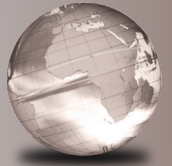


GLOBAL  
EDITION



# Essentials of Human Anatomy & Physiology

THIRTEENTH EDITION

**ELAINE N. MARIEB**

**SUZANNE M. KELLER**



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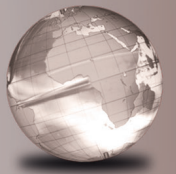
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# Essentials of Human Anatomy & Physiology

THIRTEENTH EDITION

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## About the Authors



**Elaine Marieb** After receiving her Ph.D. in zoology from the University of Massachusetts at Amherst, Elaine N. Marieb joined the faculty of the Biological Science Division of Holyoke Community College. While teaching at Holyoke Community College, where many of her students were pursuing nursing degrees, she wanted to better understand the relationship between the scientific study of the human body and the clinical aspects of the nursing practice. To that end, while continuing to teach full time, Dr. Marieb pursued her nursing education, which culminated in a Master of Science degree with a clinical specialization in gerontology from the University of Massachusetts. It is this experience that has informed the development of the unique perspective and accessibility for which her textbooks and lab manuals are so well known.

Dr. Marieb passed away in 2018 after a lifetime of supporting numerous institutions and programs. Perhaps her favorite cause was helping students, especially nontraditional students, pursue their goals in science. She gave generously to provide opportunities for them to further their education by—to name just one example—funding the E. N. Marieb Science Research Awards at Mount Holyoke College. She also believed strongly in research: she underwrote the renovation of the biology labs in Clapp Laboratory at Mount Holyoke College and provided funding for reconstruction and instrumentation of a cutting-edge cytology research laboratory at the University of Massachusetts at Amherst.

In January 2012 and 2017, Dr. Marieb provided philanthropic support to Florida Gulf Coast University as a long-term investment in education, research, and training for health care and human service



professionals in the local community. In honor of her contributions, the university is now home to the Elaine Nicpon Marieb College of Health and Human Services. Her legacy of contributing to science education lives on through the Elaine Nicpon Marieb Foundation, which provides generous support to multiple causes and organizations.

**Suzanne Keller** Suzanne M. Keller began her teaching career while she was still in graduate school. Inspired by her lifelong passion for learning, Dr. Keller quickly adopted a teaching style focused on translating challenging concepts into easy-to-understand parts using analogies and stories from her own experiences. An Iowa native, Dr. Keller uses her expertise to teach microbiology and anatomy and physiology at Indian Hills Community College, where most of her students are studying nursing or other health science programs. Dr. Keller values education as a way for students to express both themselves and their values through the careers they pursue. She supports those endeavors both in and out of the classroom by financially supporting scholarships and service-learning trips for students. Dr. Keller also enjoys sponsoring children in need with gifts for the holidays. Dr. Keller is a member of the Human Anatomy and Physiology Society (HAPS) and the Iowa Academy of Science. Additionally, Dr. Keller has served on multiple advisory boards for various projects at Pearson and has authored assignments for Mastering A&P. When not teaching or writing, Dr. Keller practices energy healing and is an Usui Reiki Master Teacher. She enjoys reading, indoor rowing, gardening, travel, family gatherings, and relaxing at home under the watchful eyes of her two canine children.

# New to the Thirteenth Edition

This edition has been thoroughly updated with numbering of the main chapter sections and subsections for easier navigation, new end-of-chapter Summary outlines, and new art in some end-of-chapter questions. A Closer Look and Focus on Career features have been updated and now include The Essentials, a summary of the key points covered in the feature. Another new feature, Study Tips, and a survey of suggested resources available to students have been included in the front of the book. Other specific chapter-by-chapter changes include the following:

## Chapter 1: The Human Body: An Orientation

- Introduced alveoli in the description of the respiratory system.
- Updated design of Table 1.1 for better readability.
- Updated Figure 1.6 to clarify that there is no solid division between the abdominal and pelvic cavities.
- Updated the caption to Figure 1.9 to clarify that the example in the art shows negative feedback.

## Chapter 2: Basic Chemistry

- Updated Table 2.5 to include vitamin D is needed for calcium absorption and vitamin K is required to make clotting proteins.
- Updated chapter opener “What, How, Why” figure to expand on how chemistry is important.
- Updated Figure 2.7 legend to explain that each covalent bond formed contains two electrons, one from each participating atom.
- Updated the explanation of hydrolysis in Figure 2.13.
- Updated Figure 2.20 to explain that an enzyme is free to bind more substrate after releasing a product from a previous reaction.
- Added a new end-of-chapter question about lipids, with art.

## Chapter 3: Cells and Tissues

- Updated the chapter opener text to include tissues and added a muscle cell to the art.
- Reordered the section covering the three major cell regions to discuss the plasma membrane first, then the nucleus.
- Added an analogy comparing gap junctions to the doors of adjoining hotel rooms.
- Updated explanation of smooth ER to include production of phospholipids.
- Updated the section on genes with current information: a single gene contains 300 to 2 million base pairs in sequence, and the human genome contains 20,000 to 25,000 genes.
- Updated the section on protein synthesis to clarify the distinction between transcription and translation. Using the analogy of the job of a court reporter, the text emphasizes that transcription products are in the same language (of nucleic acids) as DNA. This will provide a sharper contrast to translation and helps students keep them straight.
- Revised the description of simple columnar epithelium to note that the nuclei appear to form a straight line.
- Added a comment that the ability of transitional epithelium to stretch allows more urine to be stored without increasing pressure in the bladder.
- Updated the section on connective tissue to include and distinguish dense regular and dense irregular tissues based on the tissues’ ability to withstand tension in one or many directions. In the opening to this section, the functions of connective tissues have been revised to include cushioning and insulating.
- Added irritability to the characteristics of muscle tissues.
- Discussion of neoplasms, hyperplasia, and atrophy are now included in section 3.8 Tissue Repair (Wound Healing).
- Added a new Did You Get It? question about neoplasms.
- Updated Figure 3.6 to show that lysosomes fuse with ingested substances to digest them.
- Updated Figure 3.7 with new photos.
- Updated Table 3.1 to explain that intermediate filaments help form desmosomes and that chromatin structure serves to keep DNA organized and prevent breakage.
- Updated Figure 3.16 legend to explain that step 3 ensures the correct amino acid is added to the growing protein.

