Each chapter in *Human Physiology,* tenth edition, offers students numerous pedagogical features in the text and illustrations; all are consistently organized within each chapter. The consistency and variety of tools are designed to help students from all learning backgrounds conceptually understand physiology.

10 Sensory Physiology

Objectives

After studying this chapter, you should be able to …

1. explain how sensory receptors are categorized, give examples of functional categories, and explain how tonic and phasic receptors differ.
2. explain the law of specific nerve energies.
3. describe the characteristics of the generator potential.
4. give examples of different types of cutaneous receptors and describe the neural pathways for the cutaneous senses.
5. explain the concepts of receptive fields and lateral inhibition.
6. Explain how taste cells are affected by salty, sour, sweet, bitter, and umami stimuli.
7. describe the structure and function of the olfactory receptors and explain how odor discrimination might be accomplished.
8. describe the structure of the vestibular apparatus and explain how it provides information about acceleration of the body in different directions.
9. describe the functions of the outer and middle ear.
10. describe the structure of the cochlea and explain how movements of the stapes against the oval window result in vibrations of the basilar membrane.
11. explain how mechanical energy is converted into nerve impulses by the organ of Corti and how pitch perception is accomplished.
12. describe the structure of the eye and explain how images are brought to a focus on the retina.
13. explain how visual accommodation is achieved and describe the defects associated with myopia, hyperopia, and astigmatism.
14. describe the architecture of the retina and trace the pathways of light and nerve activity through the retina.
15. describe the function of rhodopsin in the rods and explain how dark adaptation is achieved.
16. explain how light affects the electrical activity of rods and their synaptic input to bipolar cells.
17. explain the trichromatic theory of color vision.
18. compar… location
19. describe the neural pathways from the retina, explaining the differences in pathways from different regions of the visual field.

Chapter at a Glance

Characteristics of Sensory Receptors 000
- Categories of Sensory Receptors 000
- Law of Specific Nerve Energies 000
- Generator (Receptor) Potential 000

Cutaneous Sensations 000
- Neural Pathways for Somatesthetic Sensations 000
- Receptive Fields and Sensory Acuity 000
- Lateral Inhibition 000

Taste and Smell 000
- Taste 000
- Smell 000

Vestibular Apparatus and Equilibrium 000
- Sensory Hair Cells of the Vestibular Apparatus 000
- Utricle and Saccule 000
- Semicircular Canals 000

The Ears and Hearing 000
- Outer Ear 000
- Middle Ear 000
- Cochlea 000
- Spiral Organ (Organ of Corti) 000

The Eyes and Vision 000
- Refraction 000
- Accommodation 000
- Visual Acuity 000

Retina 000
- Effect of Light on the Rods 000
- Electrical Activity of Retinal Cells 000
- Cones and Color Vision 000
- Visual Acuity and Sensitivity 000
- Neural Pathways from the Retina 000

Neural Processing of Visual Information 000
- Ganglion Cell Receptive Fields 000
- Lateral Geniculate Nuclei 000
- Cerebral Cortex 000

Interactions 000

• • • •

Summary 000
Review Activities 000
Related Websites 000

This chapter opener illustration is from the Tenth Edition of ***Human Physiology,*** which became the leading college physiology text.

Refresh Your Memory

Before you begin this chapter, you may want to review these concepts from previous chapters:
- Cerebral Cortex 000
- Ascending Tracts 000
- Cranial and Spinal Nerves 000

Take Advantage of the Technology

Visit the text website for these additional study resources.
- Interactive quizzing
- Online study guide
- Current news feeds
- Crossword puzzles and vocabulary flashcards
- Labeling activities

aris.mhhe.com

Objectives

Students review the objectives before reading the chapter to become familiar with the material to be covered, and check off the objectives as each major section is completed.

Chapter at a Glance

Students use the chapter outline to get an overview of the chapter, or to find specific topics.

Refresh Your Memory

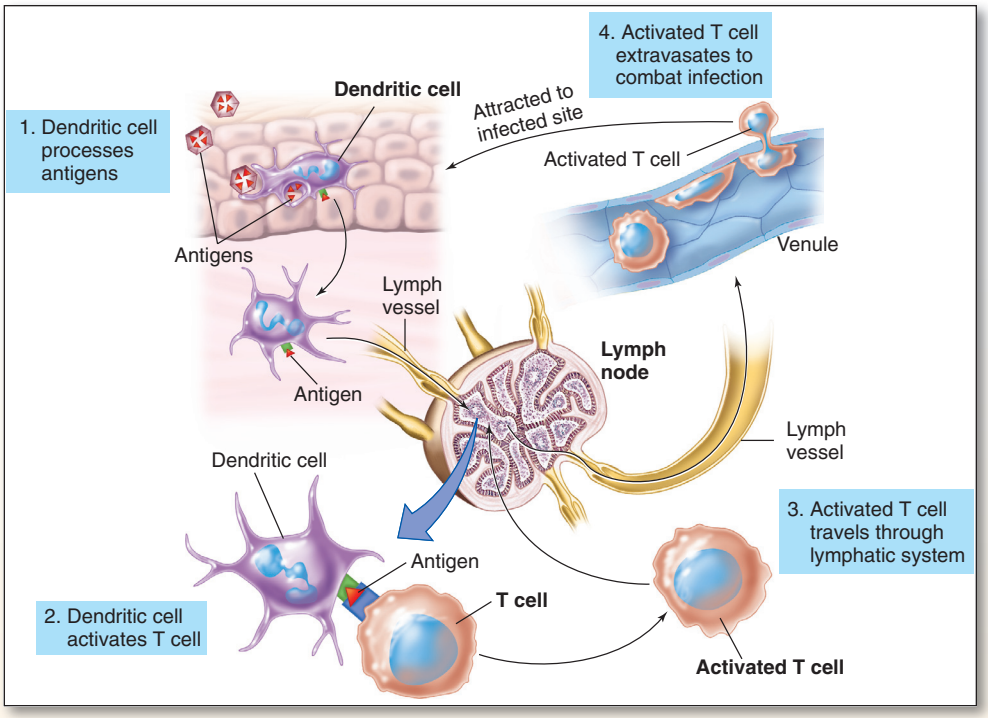
Students are encouraged to review material from previous chapters in preparation for their study of new concepts.

