
- 21 The Origin and Evolutionary  
History of Life **442**
- 22 The Evolution of Primates **461**

## **PART FIVE: The Diversity of Life**

- 23 Understanding Diversity: Systematics **478**
- 24 Viruses and Subviral Agents **499**
- 25 Bacteria and Archaea **517**
- 26 Protists **539**
- 27 Seedless Plants **563**

- 28 Seed Plants **584**
- 29 The Fungi **603**
- 30 An Introduction to Animal Diversity **628**
- 31 Sponges, Cnidarians, Ctenophores,  
and Protostomes **641**
- 32 The Deuterostomes **676**

## **PART SIX: Structure and Life Processes in Plants**

- 33 Plant Structure, Growth, and Development **710**
- 34 Leaf Structure and Function **729**
- 35 Stem Structure and Transport **745**
- 36 Roots and Mineral Nutrition **762**
- 37 Reproduction in Flowering Plants **782**
- 38 Plant Developmental Responses to External  
and Internal Signals **803**

## **PART SEVEN: Structure and Life Processes in Animals**

- 39 Animal Structure and Function: An Introduction **821**
- 40 Protection, Support, and Movement **842**
- 41 Neural Signaling **860**
- 42 Neural Regulation **882**
- 43 Sensory Systems **911**
- 44 Internal Transport **936**
- 45 The Immune System: Internal Defense **962**
- 46 Gas Exchange **991**
- 47 Processing Food and Nutrition **1010**
- 48 Osmoregulation and Disposal of Metabolic  
Wastes **1032**
- 49 Endocrine Regulation **1050**
- 50 Reproduction **1074**
- 51 Animal Development **1104**
- 52 Animal Behavior **1124**

## **PART EIGHT: The Interactions of Life: Ecology**

- 53 Introduction to Ecology: Population Ecology **1151**
- 54 Community Ecology **1171**
- 55 Ecosystems and the Biosphere **1194**
- 56 Ecology and the Geography of Life **1216**
- 57 Biological Diversity and Conservation Biology **1241**

Glossary **G-1**

Index **I-1**



## PART ONE: THE ORGANIZATION OF LIFE

- 1 A View of Life 1**
- 1.1 Major Themes of Biology 2**
- 1.2 Characteristics of Life 2**
- Organisms are composed of cells **3**
- Organisms grow and develop **3**
- Organisms regulate their metabolic processes **3**
- Organisms respond to stimuli **4**
- Organisms reproduce **5**
- Populations evolve and become adapted to the environment **5**
- 1.3 Levels of Biological Organization 6**
- Organisms have several levels of organization **6**
- Several levels of ecological organization can be identified **6**
- 1.4 Information Transfer 6**
- DNA transmits information from one generation to the next **8**
- Information is transmitted by chemical and electrical signals **8**
- Organisms also communicate information to one another **8**
- 1.5 The Energy of Life 9**
- 1.6 Evolution: The Basic Unifying Concept of Biology 10**
- Biologists use a binomial system for naming organisms **11**
- Taxonomic classification is hierarchical **11**
- Systematists classify organisms in three domains **11**
- Species adapt in response to changes in their environment **14**
- Natural selection is an important mechanism by which evolution proceeds **14**
- Populations evolve as a result of selective pressures from changes in their environment **15**
- 1.7 The Process of Science 15**
- Science requires systematic thought processes **16**
- Scientists make careful observations and ask critical questions **16**
- Chance often plays a role in scientific discovery **17**
- A hypothesis is a testable statement **17**
- Researchers must avoid bias **18**
- Scientists interpret the results of experiments and draw conclusions **18**
- A scientific theory is supported by tested hypotheses **20**
- Many hypotheses cannot be tested by direct experiment **21**
- Paradigm shifts accommodate new discoveries **21**
- Systems biology integrates different levels of information **21**
- Science has ethical dimensions **21**
- Science, technology, and society interact **22**
- 2 Atoms and Molecules: The Chemical Basis of Life 26**
- 2.1 Elements and Atoms 27**
- An atom is uniquely identified by its number of protons **28**
- Protons plus neutrons determine atomic mass **29**
- Isotopes of an element differ in number of neutrons **29**
- Electrons move in orbitals corresponding to energy levels **30**
- 2.2 Chemical Reactions 31**
- Atoms form compounds and molecules **31**
- Simplest, molecular, and structural chemical formulas give different information **31**
- One mole of any substance contains the same number of units **31**
- Chemical equations describe chemical reactions **32**
- 2.3 Chemical Bonds 32**
- In covalent bonds electrons are shared **32**
- The function of a molecule is related to its shape **34**
- Covalent bonds can be nonpolar or polar **34**
- Ionic bonds form between cations and anions **34**
- Hydrogen bonds are weak attractions **36**
- van der Waals interactions are weak forces **37**
- 2.4 Redox Reactions 37**
- 2.5 Water 38**
- Hydrogen bonds form between water molecules **38**
- Water molecules interact with hydrophilic substances by hydrogen bonding **38**
- Water helps maintain a stable temperature **39**
- 2.6 Acids, Bases, and Salts 41**
- pH is a convenient measure of acidity **41**
- Buffers minimize pH change **42**
- An acid and a base react to form a salt **43**
- 3 The Chemistry of Life: Organic Compounds 46**
- 3.1 Carbon Atoms and Organic Molecules 47**
- Isomers have the same molecular formula but different structures **48**
- Functional groups change the properties of organic molecules **49**
- Many biological molecules are polymers **50**
- 3.2 Carbohydrates 51**
- Monosaccharides are simple sugars **51**
- Disaccharides consist of two monosaccharide units **52**
- Polysaccharides can store energy or provide structure **53**
- Some modified and complex carbohydrates have special roles **55**
- 3.3 Lipids 56**
- Triacylglycerol is formed from glycerol and three fatty acids **56**
- Saturated and unsaturated fatty acids differ in physical properties **57**
- Phospholipids are components of cell membranes **57**
- Carotenoids and many other pigments are derived from isoprene units **57**
- Steroids contain four rings of carbon atoms **58**
- Some chemical mediators are lipids **59**

<b>3.4 Proteins</b> 59	Microfilaments consist of intertwined strings of actin 100
Amino acids are the subunits of proteins 60	Intermediate filaments help stabilize cell shape 102
Peptide bonds join amino acids 61	<b>4.7 Cell Coverings</b> 103
Proteins have four levels of organization 61	
The amino acid sequence of a protein determines its conformation 65	
<b>3.5 Nucleic Acids</b> 68	<b>5 Biological Membranes</b> 106
Some nucleotides are important in energy transfers and other cell functions 68	<b>5.1 The Structure of Biological Membranes</b> 107
<b>3.6 Identifying Biological Molecules</b> 69	Phospholipids form bilayers in water 107
	The fluid mosaic model explains membrane structure 108
<b>4 Organization of the Cell</b> 73	Biological membranes are two-dimensional fluids 109
<b>4.1 The Cell: Basic Unit of Life</b> 74	Biological membranes fuse and form closed vesicles 110
The cell theory is a unifying concept in biology 74	Membrane proteins include integral and peripheral proteins 111
The organization and basic functions of all cells are similar 74	Proteins are oriented asymmetrically across the bilayer 111
Cell size is limited 74	<b>5.2 Overview of Membrane Protein Functions</b> 113
Cell size and shape are adapted to function 76	<b>5.3 Cell Membrane Structure and Permeability</b> 114
<b>4.2 Methods for Studying Cells</b> 76	Biological membranes present a barrier to polar molecules 114
Light microscopes are used to study stained or living cells 76	Transport proteins transfer molecules across membranes 115
Electron microscopes provide a high-resolution image that can be greatly magnified 78	<b>5.4 Passive Transport</b> 115
Biologists use biochemical and genetic methods to connect cell structures with their functions 79	Diffusion occurs down a concentration gradient 115
<b>4.3 Prokaryotic and Eukaryotic Cells</b> 82	Osmosis is diffusion of water across a selectively permeable membrane 116
Organelles of prokaryotic cells are not surrounded by membranes 82	Facilitated diffusion occurs down a concentration gradient 118
Membranes divide the eukaryotic cell into compartments 83	<b>5.5 Active Transport</b> 120
The unique properties of biological membranes allow eukaryotic cells to carry on many diverse functions 83	Active transport systems “pump” substances against their concentration gradients 120
<b>4.4 The Cell Nucleus</b> 84	Carrier proteins can transport one or two solutes 122
Ribosomes manufacture proteins in the cytoplasm 87	Cotransport systems indirectly provide energy for active transport 122
<b>4.5 Membranous Organelles in the Cytoplasm</b> 88	<b>5.6 Exocytosis and Endocytosis</b> 123
The endoplasmic reticulum is a multifunctional network of membranes 88	In exocytosis, vesicles export large molecules 123
The ER is the primary site of membrane assembly for components of the endomembrane system 91	In endocytosis, the cell imports materials 123
The Golgi complex processes, sorts, and routes proteins from the ER to different parts of the endomembrane system 91	<b>5.7 Cell Junctions</b> 125
Lysosomes are compartments for digestion 93	Anchoring junctions connect cells of an epithelial sheet 125
Vacuoles are large, fluid-filled sacs with a variety of functions 94	Tight junctions seal off intercellular spaces between some animal cells 127
Peroxisomes metabolize small organic compounds 94	Gap junctions allow the transfer of small molecules and ions 128
Mitochondria and chloroplasts are energy-converting organelles 95	Plasmodesmata allow certain molecules and ions to move between plant cells 128
Mitochondria make ATP through aerobic respiration 95	
Chloroplasts convert light energy to chemical energy through photosynthesis 97	<b>6 Cell Communication</b> 131
<b>4.6 The Cytoskeleton</b> 98	<b>6.1 Cell Communication: An Overview</b> 132
Microtubules are hollow cylinders 98	<b>6.2 Sending Signals</b> 133
Centrosomes and centrioles function in cell division 99	<b>6.3 Reception</b> 134
Cilia and flagella are composed of microtubules 99	Cells regulate reception 135
	Three types of receptors occur on the cell surface 135
	Some receptors are located inside the cell 137
	<b>6.4 Signal Transduction</b> 138
	Signaling molecules can act as molecular switches 138
	Ion channel–linked receptors open or close channels 139
	G protein–linked receptors initiate signal transduction 139
	Second messengers are intracellular signaling agents 139

Many activated intracellular receptors are transcription factors **142**  
Scaffold proteins increase efficiency **143**  
Signals can be transmitted in more than one direction **143**  
**6.5 Responses to Signals 143**

Ras pathways involve tyrosine kinase receptors and G proteins **144**  
The response to a signal is amplified **144**  
Signals must be terminated **145**  
**6.6 Evolution of Cell Communication 146**

## PART TWO: ENERGY TRANSFER THROUGH LIVING SYSTEMS

### **7 Energy and Metabolism 150**

#### **7.1 Biological Work 151**

Organisms carry out conversions between potential energy and kinetic energy **151**

#### **7.2 The Laws of Thermodynamics 151**

The total energy in the universe does not change **151**

The entropy of the universe is increasing **152**

#### **7.3 Energy and Metabolism 152**

Enthalpy is the total potential energy of a system **153**

Free energy is available to do cell work **153**

Chemical reactions involve changes in free energy **153**

Free energy decreases during an exergonic reaction **153**

Free energy increases during an endergonic reaction **154**

Diffusion is an exergonic process **154**

Free-energy changes depend on the concentrations of reactants and products **154**

Cells drive endergonic reactions by coupling them to exergonic reactions **154**

#### **7.4 ATP, the Energy Currency of the Cell 155**

ATP donates energy through the transfer of a phosphate group **155**

ATP links exergonic and endergonic reactions **156**

The cell maintains a very high ratio of ATP to ADP **156**

#### **7.5 Energy Transfer in Redox Reactions 157**

Most electron carriers transfer hydrogen atoms **157**

#### **7.6 Enzymes 158**

All reactions have a required energy of activation **158**

An enzyme lowers a reaction's activation energy **159**

An enzyme works by forming an enzyme–substrate complex **159**

Enzymes are specific **160**

Many enzymes require cofactors **160**

Enzymes are most effective at optimal conditions **161**

Enzymes are organized into teams in metabolic pathways **162**

The cell regulates enzymatic activity **162**

Enzymes are inhibited by certain chemical agents **163**

Some drugs are enzyme inhibitors **164**

### **8 How Cells Make ATP: Energy-Releasing Pathways 167**

#### **8.1 Redox Reactions 168**

#### **8.2 The Four Stages of Aerobic Respiration 168**

In glycolysis, glucose yields two pyruvates **170**

Pyruvate is converted to acetyl CoA **171**

The citric acid cycle oxidizes acetyl groups derived from acetyl CoA **171**

The electron transport chain is coupled to ATP synthesis **176**

Aerobic respiration of one glucose yields a maximum of 36 to 38 ATPs **180**

Cells regulate aerobic respiration **181**

#### **8.3 Energy Yield of Nutrients Other Than Glucose 182**

#### **8.4 Anaerobic Respiration and Fermentation 182**

Alcohol fermentation and lactate fermentation are inefficient **183**

### **9 Photosynthesis: Capturing Light Energy 187**

#### **9.1 Light and Photosynthesis 188**

#### **9.2 Chloroplasts 189**

Chlorophyll is found in the thylakoid membrane **190**

Chlorophyll is the main photosynthetic pigment **191**

#### **9.3 Overview of Photosynthesis 192**

ATP and NADPH are the products of the light-dependent reactions: An overview **192**

Carbohydrates are produced during the carbon fixation reactions: An overview **193**

#### **9.4 The Light-Dependent Reactions 193**

Photosystems I and II each consist of a reaction center and multiple antenna complexes **194**

Noncyclic electron transport produces ATP and NADPH **194**

Cyclic electron transport produces ATP but no NADPH **196**

ATP synthesis occurs by chemiosmosis **196**

#### **9.5 The Carbon Fixation Reactions 198**

Most plants use the Calvin cycle to fix carbon **198**

Photorespiration reduces photosynthetic efficiency **200**

The initial carbon fixation step differs in C<sub>4</sub> plants and in CAM plants **200**

CAM plants fix CO<sub>2</sub> at night **202**

#### **9.6 Metabolic Diversity 202**

#### **9.7 Photosynthesis in Plants and in the Environment 203**

**10 Chromosomes, Mitosis, and Meiosis** 206**10.1 Eukaryotic Chromosomes** 207

DNA is organized into informational units called genes 207

DNA is packaged in a highly organized way in chromosomes 207

Chromosome number and informational content differ among species 208

**10.2 The Cell Cycle and Mitosis** 210

Chromosomes duplicate during interphase 210

During prophase, duplicated chromosomes become visible with the microscope 211

Prometaphase begins when the nuclear envelope breaks down 211

Duplicated chromosomes line up on the midplane during metaphase 212

During anaphase, chromosomes move toward the poles 213

During telophase, two separate nuclei form 215

Cytokinesis forms two separate daughter cells 215

Mitosis produces two cells genetically identical to the parent cell 215

Lacking nuclei, prokaryotes divide by binary fission 216

**10.3 Regulation of the Cell Cycle** 217**10.4 Sexual Reproduction and Meiosis** 219

Meiosis produces haploid cells with unique gene combinations 220

Prophase I includes synapsis and crossing-over 221

During meiosis I, homologous chromosomes separate 221

Chromatids separate in meiosis II 222

Mitosis and meiosis lead to contrasting outcomes 223

**10.5 Sexual Life Cycles** 224**11 The Basic Principles of Heredity** 228**11.1 Mendel's Principles of Inheritance** 229

Alleles separate before gametes are formed: the principle of segregation 231

Alleles occupy corresponding loci on homologous chromosomes 232

A monohybrid cross involves individuals with different alleles of a given locus 233

A dihybrid cross involves individuals that have different alleles at two loci 235

Alleles on nonhomologous chromosomes are randomly distributed into gametes: the principle of independent assortment 236

Recognition of Mendel's work came during the early 20th century 236

**11.2 Using Probability to Predict Mendelian Inheritance** 238

The rules of probability can be applied to a variety of calculations 238

**11.3 Inheritance and Chromosomes** 240

Linked genes do not assort independently 240

Calculating the frequency of crossing-over reveals the linear order of linked genes on a chromosome 240

Sex is generally determined by sex chromosomes 241

**11.4 Extensions of Mendelian Genetics** 246

Dominance is not always complete 246

Multiple alleles for a locus may exist in a population 248

A single gene may affect multiple aspects of the phenotype 248

Alleles of different loci may interact to produce a phenotype 248

In polygenic inheritance, the offspring exhibit a continuous variation in phenotypes 249