- Updated Figure 3.17 to clarify that transitional epithelium is modified stratified squamous epithelium.
- Updated Figures 3.18–3.21 line art to more three-dimensional art.
- Updated Figure 3.22 to include additional descriptions of tissue functions: epithelial tissue covers and lines structures; and connective tissue cushions and insulates.
- Art for A Closer Look: Cancer—An Intimate Enemy was updated to make the polyp and tumor more visible.

## Chapter 4: Skin and Body Membranes

- Updated Table 4.1 to clarify that fat cushions deeper structures, skin plays a role in body temperature regulation, skin helps protect from yeast, and melanocytes protect DNA.
- Clarified that serous membranes line compartments in the ventral body cavity.
- Updated the section on epidermis to clarify that each of the five strata has multiple cell layers.
- In the section on homeostatic imbalances of skin (section 4.2e), updated Concept Link about the relationship of mitosis to cancer to clarify that errors can occur during DNA replication or mitosis or both and that cancer cells can metastasize.
- Updated Figure 4.1b with a new close-up breakout image of a mucous membrane.
- Updated Figure 4.2 with a label of the synovial membrane.
- Updated Figure 4.4 to include a stratum lucidum layer.
- Updated Figure 4.5 with a new photomicrograph of the epidermis and dermis.
- Updated Figure 4.7 so that the hair in part (a) is at an angle leaving the skin and that the hair matrix in part (d) is more visible.
- Revised end-of-chapter question 9 and added art.

## Chapter 5: The Skeletal System

- Updated chapter opener art to include ligaments in the description of “What.”
- In section 5.1a, the bones’ role in providing support to the body is likened to a steel frame, replacing the former analogy to steel girders and reinforced concrete. The example of bone protection was updated to juggling a soccer ball with the head, not heading a soccer ball, which can be associated with concussion.
- Updated Figure 5.1 with a new photo.
- Reorganized Figure 5.6 by showing “before” and “after” images of bone that has undergone growth and remodeling.
- Updated Figures 5.9, 5.10, 5.12, 5.19, 5.22, 5.23, 5.24, 5.25, 5.26, and 5.32 so that all bone labels appear in boldfaced text and other structures in regular text.
- Updated Figure 5.11 label indicating the zygomatic process.
- Updated Figure 5.18 to clarify there are two sets of rib facets.
- Updated Figure 5.20 to correct the color of the xiphoid process (a bone).
- Updated Figure 5.24 by adding a dotted line at the pelvic brim of each pelvis in part (c).
- Updated Figure 5.27 art to change the angle of view, helping students see a more three-dimensional view of arch placement.
- Updated Figure 5.28 art to include a gomphosis joint and a new image of a biaxial joint (a condyloid joint).
- Updated Figure 5.30 to clarify movements represented by arrows.
- Updated Figure 5.34 with new photos.
- Updated Table 5.1 with shading to make it easier to read.
- Updated Table 5.2 by replacing line art with more realistic three-dimensional art.

## Chapter 6: The Muscular System

- Updated Figures 6.1 and 6.2 with more realistic three-dimensional art.
- Updated Figure 6.3 to include both endomysium and the sarcolemma (part a), and titin (part c).
- Updated Figure 6.4 with more realistic three-dimensional art.
- Updated Figure 6.5 to adjust placement of the inset box and updated the descriptions of steps 2 and 6.
- Updated Figure 6.7 to include more realistic art and to incorporate cross bridge formation.
- Reorganized explanations of the sarcomere as it relates to cross bridge formation.
- Reorganized and updated the explanation of excitation-contraction coupling.
- Updated Figure 6.9 with a label denoting partial relaxation and adjusted the graph showing unfused tetanus to show stimuli for each wave.
- Added a diagram to Figure 6.13e showing angles of dorsiflexion and plantar flexion.
- Updated the footnote in Figure 6.14 to clarify that the generalities explained in parts (a) and (b) are reversed for the knee and ankle.
- Updated Table 6.1 with new art for cell shape and appearance and connective tissue components.
- Added the rectus femoris as an example of a bipennate muscle in section 6.4d, Arrangement of Fascicles.
- In the Facial Muscles section, changed subheading to “Frontalis and Occipitalis.”
- Added an analogy of a wide belt to describe role of the transversus abdominis.
- Added text to the section on the brachioradialis to describe how it aids elbow flexion.
- Clarified Homeostatic Imbalance 6.5 on myasthenia gravis with regard to the presence of acetylcholine receptors and the immune response that decreases their numbers.

## Chapter 7: The Nervous System

- In section 7.1b, Functional Classification, added a memory aid to help students remember that *efferent* fibers *exit* the CNS.
- In section 7.2b, Neurons, corrected estimated length of nerve fibers from 7 feet to over 3 feet.
- In section 7.2c, Physiology: Nerve Impulses, clarified the role of  $K^+$  ions in maintaining resting membrane potential.
- In the same section, clarified that both electrical and ionic conditions must be restored before a neuron can conduct a new nerve impulse.
- In the section discussing transmission of the signal at synapses, added a Concept Link comparing events at a synapse to those at the neuromuscular junction (Figure 6.5 referenced).
- Added a comment that different “messages” are sent at synapses, depending on which neurons are “talking” and what they are “saying,” which is influenced by which neurotransmitter is released.
- Added a more detailed explanation of how Broca’s area (motor speech) helps a person to form words.
- Added an explanation that the severity of stroke (CVA) symptoms depends on the location and amount of damage.
- Updated the section on cranial nerves, including which are purely motor, purely sensory, or mixed, and included this information in Figure 7.23.
- Updated Table 7.1 art.
- Updated Table 7.2 and 7.3 for clarity and accuracy.
- Updated Figure 7.7 with more realistic three-dimensional art.
- Updated Figure 7.9 with clarification, additional detail, and an analogy for propagation of an action potential, likening it to dominoes falling or a crowd doing the “wave.”
- Updated Figure 7.10 to add calcium channels to axon terminal.
- Updated Figure 7.11 with more realistic muscle spindle art.
- Updated Figure 7.20 to arrange labels in groupings for white matter or gray matter.
- Updated Figure 7.24 to rotate and enlarge part (b).
- Updated Figure 7.26 to more realistic three-dimensional art and an easier-to-read layout.
- Updated Figure 7.27 for readability by removing dotted lines in favor of solid lines.
- Updated Table 7.4 to be listed alphabetically by target organ.
- Update Homeostatic Imbalance 7.11 with a new photo.