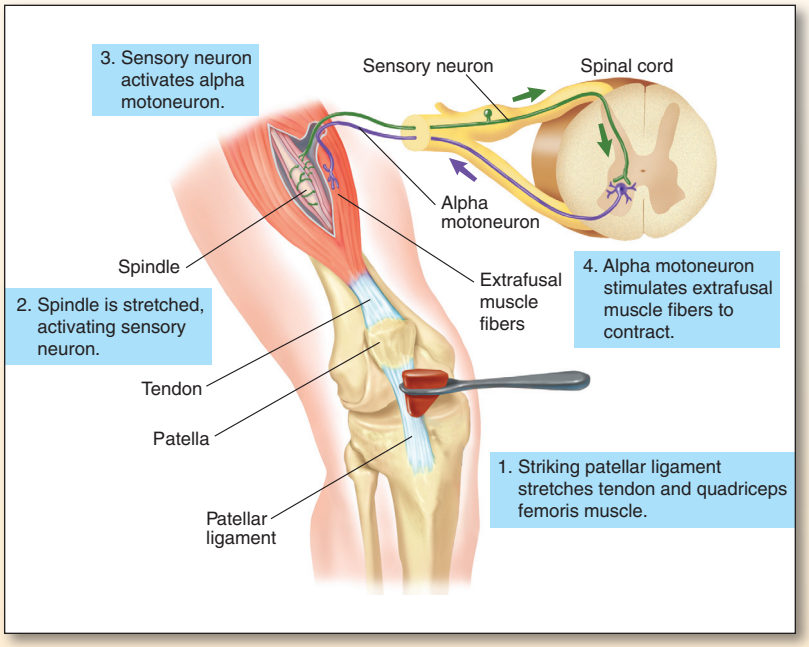
Take Advantage of the Technology

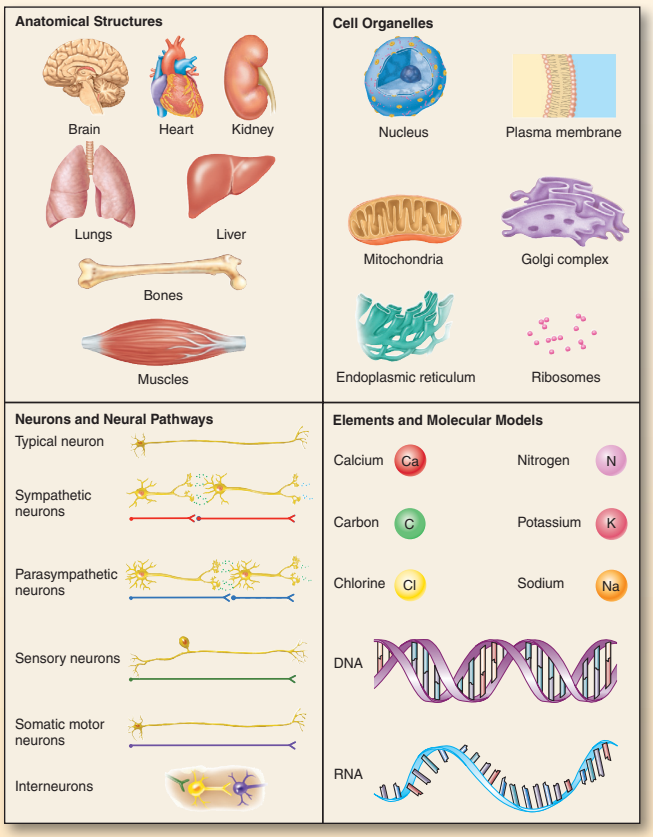
Students are invited to explore additional study resources on the *Human Physiology* website at aris.mhhe.com.

Stepped-Out Figures

Building on the extensive upgrades made to some figures in the ninth edition many figures have now been broken out into steps. Figures using this stepped-out process will aid student learning by focusing attention on one step at a time and helping students study the illustration in correct sequence.



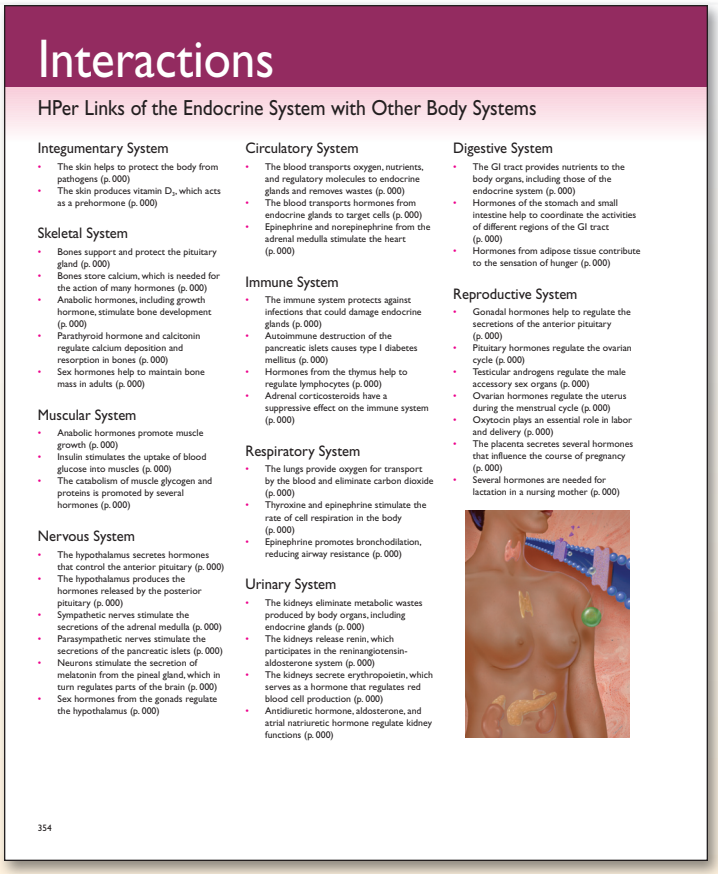




Consistent Use of Colors

Across all figures the appearance of particular structures is presented consistently. This continuity makes it easier for students to interpret each figure, thereby improving the clarity of the total presentation. This key shows a sampling of some of the structures that have been standardized.