Genes interact with the environment to shape phenotype 250

**12 DNA: The Carrier of Genetic Information** 253**12.1 Evidence of DNA as the Hereditary Material** 254

DNA is the transforming factor in bacteria 254

DNA is the genetic material in certain viruses 254

**12.2 The Structure of DNA** 257

Nucleotides can be covalently linked in any order to form long polymers 257

DNA is made of two polynucleotide chains intertwined to form a double helix 258

In double-stranded DNA, hydrogen bonds form between A and T and between G and C 261

**12.3 DNA Replication** 261

Meselson and Stahl verified the mechanism of semiconservative replication 262

Semiconservative replication explains the perpetuation of mutations 262

DNA replication requires protein "machinery" 263

Enzymes proofread and repair errors in DNA 268

Telomeres cap eukaryotic chromosome ends 268

**13 Gene Expression** 272**13.1 Discovery of the Gene-Protein Relationship** 273

Beadle and Tatum proposed the one-gene, one-enzyme hypothesis 273

**13.2 Information Flow from DNA to Protein: An Overview** 275

DNA is transcribed to form RNA 276

RNA is translated to form a polypeptide 276

Biologists cracked the genetic code in the 1960s 277

The genetic code is virtually universal 278

The genetic code is redundant 278

### 13.3 Transcription 279

The synthesis of mRNA includes initiation, elongation, and termination 280

Messenger RNA contains base sequences that do not directly code for protein 281

Eukaryotic mRNA is modified after transcription and before translation 282

Biologists debate the evolution of eukaryotic gene structure 282

### 13.4 Translation 284

An amino acid is attached to tRNA before incorporation into a polypeptide 284

The components of the translational machinery come together at the ribosomes 285

Translation begins with the formation of an initiation complex 285

During elongation, amino acids are added to the growing polypeptide chain 286

One of three stop codons signals the termination of translation 288

Transcription and translation are coupled in bacteria 288

### 13.5 Mutations 290

Base-pair substitution mutations result from the replacement of one base pair by another 290

Frameshift mutations result from the insertion or deletion of base pairs 290

Some mutations involve mobile genetic elements 290

Mutations have various causes 292

### 13.6 Variations in Gene Expression 292

Many eukaryotic genes produce “non-coding” RNAs with catalytic, regulatory, or other cellular functions 292

The definition of a gene has evolved 293

The usual direction of information flow has exceptions 293

## 14 Gene Regulation 297

### 14.1 Gene Regulation in Bacteria and Eukaryotes: An Overview 298

### 14.2 Gene Regulation in Bacteria 299

Operons in bacteria facilitate the coordinated control of functionally related genes 299

Some posttranscriptional regulation occurs in bacteria 303

### 14.3 Gene Regulation in Eukaryotic Cells 304

Eukaryotic transcription is controlled at many sites and by many regulatory molecules 305

Chromosome organization affects the expression of some genes 307

Long non-coding RNAs (lncRNAs) regulate transcription over long distances within the genome 309

The mRNAs of eukaryotes are subject to many types of posttranscriptional control 309

Posttranslational chemical modifications may alter the activity of eukaryotic proteins 312

## 15 DNA Technology and Genomics 315

### 15.1 DNA Cloning 316

Restriction enzymes are “molecular scissors” used to construct recombinant DNA molecules 316

Recombinant DNA is formed when DNA is spliced into a vector 317

Scientists use restriction enzymes and gel electrophoresis to examine cloned DNA fragments 318

The polymerase chain reaction amplifies DNA in vitro 318

cDNA clones do not contain introns 319

### 15.2 CRISPR-Based Technologies 321

CRISPR-based technologies can be used to edit genes in growing cells 321

CRISPR-based tools exploit host DNA repair systems to perform many types of recombinant DNA functions 322

Engineered CRISPR systems are used for specialized research applications 322

### 15.3 Tools for Studying DNA 323

DNA, RNA, and protein blots detect differences in related molecules separated by gel electrophoresis 324

Automated DNA sequencing methods have been developed 324

Gene databases are powerful research tools 325

Reverse transcription of mRNA to cDNA is used to measure gene expression in numerous ways 326

### 15.4 Genomics 328

Collaborative genome-wide association studies have radically changed our view of the human genome 328

Comparative genomic databases are tools for uncovering gene functions 328

RNA interference is used to study gene functions 329

### 15.5 Applications of DNA Technologies 330

DNA technology has revolutionized medicine 330

DNA fingerprinting has numerous applications 331

Transgenic organisms have many research and technological applications 331

### 15.6 CRISPR-Based Gene Drives 334

### 15.7 DNA Technology and Safety Concerns 336

## 16 Human Genetics and the Human Genome 340

### 16.1 Studying Human Genetics 341

Human chromosomes are studied by karyotyping 341

Family pedigrees help identify certain inherited conditions 342

Human gene databases allow geneticists to map the locations of genes on chromosomes 342

### 16.2 Abnormalities in Chromosome Number and Structure 344

Down syndrome is usually caused by trisomy 21 345

Most sex chromosome aneuploidies are less severe than autosomal aneuploidies 347

Abnormalities in chromosome structure cause certain disorders **348**

Genomic imprinting may determine whether inheritance is from the male or female parent **349**

**16.3 Genetic Diseases Caused by Single-Gene Mutations 351**

Many genetic diseases are inherited as autosomal recessive traits **351**

Some genetic diseases are inherited as autosomal dominant traits **353**

Some genetic diseases are inherited as X-linked recessive traits **353**

**16.4 Gene Therapy 354**

Performing clinical trials on humans always has inherent risks **354**

**16.5 Genetic Testing and Counseling 355**

Prenatal diagnosis detects chromosome abnormalities and gene defects **355**

Preimplantation genetic diagnosis is used to screen embryos produced by in vitro fertilization **356**

Genetic screening searches for genotypes or karyotypes **356**

Genetic counselors educate people about genetic diseases **357**

**16.6 Human Genetics, Society, and Ethics 357**

Genetic discrimination provokes heated debate **358**

Many ethical issues related to human genetics must be addressed **358**

## 17 Developmental Genetics 362

### 17.1 Cell Differentiation and Nuclear Equivalence 363

Most cell differences are due to differential gene expression **363**

A totipotent nucleus contains all the instructions for development **364**

The first cloned mammal was a sheep **366**

Stem cells divide and give rise to differentiated cells **367**

### 17.2 The Genetic Control of Development 369

A variety of model organisms provide insights into basic biological processes **369**

Many genes that control development have been identified in the fruit fly **369**

*Caenorhabditis elegans* has a relatively rigid developmental pattern **374**

The mouse is a model for mammalian development **377**

*Arabidopsis* is a model for studying plant development, including transcription factors **379**

### 17.3 Cancer and Cell Development 380

Oncogenes are usually altered components of cell signaling pathways that control growth and differentiation **381**

In many familial cancers, tumor suppressor genes must be inactivated before cells progress to cancer **382**

Cancer cells evolve by accumulating new mutations **382**

## PART FOUR: THE CONTINUITY OF LIFE: EVOLUTION

## 18 Introduction to Darwinian Evolution 385

### 18.1 What Is Evolution? 386

### 18.2 Pre-Darwinian Ideas about Evolution 386

### 18.3 Darwin and Evolution 387

Darwin proposed that evolution occurs by natural selection **389**

The modern synthesis combines Darwin's scientific theory of evolution with genetics **390**

Biologists study the effect of chance on evolution **390**

### 18.4 Evidence for Evolution 391

The fossil record provides strong evidence for evolution **391**

The distribution of plants and animals supports evolution **395**

Comparative anatomy of related species demonstrates similarities in their structures **396**

Molecular comparisons among organisms provide evidence for evolution **399**

Developmental biology helps unravel evolutionary patterns **400**

Evolutionary hypotheses are tested experimentally **401**

## 19 Evolutionary Change in Populations 406

### 19.1 Genotype, Phenotype, and Allele Frequencies 407

### 19.2 The Hardy–Weinberg Principle 407

Genetic equilibrium occurs if certain conditions are met **409**

Human MN blood groups are a valuable illustration of the Hardy–Weinberg principle **409**

### 19.3 Microevolution 410

Nonrandom mating changes genotype frequencies **410**

Mutation increases variation within a population **410**

In genetic drift, random events change allele frequencies **411**

Gene flow generally increases variation within a population **412**

Natural selection changes allele frequencies in a way that increases adaptation **412**

### 19.4 Genetic Variation in Populations 415

Genetic polymorphism can be studied in several ways **415**

Balanced polymorphism exists for long periods **416**

Neutral variation may give no selective advantage or disadvantage **418**

Populations in different geographic areas often exhibit genetic adaptations to local environments **418**

## 20 Speciation and Macroevolution 421

### 20.1 What Is a Species? 422

The biological species concept is based on reproductive isolation 422

The phylogenetic species concept defines species based on such evidence as molecular sequencing 422

### 20.2 Reproductive Isolation 423

Prezygotic barriers interfere with fertilization 423

Postzygotic barriers prevent gene flow when fertilization occurs 425

Biologists are discovering genes responsible for reproductive isolating mechanisms 425

### 20.3 Speciation 425

Long physical isolation and different selective pressures result in allopatric speciation 427

The evolutionary importance of hybridization is being re-evaluated 432

### 20.4 The Rate of Evolutionary Change 434

### 20.5 Macroevolution 435

Evolutionary novelties originate through modifications of pre-existing structures 435

Adaptive radiation is the diversification of an ancestral species into many species 436

Extinction is an important aspect of evolution 438

Is microevolution related to speciation and macroevolution? 439

## 21 The Origin and Evolutionary History of Life 442

### 21.1 Chemical Evolution on Early Earth 443

Organic molecules formed on primitive Earth 443

### 21.2 The First Cells 445

The origin of a simple metabolism within a membrane boundary may have occurred early in the evolution of cells 445

Molecular reproduction was a crucial step in the origin of cells 445

Biological evolution began with the first cells 447

Photosynthesis was a further step in the evolution of cells 448

Aerobes appeared after oxygen increased in the atmosphere 449

Eukaryotic cells descended from prokaryotic cells 450

### 21.3 The History of Life 451

Rocks from the Ediacaran period contain fossils of cells and simple animals 451

A diversity of organisms evolved during the Paleozoic era 451

Dinosaurs and other reptiles dominated the Mesozoic era 454

The Cenozoic era is the Age of Mammals 457

## 22 The Evolution of Primates 461

### 22.1 Primate Adaptations 462

### 22.2 Primate Classification 462

Suborder Anthropeidea includes monkeys, apes, and humans 463

Apes are our closest living relatives 465

### 22.3 Hominin Evolution 467

The earliest hominins may have lived 6 mya to 7 mya 468

*Ardipithecus*, *Australopithecus*, and *Paranthropus* are australopithecines, or “southern man apes” 468

*Homo habilis* is considered the oldest member of genus *Homo* 470

*Homo ergaster* may have arisen from *H. habilis* 471

*Homo erectus* probably evolved from *H. ergaster* 471

Archaic humans date from about 1.2 mya to 200,000 years ago 471

Neandertals appeared approximately 250,000 years ago 472

Scientists have reached a near consensus on the origin of modern *H. sapiens* 473

### 22.4 Cultural Change 474

Development of agriculture resulted in a more dependable food supply 475

Human culture has had a profound effect on the biosphere 475

## PART FIVE: THE DIVERSITY OF LIFE

## 23 Understanding Diversity: Systematics 478

### 23.1 Classifying Organisms 479

Organisms are named using a binomial system 479

Each taxonomic level is more general than the one below it 480

### 23.2 Determining the Major Branches in the Tree of Life 480

Systematics is an evolving science 480

The three domains form the three main branches of the tree of life 482

Some biologists are moving away from Linnaean categories 482

Phylogenetic trees show hypothesized evolutionary relationships 483

Systematists continue to consider other hypotheses 484

### 23.3 Reconstructing Evolutionary History 485

Homologous structures are important in determining evolutionary relationships 485

Shared derived characters provide clues about phylogeny 486

Systematists base taxonomic decisions on recent shared ancestry 487

- Molecular homologies help clarify phylogeny **487**  
 Taxa are grouped based on their evolutionary relationships **488**
- 23.4 Constructing Phylogenetic Trees 490**  
 Outgroup analysis is used in constructing and interpreting cladograms **490**  
 A cladogram is constructed by considering shared derived characters **491**  
 Each branch point represents a major evolutionary step **491**  
 Systematists use the principles of parsimony and maximum likelihood to make decisions **494**
- 23.5 Applying Phylogenetic Information 495**
- 24 Viruses and Subviral Agents 499**
- 24.1 The Status and Structure of Viruses 500**  
 Viruses are very small **500**  
 A virus consists of nucleic acid surrounded by a protein coat **500**  
 The capsid is a protective protein coat **501**  
 Some viruses are surrounded by an envelope **502**
- 24.2 Classification of Viruses 502**
- 24.3 Viral Replication 503**  
 Bacteriophages infect bacteria **503**  
 Viruses replicate inside host cells **503**
- 24.4 Viral Diseases 504**  
 Viruses cause serious plant diseases **505**  
 Viruses cause serious diseases in animals **505**
- 24.5 Evolution of Viruses 511**
- 24.6 Subviral Agents 512**  
 Satellites depend on helper viruses **512**  
 Viroids are short, single strands of naked RNA **513**  
 Prions are protein particles **513**  
 Defective interfering particles are virus mutants **514**
- 25 Bacteria and Archaea 517**
- 25.1 The Structure of Bacteria and Archaea 518**  
 Prokaryotes have several common shapes **518**  
 Prokaryotic cells do not have membrane-enclosed organelles **518**  
 A cell wall protects most prokaryotes **519**  
 Some bacteria produce capsules or slime layers **520**  
 Some prokaryotes have fimbriae or pili **520**  
 Some bacteria survive unfavorable conditions by forming endospores **520**  
 Many types of prokaryotes are motile **521**
- 25.2 Prokaryote Reproduction and Evolution 522**  
 Rapid reproduction contributes to prokaryote success **522**  
 Prokaryotes transfer genetic information **522**  
 Evolution proceeds rapidly in prokaryote populations **523**
- 25.3 Nutritional and Metabolic Adaptations 524**  
 Most prokaryotes require oxygen **525**  
 Some prokaryotes fix and metabolize nitrogen **525**
- 25.4 The Phylogeny of the Two Prokaryote Domains 525**  
 Key characters distinguish the three domains **526**  
 Taxonomy of archaea and bacteria continuously changes **526**  
 Most archaea live in marine and soil habitats, and many thrive in harsh environments **527**  
 Bacteria are the most familiar prokaryotes **528**
- 25.5 Impact on Ecology, Technology, and Commerce 528**  
 Prokaryotes form intimate relationships with other organisms **529**  
 Prokaryotes play key ecological roles **529**  
 Prokaryotes are important in many commercial processes and in technology **532**
- 25.6 Bacteria and Disease 533**  
 Many scientists have contributed to our understanding of infectious disease **533**  
 Many adaptations contribute to pathogen success **533**  
 Antibiotic resistance is a major public health problem **535**
- 26 Protists 539**
- 26.1 Diversity in the Protists 540**
- 26.2 How Did Eukaryotes Evolve? 541**  
 Mitochondria and chloroplasts probably originated from endosymbionts **541**  
 A consensus in eukaryote classification is beginning to emerge **541**
- 26.3 Excavates 544**  
 Diplomonads are small, mostly parasitic flagellates **544**  
 Parabasalids are anaerobic endosymbionts that live in animals **544**  
 Euglenoids and trypanosomes include both free-living species and parasites **545**
- 26.4 Chromalveolates 546**  
 Most dinoflagellates are a part of marine plankton **546**  
 Apicomplexans are spore-forming parasites of animals **547**  
 Ciliates use cilia for locomotion **548**  
 Water molds produce biflagellate reproductive cells **549**  
 Diatoms are stramenopiles with shells composed of two parts **551**  
 Brown algae are multicellular stramenopiles **551**  
 Most golden algae are unicellular biflagellates **552**
- 26.5 Rhizarians 553**  
 Forams extend cytoplasmic projections that form a threadlike, interconnected net **553**  
 Actinopods project slender axopods **553**
- 26.6 Archaeplastids 554**  
 Red algae do not produce motile cells **554**  
 Green algae share many similarities with land plants **555**
- 26.7 Unikonts 555**  
 Amoebozoa are unikonts with lobose pseudopodia **556**  
 Choanoflagellates are opisthokonts closely related to animals **558**



**27 Seedless Plants** 563

**27.1 Adaptations of Plants to Life on Land** 564  
The plant life cycle alternates between haploid and diploid generations 564  
Four major groups of plants exist today 565