## Chapter 8: Special Senses

- Added new analogy likening the role of eye humors in supporting the eye to water keeping a water balloon inflated.
- Expanded the explanation on accommodation to clarify that the ciliary body contracts toward the lens in order to slacken the ciliary zonule, allowing the lens to bulge.
- Added example to illustrate which fibers cross over at the optic chiasma: the right optic tract contains lateral fibers from the right eye and medial fibers from the left eye.
- Added new art showing astigmatism in A Closer Look: Bringing Things into Focus.
- Reorganized Part II to place the Hearing section before Equilibrium.
- Clarified the analogy of a diver’s fin relating to endolymph movement in the semicircular canals; when the diver kicks forward, the fin bends backward.
- Specified that the facial nerve serves the anterior two-thirds of the tongue.
- Added alcohols to the sweet category of taste; added aspartate to the umami category of taste.
- Updated Figure 8.2a with more realistic art that is enlarged to show the area of the accessory structures more clearly.
- Updated Figure 8.3a with a new leader for the “Optic nerve” label.
- Updated labels to the art in A Closer Look: Visual Pigments.
- Updated the shape of the lens in Figure 8.8b.
- Updated Figures 8.9 and 8.11 with more realistic three-dimensional art.
- Added an inset image of the cochlea in Figure 8.12a for reference.
- Updated the caption to Figure 8.12 to include information about hairs being embedded in the tectorial membrane.
- Updated the caption to Figure 8.14 to clarify the location and length of hair cells and to include more thorough descriptions of the length and stiffness of fibers along the basilar membrane.
- Updated Figures 8.15 and 8.16 with more realistic three-dimensional art.
- Updated label in Figure 8.17 to clarify that the olfactory receptor cell is a sensory neuron.
- Updated Figure 8.18c with a close-up image of one taste bud.
- Added a new end-of-chapter multiple-choice question, with art, on parts of the eye.

## Chapter 9: The Endocrine System

- Added two new end-of-chapter questions with art.
- In the section on direct gene activation, clarified that hormone actions are not always stimulatory; some hormones turn genes off.
- Clarified that *exocrine* glands have an *exit*.
- Updated organ positions shown in the chapter opener art.
- Updated Figure 9.2 to clarify that the vessel leaving the adrenal gland is a venule.
- Updated Figure 9.5 to clarify that releasing hormones come from the hypothalamus.
- Updated Figure 9.9 with new art to clarify aldosterone control.
- Updated Figure 9.10 with examples of short- and long-term stress.
- Updated image of pineal gland in Table 9.1 for better visibility.

## Chapter 10: Blood

- Added new end-of-chapter question, with art.
- Clarified that carbon dioxide carried by hemoglobin is carried at a different binding site from oxygen.
- Clarified that red blood cells in people with sickle cell anemia sickle under any low-oxygen conditions (not just increased use of oxygen).
- Added fungi to the list of organisms leukocytes protect the body against.
- Clarified that granulocytes and agranulocytes are named for the presence or absence of granules after the cells are stained with Wright’s stain.
- Added a memory device to help students distinguish lymphocytes from leukocytes: all lymphocytes are leukocytes, but not all leukocytes are lymphocytes.
- Clarified that some red blood cell components are reused or recycled to their building blocks.
- In the discussion of erythropoietin release, added that the kidneys are a convenient place to monitor blood.

- Added that thrombopoietin is produced by the liver.
- In the discussion of hemophilia and the potential for transmission of viral diseases via blood transfusion, changed the mention of AIDS to HIV.
- Updated Table 10.3, ABO Blood Groups, with new blood type frequency numbers from the Red Cross; removed Native American column and added Latino column.
- Updated the description of fetal hemoglobin to include that it has a higher affinity for oxygen.
- Updated Figure 10.2 with a new photo.
- Updated Homeostatic Imbalance 10.1 with a new photo of a sickled cell.
- Updated the lymphocyte image in Figure 10.3.
- Updated steps 2 and 3 in Figure 10.5 to emphasize that more platelets are drawn to the injured area and that a complex cascade results in fibrin production.
- Updated Figure 10.6 with a new photo.
- Updated the photo in Focus On Careers: Phlebotomy Technician.
- Rearranged blood types in Figure 10.7.

### Chapter 11: The Cardiovascular System

- Rewrote the section Regulation of Stroke Volume to include discussion of preload, contractility, and afterload.
- Rewrote section describing capillary beds to incorporate our current understanding of their structure.
- Added new end-of-chapter question, with art.
- Emphasized that heart valves maintain one-way blood flow.
- Clarified that rapid heart rate after blood loss circulates remaining blood more quickly.
- Defined *osmotic pressure* as the ability of a solution to pull water toward itself.
- In Figure 11.3, updated the label identifying the epicardium for consistency with respect to the heart wall.
- Updated Figure 11.6 with more realistic three-dimensional art.
- Updated Figure 11.8 with more realistic three-dimensional art and added new components to help students learn the events of each part of the cardiac cycle and whether valves are open or closed.
- Updated ECG figure in A Closer Look: Electrocardiography with more realistic three-dimensional art.
- Updated Figure 11.12 to reflect the current understanding of capillary bed structures.
- Updated A Closer Look: Atherosclerosis with a new photo.

### Chapter 12: The Lymphatic System and Body Defenses

- Clarified that lymph nodes are often the site of lymphocyte activation.
- Noted that only some of the microbes on the body/skin have the potential to cause disease.
- Explained that the role of perforin is to poke holes in membranes.
- Added *opsonization* as a vocabulary term.
- Clarified that attenuated organisms are less able or unable to cause disease.
- Described cytotoxic T cell response as direct “cell-to-cell combat.”
- Added an explanation that the two-step process for T cell activation prevents an immune response when one is not needed.
- Added new A Closer Look box on COVID-19.
- Updated Figure 12.4 with more realistic three-dimensional art.
- Updated Figure 12.5 to add red bone marrow.
- Updated Figure 12.7 art.
- Updated Figure 12.8 with more realistic three-dimensional art that also more clearly demonstrates diapedesis.
- Updated Figure 12.9 art.
- Updated Figure 12.13 labels with regard to antigen exposure and reexposure.
- Updated Figure 12.15 to remove computer-generated image.
- Updated Table 12.2 antibody art.
- Updated Figure 12.16 to include opsonization and enhance readability.
- Updated Figure 12.17 to provide more contrasting colors for the antigen and T cell receptors in order to improve readability.
- Updated Homeostatic Imbalance 12.4 art showing an outpouring of fluid from capillaries.