True learning is not complete until principles can be analyzed and applied, rather than merely comprehended. The many features presented in *Human Physiology* help students fine-tune their studies by encouraging them to establish connections between body systems, summarize the main concepts of the chapter, and then answer questions of varying degrees of difficulty.



Interactions

HPer Links of the Endocrine System with Other Body Systems

Integumentary System
- The skin helps to protect the body from pathogens (p. 000)
- The skin produces vitamin D_3, which acts as a prehormone (p. 000)

Skeletal System
- Bones support and protect the pituitary gland (p. 000)
- Bones store calcium, which is needed for the action of many hormones (p. 000)
- Anabolic hormones, including growth hormone, stimulate bone development (p. 000)
- Parathyroid hormone and calcitonin regulate calcium deposition and resorption in bones (p. 000)
- Sex hormones help to maintain bone mass in adults (p. 000)

Muscular System
- Anabolic hormones promote muscle growth (p. 000)
- Insulin stimulates the uptake of blood glucose into muscles (p. 000)
- The catabolism of muscle glycogen and proteins is promoted by several hormones (p. 000)

Nervous System
- The hypothalamus secretes hormones that control the anterior pituitary (p. 000)
- The hypothalamus produces the hormones released by the posterior pituitary (p. 000)
- Sympathetic nerves stimulate the secretions of the adrenal medulla (p. 000)
- Parasympathetic nerves stimulate the secretions of the pancreatic islets (p. 000)
- Neurons stimulate the secretion of melatonin from the pineal gland, which in turn regulates parts of the brain (p. 000)
- Sex hormones from the gonads regulate the hypothalamus (p. 000)

Circulatory System
- The blood transports oxygen, nutrients, and regulatory molecules to endocrine glands and removes wastes (p. 000)
- The blood transports hormones from endocrine glands to target cells (p. 000)
- Epinephrine and norepinephrine from the adrenal medulla stimulate the heart (p. 000)

Immune System
- The immune system protects against infections that could damage endocrine glands (p. 000)
- Autoimmune destruction of the pancreatic islets causes type I diabetes mellitus (p. 000)
- Hormones from the thymus help to regulate lymphocytes (p. 000)
- Adrenal corticosteroids have a suppressive effect on the immune system (p. 000)

Respiratory System
- The lungs provide oxygen for transport by the blood and eliminate carbon dioxide (p. 000)
- Thyroxine and epinephrine stimulate the rate of cell respiration in the body (p. 000)
- Epinephrine promotes bronchodilation, reducing airway resistance (p. 000)

Urinary System
- The kidneys eliminate metabolic wastes produced by body organs, including endocrine glands (p. 000)
- The kidneys release renin, which participates in the reninangiotensin-aldosterone system (p. 000)
- The kidneys secrete erythropoietin, which serves as a hormone that regulates red blood cell production (p. 000)
- Antidiuretic hormone, aldosterone, and atrial natriuretic hormone regulate kidney functions (p. 000)

Digestive System
- The GI tract provides nutrients to the body organs, including those of the endocrine system (p. 000)
- Hormones of the stomach and small intestine help to coordinate the activities of different regions of the GI tract (p. 000)
- Hormones from adipose tissue contribute to the sensation of hunger (p. 000)

Reproductive System
- Gonadal hormones help to regulate the secretions of the anterior pituitary (p. 000)
- Pituitary hormones regulate the ovarian cycle (p. 000)
- Testicular androgens regulate the male accessory sex organs (p. 000)
- Ovarian hormones regulate the uterus during the menstrual cycle (p. 000)
- Oxytocin plays an essential role in labor and delivery (p. 000)
- The placenta secretes several hormones that influence the course of pregnancy (p. 000)
- Several hormones are needed for lactation in a nursing mother (p. 000)

354

Interactions

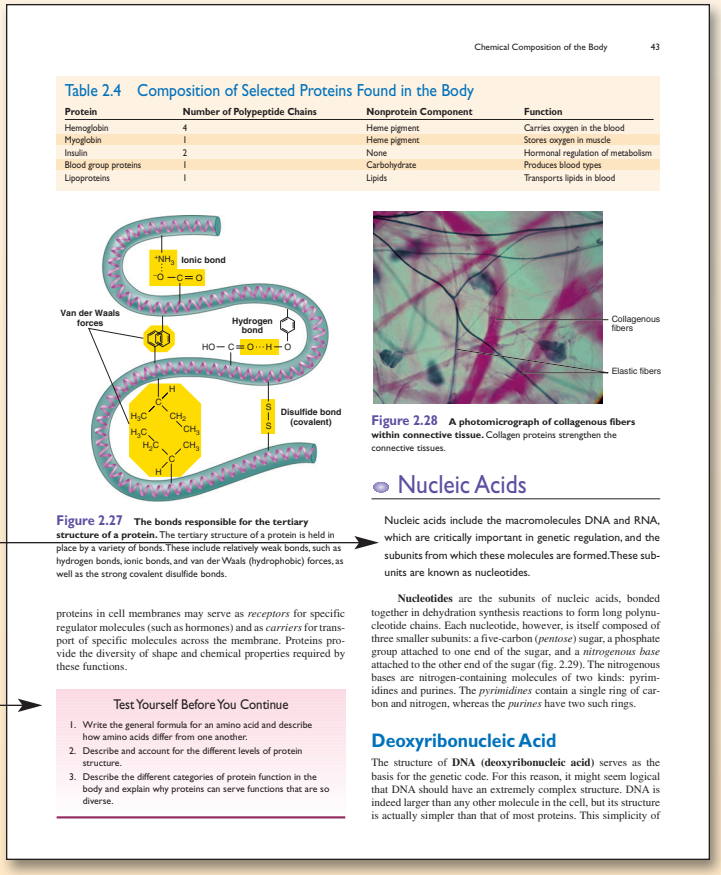
Interactions: HPer Links are resource pages that list the many ways a major concept applies to the study of different body systems, and the ways a given system interacts with other body systems. Each application or interaction includes a page reference to related material in the textbook. Students use the cross-references offered on the Interactions pages to find interrelated topics in the textbook.

Section Previews

Each major section begins with a concise statement of the section's central concepts, or organizing themes, which will be illustrated and explained in detail in the text that follows. These brief introductions give students a framework to work from as they learn new material.