**27.2 Bryophytes** 568  
Moss gametophytes are differentiated into “leaves” and “stems” 568  
Liverwort gametophytes are either thalloid or leafy 571  
Hornwort gametophytes are inconspicuous thalloid plants 572  
Bryophytes are used for experimental studies 572  
Recap: details of bryophyte evolution are based on fossils and on structural and molecular evidence 573

**27.3 Seedless Vascular Plants** 574  
Club mosses are small plants with rhizomes and short, erect branches 574  
Ferns are a diverse group of spore-forming vascular plants 575  
Whisk ferns are classified as reduced ferns 576  
Horsetails are an evolutionary line of ferns 576  
Some ferns and club mosses are heterosporous 577  
Seedless vascular plants are used for experimental studies 578  
Seedless vascular plants arose more than 420 mya 580

**28 Seed Plants** 584

**28.1 An Introduction to Seed Plants** 585

**28.2 Gymnosperms** 586  
Conifers are woody plants that produce seeds in cones 586  
Pines represent a typical conifer life cycle 588  
Cycads have seed cones and compound leaves 589  
*Ginkgo biloba* is the only living species in its phylum 590  
Gnetophytes include three unusual genera 591

**28.3 Flowering Plants** 591  
Monocots and eudicots are the two largest classes of flowering plants 592  
Sexual reproduction takes place in flowers 593  
The life cycle of flowering plants includes double fertilization 594  
Seeds and fruits develop after fertilization 596  
Flowering plants have many adaptations that account for their success 596  
Floral structure provides insights into the evolutionary process 596

**28.4 The Evolution of Seed Plants** 597  
Our understanding of the evolution of flowering plants has made great progress in recent years 597  
The basal angiosperms comprise three clades 599  
The core angiosperms comprise magnoliids, monocots, and eudicots 600

**29 The Fungi** 603

**29.1 Characteristics of Fungi** 604  
Fungi absorb food from the environment 604  
Fungi have cell walls that contain chitin 604  
Most fungi consist of a network of filaments 604

**29.2 Fungal Reproduction** 605  
Many fungi reproduce asexually 605  
Most fungi reproduce sexually 605

**29.3 Fungal Diversity** 607  
Fungi are assigned to the opisthokont clade 607  
Diverse groups of fungi have evolved 607  
Chytrids have flagellate spores 608  
Zygomycetes reproduce sexually by forming zygosporangia 609  
Microsporidia have been a taxonomic mystery 610  
Glomeromycetes have a symbiotic relationship with plant roots 611  
Ascomycetes reproduce sexually by forming ascospores 612  
Basidiomycetes reproduce sexually by forming basidiospores 615

**29.4 Ecological Importance of Fungi** 618  
Fungi form symbiotic relationships with some animals 618  
Mycorrhizae are symbiotic associations between fungi and plant roots 618  
A lichen consists of one or more fungi and a photoautotroph 619

**29.5 Economic, Biological, and Medical Impact of Fungi** 621  
Fungi provide beverages and food 621  
Fungi are important to modern biology and medicine 622  
Fungi are used in bioremediation and to biologically control pests 623  
Some fungi cause diseases in humans and other animals 623  
Fungi cause many important plant diseases 623

**30 An Introduction to Animal Diversity** 628

**30.1 Animal Characteristics** 629

**30.2 Adaptations to Ocean, Freshwater, and Terrestrial Habitats** 630  
Marine habitats offer many advantages 630  
Some animals are adapted to freshwater habitats 630  
Terrestrial living requires major adaptations 630

**30.3 Animal Evolution** 631  
Molecular systematics helps biologists interpret the fossil record 631  
Biologists develop hypotheses about the evolution of development 631

### 30.4 Reconstructing Animal Phylogeny 632

Animals exhibit two main types of body symmetry 632

Animal body plans are linked to the level of tissue development 633

Most bilateral animals have a body cavity lined with mesoderm 634

Bilateral animals form two main clades based on differences in development 635

Biologists have identified major animal clades based on structure, development, and molecular data 635

Segmentation apparently evolved three times 636

## 31 Sponges, Cnidarians, Ctenophores, and Protostomes 641

### 31.1 Sponges, Cnidarians, and Ctenophores 642

Sponges have collar cells and other specialized cells 642

Cnidarians have unique stinging cells 644

Comb jellies have adhesive glue cells that trap prey 648

### 31.2 The Lophotrochozoa 649

Flatworms are bilateral acoelomates 649

Nemertean are characterized by their proboscis 652

Mollusks have a muscular foot, visceral mass, and mantle 653

Annelids are segmented worms 657

The lophophorates are distinguished by a ciliated ring of tentacles 659

Rotifers have a crown of cilia 661

### 31.3 The Ecdysozoa 662

Roundworms are of great ecological importance 662

Arthropods are characterized by jointed appendages and an exoskeleton of chitin 662

## 32 The Deuterostomes 676

### 32.1 What are Deuterostomes? 677

### 32.2 Echinoderms 677

Feather stars and sea lilies are suspension feeders 678

Many sea stars capture prey 678

Basket stars and brittle stars make up the largest group of echinoderms 680

Sea urchins and sand dollars have movable spines 680

Sea cucumbers are elongated, sluggish animals 680

### 32.3 The Chordates: Major Characteristics 681

### 32.4 Invertebrate Chordates 682

Tunicates are common marine animals 682

Lancelets clearly exhibit chordate characteristics 682

Systematists debate chordate phylogeny 683

### 32.5 Introducing the Vertebrates 684

The vertebral column is a derived vertebrate character 684

Vertebrate taxonomy is a work in progress 686

### 32.6 Jawless Fishes 686

### 32.7 Evolution of Jaws and Limbs: Jawed Fishes and Tetrapods 688

Most cartilaginous fishes inhabit marine environments 688

Ray-finned fishes gave rise to modern bony fishes 690

Tetrapods evolved from sarcopterygian ancestors 691

Amphibians were the first successful land vertebrates 693

### 32.8 Amniotes: Terrestrial Vertebrates 694

Our understanding of amniote phylogeny is changing 695

Reptiles have many terrestrial adaptations 695

Biologists assign reptiles to two major lineages 696

Lizards and snakes are common modern reptiles 696

Tuatara superficially resemble lizards 698

Turtles have protective shells 698

Crocodylians have an elongated skull 699

How do we know that birds are really dinosaurs? 699

Early birds were transitional forms 699

Modern birds are adapted for flight 700

Mammals (class Mammalia) have many unique characters 702

New fossil discoveries are changing our understanding of the early evolution of mammals 702

Modern mammals are assigned to three subclasses 703

## PART SIX: STRUCTURE AND LIFE PROCESSES IN PLANTS

## 33 Plant Structure, Growth, and Development 710

### 33.1 The Plant Body 711

The plant body consists of cells and tissues 711

The ground tissue system is composed of three simple tissues 711

The vascular tissue system consists of two complex tissues 716

The dermal tissue system consists of two complex tissues 718

### 33.2 Plant Meristems 720

Primary growth takes place at apical meristems 721

Secondary growth takes place at lateral meristems 721

### 33.3 Development of Form 722

The plane and symmetry of cell division affect plant form 723

The orientation of cellulose microfibrils affects the direction of cell expansion 724

Cell differentiation depends in part on a cell's location 724

Morphogenesis occurs through pattern formation 725

## 34 Leaf Structure and Function 729

### 34.1 Leaf Form and Structure 730

Leaf structure is adapted for maximum light absorption 730

### 34.2 Stomatal Opening and Closing 736

Blue light triggers stomatal opening 736

Additional factors affect stomatal opening and closing 737

### **34.3 Transpiration and Guttation 737**

Some plants exude liquid water **738**

### **34.4 Leaf Abscission 739**

In many leaves, abscission occurs at an abscission zone near the base of the petiole **739**

### **34.5 Modified Leaves 740**

Modified leaves of carnivorous plants capture insects **742**

## **35 Stem Structure and Transport 745**

### **35.1 Stem Growth and Structure 746**

Herbaceous eudicot and monocot stems differ in internal structure **746**

Woody plants have stems with secondary growth **748**

### **35.2 Water Transport 754**

Water and minerals are transported in xylem **754**

Water movement can be explained by a difference in water potential **755**

According to the tension–cohesion model, water is pulled up a stem **755**

Root pressure pushes water from the root up a stem **756**

### **35.3 Translocation of Sugar in Solution 757**

The pressure–flow model explains translocation in phloem **757**

## **36 Roots and Mineral Nutrition 762**

### **36.1 Root Structure and Function 763**

Roots have root caps and root hairs **763**

The arrangement of vascular tissues distinguishes the roots of herbaceous eudicots and monocots **764**

Woody plants have roots with secondary growth **767**

Some roots are specialized for unusual functions **768**

### **36.2 Root Associations and Interactions 769**

Mycorrhizae facilitate the uptake of essential minerals by roots **771**

Rhizobial bacteria fix nitrogen in the roots of leguminous plants **772**

### **36.3 The Soil Environment 773**

Soil comprises inorganic minerals, organic matter, air, and water **773**

About 50% of soil volume is composed of pore spaces **775**

Soil organisms form a complex ecosystem **775**

Soil pH affects soil characteristics and plant growth **775**

Soil provides most of the minerals found in plants **776**

Soil can be damaged by human mismanagement **778**

## **37 Reproduction in Flowering Plants 782**

### **37.1 The Flowering Plant Life Cycle 783**

Flowers develop at apical meristems **783**

Each part of a flower has a specific function **783**

### **37.2 Pollination 786**

Many plants have mechanisms that prevent self-pollination **786**

Flowering plants and their animal pollinators have coevolved **786**

Some flowering plants depend on wind to disperse pollen **788**

### **37.3 Fertilization and Seed and Fruit Development 789**

A unique double fertilization process occurs in flowering plants **790**

Embryonic development in seeds is orderly and predictable **790**

The mature seed contains an embryonic plant and storage materials **791**

Fruits are mature, ripened ovaries **792**

Seed dispersal is highly varied **794**

### **37.4 Germination and Early Growth 796**

Some seeds do not germinate immediately **797**

Eudicots and monocots exhibit characteristic patterns of early growth **797**

### **37.5 Asexual Reproduction in Flowering Plants 797**

Apomixis is the production of seeds without the sexual process **799**

### **37.6 A Comparison of Sexual and Asexual Reproduction 800**

Sexual reproduction has some disadvantages **800**

## **38 Plant Developmental Responses to External and Internal Signals 803**

### **38.1 Tropisms 804**

### **38.2 Plant Hormones and Development 805**

Plant hormones act by signal transduction **805**

Auxins promote cell elongation **807**

Gibberellins promote stem elongation **809**

Cytokinins promote cell division **810**

Ethylene promotes abscission and fruit ripening **811**

Abscisic acid promotes seed dormancy **812**

Brassinosteroids are plant steroid hormones **812**

Identification of a universal flower-promoting signal remains elusive **813**

### **38.3 Light Signals and Plant Development 813**

Phytochrome detects day length **814**

Competition for sunlight among shade-avoiding plants involves phytochrome **815**

Phytochrome is involved in other responses to light, including germination **816**

Phytochrome acts by signal transduction **816**

Light influences circadian rhythms **816**

### **38.4 Responses to Herbivores and Pathogens 817**

Jasmonic acid activates several plant defenses **818**

Methyl salicylate may induce systemic acquired resistance **818**

**39 Animal Structure and Function: An Introduction** 821**39.1 Tissues, Organs, and Organ Systems** 822

Epithelial tissues cover the body and line its cavities 822

Glands are made of epithelial cells 823

Epithelial cells form membranes 823

Connective tissues support other body structures 823

Muscle tissue is specialized to contract 828

Nervous tissue controls muscles and glands 829

Tissues and organs make up the organ systems of the body 830

**39.2 Regulating the Internal Environment** 834

Negative feedback systems restore homeostasis 834

A few positive feedback systems operate in the body 835

**39.3 Regulating Body Temperature** 836

Ectotherms absorb heat from their surroundings 836

Endotherms derive heat from metabolic processes 836

Many animals adjust to challenging temperature changes 839

**40 Protection, Support, and Movement** 842**40.1 Epithelial Coverings** 843

Invertebrate epithelium may secrete a cuticle 843

Vertebrate skin functions in protection and temperature regulation 843

**40.2 Skeletal Systems** 844

In hydrostatic skeletons body fluids transmit force 844

Mollusks and arthropods have nonliving exoskeletons 845

Internal skeletons are capable of growth 845

The vertebrate skeleton has two main divisions 846

A typical long bone amplifies the motion generated by muscles 846

Bones are remodeled throughout life 847

Joints are junctions between bones 847

**40.3 Muscle Contraction** 848

Invertebrate muscle varies among groups 848

Vertebrate skeletal muscles act antagonistically to one another 849

A vertebrate muscle may consist of thousands of muscle fibers 849

Contraction occurs when actin and myosin filaments move past one another 850

ATP powers muscle contraction 853

The type of muscle fibers determines strength and endurance 855

Several factors influence the strength of muscle contraction 855

Smooth muscle and cardiac muscle are involuntary 856

**41 Neural Signaling** 860**41.1 Neural Signaling: An Overview** 861**41.2 Neurons and Glial Cells** 862

Neurons receive stimuli and transmit neural signals 862

Certain regions of the CNS produce new neurons 862

Axons aggregate to form nerves and tracts 863

Glial cells play critical roles in neural function 863

**41.3 Transmitting Information along the Neuron** 865

Ion channels and pumps maintain the resting potential of the neuron 865

Ions cross the plasma membrane by diffusion through ion channels 866

Ion pumping maintains the gradients that determine the resting potential 867

Graded local signals vary in magnitude 867

Axons transmit signals called action potentials 867

An action potential is generated when the voltage reaches threshold level 867

The neuron repolarizes and returns to a resting state 868

The action potential is an all-or-none response 869

An action potential is self-propagating 870

Several factors determine the velocity of an action potential 871

**41.4 Transmitting Information across Synapses** 872

Signals across synapses can be electrical or chemical 872

Neurons use neurotransmitters to signal other cells 873

Neurotransmitters bind with receptors on postsynaptic cells 873

Activated receptors can send excitatory or inhibitory signals 874

**41.5 Neural Integration** 877

Postsynaptic potentials are summed over time and space 877

Where does neural integration take place? 877

**41.6 Neural Circuits: Complex Information Signaling** 877**42 Neural Regulation** 882**42.1 Invertebrate Nervous Systems: Trends in Evolution** 883**42.2 Overview of the Vertebrate Nervous System** 884**42.3 Evolution of the Vertebrate Brain** 885

The hindbrain develops into the medulla, pons, and cerebellum 886

The midbrain is prominent in fishes and amphibians 886

The forebrain gives rise to the thalamus, hypothalamus, and cerebrum 887

**42.4 The Human Central Nervous System** 888

The spinal cord transmits impulses to and from the brain 888

The most prominent part of the human brain is the cerebrum 889

Axons in the white matter of the cerebrum connect parts of the brain **892**

The body follows a circadian rhythm of sleep and wakefulness **892**

The limbic system affects emotional aspects of behavior **896**

Learning and memory involve long-term changes at synapses **897**

Language involves comprehension and expression **901**

#### **42.5 The Peripheral Nervous System 901**

The somatic division helps the body adjust to the external environment **901**

The autonomic division regulates the internal environment **901**

#### **42.6 Effects of Drugs on the Nervous System 903**

Drug addiction is a serious issue **904**

Opioid overdose is an epidemic **904**

### **43 Sensory Systems 911**

#### **43.1 How Sensory Systems Work 912**

Sensory receptors receive information **912**

Sensory receptors transduce energy **912**

Sensory input is integrated at many levels **912**

We can classify sensory receptors based on location of stimuli or on the type of energy they transduce **914**

#### **43.2 Thermoreceptors 915**

#### **43.3 Electroreceptors and Magnetic Reception 916**

#### **43.4 Nociceptors 916**

#### **43.5 Mechanoreceptors 916**

Tactile receptors are located in the skin **917**

Proprioceptors help coordinate muscle movement **918**

Many invertebrates have gravity receptors called statocysts **918**

Hair cells are characterized by stereocilia **919**

Lateral line organs supplement vision in fishes **919**

The vestibular apparatus maintains equilibrium **919**

Auditory receptors are located in the cochlea **921**

#### **43.6 Chemoreceptors 924**

Taste receptors detect dissolved food molecules **925**

The olfactory epithelium is responsible for the sense of smell **925**

Many animals communicate with pheromones **926**

#### **43.7 Photoreceptors 926**

Invertebrates have several types of light-sensing organs **926**

Vertebrate eyes form sharp images **927**

The retina contains light-sensitive rods and cones **929**

Light activates rhodopsin **930**

Color vision depends on three types of cones **931**

Integration of visual information begins in the retina **931**

### **44 Internal Transport 936**

#### **44.1 Types of Circulatory Systems 937**

Many invertebrates have an open circulatory system **937**

Some invertebrates have a closed circulatory system **938**

Vertebrates have a closed circulatory system **938**

#### **44.2 Vertebrate Blood 939**

Plasma is the fluid component of blood **939**

Red blood cells transport oxygen **939**

White blood cells defend the body against disease organisms **940**

Platelets function in blood clotting **941**

#### **44.3 Vertebrate Blood Vessels 942**

#### **44.4 Evolution of the Vertebrate Circulatory System 944**

#### **44.5 The Human Heart 946**

Each heartbeat is initiated by a pacemaker **947**

The cardiac cycle consists of alternating periods of contraction and relaxation **948**