### Chapter 13: The Respiratory System

- Added new end-of-chapter question, with art.
- Added discussion of tubal tonsils to the pharynx section.
- Updated Figure 13.2 to include a tubal tonsil.
- Created a new version of Figure 13.10 on gas exchange in the body.
- Rewrote section 13.2a, Mechanics of Breathing, addressing the relationship of volume to pressure.
- Added clarification to the description of negative pressure in the intrapleural space.
- Added new Concept Link relating pressure changes in breathing to the pressure differences needed to drive filtration or blood flow.
- Updated statistics related to COPD, allergy/asthma, lung cancer, and SIDS throughout the chapter.
- Updated art in Homeostatic Imbalance 13.13 about COPD.
- Updated caption to Figure 13.11 regarding the conversion of CO<sub>2</sub> to bicarbonate occurring in red blood cells before bicarbonate ion diffuses into the plasma for transport.
- Made *eupnea* a vocabulary term.

### Chapter 14: The Digestive System and Body Metabolism

- Added an updated, more detailed explanation of mesentery.
- Updated Homeostatic Imbalance 14.4 to provide a more detailed description of gallstones and how they cause pain.
- In section 14.2a, Overview of Gastrointestinal Processes and Controls, added description of nucleic acid digestion.
- Added a new section: 14.2f, The Microbiota.
- Added a new Homeostatic Imbalance 14.11 on *Clostridioides difficile*.
- Updated discussion of carbohydrate metabolism (section 14.4a) with new descriptions of electron transport chain, comparing the flow of electrons down the ETC to a hydroelectric dam being powered by moving water; also included more detail about how this leads to ATP production.
- Updated Figure 14.4 to show labels of stomach structures in boldface text and to add a label for the mucosa in part (c).
- Updated Figure 14.5 art with highlighting of certain labels and with more visible structures; also added part (c) showing mesentery.
- Updated Figure 14.8 labels so that only segments of the large intestine are in boldface text.
- Updated Figure 14.10 to reflect periodontal ligament instead of periodontal membrane.
- Updated Figure 14.11 art to more clearly represent segmentation and peristalsis.
- Updated Figure 14.12 art.
- Updated Figure 14.13 style; lingual and gastric lipases were also added and noted to be of minor importance.
- Updated Figure 14.14 line art to more three-dimensional art.
- Updated Figure 14.16 art and descriptions of hormonal controls of pancreatic juice and bile secretion.
- Updated Figure 14.17 with a new MyPlate graphic and removed the Healthy Eating Pyramid.
- Updated Figure 14.18 legend to clarify that arginine and histidine are essential amino acids in infants but not adults.
- Updated the analogy for carbohydrate metabolism, likening it to a campfire burning wood.
- Added a new photo in A Closer Look: Peptic Ulcers.
- Updated Figure 14.21 with completely new art to represent and explain the events occurring at the electron transport chain.

### Chapter 15: The Urinary System

- Added two new end-of-chapter questions, with art.
- Updated chapter opener art regarding kidney position.
- Updated Figures 15.1 and 15.3 so that only urinary organs or structures are labeled with boldface text.
- Updated Figure 15.7 with completely new art representing an empty or distended bladder.
- Updated Figure 15.11.
- Updated Concept Link on pH to remind students only free hydrogen ions influence pH.
- Updated the captions to Figure 15.11 and Figure 15.12 to more clearly link blood pressure homeostasis to the thirst mechanism for regulating water intake (to show that the intersection of the two concepts are the hypothalamic osmoreceptors).

- Added a new photo to A Closer Look: Renal Failure.
- Added a new photo to Focus On Careers: Licensed Practical Nurse.
- Updated and expanded the explanation of the roles of angiotensin II.
- Corrected an error in which NaOH was mistakenly listed as a strong acid instead of a strong base.

### Chapter 16: The Reproductive System

- Updated Homeostatic Imbalance 16.1 on prostatic hypertrophy.
- Updated section 16.4a, Oogenesis and the Ovarian Cycle, to include clarification on how primary oocyte numbers decrease from 1 to 2 million at birth to 400,000 at puberty; also distinguished between primordial and primary follicles.
- Updated possible causes of *mittelschmerz*.
- Updated Homeostatic Imbalance 16.7 to indicate that fewer than 1% of breast cancers occur in men.
- Updated the photo in Figure 16.14c.
- Updated section 16.6a, Accomplishing Fertilization, to explain that sperm can survive up to 5 days in the female reproductive tract.
- Replaced art in Table 16.1 with photos.
- Updated section 16.7, Developmental Aspects of the Reproductive System, to include a description of how gonads develop at week 6 of pregnancy; also updated the discussion of hormone replacement therapy.

- Updated the flowchart of types of birth control in A Closer Look: Contraception.
- Updated Figure 16.2 so that only the labels showing male reproductive organs or structures are in boldface.
- Updated Figure 16.3 with new, more three-dimensional art and added background colors to help students identify where each step occurs in the seminiferous tubule.
- Updated Figure 16.6 on hormonal control of testosterone release and sperm production.
- Updated Figure 16.8 so that only the labels showing female reproductive organs or structures are in boldface.
- Updated Figure 16.10 to include brief explanations of events during each time period represented.
- Updated Figure 16.12 art and explanation of the ovarian cycle.
- Updated Figure 16.13 label indicating the suspensory ligament.
- Updated Figure 16.18 with new, more accurate leader for the chorion label.
- Updated Figure 16.20 with a new photo that has better color.
- Updated Figure 16.21 with new art.
- Updated description of sperm motion from whiplike to rolling and one-sided; the head rotates while the tail beats to one side but not the other.

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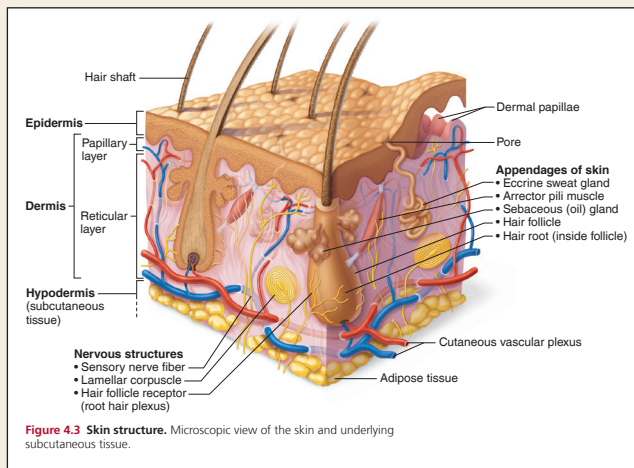
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# Study Tips

In your A&P course, you will be navigating a lot of information, but don't worry; there's an abundance of help and resources available to you! Below we share some study tips that will help you make the most of your time and effort to master your course material. If you have a study process that you feel works for you, stick with it—and also consider trying some of our suggestions to strengthen your study habits and help you get the most out of your study time.