Test Yourself Before You Continue

Each major chapter section ends with a set of learning activities and essay questions that relate only to the material presented in the section. Students are encouraged to answer the essay questions, draw the outlines and flowcharts requested, and otherwise actively participate in their learning of this material. Thus, these sections serve as both a "reality check" for the student and a mechanism for active learning.



Chemical Composition of the Body 43

Table 2.4 Composition of Selected Proteins Found in the Body

Protein	Number of Polypeptide Chains	Nonprotein Component	Function
Hemoglobin	4	Heme pigment	Carries oxygen in the blood
Myoglobin	1	Heme pigment	Stores oxygen in muscle
Insulin	2	None	Hormonal regulation of metabolism
Blood group proteins	1	Carbohydrate	Produces blood types
Lipoproteins	1	Lipids	Transports lipids in blood

Figure 2.27 The bonds responsible for the tertiary structure of a protein. The tertiary structure of a protein is held in place by a variety of bonds. These include relatively weak bonds, such as hydrogen bonds, ionic bonds, and van der Waals (hydrophobic) forces, as well as the strong covalent disulfide bonds.

proteins in cell membranes may serve as *receptors* for specific regulator molecules (such as hormones) and as *carriers* for transport of specific molecules across the membrane. Proteins provide the diversity of shape and chemical properties required by these functions.

Test Yourself Before You Continue

1. Write the general formula for an amino acid and describe how amino acids differ from one another.
2. Describe and account for the different levels of protein structure.
3. Describe the different categories of protein function in the body and explain why proteins can serve functions that are so diverse.

Figure 2.28 A photomicrograph of collagenous fibers within connective tissue. Collagen proteins strengthen the connective tissues.

Nucleic Acids

Nucleic acids include the macromolecules DNA and RNA, which are critically important in genetic regulation, and the subunits from which these molecules are formed. These subunits are known as nucleotides.

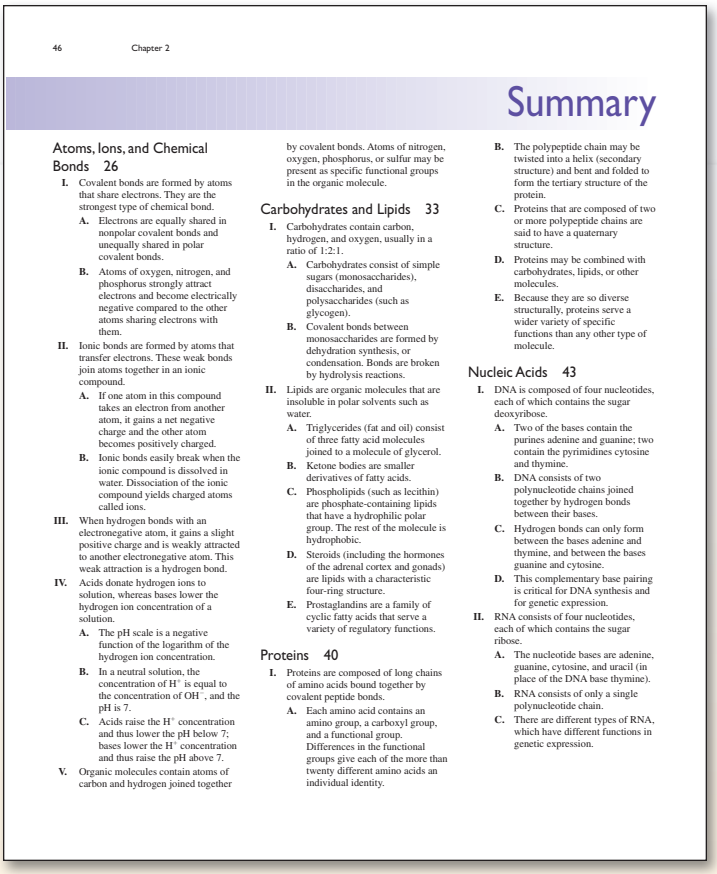
Nucleotides are the subunits of nucleic acids, bonded together in dehydration synthesis reactions to form long polynucleotide chains. Each nucleotide, however, is itself composed of three smaller subunits: a five-carbon (*pentose*) sugar, a phosphate group attached to one end of the sugar, and a *nitrogenous base* attached to the other end of the sugar (fig. 2.29). The nitrogenous bases are nitrogen-containing molecules of two kinds: pyrimidines and purines. The *pyrimidines* contain a single ring of carbon and nitrogen, whereas the *purines* have two such rings.

Deoxyribonucleic Acid

The structure of **DNA (deoxyribonucleic acid)** serves as the basis for the genetic code. For this reason, it might seem logical that DNA should have an extremely complex structure. DNA is indeed larger than any other molecule in the cell, but its structure is actually simpler than that of most proteins. This simplicity of

Summaries

At the end of each chapter, the material is summarized in outline form. This outline summary is organized by major section headings with page references, followed by the key points in the section. Students may read the summary after studying the chapter to be sure that they haven't missed any points, and can use the chapter summaries to help review for examinations.



46 Chapter 2

Summary

Atoms, Ions, and Chemical Bonds 26

I. Covalent bonds are formed by atoms that share electrons. They are the strongest type of chemical bond.
   A. Electrons are equally shared in nonpolar covalent bonds and unequally shared in polar covalent bonds.
   B. Atoms of oxygen, nitrogen, and phosphorus strongly attract electrons and become electrically negative compared to the other atoms sharing electrons with them.

II. Ionic bonds are formed by atoms that transfer electrons. These weak bonds join atoms together in an ionic compound.
   A. If one atom in this compound takes an electron from another atom, it gains a net negative charge and the other atom becomes positively charged.
   B. Ionic bonds easily break when the ionic compound is dissolved in water. Dissociation of the ionic compound yields charged atoms called ions.

III. When hydrogen bonds with an electronegative atom, it gains a slight positive charge and is weakly attracted to another electronegative atom. This weak attraction is a hydrogen bond.

IV. Acids donate hydrogen ions to solution, whereas bases lower the hydrogen ion concentration of a solution.
   A. The pH scale is a negative function of the logarithm of the hydrogen ion concentration.
   B. In a neutral solution, the concentration of H^+ is equal to the concentration of OH^-, and the pH is 7.
   C. Acids raise the H^+ concentration and thus lower the pH below 7; bases lower the H^+ concentration and thus raise the pH above 7.