The nervous system regulates heart rate **949**

Stroke volume depends on venous return **950**

Cardiac output varies with the body's need **950**

#### **44.6 Blood Pressure 950**

Blood pressure varies in different blood vessels **952**

Blood pressure is carefully regulated **952**

#### **44.7 The Pattern of Circulation 953**

The pulmonary circulation oxygenates the blood **954**

The systemic circulation delivers blood to the tissues **954**

#### **44.8 The Lymphatic System 955**

The lymphatic system consists of lymphatic vessels and lymph tissue **955**

The lymphatic system plays an important role in fluid homeostasis **956**

#### **44.9 Cardiovascular Disease 956**

Atherosclerosis develops progressively **957**

Atherosclerosis has many effects **958**

Cardiovascular disease can be treated **958**

The risk of cardiovascular disease can be lowered **959**

### **45 The Immune System: Internal Defense 962**

#### **45.1 Evolution of Immune Responses 963**

Invertebrates launch innate immune responses **963**

Vertebrates launch both innate and adaptive immune responses **964**

#### **45.2 Innate Immune Responses in Vertebrates 965**

Physical barriers and chemical weapons stop most pathogens **965**

Cells of the innate immune system destroy pathogens **965**

Cytokines are important signaling molecules **966**

Complement promotes destruction of pathogens and enhances inflammation **967**

Inflammation is a protective response **967**

#### **45.3 Adaptive Immune Responses in Vertebrates 969**

Many types of cells are involved in adaptive immune responses **969**

The major histocompatibility complex is responsible for recognition of self **971**

#### **45.4 Cell-Mediated Immunity 972**

- 45.5 Antibody-Mediated Immunity 973**  
 A typical antibody consists of four polypeptide chains **974**  
 Antibodies are grouped in five classes **976**  
 Antigen–antibody binding activates other defenses **977**  
 The immune system responds to millions of different antigens **977**  
 Monoclonal antibodies are highly specific **978**  
 Immunological memory is responsible for long-term immunity **979**
- 45.6 Response to Disease, Immune Failures, and Harmful Reactions 980**  
 Cancer cells evade the immune system **981**  
 Immunodeficiency disease can be acquired or inherited **982**  
 HIV is the major cause of acquired immunodeficiency in adults **982**  
 In an autoimmune disease, the body attacks its own tissues **984**  
 Rh incompatibility can result in hypersensitivity **985**  
 Allergic reactions are directed against ordinary environmental antigens **985**  
 Graft rejection is an immune response against transplanted tissue **987**
- 46 Gas Exchange 991**
- 46.1 Adaptations for Gas Exchange in Air or Water 992**
- 46.2 Types of Respiratory Surfaces 992**  
 The body surface may be adapted for gas exchange **992**  
 Tracheal tube systems deliver air directly to the cells **992**  
 Gills are the respiratory surfaces in many aquatic animals **994**  
 Terrestrial vertebrates exchange gases through lungs **994**
- 46.3 The Mammalian Respiratory System 997**  
 The airway conducts air into the lungs **997**  
 Gas exchange occurs in the alveoli of the lungs **998**  
 Ventilation is accomplished by breathing **998**  
 The quantity of respired air can be measured **998**  
 Gas exchange takes place in the alveoli **998**  
 Gas exchange takes place in the tissues **1001**  
 Respiratory pigments increase capacity for oxygen transport **1001**  
 Carbon dioxide is transported mainly as bicarbonate ions **1002**  
 Breathing is regulated by respiratory centers in the brain **1002**  
 Hyperventilation reduces carbon dioxide concentration **1004**  
 High flying or deep diving can disrupt homeostasis **1004**  
 Some mammals are adapted for diving **1004**
- 46.4 Breathing Polluted Air 1005**
- 47 Processing Food and Nutrition 1010**
- 47.1 Nutritional Styles and Adaptations 1011**  
 Animals are adapted to their mode of nutrition **1011**  
 Some invertebrates have a digestive cavity with a single opening **1012**  
 Most animal digestive systems have two openings **1013**
- 47.2 The Vertebrate Digestive System 1013**  
 Food processing begins in the mouth **1015**  
 The pharynx and esophagus conduct food to the stomach **1016**  
 Food is mechanically and enzymatically digested in the stomach **1016**  
 Most enzymatic digestion takes place in the small intestine **1017**  
 The liver secretes bile **1019**  
 The pancreas secretes digestive enzymes **1019**  
 Nutrients are digested as they move through the digestive tract **1019**  
 Nerves and hormones regulate digestion **1020**  
 Absorption takes place mainly through the villi of the small intestine **1021**  
 The large intestine eliminates waste **1021**
- 47.3 Required Nutrients 1022**  
 Carbohydrates provide energy **1022**  
 Lipids provide energy and are used to make biological molecules **1023**  
 Proteins serve as enzymes and as structural components of cells **1024**  
 Vitamins are organic compounds essential for normal metabolism **1024**  
 Minerals are inorganic nutrients **1026**  
 Antioxidants inactivate reactive molecules **1026**  
 Phytochemicals play important roles in maintaining health **1027**
- 47.4 Energy Metabolism 1027**  
 Energy metabolism is regulated by complex signaling **1028**  
 Obesity is a serious nutritional problem **1028**  
 Undernutrition can cause serious health problems **1029**
- 48 Osmoregulation and Disposal of Metabolic Wastes 1032**
- 48.1 Maintaining Fluid and Electrolyte Balance 1033**
- 48.2 Metabolic Waste Products 1033**
- 48.3 Osmoregulation and Excretion in Invertebrates 1034**  
 Nephridial organs are specialized for osmoregulation and/or excretion **1034**  
 Malpighian tubules conserve water **1035**
- 48.4 Osmoregulation and Excretion in Vertebrates 1036**  
 Freshwater vertebrates must rid themselves of excess water **1036**  
 Marine vertebrates must replace lost fluid **1036**

Terrestrial vertebrates must conserve water **1037**  
**48.5 The Urinary System of Mammals 1038**  
The nephron is the functional unit of the kidney **1040**  
Urine is produced by glomerular filtration, tubular reabsorption, and tubular secretion **1041**  
Glomerular filtration is not selective with regard to ions and small molecules **1041**  
Urine becomes concentrated as it passes through the renal tubule **1043**  
Urine consists of water, nitrogenous wastes, and salts **1044**  
Hormones regulate kidney function **1044**

## **49 Endocrine Regulation 1050**

**49.1 An Overview of Endocrine Regulation 1051**  
The endocrine system and nervous system interact to regulate the body **1051**  
Negative feedback systems regulate endocrine activity **1051**  
Hormones are assigned to four chemical groups **1052**  
**49.2 Types of Endocrine Signaling 1053**  
Neurohormones are transported in the blood **1053**  
Some local regulators are considered hormones **1053**  
**49.3 Mechanisms of Hormone Action 1055**  
Lipid-soluble hormones enter target cells and activate genes **1055**  
Water-soluble hormones bind to cell-surface receptors **1056**  
**49.4 Neuroendocrine Regulation in Invertebrates 1058**  
**49.5 Endocrine Regulation in Vertebrates 1058**  
Homeostasis depends on normal concentrations of hormones **1058**  
The hypothalamus regulates the pituitary gland **1058**  
The posterior pituitary gland releases hormones produced by the hypothalamus **1059**  
The anterior pituitary gland regulates growth and other endocrine glands **1059**  
Thyroid hormones increase metabolic rate **1062**  
Negative feedback systems regulate thyroid secretion **1064**  
The parathyroid glands regulate calcium concentration **1065**  
The islets of the pancreas regulate blood glucose concentration **1065**  
The adrenal glands help the body respond to stress **1068**  
Many other hormones help regulate life processes **1071**

## **50 Reproduction 1074**

**50.1 Asexual and Sexual Reproduction 1075**  
Asexual reproduction is an efficient strategy **1075**  
Most animals reproduce sexually **1075**  
Sexual reproduction increases genetic variability **1076**  
**50.2 Human Reproduction: The Male 1077**  
The testes produce gametes and hormones **1077**  
A series of ducts store and transport sperm **1079**

The accessory glands produce the fluid portion of semen **1079**  
The penis transfers sperm to the female **1080**  
Testosterone has multiple effects **1081**  
The hypothalamus, pituitary gland, and testes regulate male reproduction **1081**  
**50.3 Human Reproduction: The Female 1082**  
The ovaries produce gametes and sex hormones **1083**  
The oviducts transport the secondary oocyte **1084**  
The uterus incubates the embryo **1084**  
The vagina receives sperm **1085**  
The vulva are external genital structures **1085**  
Breasts function in lactation **1086**  
The hypothalamus, pituitary gland, and ovaries regulate female reproduction **1086**  
Menstrual cycles stop at menopause **1089**  
Most mammals have estrous cycles **1091**  
**50.4 Fertilization, Pregnancy, and Birth 1091**  
Fertilization is the fusion of sperm and egg **1091**  
Hormones are necessary to maintain pregnancy **1093**  
The birth process depends on a positive feedback system **1093**  
**50.5 Human Sexual Response 1094**  
**50.6 Birth Control Methods and Abortion 1096**  
Many birth control methods are available **1096**  
Most hormonal contraceptives prevent ovulation **1096**  
Intrauterine devices are widely used **1097**  
Barrier methods of contraception include the diaphragm and condom **1098**  
Emergency contraception is available **1098**  
Sterilization renders an individual incapable of producing offspring **1098**  
Future contraceptives may control regulatory peptides **1099**  
Abortions can be spontaneous or induced **1099**  
**50.7 Sexually Transmitted Infections 1099**

## **51 Animal Development 1104**

**51.1 Development of Form 1105**  
**51.2 Fertilization 1105**  
The first step in fertilization involves contact and recognition **1105**  
Sperm entry is regulated **1106**  
Fertilization activates the egg **1107**  
Sperm and egg pronuclei fuse, restoring the diploid state **1107**  
**51.3 Cleavage 1107**  
The pattern of cleavage is affected by yolk **1107**  
Cleavage may distribute developmental determinants **1109**  
Cleavage provides building blocks for development **1110**  
**51.4 Gastrulation 1110**  
The amount of yolk affects the pattern of gastrulation **1111**

- 51.5 Organogenesis** 1113
- 51.6 Extraembryonic Membranes** 1115
- 51.7 Human Development** 1115
  - The placenta is an organ of exchange 1116
  - Organ development begins during the first trimester 1118
  - Development continues during the second and third trimesters 1118
  - More than one mechanism can lead to a multiple birth 1119
  - Environmental factors affect the embryo 1119
  - The neonate must adapt to its new environment 1119
  - Aging is not a uniform process 1121

## **52 Animal Behavior** 1124

- 52.1 Behavior and Adaptation** 1125
  - Behaviors have benefits and costs 1125
  - Genes interact with environment 1125
  - Behavior depends on physiological readiness 1126
  - Many behavior patterns depend on motor programs 1127
- 52.2 Learning: Changing Behavior as a Result of Experience** 1127
  - An animal habituates to irrelevant stimuli 1128
  - Imprinting occurs during an early critical period 1129
  - In classical conditioning, a reflex becomes associated with a new stimulus 1129
  - In operant conditioning, spontaneous behavior is reinforced 1129

- Animal cognition is controversial 1130
- Play may be practice behavior 1131
- 52.3 Behavioral Responses to Environmental Stimuli** 1131
  - Biological rhythms regulate many behaviors 1131
  - Environmental signals trigger physiological responses that lead to migration 1132
- 52.4 Foraging Behavior** 1133
- 52.5 Costs and Benefits of Social Behavior** 1134
  - Communication is necessary for social behavior 1135
  - Dominance hierarchies establish social status 1136
  - Many animals defend a territory 1137
  - Some insect societies are highly organized 1138
- 52.6 Sexual Selection** 1140
  - Animals of the same sex compete for mates 1140
  - Animals select quality mates 1140
  - Sexual selection favors polygynous mating systems 1141
  - Some animals care for their young 1142
- 52.7 Helping Behavior** 1143
  - Altruistic behavior can be explained by inclusive fitness 1145
  - Helping behavior may have alternative explanations 1145
  - Some animals help nonrelatives 1145
- 52.8 Culture in Vertebrate Societies** 1146
  - Some vertebrates transmit culture 1146
  - Sociobiology explains human social behavior in terms of adaptation 1147

## **PART EIGHT: THE INTERACTIONS OF LIFE: ECOLOGY**

## **53 Introduction to Ecology: Population Ecology** 1151

- 53.1 Features of Populations** 1152
  - Density and dispersion are important features of populations 1152
- 53.2 Changes in Population Size** 1154
  - Dispersal affects the growth rate in some populations 1154
  - Each population has a characteristic intrinsic rate of increase 1154
  - No population can increase exponentially indefinitely 1155
- 53.3 Factors Influencing Population Size** 1156
  - Density-dependent factors regulate population size 1156
  - Density-independent factors are generally abiotic 1159
- 53.4 Life History Traits** 1160
  - Life tables and survivorship curves indicate mortality and survival 1161
- 53.5 Metapopulations** 1163
- 53.6 Human Populations** 1164
  - Not all countries have the same growth rate 1165
  - The age structure of a country helps predict future population growth 1166
  - Environmental degradation is related to population growth and resource consumption 1167

## **54 Community Ecology** 1171

- 54.1 Community Structure and Functioning** 1172
  - Community interactions are complex and often not readily apparent 1173
  - The niche is a species' ecological role in the community 1173
  - Competition is intraspecific or interspecific 1175
  - Natural selection shapes the bodies and behaviors of both predator and prey 1178
  - Symbiosis involves a close association between species 1180
- 54.2 Strength and Direction of Community Interactions** 1183
  - Other species of a community depend on or are greatly affected by keystone species 1183
  - Dominant species influence a community as a result of their greater size or abundance 1184
  - Ecosystem regulation occurs from the bottom up and top down 1184
- 54.3 Community Biodiversity** 1185
  - Ecologists seek to explain why some communities have more species than others 1186



Species richness may promote community stability **1187**  
**54.4 Community Development** **1189**  
Disturbance influences succession and species richness **1190**  
Ecologists continue to study community structure **1190**

## **55 Ecosystems and the Biosphere** **1194**

**55.1 Energy Flow through Ecosystems** **1195**  
Ecological pyramids illustrate how ecosystems work **1196**  
Ecosystems vary in productivity **1197**  
Some toxins persist in the environment **1199**  
**55.2 Cycles of Matter in Ecosystems** **1201**  
Carbon dioxide is the pivotal molecule in the carbon cycle **1201**  
Bacteria and archaea are essential to the nitrogen cycle **1202**  
The phosphorus cycle lacks a gaseous component **1204**  
Water moves among the ocean, land, and atmosphere in the hydrologic cycle **1205**  
**55.3 Abiotic Factors in Ecosystems** **1206**  
The sun warms Earth **1206**  
The atmosphere contains several gases essential to organisms **1208**  
The global ocean covers most of Earth's surface **1209**  
Climate profoundly affects organisms **1210**  
Fires are a common disturbance in some ecosystems **1211**  
**55.4 Studying Ecosystem Processes** **1212**

## **56 Ecology and the Geography of Life** **1216**

**56.1 Biomes** **1217**  
Tundra is the cold, boggy plains of the far north **1217**  
Boreal forest is the evergreen forest of the north **1219**  
Temperate rain forest has cool weather, dense fog, and high precipitation **1219**  
Temperate deciduous forest has a canopy of broad-leaf trees **1220**  
Temperate grasslands occur in areas of moderate precipitation **1220**

Chaparral is a thicket of evergreen shrubs and small trees **1221**  
Deserts are arid ecosystems **1222**  
Savanna is a tropical grassland with scattered trees **1223**  
There are two basic types of tropical forests **1224**  
**56.2 Aquatic Ecosystems** **1226**  
Freshwater ecosystems are linked to land and marine ecosystems **1226**  
Estuaries occur where fresh water and salt water meet **1230**  
Marine ecosystems dominate Earth's surface **1231**  
**56.3 Ecotones** **1235**  
**56.4 Biogeography** **1235**  
Land areas are divided into biogeographic realms **1236**

## **57 Biological Diversity and Conservation Biology** **1241**

**57.1 The Biodiversity Crisis** **1242**  
Endangered species have certain characteristics in common **1243**  
Human activities contribute to declining biological diversity **1245**  
**57.2 Conservation Biology** **1248**  
In situ conservation is the best way to preserve biological diversity **1249**  
Ex situ conservation attempts to save species on the brink of extinction **1252**  
The Endangered Species Act provides some legal protection for species and habitats **1252**  
International agreements provide some protection for species and habitats **1253**  
**57.3 Deforestation** **1253**  
Why are tropical rain forests continuing to disappear? **1254**  
Why are boreal forests disappearing? **1255**  
**57.4 Climate Change** **1255**  
Greenhouse gases cause climate change **1256**  
What are the probable effects of climate change? **1257**  
**The Future?** **1260**

**Glossary** **G-1**

**Index** **I-1**

This eleventh edition of Solomon, Martin, Martin, and Berg's *Biology* conveys our vision of the dynamic science of biology and how it affects every aspect of our lives, from our own health and behavior to the challenging global environmental issues that confront us. New discoveries in the biological sciences continue to increase our understanding of both the unity and diversity of life's processes and adaptations. With this understanding, we become ever more aware of our interdependence with the vast diversity of organisms with which we share planet Earth.