**1 Start with the basics: Read your textbook carefully!** Each chapter is written in a conversational style, with straightforward explanations, familiar analogies, and a variety of features to help you learn and remember.



**Figures** help you visualize intricate concepts—at just the right level of detail—that might be difficult to understand from the written words alone. Sometimes a picture really is worth a thousand words!

Just as bricks and lumber are used to build a house, **cells** are the structural units of all living things, from one-celled organisms such as amoebas to complex multicellular organisms such as humans, dogs, and trees. The human body con-

## Learning Objectives

- ✓ Name and describe the four concepts of the cell theory.
- ✓ List four elements that make up the bulk of living matter.

**Learning Outcomes** cue you to the most important concepts you will need to learn.

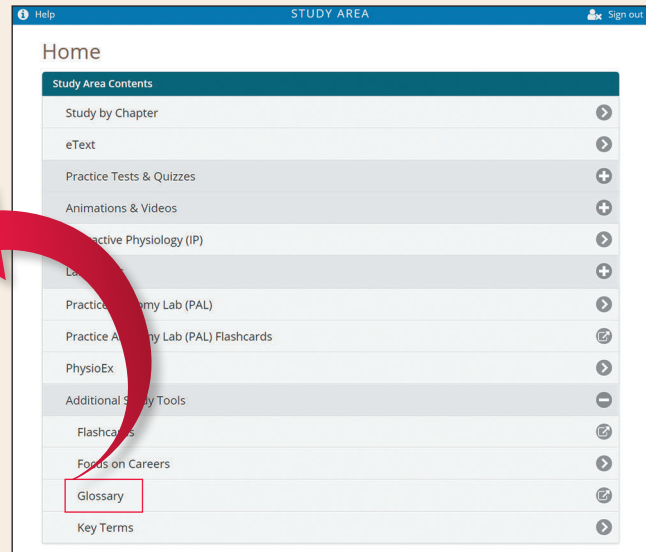
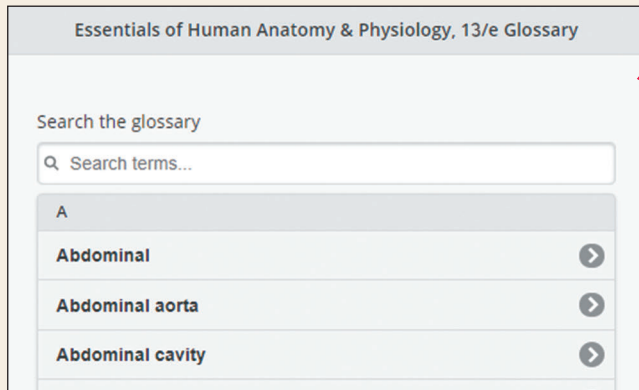
**Tables** summarize key information covered in the text and can serve as handy learning tools and memory refreshers.

**Table 3.1 Parts of the Cell: Structure and Function**

Cell part*	Structure	Functions
<b>Plasma Membrane (Figure 3.1)</b>	<p>Sugar group Protein Cholesterol</p>	<p>Membrane made of a double layer of lipids (phospholipids and cholesterol) with proteins embedded within. Most externally facing proteins and some lipids have attached sugar groups.</p> <p>Serves as an external cell barrier and acts in transport of substances into or out of the cell. Maintains an electrical condition (membrane potential) that is essential for the function of excitable cells. Externally facing proteins act as receptors (for hormones, neurotransmitters, and so on), transport proteins, and in cell-to-cell recognition.</p>
<b>Cytoplasm</b>		<p>Cellular region between the nuclear and plasma membranes. Consists of fluid <b>cytosol</b> containing dissolved solutes, <b>organelles</b> (the metabolic machinery of the cytoplasm), and <b>inclusions</b> (stored nutrients, secretory products, pigment granules).</p>
<b>Organelles</b>	<p>Mitochondria (Figure 3.4)</p>	<p>Rodlike, double-membrane structures; inner membrane folded into projections called cristae.</p> <p>Site of aerobic respiration (the "burning" of glucose) and ATP synthesis; powerhouse of the cell.</p>

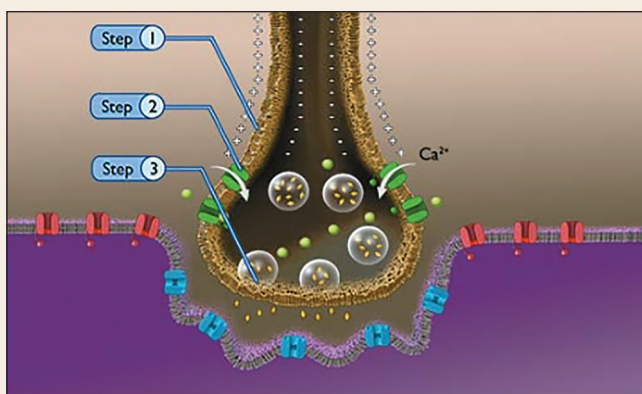
**Key terms** are **boldfaced** in text to help you spot vocabulary words you need to know.

Look up the terms you don't know. Some key terms are included in the Glossary at the end of your book. In addition, the comprehensive glossary in **Mastering A&P** includes *all* the boldfaced terms appearing in the book.



**2 Recognize that learning physiology poses different challenges from learning anatomy.** Memorization is great for helping you learn anatomy, but for learning physiology, you need to understand processes at a level where you can explain what is happening *under different conditions*. This level of understanding is not something you can gain from just memorization. So how do you gain it? Take advantage of these tools:

**A&P Flix and video animations** show you three-dimensional, movie-quality animations that bring to life key physiological processes.



**Interactive Physiology 2.0** provides tutorials, games, and quizzes that will help you deepen your understanding of complex physiological processes. As the name says, it's interactive, with detailed, high-end graphics and quick navigation!

**3 Ask questions!** Asking questions is essential to learning and to deepening your understanding. Don't hesitate to ask questions about anything you find confusing or want to know more about. Remember, there is no such thing as a stupid question.