V. Organic molecules contain atoms of carbon and hydrogen joined together by covalent bonds. Atoms of nitrogen, oxygen, phosphorus, or sulfur may be present as specific functional groups in the organic molecule.

Carbohydrates and Lipids 33

I. Carbohydrates contain carbon, hydrogen, and oxygen, usually in a ratio of 1:2:1.
   A. Carbohydrates consist of simple sugars (monosaccharides), disaccharides, and polysaccharides (such as glycogen).
   B. Covalent bonds between monosaccharides are formed by dehydration synthesis, or condensation. Bonds are broken by hydrolysis reactions.

II. Lipids are organic molecules that are insoluble in polar solvents such as water.
   A. Triglycerides (fat and oil) consist of three fatty acid molecules joined to a molecule of glycerol.
   B. Ketone bodies are smaller derivatives of fatty acids.
   C. Phospholipids (such as lecithin) are phosphate-containing lipids that have a hydrophilic polar group. The rest of the molecule is hydrophobic.
   D. Steroids (including the hormones of the adrenal cortex and gonads) are lipids with a characteristic four-ring structure.
   E. Prostaglandins are a family of cyclic fatty acids that serve a variety of regulatory functions.

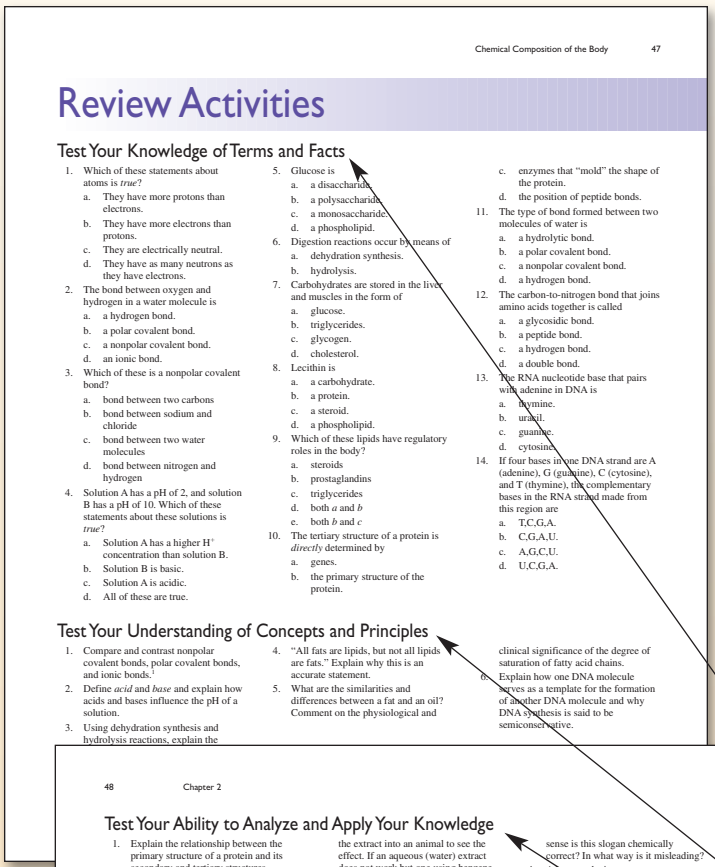
Proteins 40

I. Proteins are composed of long chains of amino acids bound together by covalent peptide bonds.
   A. Each amino acid contains an amino group, a carboxyl group, and a functional group. Differences in the functional groups give each of the more than twenty different amino acids an individual identity.
   B. The polypeptide chain may be twisted into a helix (secondary structure) and bent and folded to form the tertiary structure of the protein.
   C. Proteins that are composed of two or more polypeptide chains are said to have a quaternary structure.
   D. Proteins may be combined with carbohydrates, lipids, or other molecules.
   E. Because they are so diverse structurally, proteins serve a wider variety of specific functions than any other type of molecule.

Nucleic Acids 43

I. DNA is composed of four nucleotides, each of which contains the sugar deoxyribose.
   A. Two of the bases contain the purines adenine and guanine; two contain the pyrimidines cytosine and thymine.
   B. DNA consists of two polynucleotide chains joined together by hydrogen bonds between their bases.
   C. Hydrogen bonds can only form between the bases adenine and thymine, and between the bases guanine and cytosine.
   D. This complementary base pairing is critical for DNA synthesis and for genetic expression.

II. RNA consists of four nucleotides, each of which contains the sugar ribose.
   A. The nucleotide bases are adenine, guanine, cytosine, and uracil (in place of the DNA base thymine).
   B. RNA consists of only a single polynucleotide chain.
   C. There are different types of RNA, which have different functions in genetic expression.