### **Biology: The Student-Friendly Biology Textbook**

We want beginning students to experience learning biology as an exciting journey of discovery. In the eleventh edition of *Biology*, we explore Earth's diverse organisms, their remarkable adaptations to the environment, and their evolutionary and ecological relationships. We present the workings of science and the contributions of scientists whose discoveries not only expand our knowledge of biology but also help shape and protect the future of our planet. *Biology* provides insight into what science is, how scientists work, what scientists have contributed, and how scientific knowledge affects daily life.

Since the first edition of *Biology*, we have worked very hard to present the principles of biology in an integrated way that is accurate, interesting, and conceptually accessible to students. In this eleventh edition of *Biology*, we continue this tradition. We also continue to present biology in an inquiry-based framework. Some professors interpret inquiry as a learning method that takes place in the laboratory as students perform experiments. While laboratory research is certainly an integral part of inquiry-based learning, inquiry is also a way of learning in which students actively pursue knowledge outside the laboratory. In *Biology*, we have always presented the history of scientific advances, including scientific debates, to help students understand that science is a process—that is, a field of investigative inquiry—as well as a body of knowledge, the product of inquiry. In the eleventh edition of *Biology*, we further integrate inquiry-based learning into the textbook, as discussed in the following sections.

Throughout the text, we stimulate interest by relating concepts to experiences within the student's frame of reference. By helping students make such connections, we facilitate their mastery of general concepts. The combined effect of an engaging writing style, interesting and exciting features, and our well-tested *Learning System* provides the ingredients for students to succeed in their study of biology.

### **The Solomon/Martin/Martin/Berg Learning System**

In the eleventh edition, we have continued to refine our highly successful *Learning System*. This system provides the student with the learning strategies needed to integrate biological concepts and demonstrate mastery of these concepts. Learning biology is challenging because it requires learning many new terms and facts that must then be integrated into the framework of biological principles. To help students focus on important principles and concepts, we provide *Learning Outcomes* for the course and *Learning Objectives* for each major section of every chapter. At the end of each section, we provide *Checkpoint* questions based on the *Learning Objectives* so that students can assess their level of understanding of the material presented in the section. At the end of each chapter, we include a *Summary: Focus on Learning Objectives* that is organized around the *Learning Objectives* and emphasizes key terms in context. The *Summary* is followed by *Test Your Understanding*, a set of questions organized according to Bloom's taxonomy. Questions include *Know and Comprehend* multiple-choice exercises as well as a variety of questions that encourage the student to *Apply and Analyze* and *Evaluate and Synthesize* the topics in the chapter.

Students are directed to [www.cengagebrain.com](http://www.cengagebrain.com), a powerful online tool that offers access to *MindTap* and additional study materials. See the Resources for Students section of the Preface for details.

### **Pedagogical Features**

Our *Learning System* includes numerous learning strategies that help students increase their success:

- Our updated *art program* reinforces concepts discussed in the text and presents complex processes in clear steps. *Key Experiment* figures emphasize the scientific process in both classic and modern research. These figures encourage students to evaluate investigative approaches that scientists have taken. Examples include Figures 4-12, 8-9, and 52-1. *Key Point* figures state important concepts in process diagrams of complex topics. Examples include Figures 4-11, 4-15, 27-2, 31-32, and 42-6. Many of the *Key Point* figures have numbered parts that show sequences of events in biological processes or life cycles.
- Numerous photographs, both alone and combined with line art, help students grasp concepts by connecting the “real” to the “ideal.” The line art uses features such as *orientation icons* to help students put the detailed figures into the broader context. We use symbols and colors consistently throughout the book to help students connect

concepts. For example, the same four colors and shapes are used throughout the book to identify guanine, cytosine, adenine, and thymine. Similarly, the same colors are used consistently in illustrations and tables to indicate specific clades of organisms. *Research Method* figures describe why biologists use a particular method and explain how the method is executed. Examples include Figures 4-7 and 15-9.

- Many questions carry special designations: *Predict*; *Connect*; *Visualize*; *Evolution Link*; *Interpret Data*; or *Science, Technology, and Society*. These questions emphasize that learning is enhanced by many diverse approaches.
- *Inquiring About* boxes explore issues of special relevance to students, such as the effects of smoking, how traumatic experiences affect the body, and breast cancer. These boxes also provide a forum for discussing some interesting topics in more detail, such as the smallest ancient humans, ancient plants and coal formation, hydrothermal vent communities, declining amphibian populations, and stratospheric ozone depletion.
- A list of *Key Concepts* at the beginning of each chapter provides a chapter overview and helps the student focus on important principles discussed in the chapter.
- *Learning Objectives* at the beginning of each major section in the chapter indicate, in behavioral terms, what the student must do to demonstrate mastery of the material in that section.
- Each major section of the chapter is followed by a series of *Checkpoint* questions that assess comprehension by asking the student to describe, explain, compare, contrast, or illustrate important concepts. The *Checkpoint* questions are based on the section *Learning Objectives*.
- *Concept Statement Subheads* introduce sections, previewing and summarizing the key idea or ideas to be discussed in that section.
- *Sequence Summaries* within the text simplify and summarize information presented in paragraph form. For example, paragraphs describing blood circulation through the body or the steps by which cells take in certain materials are followed by a *Sequence Summary* listing the sequence of structures or steps.
- Numerous *tables*, many illustrated, help the student organize and summarize material presented in the text. Many tables are color-coded.
- A *Summary: Focus on Learning Objectives* at the end of each chapter is organized around the chapter *Learning Objectives*. This summary provides a review of the material, and because selected key terms are boldfaced in the summary, students learn vocabulary words within the context of related concepts.
- *Test Your Understanding* end-of-chapter questions are organized according to Bloom's taxonomy, providing students with the opportunity to evaluate their understanding

of the material in the chapter. *Know and Comprehend* multiple-choice questions reinforce important terms and concepts. *Apply and Analyze* questions challenge students to integrate their knowledge. Higher-level *Evaluate and Synthesize* questions encourage students to apply the concepts just learned to new situations or to make connections among important concepts. Each chapter has one or more *Evolution Link* questions, and many chapters contain one or more *Interpret Data* questions that require students to actively interpret experimental data presented in the chapter. Also included are *Predict*, *Connect*, *Visualize*, and *Science, Technology, and Society* questions. Answers to the *Test Your Understanding* questions are provided in Appendix E online at [www.cengagebrain.com](http://www.cengagebrain.com).

- The *Glossary* at the end of the book, the most comprehensive glossary found in any biology text, provides precise definitions of terms. The *Glossary* is especially useful because it is extensively cross-referenced and includes pronunciations for many terms. The vertical yellow bar along the margin facilitates rapid access to the *Glossary*. *MindTap* also includes glossary flash cards with pronunciations.

## Course Learning Outcomes

At the end of a successful study of introductory biology, the student can demonstrate mastery of biological concepts by responding accurately to the following *Course Learning Outcomes*:

- Design an experiment to test a given hypothesis, using the procedure and terminology of the scientific method.
- Cite the cell theory and relate the structure of organelles to their functions in both prokaryotic and eukaryotic cells.
- Describe the mechanisms of evolution, explain why evolution is the principal unifying concept in biology, and discuss natural selection as the primary agent of evolutionary change.
- Explain the role of genetic information in all species and discuss applications of genetics that affect society.
- Describe several mechanisms by which cells and organisms transfer information, including the use of nucleic acids in genetic transmission of information, signal transduction, chemical signals (such as hormones and pheromones), electrical signals (such as neural transmission), sounds, and visual displays.
- Provide examples (at various levels of complexity) of interactions among biological systems that illustrate the interdependence of these systems.
- Explain how any given structure is related to its function.
- Argue for or against the classification of organisms in three domains and several kingdoms or supergroups, characterizing each of these clades; based on your knowledge

- of genetics and evolution, give specific examples of the unity and diversity of organisms in different domains and supergroups.
- Compare the structural adaptations, life processes, and life cycles of a prokaryote, protist, fungus, plant, and animal.
  - Define *homeostasis* and give examples of regulatory mechanisms, including feedback systems.
  - Trace the flow of matter and energy through a photosynthetic cell and a nonphotosynthetic cell and through the biosphere, comparing the roles of producers, consumers, and decomposers.
  - Describe the study of ecology at the levels of an individual organism, a population, a community, and an ecosystem.

## What's New: An Overview of *Biology*, Eleventh Edition

Five themes are interwoven throughout *Biology*: the evolution of life, the transmission of biological information, the flow of energy through living systems, interactions among biological systems, and the inter-relationship of structure and function. As we introduce the concepts of modern biology, we explain how these themes are connected and how life depends on them.

Educators present the major topics of an introductory biology course in a variety of orders. For this reason, we carefully designed the eight parts of this book so that they do not depend heavily on preceding chapters and parts. This flexible organization means that an instructor can present the 57 chapters in any number of sequences with pedagogical success. Chapter 1, which introduces the student to the major principles of biology, provides a comprehensive springboard for future discussions, whether the professor prefers a “top-down” or “bottom-up” approach.

In this edition as in previous editions, we examined every line of every chapter for accuracy and currency. We carefully updated each topic and verified new material. The following brief summary provides a general overview of the organization of *Biology* and some of the changes made to the eleventh edition.

### Part 1 The Organization of Life

The six chapters that make up Part 1 provide basic principles of biology and the concepts of chemistry and cell biology that lay the foundation upon which the remaining parts of the book build. We begin Chapter 1 with a discussion of the promise and challenges of CRISPR research. We then introduce the main themes of the book: evolution, information transfer, energy transfer, interactions in biological systems, and the inter-relationship of structure and function.

Chapter 1 examines several fundamental concepts in biology and the nature of the scientific process, including a discussion of systems biology. Chapters 2 and 3, which focus on the molecular level of organization, establish the foundations in chemistry necessary for understanding biological processes. Chapters 4, 5, and 6 focus on the cellular level of organization, including cell structure and function, cell membranes, and cell signaling. We emphasize the interdisciplinary nature of cell research. Topics discussed include transport between the nucleus and cytoplasm, routing of proteins through the endomembrane system, and cell communication.

### Part 2 Energy Transfer through Living Systems

Because all living cells need energy for life processes, the flow of energy through living systems—that is, capturing energy and converting it to usable forms—is a basic theme of *Biology*. Chapter 7 examines how cells capture, transfer, store, and use energy. Chapters 8 and 9 discuss the metabolic adaptations by which organisms obtain and use energy through cellular respiration and photosynthesis.

### Part 3 The Continuity of Life: Genetics

We have updated and expanded the eight chapters of Part 3 for the eleventh edition. We begin this unit by discussing mitosis and meiosis in Chapter 10. Chapter 11 builds on this foundation as it considers Mendelian genetics and related patterns of inheritance. We then turn our attention to the structure and replication of DNA in Chapter 12. The discussion of RNA and protein synthesis in Chapter 13 includes insights into how the small percentage of DNA that codes for polypeptides relates to the much larger percentage of the genome that is expressed. We provide information establishing that much of the genome encodes different classes of non-protein-coding RNAs, including microRNAs and long non-coding RNAs. The regulatory functions of these RNAs are further explored in Chapter 14, which also includes information on eukaryotic promoters, enhancers, and silencers as well as on epigenetic inheritance. In Chapter 15 we focus on DNA technology and genomics, including a discussion of rapid DNA sequencing and CRISPR-mediated gene editing. We discuss the importance of gene databases as tools for understanding gene regulation, gene functions, and molecular evolution. We have also added a section on genetically engineered gene drive systems. These chapters build the necessary foundation for exploring human genetics and the human genome in Chapter 16, which includes sections on genomic imprinting and on genome-wide association studies. In Chapter 17 we introduce the role of genes in development, emphasizing studies on specific model organisms that have led to spectacular advances in this field. We discuss

induced pluripotent stem cells and present a comprehensive view of cancer and its relationship to cell signaling. We link these advances to the application of genome-wide association studies and whole genome sequencing.

## Part 4 The Continuity of Life: Evolution

Although we explore evolution as the cornerstone of biology throughout the book, in Part 4 we discuss evolutionary concepts in depth. We provide the history behind the discovery of the scientific theory of evolution, the mechanisms by which it occurs, and the methods by which it is studied and tested. Chapter 18 introduces the Darwinian concept of evolution and presents several kinds of evidence that support the scientific theory of evolution. In Chapter 19 we examine evolution at the population level. Chapter 20 describes the evolution of new species and discusses aspects of macroevolution. Chapter 21 summarizes the evolutionary history of life on Earth. In Chapter 22 we recount the evolution of primates, including humans. We explore recent molecular and fossil findings, including those relating to human relatives such as the Denisovans (a sister species to the Neandertals) as well as *Australopithecus sediba* and *Homo naledi*, species whose fossils exhibit unique mixtures of apelike and human-like features.

## Part 5 The Diversity of Life

Emphasizing the cladistic approach, we use an evolutionary framework to discuss each group of organisms. We present current hypotheses of how groups of organisms are related. In Chapter 23 we discuss *why* organisms are classified and provide insight into the scientific process of deciding *how* they are classified. New advances have enabled us to further clarify the connection between evolutionary history and systematics in the eleventh edition. Chapter 24 focuses entirely on viruses and subviral agents. Topics include giant viruses, viral origins, and the evolutionary importance of viruses. Chapter 25 is devoted to the prokaryotes, both bacteria and archaea. Information about the evolution, structure, ecology, and phylogeny of archaea has been updated and expanded. Implications of research on the human microbiome are discussed and discussion of antibiotic resistance has been expanded.

Chapter 26 describes the protists in the context of five “supergroups” of eukaryotes. Chapters 27 and 28 present the members of the plant kingdom. Chapter 27 considers the evolution of land plants and the evolution of seedless vascular plants. Discussion of the origin and early evolution of angiosperms is included in Chapter 28. Chapter 29 describes the fungi. In Chapters 30 through 32, we discuss the diversity of animals. We have updated the discussions of phylogenetic relationships to reflect recent research.

## Part 6 Structure and Life Processes in Plants

Part 6 introduces students to the fascinating plant world. Here we stress relationships between structure and function in plant cells, tissues, organs, and individual organisms. In Chapter 33 we consider plant structure, growth, and differentiation in the context of cell division, cell expansion, cell differentiation, tissue culture, morphogenesis, pattern formation, positional information, and *Arabidopsis* mutants. Chapters 34 through 36 discuss the structural and physiological adaptations of leaves, stems, and roots; these chapters include special consideration of plant transport systems. Chapter 37 describes reproduction in flowering plants, including asexual reproduction, flowers, fruits, and seeds. Chapter 38 focuses on growth responses and regulation of growth, including the latest findings generated by the continuing explosion of knowledge in plant biology, particularly at the molecular level.