**4 Check yourself as you go.** Before you complete graded homework, give yourself a realistic and honest view of where you are with your learning. How do you do that? Practice *without* your book or notes. Below we list some of your practice options.

See how much you've learned by taking the **chapter quizzes** in the **Mastering A&P Study Area**.

**Reading Quiz**

Chapter 4: Skin and Body Membranes

After reading the following questions carefully, please choose the best response.

**1** This type of membrane lines body cavities that are open to the exterior.

**SHOW HINT**

- serous
- mucous
- cutaneous
- visceral

Learning: Skin and Body Membranes

time: estimated time to complete 29 min

accuracy:

progress: 0 mastered, 0 incorrect, 0 in progress, 25 not seen, 25 total questions

message: If you are unsure about a choice, click once. If you are sure about a choice, click twice.

**QUESTION**

The terms sheath, bulb, and follicle all relate to which of the following?

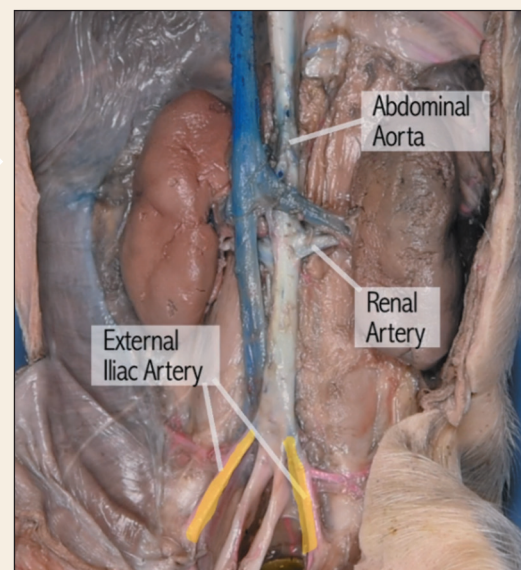
**ANSWER**

- Homeostasis
- Hormones
- Hair
- Sweat
- I DON'T KNOW YET

submit

Use **Dynamic Study Modules** to help build your foundational knowledge. The system will help you identify where you need the most work and what areas you should concentrate on in your practice by automatically providing questions on those topics. You can access the Dynamic Study Modules by going to the **Mastering A&P** home page.

**Practice Anatomy Lab (PAL)** is a virtual study and practice tool that shows you anatomical models and detailed photos of lab specimens, including histology, the human cadaver, cat, and fetal pig. PAL is easy to use and includes built-in audio pronunciations, rotatable bones, and more. You can access PAL in the **Mastering A&P Study Area**.



You'll find other practice options on **Mastering A&P**. Go to the home page to check them out.

In your textbook, keep an eye out for these images. They will point you to the appropriate location to find various tools on **Mastering A&P**.

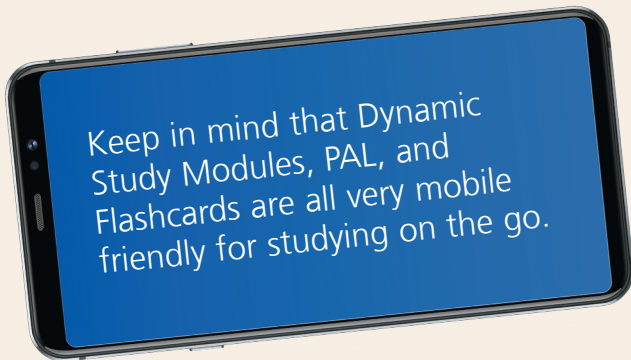
Access more study tools at **Mastering A&P > Study Area**

eText Video **Mastering A&P > Study Area > Interactive Physiology (IP)**

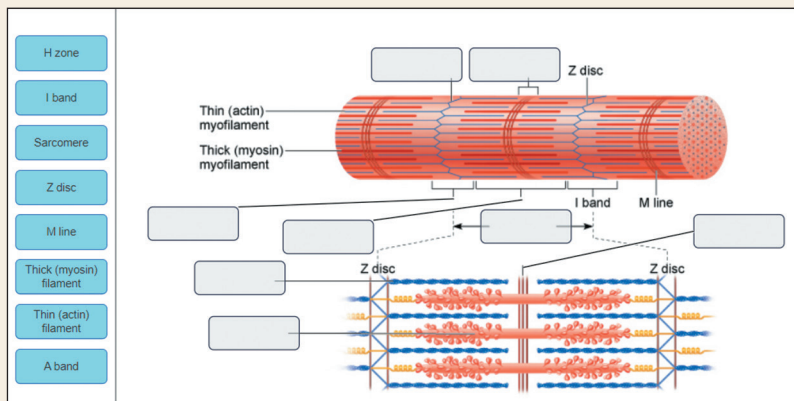
eText Video **Mastering A&P > Study Area > Animations & Videos > A&P Flix**

Access more practice questions at **Mastering A&P > Study Area > Study by Chapter**

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Interactive Physiology (IP)	➤
Lab Videos	⊖
A&P Flix	➤
Bone & Dissection Videos	➤
Videos of PhysioEx Lab Experiments	➤
Practice Anatomy Lab (PAL)	➤
Practice Anatomy Lab (PAL) Flashcards	📄
PhysioEx	➤
Additional Study Tools	⊖
Flashcards	📄
Focus on Careers	➤
Glossary	📄
Key Terms	➤



**5 Complete homework on Mastering A&P.** This is another important tool to check your understanding.



**6 Recognize that learning is not a linear process.** You can complete these study tips in order or customize them to your preferences. You will probably want to go back and forth, repeating some steps along the way as you build your knowledge and zero in on what you need help with.