Chemical Composition of the Body 47

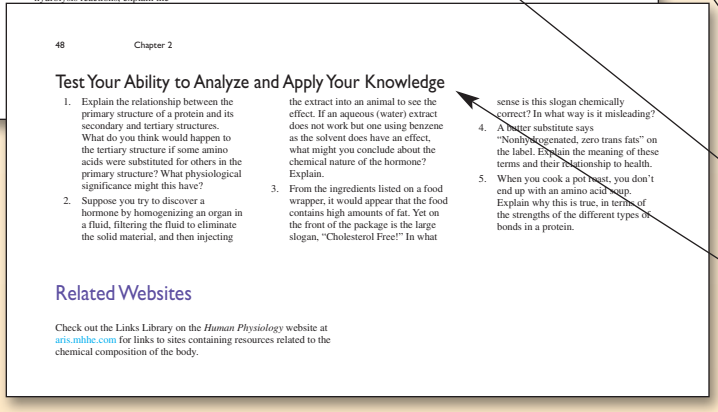
Review Activities

Test Your Knowledge of Terms and Facts

1. Which of these statements about atoms is *true*?
   a. They have more protons than electrons.
   b. They have more electrons than protons.
   c. They are electrically neutral.
   d. They have as many neutrons as they have electrons.
2. The bond between oxygen and hydrogen in a water molecule is
   a. a hydrogen bond.
   b. a polar covalent bond.
   c. a nonpolar covalent bond.
   d. an ionic bond.
3. Which of these is a nonpolar covalent bond?
   a. bond between two carbons
   b. bond between sodium and chloride
   c. bond between two water molecules
   d. bond between nitrogen and hydrogen
4. Solution A has a pH of 2, and solution B has a pH of 10. Which of these statements about these solutions is *true*?
   a. Solution A has a higher H^+ concentration than solution B.
   b. Solution B is basic.
   c. Solution A is acidic.
   d. All of these are true.
5. Glucose is
   a. a disaccharide.
   b. a polysaccharide.
   c. a monosaccharide.
   d. a phospholipid.
6. Digestion reactions occur by means of
   a. dehydration synthesis.
   b. hydrolysis.
7. Carbohydrates are stored in the liver and muscles in the form of
   a. glucose.
   b. triglycerides.
   c. glycogen.
   d. cholesterol.
8. Lecithin is
   a. a carbohydrate.
   b. a protein.
   c. a steroid.
   d. a phospholipid.
9. Which of these lipids have regulatory roles in the body?
   a. steroids
   b. prostaglandins
   c. triglycerides
   d. both *a* and *b*
   e. both *b* and *c*
10. The tertiary structure of a protein is *directly* determined by
   a. genes.
   b. the primary structure of the protein.
   c. enzymes that "mold" the shape of the protein.
   d. the position of peptide bonds.
11. The type of bond formed between two molecules of water is
   a. a hydrolytic bond.
   b. a polar covalent bond.
   c. a nonpolar covalent bond.
   d. a hydrogen bond.
12. The carbon-to-nitrogen bond that joins amino acids together is called
   a. a glycosidic bond.
   b. a peptide bond.
   c. a hydrogen bond.
   d. a double bond.
13. The RNA nucleotide base that pairs with adenine in DNA is
   a. thymine.
   b. uracil.
   c. guanine.
   d. cytosine.
14. If four bases in one DNA strand are A (adenine), G (guanine), C (cytosine), and T (thymine), the complementary bases in the RNA strand made from this region are
   a. T,C,G,A.
   b. C,G,A,U.
   c. A,G,C,U.
   d. U,C,G,A.

Test Your Understanding of Concepts and Principles

1. Compare and contrast nonpolar covalent bonds, polar covalent bonds, and ionic bonds.
2. Define *acid* and *base* and explain how acids and bases influence the pH of a solution.
3. Using dehydration synthesis and hydrolysis reactions, explain the clinical significance of the degree of saturation of fatty acid chains.
4. "All fats are lipids, but not all lipids are fats." Explain why this is an accurate statement.
5. What are the similarities and differences between a fat and an oil? Comment on the physiological and
6. Explain how one DNA molecule serves as a template for the formation of another DNA molecule and why DNA synthesis is said to be semiconservative.



48 Chapter 2

Test Your Ability to Analyze and Apply Your Knowledge

1. Explain the relationship between the primary structure of a protein and its secondary and tertiary structures. What do you think would happen to the tertiary structure if some amino acids were substituted for others in the primary structure? What physiological significance might this have?
2. Suppose you try to discover a hormone by homogenizing an organ in a fluid, filtering the fluid to eliminate the solid material, and then injecting the extract into an animal to see the effect. If an aqueous (water) extract does not work but one using benzene as the solvent does have an effect, what might you conclude about the chemical nature of the hormone? Explain.
3. From the ingredients listed on a food wrapper, it would appear that the food contains high amounts of fat. Yet on the front of the package is the large slogan, "Cholesterol Free!" In what sense is this slogan chemically correct? In what way is it misleading?
4. A better substitute says "Nonhydrogenated, zero trans fats" on the label. Explain the meaning of these terms and their relationship to health.
5. When you cook a pot roast, you don't end up with an amino acid soup. Explain why this is true, in terms of the strengths of the different types of bonds in a protein.

Related Websites

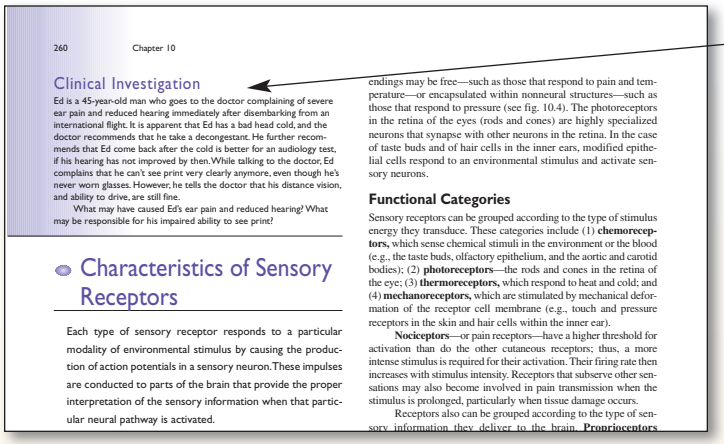
Check out the Links Library on the *Human Physiology* website at aris.mhhe.com for links to sites containing resources related to the chemical composition of the body.

Review Activities

A battery of questions collectively titled Review Activities follows each chapter summary. These self-examinations are organized into three increasingly difficult learning levels to help students progress from simple memorization to higher levels of understanding.

- Test Your Knowledge of Terms and Facts is a series of multiple-choice questions that prompt students to recall key terms and facts presented in the chapter. Answers to these questions are found in Appendix B.
- Test Your Understanding of Concepts and Principles consists of brief essay questions that require students to demonstrate their understanding of chapter material.
- Test Your Ability to Analyze and Apply Your Knowledge presents questions that stimulate critical thinking by challenging students to utilize chapter concepts to solve a problem.

True conceptual understanding often occurs in the context of real-life situations. Therefore, clinical information is presented throughout the text to provide concrete examples that demonstrate the real-life application of complex physiological concepts and further students' comprehension.


260 Chapter 10

Clinical Investigation

Ed is a 45-year-old man who goes to the doctor complaining of severe ear pain and reduced hearing immediately after disembarking from an international flight. It is apparent that Ed has a bad head cold, and the doctor recommends that he take a decongestant. He further recommends that Ed come back after the cold is better for an audiology test, if his hearing has not improved by then. While talking to the doctor, Ed complains that he can't see print very clearly anymore, even though he's never worn glasses. However, he tells the doctor that his distance vision, and ability to drive, are still fine.

What may have caused Ed's ear pain and reduced hearing? What may be responsible for his impaired ability to see print?