## Part 7 Structure and Life Processes in Animals

In Part 7 we provide a strong emphasis on comparative animal physiology, showing the structural, functional, and behavioral adaptations that help animals meet environmental challenges. We use a comparative approach to examine how various animal groups have solved both similar and diverse problems. In Chapter 39 we discuss the basic tissues and organ systems of the animal body, homeostasis, and the ways that animals regulate their body temperature. Chapter 40 focuses on different types of body coverings, skeletons, and muscles, and discusses how they function. In Chapters 41 through 43, we discuss neural signaling, neural regulation, and sensory reception. In Chapters 44 through 51, we compare how different animal groups carry on life processes, such as internal transport, internal defense, gas exchange, digestion, osmoregulation and disposal of metabolic wastes, endocrine regulation, reproduction, and development. Each chapter in Part 7 considers the adaptations for the life processes being discussed. Part 7 ends with a discussion of behavioral adaptations in Chapter 52. Reflecting recent research findings, we have updated or added new material on many topics, including neurotransmitters, cardiovascular disease, immune function, nutrition, regulation of appetite and energy metabolism, the mesentery, endocrine function, contraception, sexually transmitted infections, and transmission of culture in vertebrates.

## Part 8 The Interactions of Life: Ecology

In Part 8 we discuss the ecology of populations, communities, and ecosystems and the application of ecological principles to disciplines such as conservation biology. Throughout Chapters 53 through 57, we focus on human interdependence with

other organisms, how we have disrupted the biosphere, and what we can do to stop global climate change, decreases in species diversity, and other negative human impacts.

In Chapter 53 we focus on population ecology. In Chapter 54 we focus on community ecology. We discuss research advances that facilitate understanding of community structure, interactions, synergy, and potential medical benefits. For example, we discuss research on the keystone wolves of Yellowstone and ecosystem cascade effects. We have added a new box, *Inquiring About: The Human Microbiota: Our Many Symbionts*, which introduces students to the various relationships we have with our microbiota, including health, metabolism, and immune functions.

In Chapter 55 we discuss ecosystems and the biosphere. We present updated discussions on community composition research, illustrating the potential for balance between species richness and agricultural productivity. Chapter 56 focuses on ecology and the geography of life. We discuss the degradation of permafrost and the resulting concerns for global climate change. We have added a discussion of research suggesting ecotones as potential global climate change indicators and have expanded research information on coral reef bleaching and recovery and the effects of global warming.

In Chapter 57 we discuss biological diversity and conservation biology. We have expanded information on human-caused extinctions and decreases in biodiversity. We include updated information on biodiversity hotspots and conservation partnerships.

This chapter includes new conservation biology research on ecosystem restoration partnerships. We have also expanded information linking global climate change with sea level rise and the increasing diseases spread by mosquitos.

## A Comprehensive Package for Learning and Teaching

A carefully designed supplement package is available to further facilitate learning. In addition to print resources, we are pleased to present student multimedia tools that have been developed in conjunction with the text.

### Resources for Students

**MindTap** A fully online learning experience built on Cengage Learning content. *MindTap* combines student learning tools—readings, study tools, animations, activities, and assessments—into a singular Learning Path that guides students through their course. New features for the eleventh edition include Data Analysis activities and Mastery Training powered by Cerego. Mastery Training uses the science of how we learn to support students' understanding of the key concepts in each chapter and can be accessed through your computer or the mobile app.

Each *MindTap* product offers the full, mobile-ready textbook combined with superior and proven learning tools at one affordable price. Students who purchase digital access can add a print option at any time.

**A Problem-Based Guide to Basic Genetics** by Donald Cronkite of Hope College. This brief guide provides students with a systematic approach to solving genetics problems along with numerous solved problems and practice problems.

**Spanish Glossary** This glossary includes key terms and definitions in Spanish.

### Additional Resources for Instructors

This edition includes a comprehensive package of supplements, available to qualified adopters. Please ask your local sales representative for details.

**Instructor Companion Site** Everything you need for your course in one place! This collection of book-specific lecture and class tools is available online via [www.cengage.com/login](http://www.cengage.com/login). Access and download PowerPoint presentations, images, instructor's manual, videos, and more.

**Cengage Learning Testing Powered by Cognero** A flexible, online system that allows you to import, edit, and manipulate test bank content from the test bank or elsewhere, including your own favorite test questions; create multiple test versions in an instant; and deliver tests from your LMS, your classroom, or wherever you want.

**MindTap** A fully online, highly personalized learning experience built on Cengage Learning content. *MindTap* combines student learning tools—readings, multimedia, activities, and assessments—into a singular Learning Path that guides students through their course. Instructors personalize the experience by customizing authoritative Cengage Learning content and learning tools, including the ability to add their own content in the Learning Path via apps that integrate into the *MindTap* framework seamlessly with Learning Management Systems.

*MindTap* for Biology is easy to use and saves instructors time by allowing them to:

- Seamlessly deliver appropriate content from a number of providers.
- Break course content down into movable objects to promote personalization, encourage interactivity, and ensure student engagement.
- Customize the course—from tools to text—and make adjustments “on the fly,” making it possible to intertwine breaking news into their lessons.

- Bring interactivity into learning through the integration of multimedia assets.
- Track students' use, activities, and comprehension in real time, which provides opportunities for early intervention to influence progress and outcomes. Grades are visible and archived so that students and instructors always have access to current standings in the class.

## Acknowledgments

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We have learned a great deal from tens of thousands of students who have taken on the challenge of learning biology. Although they have varied in their life goals and academic preparation, most have found that they needed to modify their approach to learning to be successful.

You already know that memorization and cramming are unsuccessful, and you probably also know that many students fall back on these methods as default strategies. So, what really works?

### Use the Wealth of Learning Aids That Accompany *Biology*

The *Learning System* we use in this book is described in the Preface. Using the strategies of the *Learning System* will help you master the language and concepts of biology. You will also want to use the many online tools available to *Biology* students. These tools, described in the Resources for Students section of the Preface, are included in *MindTap* available at [www.cengagebrain.com](http://www.cengagebrain.com). In addition to these learning strategies, you can make the task of learning biology easier by using approaches that have been successful for a broad range of our students over the years.

### Be Open to Many Learning Styles

There is a popular belief that each person has an innate “learning style” that is most successful for them. In fact, there is very little scientific evidence to support this view. What works will depend on the nature of the material being learned, and in most cases a mix of activities and a variety of sensory inputs will be most effective. *Biology* includes many kinds of questions to encourage you to think and learn in different ways. Make learning a part of your life as you think, listen, draw, write, argue, describe, speak, observe, explain, and experiment.

### Know Your Professor’s Expectations

Determine what your professor wants you to know and how your learning will be assessed. Some professors test almost exclusively on material covered in lecture. Others rely on their students’ learning most of, or even all, the content assigned in chapters. Find out what your professor’s requirements are because the way you study will vary accordingly.

If lectures are the main source of examination questions, make your lecture notes as complete and organized as possible. Before going to class, skim over the chapter, identifying key terms and examining the main figures, so that you can take effective lecture notes. Spend no more than 1 hour on this. Within 24 hours after class, type (or rewrite) your notes. Before typing them, however, read the notes and make marginal notes about anything that is not clear. Then read the corresponding

material in your text. Do not copy the information; instead, process it and write out an explanation in your own words. Read the entire chapter, including parts that are not covered in lecture. This extra information will give you breadth of understanding and will help you grasp key concepts. In addition, you should make an effort to employ as many of the techniques described in the next paragraphs as possible.

If the assigned readings in the text are going to be tested, you must use your text intensively. After reading the chapter introduction, read the list of *Learning Objectives* for the first section. These objectives are written in behavioral terms; that is, they ask you to “do” something to demonstrate mastery. The objectives give you a concrete set of goals for each section of the chapter. At the end of each section, you will find *Checkpoint* questions keyed to the *Learning Objectives*. Carefully examine each figure, making certain that you understand what it is illustrating. Answer the question at the end of each *Key Point* figure and at the end of each *Key Experiment*.

Read each chapter section actively. Highlighting and underlining are not always active learning techniques; sometimes they postpone learning. (“This part is important; I’ll learn it later.”) An active learner always has questions in mind and is constantly making connections. For example, there are many processes that must be understood in biology. Don’t try to blindly memorize them; instead, think about causes and effects so that every process becomes a story. Eventually, you’ll see that many processes are connected by common elements.

To master the material, you will probably have to read each chapter more than once. Each time will be much easier than the previous time because you’ll be reinforcing concepts that you have already partially learned.

Write a chapter outline and flesh out your outline by adding important concepts and boldface terms with definitions in your own words (not copied from the book or cut and pasted). Use this outline when preparing for the exam.

Now it is time to test yourself. Answer the *Test Your Understanding* questions (*Know and Comprehend*, *Apply and Analyze*, and *Evaluate and Synthesize*) at the end of the chapter. You will sharpen your thinking if you take the time to type or write out your answers. The answers are in Appendix E online at [www.cengagebrain.com](http://www.cengagebrain.com), but do not be too quick to check them. Think about them and discuss them with your fellow students if possible. Consider each question as a kind of springboard that leads to other questions. Finally, review the *Learning Objectives* in the *Summary* and try to answer them before reading the summary provided.

### Learn the Vocabulary

One stumbling block for many students is learning the many terms that make up the language of biology. In fact, it would be much more difficult to learn and communicate if we did

not have this terminology because words are really tools for thinking. Learning terminology generally becomes easier if you realize that most biological terms are modular. They consist of mostly Latin and Greek roots; once you learn many of these roots, you will have a good idea of the meaning of a new word even before it is defined. For this reason, we have included Appendix C, *Understanding Biological Terms*, online at [www.cengagebrain.com](http://www.cengagebrain.com). To be sure that you understand the precise definition of a term, use the *Index* and the *Glossary*. The more you use biological terms in speech and writing, the more comfortable you will be with the language of biology.

## Develop a Framework for Your Learning

Always aim to get the big picture before adding details. When attempting to learn a complex process, a struggling student will typically begin with the first part, try to learn all the details, and then give up. Instead, begin by making sure that you have a basic understanding of what is happening in the overall process. To encourage you in this way of thinking, we have modeled this approach in *Biology*. As just one example out of many, glycolysis is a multistep process

covered in Chapter 8. Before presenting all the details, we provide an overview figure that emphasizes what the process accomplishes.

## Form a Study Group

Active learning is facilitated if you do some of your studying collaboratively in a small group. In a study group, the roles of teacher and learner can be interchanged: a good way to learn material is to teach, through a process that cognitive scientists describe as *elaborative rehearsal* (not to be confused with memorization). A study group has other advantages: it can make learning more fun, lets you meet challenges in a non-threatening environment, and can provide some emotional support. When combined with individual study of text and lecture notes, study groups can be effective learning tools.

Our author team hopes that your study of biology will be an exciting journey for you, as it continues to be for us.

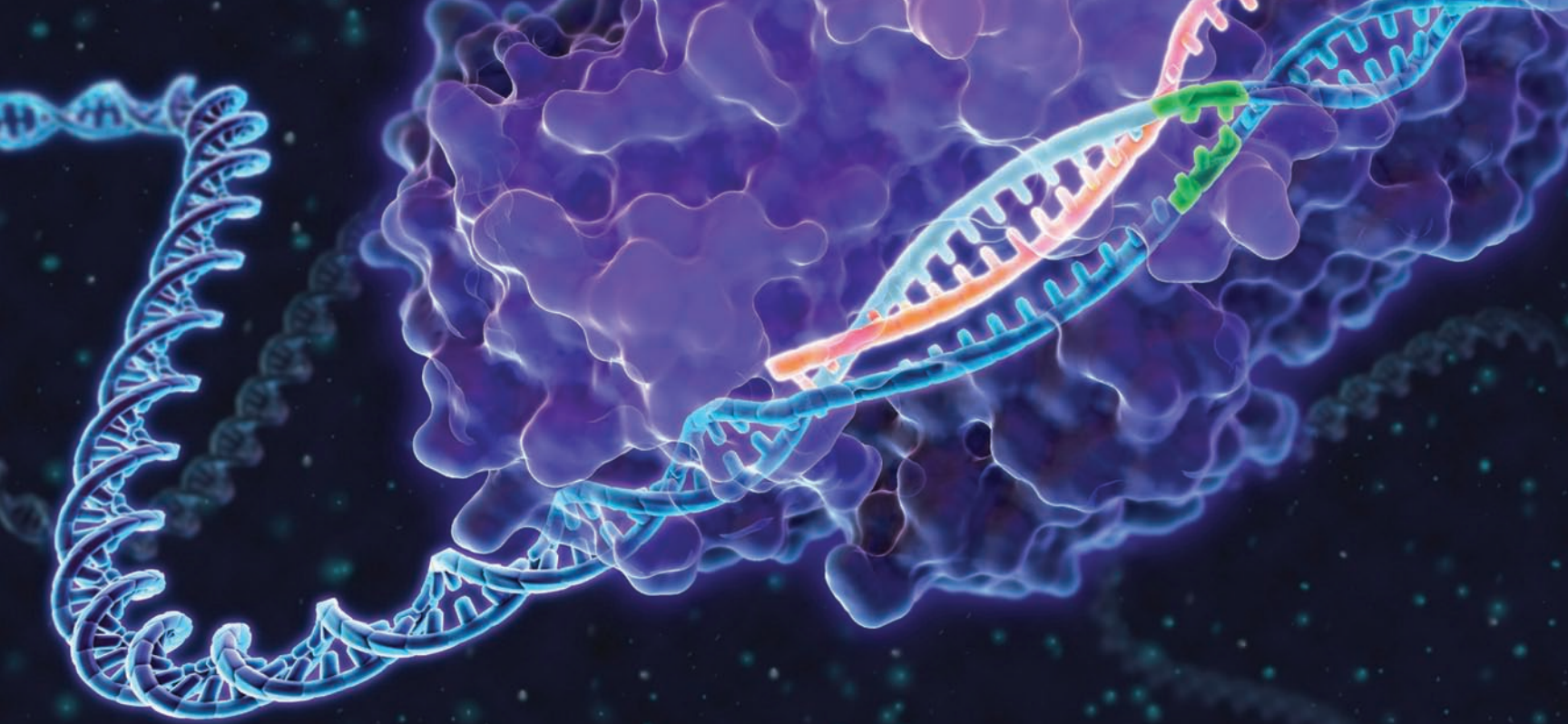
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# 1 A View of Life

This is a very exciting time to study **biology**, the science of life. Biologists are making remarkable new discoveries that affect every aspect of our lives, including our health, food, safety, relationships with humans and other organisms, and the environment of our planet. New knowledge provides new insights into the human species and the millions of other organisms with which we share planet Earth. Biology affects our personal, governmental, and societal decisions.

One of the most exciting areas of current research is genetic engineering, specifically CRISPR, a breakthrough technology that allows researchers to edit genes. CRISPR (clustered regularly interspaced short palindromic repeats) are sections of prokaryotic (archaeal and bacterial) DNA that have short repeating base sequences. Near each CRISPR there are groups of *cas* genes. The CRISPR/Cas system protects prokaryotes from foreign genetic material (which is carried and inserted into their genetic material by plasmids and phages). RNA in nearby spacer sequences works with Cas proteins to recognize and remove the foreign DNA or RNA.

**PHOTO: CRISPR editing a genome (genetic material in a cell).**

This molecular model of gene editing using CRISPR (clustered regularly interspaced short palindromic repeats) shows a Cas9 protein (purple) attached to the DNA of a cell using a guide RNA (orange) that matches a target DNA sequence (light blue). The Cas9 protein separates the DNA strands of the double helix. The green area of the DNA identifies the location where the Cas9 protein is attached and “cuts” the target DNA, changing the gene sequence. Evan Oto/Science Source



## KEY CONCEPTS

- 1.1** Basic themes of biology include evolution, interactions of biological systems, inter-relationships of structure and function, information transfer, and energy transfer.
- 1.2** Characteristics of life include cellular structure, growth and development, self-regulated metabolism, response to stimuli, and reproduction.
- 1.3** Biological organization is hierarchical and includes chemical, cell, tissue, organ, organ system, and organism levels; ecological organization includes population, community, ecosystem, and biosphere levels.
- 1.4** Information transfer includes DNA transfer of information from one generation to the next, chemical and electrical signals within and among the cells of every organism, and sensory receptors and response systems that allow organisms to communicate with one another and interact with their environment.
- 1.5** Individual organisms and entire ecosystems depend on a continuous input of energy. Energy is transferred within cells and from one organism to another.
- 1.6** Evolution is the process by which populations of organisms change over time, adapting to changes in their environment; the tree of life includes three major branches, or domains.
- 1.7** Biologists ask questions, develop hypotheses, make predictions, and collect data by careful observation and by performing experiments; based on their results, they come to conclusions and then share their work with other scientists and with the public.

Researchers are now using CRISPR as a tool for editing genes rapidly and inexpensively (see image). By “knocking out” specific genes, scientists discover the function of these genes. CRISPR identifies the specific region of DNA that has been targeted. It then cuts out and removes the gene of interest. You will learn more about CRISPR when you study genetics later in this book.