# 1 The Human Body: An Orientation

## WHAT

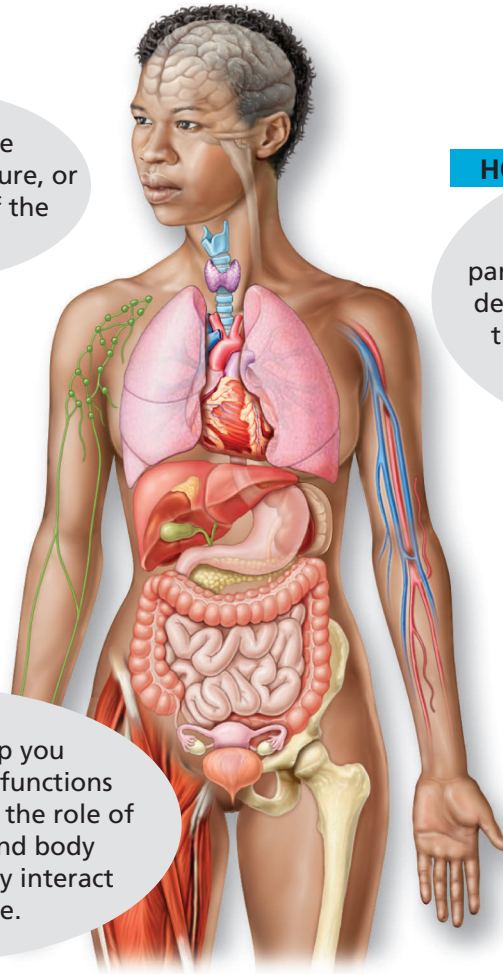
Anatomy is the study of the structure, or physical form, of the body.

## HOW

The function, or physiology, of each body part and the body as a whole is dependent on the anatomy of those parts; in other words, structure determines function.

## WHY

This text will help you learn structures and functions so you can understand the role of individual organs and body systems and how they interact to support life.



Instructors may assign a related “Building Vocabulary” activity using **Mastering A&P**

## 1.1 An Overview of Anatomy and Physiology

### Learning Objectives

- ✓ Define *anatomy* and *physiology*.
- ✓ Explain how anatomy and physiology are related.

Most of us are naturally curious about our bodies; we want to know what makes us tick. Infants can keep themselves happy for a long time staring at their own hands or pulling their mother’s nose. Older children wonder where food goes when they swallow it, and some believe that they will grow a watermelon in their belly if they swallow the seeds.

Adults become upset when their hearts pound, when they have uncontrollable hot flashes, or when they cannot keep their weight down.

Anatomy and physiology, subdivisions of biology, explore many of these topics as they describe how our bodies are put together and how they work.

### 1.1a Anatomy

**Anatomy** (ah-nat’o-me) is the study of the structure and shape of the body and its parts and their relationships to one another. Whenever we each look at our own body or study large body structures such as the heart or bones, we are observing *gross anatomy*; that is, we are studying large, easily observable structures.

Indeed, the term *anatomy*, derived from the Greek words meaning to cut (*tomy*) apart (*ana*), is related most closely to gross anatomical studies because in such studies, preserved animals or their organs are dissected (cut up) to be examined. *Microscopic anatomy*, in contrast, is the study of body structures that are too small to be seen with the naked eye. The cells and tissues of the body can only be seen through a microscope.

### 1.1b Physiology

**Physiology** (fiz"e-ol'o-je) is the study of how the body and its parts work or function (*physio* = nature; *ology* = the study of). Like anatomy, physiology has many subdivisions. For example, *neurophysiology* explains the workings of the nervous system, and *cardiac physiology* studies the function of the heart.

### 1.1c Relationship between Anatomy and Physiology

Anatomy and physiology are always inseparable. The parts of your body form a well-organized unit, and each of those parts has a job to do to make the body operate as a whole. Structure determines what functions can take place. For example, the lungs are not muscular chambers like the heart and so cannot pump blood through the body, but because the walls of their air sacs are very thin, they *can* exchange gases and provide oxygen to the body. We stress the intimate relationship between anatomy and physiology throughout this text to make your learning meaningful.

#### Did You Get It?

1. Why would you have a hard time learning and understanding physiology if you did not also understand anatomy?
2. Kidney function, bone growth, and beating of the heart are all topics of anatomy. True or false?

For answers, see Appendix A.

#### CONCEPT LINK

Throughout this text, Concept Links will highlight links between concepts and/or organ systems. Keep in mind that although discussions of the systems are separated into chapters for detailed study, the overall goal of this text is for you not only to gain an understanding of each individual system, but also to learn how the body systems interact to sustain life.

## 1.2 Levels of Structural Organization

### Learning Objectives

- ✓ Name the six levels of structural organization that make up the human body, and explain how they are related.
- ✓ Name the organ systems of the body, and briefly state the major functions of each system.
- ✓ Identify and classify by organ system all organs discussed.