Characteristics of Sensory Receptors

Each type of sensory receptor responds to a particular modality of environmental stimulus by causing the production of action potentials in a sensory neuron. These impulses are conducted to parts of the brain that provide the proper interpretation of the sensory information when that particular neural pathway is activated.

endings may be free—such as those that respond to pain and temperature—or encapsulated within nonneural structures—such as those that respond to pressure (see fig. 10.4). The photoreceptors in the retina of the eyes (rods and cones) are highly specialized neurons that synapse with other neurons in the retina. In the case of taste buds and of hair cells in the inner ears, modified epithelial cells respond to an environmental stimulus and activate sensory neurons.

Functional Categories

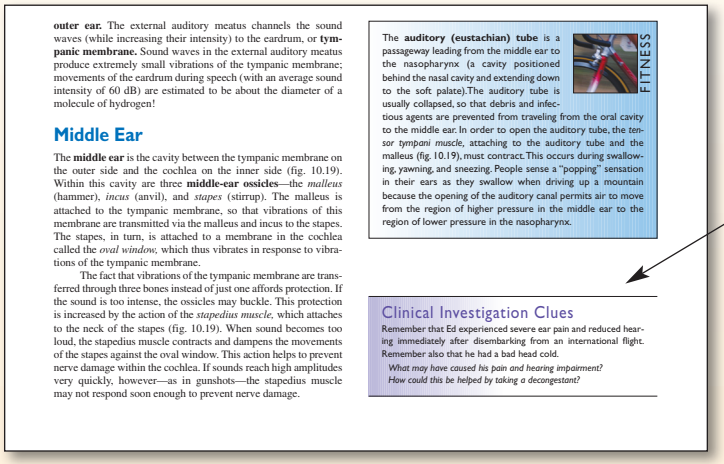
Sensory receptors can be grouped according to the type of stimulus energy they transduce. These categories include (1) **chemoreceptors,** which sense chemical stimuli in the environment or the blood (e.g., the taste buds, olfactory epithelium, and the aortic and carotid bodies); (2) **photoreceptors**—the rods and cones in the retina of the eye; (3) **thermoreceptors,** which respond to heat and cold; and (4) **mechanoreceptors,** which are stimulated by mechanical deformation of the receptor cell membrane (e.g., touch and pressure receptors in the skin and hair cells within the inner ear).

Nociceptors—or pain receptors—have a higher threshold for activation than do the other cutaneous receptors; thus, a more intense stimulus is required for their activation. Their firing rate then increases with stimulus intensity. Receptors that subserve other sensations may also become involved in pain transmission when the stimulus is prolonged, particularly when tissue damage occurs.

Receptors also can be grouped according to the type of sensory information they deliver to the brain. **Proprioceptors**

Clinical Investigation

Clinical Investigations are diagnostic case studies provided at the very beginning of each chapter. These thought-provoking cases are designed to engage students' interest and motivate them to delve into the content of each chapter. Students must read the chapter, understand the concepts, and look for clues in order to arrive at the correct diagnosis.


outer ear. The external auditory meatus channels the sound waves (while increasing their intensity) to the eardrum, or **tympanic membrane.** Sound waves in the external auditory meatus produce extremely small vibrations of the tympanic membrane; movements of the eardrum during speech (with an average sound intensity of 60 dB) are estimated to be about the diameter of a molecule of hydrogen!

Middle Ear

The **middle ear** is the cavity between the tympanic membrane on the outer side and the cochlea on the inner side (fig. 10.19). Within this cavity are three **middle-ear ossicles**—the *malleus* (hammer), *incus* (anvil), and *stapes* (stirrup). The malleus is attached to the tympanic membrane, so that vibrations of this membrane are transmitted via the malleus and incus to the stapes. The stapes, in turn, is attached to a membrane in the cochlea called the *oval window,* which thus vibrates in response to vibrations of the tympanic membrane.

The fact that vibrations of the tympanic membrane are transferred through three bones instead of just one affords protection. If the sound is too intense, the ossicles may buckle. This protection is increased by the action of the *stapedius muscle,* which attaches to the neck of the stapes (fig. 10.19). When sound becomes too loud, the stapedius muscle contracts and dampens the movements of the stapes against the oval window. This action helps to prevent nerve damage within the cochlea. If sounds reach high amplitudes very quickly, however—as in gunshots—the stapedius muscle may not respond soon enough to prevent nerve damage.

FITNESS

The **auditory (eustachian) tube** is a passageway leading from the middle ear to the nasopharynx (a cavity positioned behind the nasal cavity and extending down to the soft palate). The auditory tube is usually collapsed, so that debris and infectious agents are prevented from traveling from the oral cavity to the middle ear. In order to open the auditory tube, the *tensor tympani muscle,* attaching to the auditory tube and the malleus (fig. 10.19), must contract. This occurs during swallowing, yawning, and sneezing. People sense a "popping" sensation in their ears as they swallow when driving up a mountain because the opening of the auditory canal permits air to move from the region of higher pressure in the middle ear to the region of lower pressure in the nasopharynx.

Clinical Investigation Clues

Remember that Ed experienced severe ear pain and reduced hearing immediately after disembarking from an international flight. Remember also that he had a bad head cold.

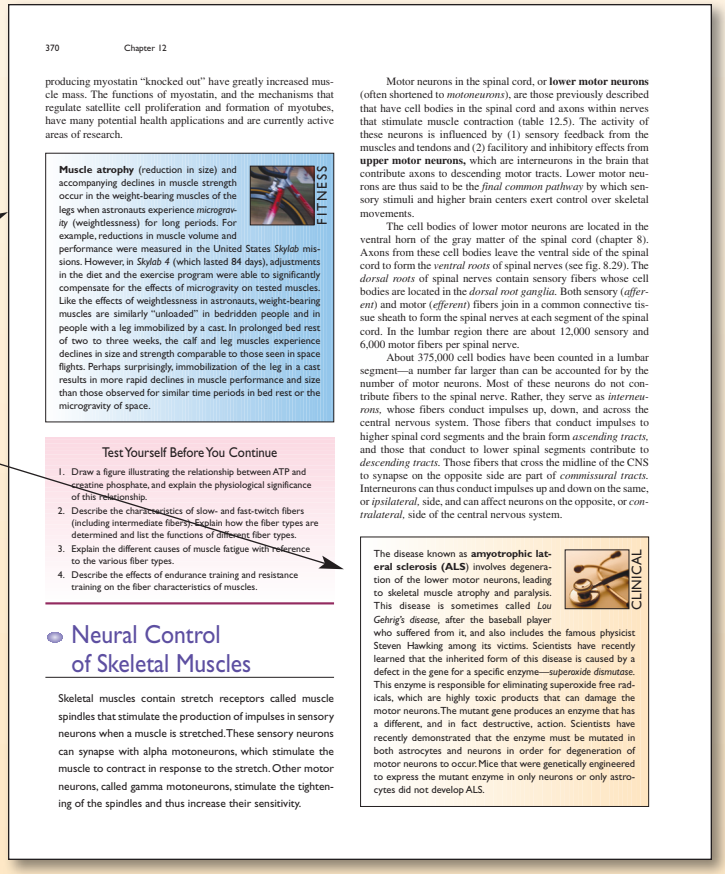
What may have caused his pain and hearing impairment?
How could this be helped by taking a decongestant?