CRISPR/Cas9 technology has been used to successfully deactivate specific human genes, modify yeasts for biofuel production, and modify agricultural crops. Scientists are researching how CRISPR technology could produce mutant model stem cell lines for studying disease, eliminate proteins that cause rejection in organ transplants, and selectively cut out or alter any targeted human gene. CRISPR research will almost certainly lead to more effective ways of preventing and treating cancer and HIV, and of dramatically decreasing the spread of mosquito-transmitted diseases, such as Zika and malaria.

CRISPR technology is just one of hundreds of exciting areas of biological research that bring together science, technology, and society. Whatever your college major or career goals, knowledge of biological concepts is a vital tool for understanding our world and for meeting many of the personal, societal, and global challenges that confront us. Among these challenges are the expanding human population, decreasing biological diversity, diminishing natural resources, global climate change, and prevention and cure of diseases, such as heart disease, cancer, diabetes, and Alzheimer’s disease. Meeting these challenges will require the combined efforts of biologists and other scientists, health professionals, educators, politicians, and biologically informed citizens.

This book is a starting point for your exploration of biology. It will provide you with the basic knowledge and the tools to become a part of this fascinating science as well as a more informed member of society.

## 1.1 Major Themes of Biology

### LEARNING OBJECTIVE

- 1 Describe five basic themes of biology.

In this first chapter we introduce five major themes of biology. These themes are interconnected with one another and with almost every concept that we discuss in this book.

1. **Biological systems interact.** Every organism is a biological system made up of millions of other biological systems. Each of its cells is a biological system, as is each organ (e.g., heart and liver) and body system (e.g., cardiovascular system and digestive system). Each of the multitude of microorganisms (e.g., bacteria) that inhabit an organism is also a biological system. Making this concept even more interesting, an organism cannot survive on its own. Every organism is a biological system that is interdependent with many other biological systems. Clearly, scientists can study biological systems and their interactions at many different levels.
2. **Structure and function are interrelated in all biological systems.** The structure of neurons that function to transmit information is very different from the structure of red

blood cells, which function to transport oxygen. Similarly, on the level of organisms, the canine teeth of carnivorous mammals are adapted for stabbing their prey and ripping flesh. In contrast, horses and other herbivorous mammals have teeth adapted for cutting off bits of vegetation and grinding plant material. In each case, structure and function are inter-related.

3. **Information must be transmitted within organisms and among organisms.** Each organism must be able to receive information from the surrounding environment. The survival and function of every cell and every organism depend on the orderly transmission of information. As we will learn, evolution depends on the transmission of genetic information from one generation to another.
4. **Life depends on a continuous input of energy from the sun because every activity of a living cell or organism requires energy.** Energy from the sun flows through individual organisms and through ecosystems. Within living cells energy is continuously transferred from one chemical compound to another.
5. **Evolution is the process by which populations of organisms change over time.** Scientists have accumulated a wealth of evidence showing that the diverse life-forms on this planet are related and that populations have *evolved*—that is, have changed over time—from earlier forms of life. The process of *evolution* is the framework for the science of biology and is a major theme of this book.

The interaction of biological systems, the inter-relationship of structure and function, information transfer, energy transfer, and the process of evolution are forces that give life its unique characteristics. You will find reference to one or more of these unifying themes in every chapter of *Biology*. We begin our study of biology by developing a more precise understanding of the fundamental characteristics of living systems and of the levels of biological organization. We then take a closer look at some of the major themes of biology. We end Chapter 1 with a discussion of the process of science.

### CHECKPOINT 1.1

- Why are information transmission, energy transfer, and evolution considered basic to life?
- **CONNECT** What are some ways in which an organism is dependent on other biological systems?

## 1.2 Characteristics of Life

### LEARNING OBJECTIVE

- 2 Distinguish between living systems and nonliving things by describing the features that characterize living organisms.

We easily recognize that a pine tree, a butterfly, and a horse are living systems, whereas a rock is not. Despite their diversity,

the organisms that inhabit our planet share a common set of characteristics that distinguish them from nonliving things. These features include a precise kind of organization, growth and development, self-regulated metabolism, the ability to respond to stimuli, reproduction, and adaptation to environmental change.

## Organisms are composed of cells

Although they vary greatly in size and appearance, all organisms consist of basic units called **cells**. New cells are formed only by the division of previously existing cells. As will be discussed in Chapter 4, these concepts are expressed in the **cell theory**, another fundamental unifying concept of biology.

Some of the simplest life-forms, such as protozoa, are **unicellular** organisms, meaning that each consists of a single cell (FIG. 1-1a). In contrast, the body of a maple tree or a buffalo is made of billions of cells (FIG. 1-1b). In such complex **multicellular** organisms, life processes depend on the coordinated functions of component cells that are organized to form tissues, organs, and organ systems.

Every cell is enveloped by a protective **plasma membrane** that separates it from the surrounding external environment. The plasma membrane regulates passage of materials between the cell and its environment. Cells have specialized molecules—deoxyribonucleic acid, more simply known as **DNA**—that contain genetic instructions and transmit genetic information. Cells typically have internal structures called **organelles** that are specialized to perform specific functions. For example, **mitochondria**, which we can think of as the power plants of the cell, convert energy in food molecules into energy forms that can be more conveniently used by the cell.

There are two fundamentally different types of cells: prokaryotic and eukaryotic. **Prokaryotic cells** are microscopic organisms classified in two large groups (called **domains**): **domain Bacteria** and **domain Archaea**. Prokaryotic cells do not have a nucleus or other membrane-enclosed organelles. All other organisms are characterized by their **eukaryotic cells**. These cells typically contain a variety of organelles enclosed by membranes, including a **nucleus**, which contains DNA, the genetic information.

## Organisms grow and develop

**Biological growth** involves an increase in the size of individual cells of an organism, in the number of cells, or in both. Growth may be uniform in the various parts of an organism, or it may be greater in some parts than in others, causing the body proportions to change as growth occurs. Some organisms—most trees, for example—continue to grow throughout their lives. Many animals have a defined growth period that terminates when a characteristic adult size is reached. An intriguing aspect of the growth process is that each part of the organism typically continues to function as it grows.

Organisms develop as well as grow. **Development** includes all the changes that take place during an organism's life. The structures and body form that develop are exquisitely adapted



Wim van Egmond/Visuals Unlimited/Getty Images

250  $\mu\text{m}$

(a) Unicellular organisms consist of one cell that performs all the functions essential to life. Ciliates, such as this *Paramecium*, move about by beating their hairlike cilia.



McMurray Photography

(b) Multicellular organisms, such as this African buffalo (*Syncerus caffer*) and the plants on which it grazes, may consist of billions of cells specialized to perform specific functions.

**Figure 1-1** Unicellular and multicellular life-forms

to the functions the organism must perform. Like many other organisms, every human begins life as a fertilized egg that then grows and develops.

## Organisms regulate their metabolic processes

Within all organisms, chemical reactions and energy transformations occur that are essential to nutrition, the growth and repair of cells, and the conversion of energy into usable forms. The sum of all the chemical activities of the organism is its **metabolism**.

Metabolic processes occur continuously in every organism, and they must be carefully regulated to maintain **homeostasis**,

an appropriate, balanced internal environment. The term *homeostasis* also refers to the automatic tendency of the organism to maintain a steady state. For example, when a particular substance is required, cell processes that produce it must be turned on. When enough of a cell product has been made, its manufacture must be decreased or turned off. These *homeostatic mechanisms* are self-regulating control systems that are remarkably sensitive and efficient.

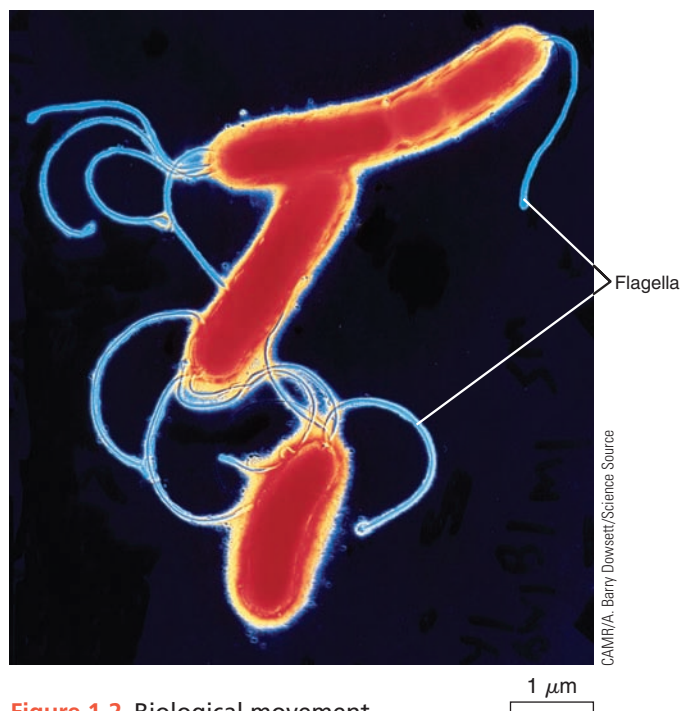
The regulation of glucose (a simple sugar) concentration in the blood of complex animals is a good example of a homeostatic mechanism. Your cells require a constant supply of glucose molecules, which they break down to obtain energy. The circulatory system delivers glucose and other nutrients to all the cells. When the concentration of glucose in the blood rises above normal limits, glucose is stored in the liver and in muscle cells. When you have not eaten for a few hours, the glucose concentration begins to fall. Your body mobilizes stored glucose. If necessary, the body converts other stored nutrients to glucose, bringing the glucose concentration in the blood back to normal levels. When the glucose concentration decreases, you also feel hungry and can restore nutrients by eating.

## Organisms respond to stimuli

All forms of life respond to **stimuli**, physical or chemical changes in their internal or external environment. Stimuli that evoke a response in most organisms are changes in the color, intensity, or direction of light; changes in temperature, pressure, or sound; and changes in the chemical composition of the surrounding soil, air, or water. Responding to stimuli often involves movement, although not always locomotion (moving from one place to another).

In simple organisms, the entire individual may be sensitive to stimuli. Certain unicellular organisms, for example, respond to bright light by retreating. In some organisms, locomotion is achieved by the slow oozing of the cell, the process of *amoeboid movement*. Other organisms move by beating tiny, hairlike extensions of the cell called **cilia** or longer structures known as **flagella** (FIG. 1-2). Some bacteria move by rotating their flagella.

Most animals move very obviously. They wiggle, crawl, swim, run, or fly by contracting muscles. Sponges, corals, and oysters have free-swimming larval stages, but most are **sessile** as adults, meaning that they do not move from place to place. In fact, they may remain firmly attached to a surface, such as the sea bottom or a rock. Many sessile organisms have cilia or flagella that beat rhythmically, bringing them food and oxygen in the surrounding water. Complex animals, such as grasshoppers, lizards, and humans, have highly



**Figure 1-2** Biological movement

These bacteria (*Helicobacter pylori*), equipped with flagella for locomotion, have been linked to stomach ulcers. The photograph was taken using a scanning electron microscope. The bacteria are not really red and blue. Their color has been artificially enhanced.

specialized cells that respond to specific types of stimuli. For example, cells in the retina of the vertebrate eye respond to light.

Although their responses may not be as obvious as those of animals, plants do respond to light, gravity, water, touch, and other stimuli. For example, plants orient their leaves to the sun and grow toward light. Many plant responses involve different growth rates of various parts of the plant body. A few plants, such as the Venus flytrap of the Carolina swamps, are very sensitive to touch and catch insects (FIG. 1-3). Their leaves are hinged along the midrib, and they have a scent



(a) When hairs on the leaf surface of the Venus flytrap (*Dionaea muscipula*) detect the touch of an insect, the leaf responds by folding.



(b) The edges of the leaf come together and interlock, preventing the insect's escape. The leaf then secretes enzymes that kill and digest the insect.

**Figure 1-3** Plants respond to stimuli

that attracts insects. Trigger hairs on the leaf surface detect the arrival of an insect and stimulate the leaf to fold. When the edges come together, they interlock, preventing the insect's escape. The leaf then secretes enzymes that kill and digest the insect. The Venus flytrap usually grows in nitrogen-deficient soil. The plant obtains part of the nitrogen required for its growth from the insects it "eats."

## Organisms reproduce

At one time, people thought worms arose spontaneously from horsehair in a water trough, maggots from decaying meat, and frogs from the mud of the Nile. Thanks to the work of a great many scientists, beginning with pioneering studies by Italian physician Francesco Redi in the 17th century and French chemist Louis Pasteur in the 19th century, we know that organisms arise only from previously existing organisms.

Simple organisms, such as amoebas, perpetuate themselves by **asexual reproduction** (FIG. 1-4a). When an amoeba has grown to a certain size, it reproduces by splitting to form two new amoebas. Before an amoeba divides, its hereditary material (set of *genes*) is duplicated, and one complete set is distributed to each new cell. Except for size, each new amoeba is similar to the parent cell. The only way that variation occurs among asexually reproducing organisms is by genetic **mutation**, a permanent change in the genes.

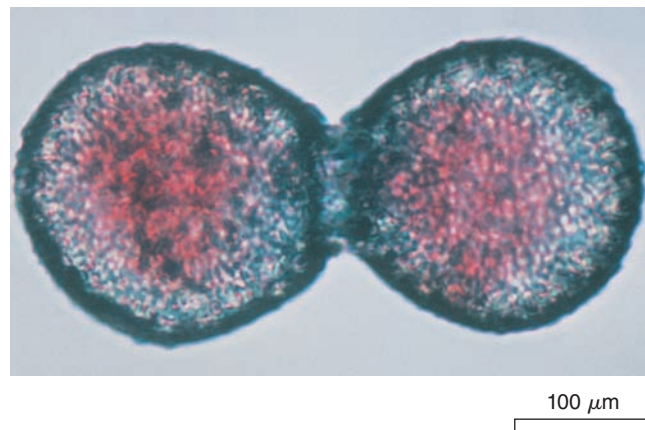
In most plants and animals, **sexual reproduction** is carried out by the fusion of an egg and a sperm cell to form a fertilized egg (FIG. 1-4b). The new organism develops from the fertilized egg. Offspring produced by sexual reproduction are the product of the interaction of various genes contributed by the mother and the father. Genetic variation is important in the vital processes of evolution and adaptation.

## Populations evolve and become adapted to the environment

The ability of a population to evolve over many generations and adapt to its environment equips it to survive in a changing world. **Adaptations** are inherited characteristics that enhance an organism's ability to survive in a particular environment. The long, flexible tongue of the frog is an adaptation for catching insects. The feathers and lightweight bones of birds are adaptations for flying, and their thick fur coats allow polar bears to survive in frigid temperatures. Adaptations may be structural, physiological, biochemical, behavioral, or a combination of all four (FIG. 1-5). Every biologically successful organism is a complex collection of coordinated adaptations produced through evolutionary processes.

### CHECKPOINT 1.2

- What characteristics distinguish a living organism from a rock?
- **PREDICT** What would be the consequences to an organism if its homeostatic mechanisms failed? Explain your answer.



Cabisco/Visuals Unlimited, Inc.

**(a) Asexual reproduction.** One individual gives rise to two or more offspring that are similar to the parent. *Diffflugia*, a unicellular amoeba, is shown dividing to form two amoebas.



iStock.com/PK6289

**(b) Sexual reproduction.** Typically, each of two parents contributes a gamete (sperm or egg). Gametes fuse to produce the offspring, which has a combination of the traits of both parents. A pair of cucumber beetles is shown mating.

**Figure 1-4** Asexual and sexual reproduction



McMurray Photography

**Figure 1-5** Adaptations

These Burchell's zebras (*Equus burchelli*), photographed in Tanzania, are behaviorally adapted to position themselves to watch for lions and other predators. Stripes are thought to be an adaptation for visual protection against predators. They serve as camouflage or to break up form when spotted from a distance. The zebra stomach is adapted for feeding on coarse grass passed over by other grazers, an adaptation that helps the animal survive when food is scarce.



## 1.3 Levels of Biological Organization



### LEARNING OBJECTIVE

- 3 Construct a hierarchy of biological organization, including levels characteristic of individual organisms and levels characteristic of ecological systems.

Whether we study a single organism or the world of life as a whole, we can identify a hierarchy of biological organization (FIG. 1-6). At every level, structure and function are precisely coordinated. One way to study a particular level is by looking at its components. Biologists can gain insights about cells by studying atoms and molecules. Learning about a structure by studying its parts is called **reductionism**. However, the whole is more than the sum of its parts. Each level has **emergent properties**, characteristics not found at lower levels. For example, populations of organisms have emergent properties such as population density, age structure, and birth and death rates. The *individuals* that make up a population do not have these characteristics. Consider also the human brain. The brain is composed of billions of neurons (nerve cells). However, we could study every one of these individual neurons and have no clue about the functional capacities of the brain. Only when the neurons interact are the emergent properties, such as the capacity for thought, judgment, and motor coordination, evident.