Clinical Investigation Clues

Scattered within each chapter, these short boxes remind students of the ongoing clinical investigation case study and provide clues to the solution. Clues are carefully placed so they always relate to the information presented in the preceding text. These clues help reinforce comprehension of the text material and spur students to continue reading so they can gather all of the pertinent information needed to solve the case study. After attempting to diagnose the case, students can find the solution to each Clinical Investigation in Appendix A.

Boxed Clinical and Fitness Applications

Applications—in clinical medicine, general health, and physical fitness—of basic physiological principles are found intermittently throughout the body of the text. Placement of these applications is precise—they always relate to concepts that have been presented immediately preceding the application. As such, they provide immediate reinforcement for students learning the fundamental principles on which the applications are based. This is preferable to longer but fewer applications in the style of magazine articles that are separated from the text information. The immediate reinforcement allows students to see the practical importance of learning the material they have just studied.


370 Chapter 12

producing myostatin "knocked out" have greatly increased muscle mass. The functions of myostatin, and the mechanisms that regulate satellite cell proliferation and formation of myotubes, have many potential health applications and are currently active areas of research.

FITNESS

Muscle atrophy (reduction in size) and accompanying declines in muscle strength occur in the weight-bearing muscles of the legs when astronauts experience *microgravity* (weightlessness) for long periods. For example, reductions in muscle volume and performance were measured in the United States *Skylab* missions. However, in *Skylab 4* (which lasted 84 days), adjustments in the diet and the exercise program were able to significantly compensate for the effects of microgravity on tested muscles. Like the effects of weightlessness in astronauts, weight-bearing muscles are similarly "unloaded" in bedridden people and in people with a leg immobilized by a cast. In prolonged bed rest of two to three weeks, the calf and leg muscles experience declines in size and strength comparable to those seen in space flights. Perhaps surprisingly, immobilization of the leg in a cast results in more rapid declines in muscle performance and size than those observed for similar time periods in bed rest or the microgravity of space.

Test Yourself Before You Continue

1. Draw a figure illustrating the relationship between ATP and creatine phosphate, and explain the physiological significance of this relationship.
2. Describe the characteristics of slow- and fast-twitch fibers (including intermediate fibers). Explain how the fiber types are determined and list the functions of different fiber types.
3. Explain the different causes of muscle fatigue with reference to the various fiber types.
4. Describe the effects of endurance training and resistance training on the fiber characteristics of muscles.

Neural Control of Skeletal Muscles

Skeletal muscles contain stretch receptors called muscle spindles that stimulate the production of impulses in sensory neurons when a muscle is stretched. These sensory neurons can synapse with alpha motoneurons, which stimulate the muscle to contract in response to the stretch. Other motor neurons, called gamma motoneurons, stimulate the tightening of the spindles and thus increase their sensitivity.

Motor neurons in the spinal cord, or **lower motor neurons** (often shortened to *motoneurons*), are those previously described that have cell bodies in the spinal cord and axons within nerves that stimulate muscle contraction (table 12.5). The activity of these neurons is influenced by (1) sensory feedback from the muscles and tendons and (2) facilitory and inhibitory effects from **upper motor neurons,** which are interneurons in the brain that contribute axons to descending motor tracts. Lower motor neurons are thus said to be the *final common pathway* by which sensory stimuli and higher brain centers exert control over skeletal movements.

The cell bodies of lower motor neurons are located in the ventral horn of the gray matter of the spinal cord (chapter 8). Axons from these cell bodies leave the ventral side of the spinal cord to form the *ventral roots* of spinal nerves (see fig. 8.29). The *dorsal roots* of spinal nerves contain sensory fibers whose cell bodies are located in the *dorsal root ganglia.* Both sensory (*afferent*) and motor (*efferent*) fibers join in a common connective tissue sheath to form the spinal nerves at each segment of the spinal cord. In the lumbar region there are about 12,000 sensory and 6,000 motor fibers per spinal nerve.

About 375,000 cell bodies have been counted in a lumbar segment—a number far larger than can be accounted for by the number of motor neurons. Most of these neurons do not contribute fibers to the spinal nerve. Rather, they serve as *interneurons,* whose fibers conduct impulses up, down, and across the central nervous system. Those fibers that conduct impulses to higher spinal cord segments and the brain form *ascending tracts,* and those that conduct to lower spinal segments contribute to *descending tracts.* Those fibers that cross the midline of the CNS to synapse on the opposite side are part of *commissural tracts.* Interneurons can thus conduct impulses up and down on the same, or *ipsilateral,* side, and can affect neurons on the opposite, or *contralateral,* side of the central nervous system.

CLINICAL

The disease known as **amyotrophic lateral sclerosis (ALS)** involves degeneration of the lower motor neurons, leading to skeletal muscle atrophy and paralysis. This disease is sometimes called *Lou Gehrig's disease,* after the baseball player who suffered from it, and also includes the famous physicist Steven Hawking among its victims. Scientists have recently learned that the inherited form of this disease is caused by a defect in the gene for a specific enzyme—*superoxide dismutase.* This enzyme is responsible for eliminating superoxide free radicals, which are highly toxic products that can damage the motor neurons. The mutant gene produces an enzyme that has a different, and in fact destructive, action. Scientists have recently demonstrated that the enzyme must be mutated in both astrocytes and neurons in order for degeneration of motor neurons to occur. Mice that were genetically engineered to express the mutant enzyme in only neurons or only astrocytes did not develop ALS.