### Organisms have several levels of organization

The chemical level, the most basic level of organization, includes atoms and molecules. An **atom** is the smallest unit of a chemical element that retains the characteristic properties of that element. For example, an atom of hydrogen is the smallest possible amount of hydrogen. Atoms combine chemically to form **molecules**. Two atoms of hydrogen combine with one atom of oxygen to form a single molecule of water. Although composed of two types of atoms that are gases under conditions found on Earth, water can exist as a gas, liquid, or solid. The properties of water are very different from those of its hydrogen and oxygen components, an example of emergent properties.

At the cellular level, many types of atoms and molecules associate with one another to form *cells*. However, a cell is much more than a heap of atoms and molecules. Its emergent properties make it the basic structural and functional unit of life, the simplest component of living matter that can carry on all the activities necessary for life.

During the evolution of multicellular organisms, cells associated to form **tissues**. For example, most animals have muscle tissue and nervous tissue. Plants have epidermis, a tissue that serves as a protective covering, and vascular tissues that move materials throughout the plant body. In most complex organisms, tissues organize into functional structures called **organs**, such as the heart and stomach in animals and

roots and leaves in plants. In animals, each major group of biological functions is performed by a coordinated group of tissues and organs called an **organ system**. The circulatory and digestive systems are examples of organ systems. Functioning together with great precision, organ systems make up a complex, multicellular **organism**. Again, emergent properties are evident. An organism is much more than its component organ systems.

### Several levels of ecological organization can be identified

Organisms interact to form still more complex levels of biological organization. All the members of one species living in the same geographic area at the same time make up a **population**. The populations of various types of organisms that inhabit a particular area and interact with one another form a **community**. A community can consist of hundreds of different types of organisms. The human body, for example, harbors a community of hundreds of species of microorganisms, its *microbiota*, that critically affect human health.

A community together with its nonliving environment is an **ecosystem**. An ecosystem can be as small as a pond (or even a puddle) or as vast as the Great Plains of North America or the Arctic tundra. All Earth's ecosystems together are known as the **biosphere**. The biosphere includes all systems of Earth that are inhabited by living organisms: the atmosphere, the hydrosphere (water in any form), and the lithosphere (Earth's crust). The study of how organisms relate to one another and to their physical environment is called **ecology** (derived from the Greek *oikos*, meaning "house").



### CHECKPOINT 1.3

- What are the levels of organization within an organism?
- **PREDICT** At which level do you think more biological systems would be interacting: organism, population, or ecosystem? Justify your answer.

## 1.4 Information Transfer



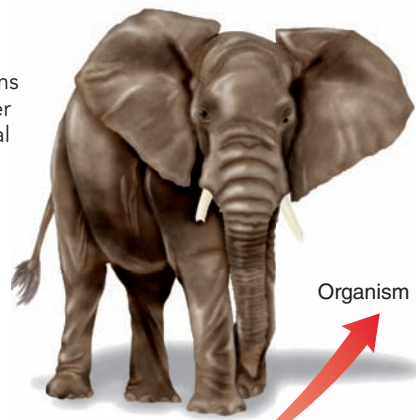
### LEARNING OBJECTIVE

- 4 Summarize the importance of information transfer within and between living systems, giving specific examples.

Biological systems receive and respond to information. They also store information in the form of DNA (or RNA). An organism inherits the information it needs to grow, develop, carry on self-regulated metabolism, respond to stimuli, and reproduce. Each organism must also have precise instructions for making the molecules necessary for its cells to communicate. The information an organism requires to carry on these life processes is coded and transmitted in the form of chemical substances and electrical impulses.

**Organism**

Organ systems work together in a functional organism.



Organism



Population

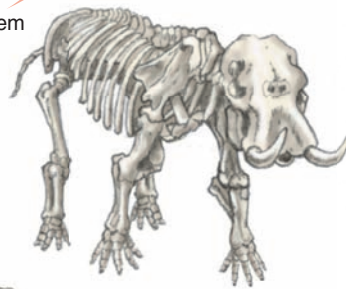
**Population**

A population consists of organisms of the same species.

**Organ system**

(e.g., skeletal system) Tissues and organs make up organ systems.

Organ system



**Organ**

(e.g., bone) Tissues form organs.

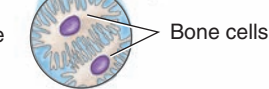
Organ



**Tissue**

(e.g., bone tissue) Cells associate to form tissues.

Tissue

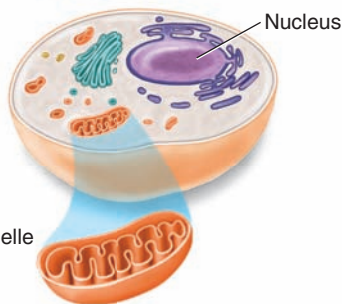


Bone cells

**Cellular level**

Atoms and molecules make up the cytoplasm and form organelles, such as the nucleus and mitochondria (the site of many energy transformations). Organelles perform various functions of the cell.

Cell



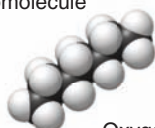
Nucleus

Organelle

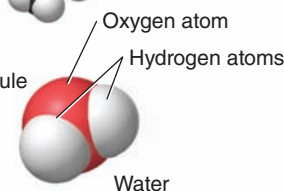
**Chemical level**

Atoms join to form molecules. Macromolecules are large molecules such as proteins and DNA.

Macromolecule



Molecule



Oxygen atom

Hydrogen atoms

Water

Community



**Community**

The populations of different species that populate the same area make up a community.

Ecosystem



**Ecosystem**

A community together with the nonliving environment forms an ecosystem.

Biosphere



**Biosphere**

Earth and all its communities constitute the biosphere.

**Figure 1-6** The hierarchy of biological organization

## DNA transmits information from one generation to the next

Humans give birth only to human babies, not to giraffes or rosebushes. In organisms that reproduce sexually, each offspring is a combination of the traits of its parents. In 1953, James Watson and Francis Crick worked out the structure of DNA, the large molecule that makes up the **genes**, units of hereditary information (FIG. 1-7). A DNA molecule consists of two chains of atoms twisted into a helix. As will be described in Chapter 3, each chain is made up of a sequence of chemical subunits called **nucleotides**. There are four types of nucleotides in DNA, and each sequence of three nucleotides is part of the genetic code.

Watson and Crick's work, building on the earlier findings of many researchers, led to the understanding of the genetic code. The information coded in sequences of nucleotides in DNA transmits genetic information from generation to generation. The code works somewhat like an alphabet of 4 letters (A, G, C, T). The nucleotides can "spell" an amazing variety of instructions for making organisms as diverse as bacteria, frogs, and redwood trees. The genetic code is universal—that is, virtually identical in all organisms—and is a dramatic example of the unity of life.

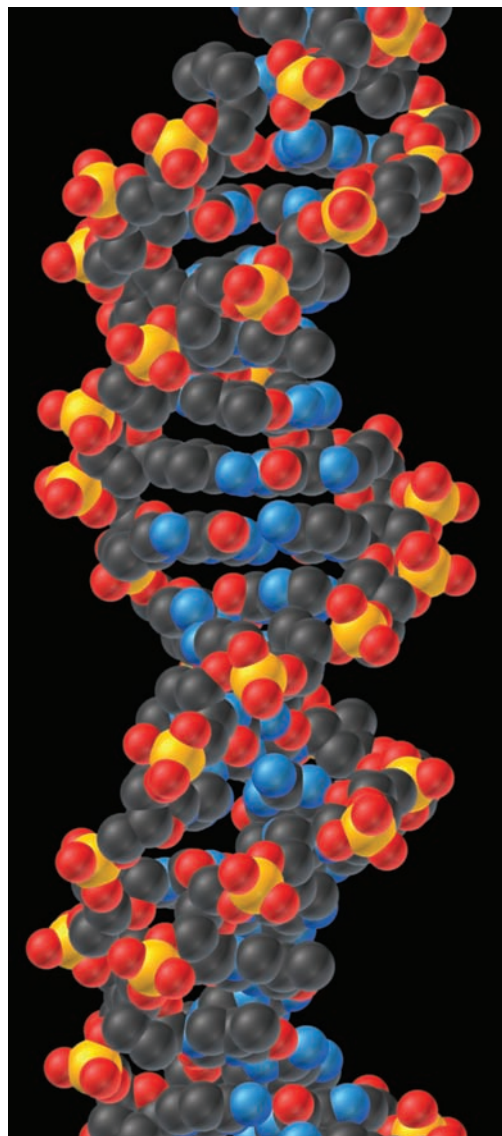
## Information is transmitted by chemical and electrical signals

Genes control the development and functioning of every organism. As you will learn in later chapters, the information carried by the DNA that makes up the genes has many functions, including providing the "recipes" for making all the proteins required by the organism. **Proteins** are large molecules important in determining the structure and function of cells and tissues. For example, brain cells differ from muscle cells in large part because they have different types of proteins. Some proteins are important in communication within and among cells. Certain proteins on the surface of a cell serve as markers so that other cells "recognize" them. Other cell-surface proteins serve as receptors that combine with chemical messengers.

Cells use proteins and many other types of molecules to communicate with one another. In a multicellular organism, cells produce chemical compounds, such as **hormones**, that signal other cells. Hormones and other chemical messengers can signal cells in distant organs to secrete a particular required substance or change some metabolic activity. In this way chemical signals help regulate growth, development, and metabolic processes. The mechanisms involved in **cell signaling** often involve complex biochemical processes.

Cell signaling is currently an area of intense research. A major focus has been the transfer of information among cells of the immune system. A better understanding of how cells communicate promises new insights into how the body protects itself against disease organisms. Learning to manipulate cell signaling may lead to new methods of delivering drugs into cells and new treatments for cancer and other diseases.

Many organisms use electrical signals to transmit information. Most animals have nervous systems that transmit information by way of both electrical impulses and chemical



**Figure 1-7** DNA

DNA is the hereditary material that transmits information from one generation to the next. As shown in this model, DNA is a macromolecule that consists of two chains of atoms twisted into a helix. Each chain consists of subunits called nucleotides. The sequence of nucleotides makes up the genetic code.

compounds known as **neurotransmitters**. Information transmitted from one part of the body to another is important in regulating life processes. In complex animals, the nervous system gives the animal information about its outside environment by transmitting signals from sensory receptors such as the eyes and ears to the brain. Neurons in the brain make appropriate decisions and transmit signals to specific muscles or glands.

## Organisms also communicate information to one another

Organisms communicate information to other organisms by releasing chemicals, sounds, and visual displays. Typically, organisms use a combination of several types of communication

signals. A dog may signal aggression by growling, using a particular facial expression, and laying its ears back. Many animals perform complex courtship rituals in which they display parts of their bodies, often elaborately decorated, to attract a mate.

Seaweed algae compete with coral for light and space. Marine biologists studying endangered coral reefs have discovered that certain seaweed algae secrete chemical compounds that kill coral. Researchers have reported that some coral can fight back. When they come into contact with toxic seaweed, the coral release chemical compounds that signal certain species of goby fish. In response to this chemical signal, the fish eat the seaweed. This action helps preserve their coral reef habitat.

### ✓ CHECKPOINT 1.4

- What is the function of DNA?
- How does a nervous system transmit information?

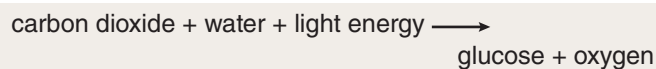
## 1.5 The Energy of Life

### 🎯 LEARNING OBJECTIVE

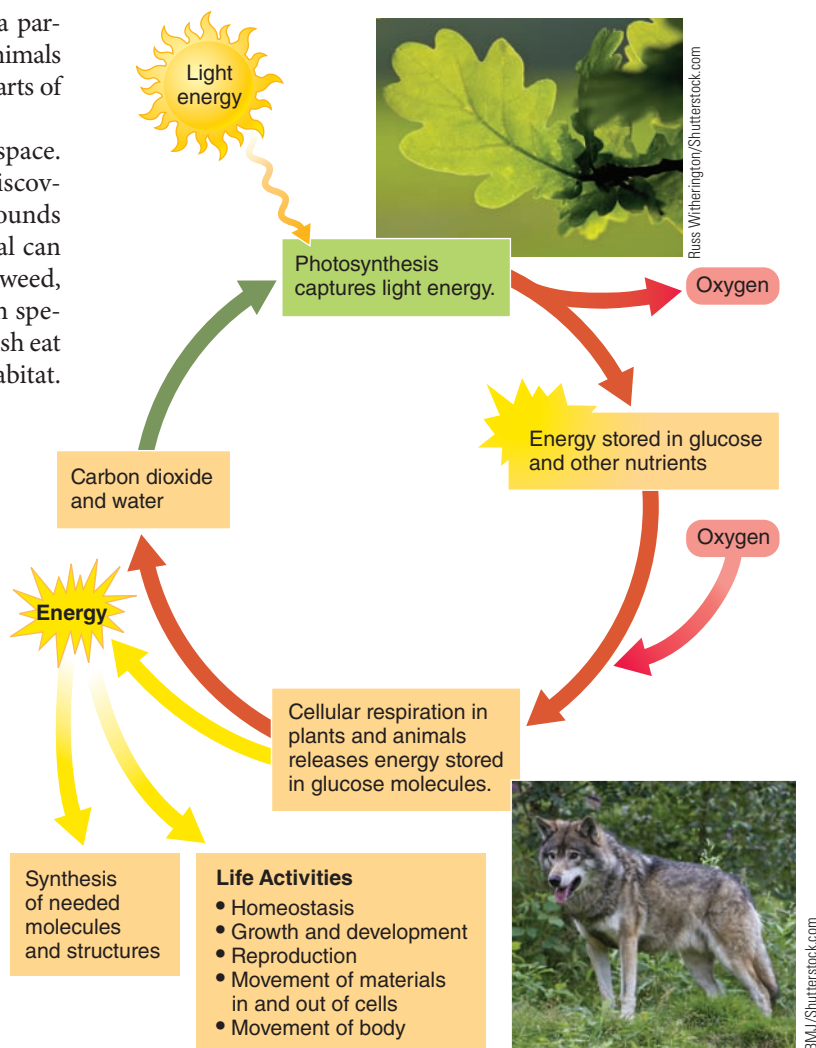
- 5 Summarize the flow of energy through ecosystems and contrast the roles of producers, consumers, and decomposers.

The sun provides most of the energy that powers life on Earth. All life processes, including thousands of chemical transactions that maintain life's organization, require a continuous input of energy. Organisms can neither create energy nor use it with complete efficiency. During every energy transaction, some energy is converted to heat and dispersed into the environment. Energy flows through individual organisms and through ecosystems.

A self-sufficient ecosystem consists of a physical environment inhabited by three types of organisms: producers, consumers, and decomposers. These organisms depend on one another and on the environment for nutrients, energy, oxygen, and carbon dioxide. Plants, algae, and certain bacteria and archaea are **producers**, or **autotrophs**, organisms that use simple raw materials (inorganic compounds) to produce organic compounds (which may be used for food). Most of these organisms carry on **photosynthesis**, the process during which autotrophs use carbon dioxide, water, and light energy to synthesize complex molecules such as glucose and other sugars (FIG. 1-8):



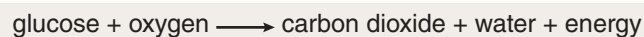
The light energy is transformed into chemical energy, which is stored within the chemical bonds of the glucose and other food molecules produced. Oxygen, which is required by the cells of most organisms including plant cells, is produced as a byproduct of photosynthesis.



**Figure 1-8** Energy flow within and among organisms

Algae and certain plant cells carry on photosynthesis, a process that uses light energy to produce glucose from carbon dioxide and water. Energy is stored in the chemical bonds of glucose and other nutrients produced from glucose. Through the process of cellular respiration, cells of all organisms, including algae and plant cells, then break down glucose and other nutrients. The energy released can be used to produce needed molecules and to fuel other life activities.

Recall that all of the energy transformations and chemical processes that occur within an organism are referred to as its *metabolism*. Energy is necessary to carry on the metabolic activities essential for growth, repair, and maintenance. Each cell of an organism requires nutrients that contain energy. During **cellular respiration**, cells capture energy stored in glucose and other nutrient molecules through a series of carefully regulated chemical reactions. We can summarize these reactions as follows:



When chemical bonds are broken during cellular respiration, their stored energy is made available for life processes. Cells use this energy to do work, including the synthesis of required materials, such as new cell components. Virtually all cells carry on cellular respiration.