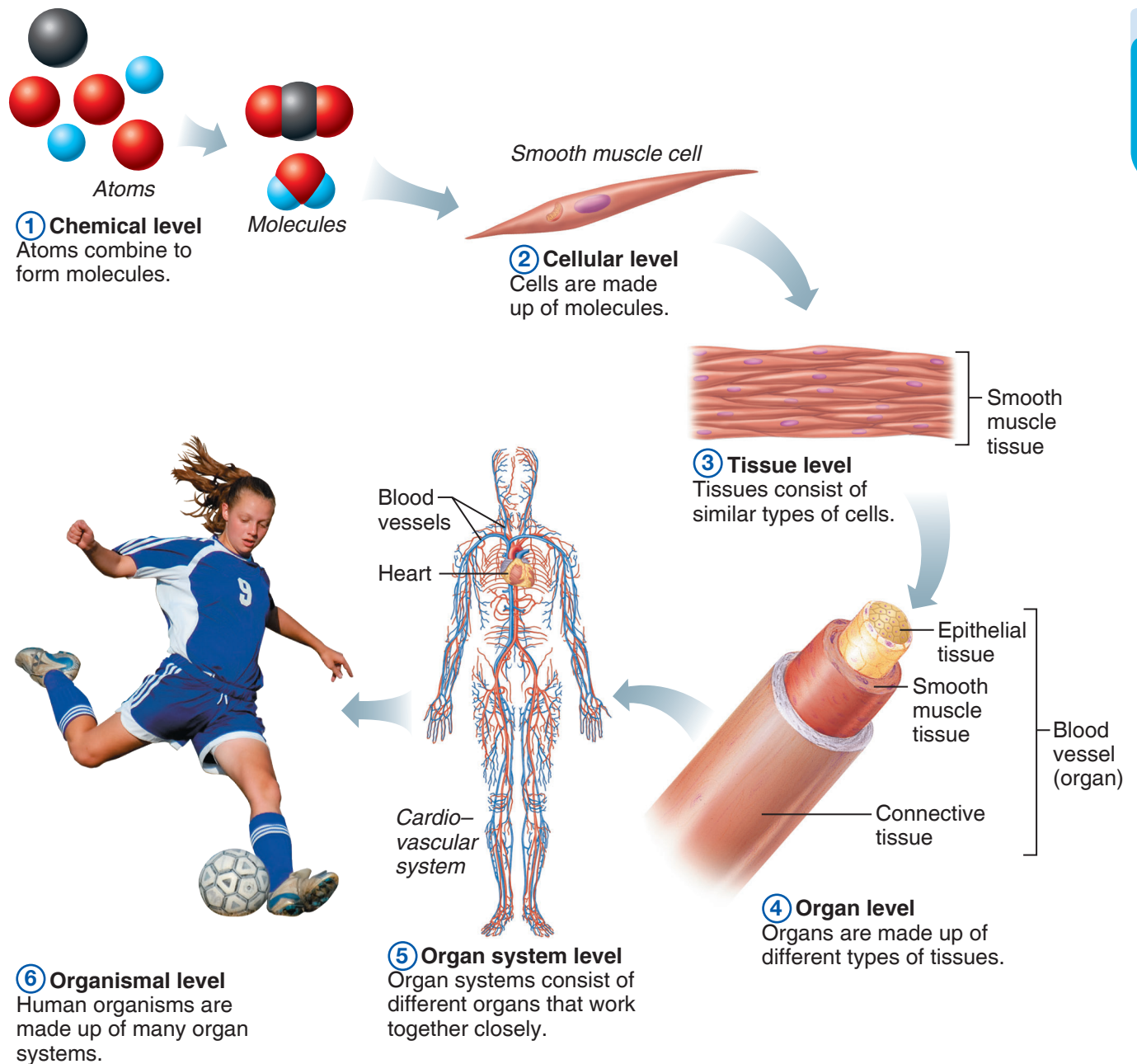
### 1.2a From Atoms to Organisms

The human body exhibits many levels of structural complexity (**Figure 1.1**). The simplest level of the structural ladder is the *chemical level* (covered in Chapter 2). At this level, **atoms**, tiny building blocks of matter, combine to form *molecules* such as water, sugar, and proteins, like those that make up our muscles. Molecules, in turn, associate in specific ways to form microscopic **cells**, the smallest units of all living things. (We will examine the *cellular level* in Chapter 3.) All cells have some common structures and functions, but individual cells vary widely in size, shape, and their particular roles in the body.

The simplest living creatures are composed of single cells, but in complex organisms such as trees or human beings, the structural ladder continues on to the *tissue level*. **Tissues** consist of groups of similar cells that have a common function. There are four basic tissue types, and each plays a definite but different role in the body. (We discuss tissues in Chapter 3.)

An **organ** is a structure composed of two or more tissue types that performs a specific function for the body. At the *organ level* of organization, extremely complex functions become possible. For example, the small intestine, which digests and absorbs food, is composed of all four tissue types. An **organ system** is a group of organs that work together to accomplish a common purpose. For example, the heart and blood vessels of the cardiovascular system circulate blood continuously to carry nutrients and oxygen to all body cells.

In all, 11 organ systems make up the living human being, or the **organism**, which represents the highest level of structural organization, the *organismal level*. The organismal level is the sum total of all structural levels working together to keep us alive. The



**Figure 1.1 Levels of structural organization.** In this diagram, components of the cardiovascular system are used to illustrate the levels of structural organization in a human being.

major organs of each system are shown in **Figure 1.2** on pp. 27–28. Refer to the figure as you read through the following descriptions of the organ systems.

## 1.2b Organ System Overview

### Integumentary System

The **integumentary** (in-tegʹu-menʹtar-e) **system** is the external covering of the body, or the skin, including the hair and fingernails (Figure 1.2a). It waterproofs

the body and cushions and protects the deeper tissues from injury. With the help of sunlight, it produces vitamin D. It also excretes salts in perspiration and helps regulate body temperature. Sensory receptors located in the skin alert us to what is happening at the body surface.

### Skeletal System

The **skeletal system** consists of bones, cartilages, and joints (Figure 1.2b). It supports the body and

provides a framework that the skeletal muscles use to cause movement. It also has protective functions (for example, the skull encloses and protects the brain), and the cavities of the skeleton are the sites where blood cells are formed. The hard substance of bones acts as a storehouse for minerals.

### Muscular System

The muscles of the body have only one function—to *contract*, or shorten. When this happens, movement occurs. The mobility of the body as a whole reflects the activity of *skeletal muscles*, the large, fleshy muscles attached to bones (Figure 1.2c). When these contract, you are able to stand erect, walk, jump, grasp, throw a ball, or smile. The skeletal muscles form the **muscular system**. These muscles are distinct from the muscles of the heart and of other hollow organs, which move fluids (such as blood or urine) or other substances (such as food) along specific pathways within the body.

### Nervous System

The **nervous system** is the body's fast-acting control system. It consists of the brain, spinal cord, nerves, and sensory receptors (Figure 1.2d). The body must be able to respond to stimuli coming from outside the body (such as light, sound, or changes in temperature) and from inside the body (such as decreases in oxygen or stretching of tissue). The *sensory receptors* detect changes in temperature, pressure, or light, and send messages (via electrical signals called *nerve impulses*) to the central nervous system (brain and spinal cord) so that it is constantly informed about what is going on. The central nervous system then assesses this information and responds by activating the appropriate body *effectors* (muscles or glands, which are organs that produce secretions).

### Endocrine System

Like the nervous system, the **endocrine** (en'do-krin) **system** controls body activities, but it acts much more slowly. *Endocrine glands* produce chemical molecules called *hormones* and release them into the blood to travel to distant target organs.

The endocrine glands include the pituitary, thyroid, parathyroids, adrenals, thymus, pancreas, pineal, ovaries (in the female), and testes (in the male) (Figure 1.2e). The endocrine glands are not connected anatomically in the same way that the parts of other organ systems are. What they have in common is that they all secrete hormones, which regulate other structures. The body functions

controlled by hormones are many and varied, involving every cell in the body. Growth, reproduction, and the use of nutrients by cells are all controlled (at least in part) by hormones.

### Cardiovascular System

The primary organs of the **cardiovascular system** are the heart and blood vessels (Figure 1.2f). Using blood as a carrier, the cardiovascular system delivers oxygen, nutrients, hormones, and other substances to, and picks up wastes such as carbon dioxide from, cells near sites of exchange. White blood cells and chemicals in the blood help to protect the body from such foreign invaders as bacteria, viruses, and tumor cells. The heart propels blood out of its chambers into blood vessels to be transported to all body tissues.

### Lymphatic System

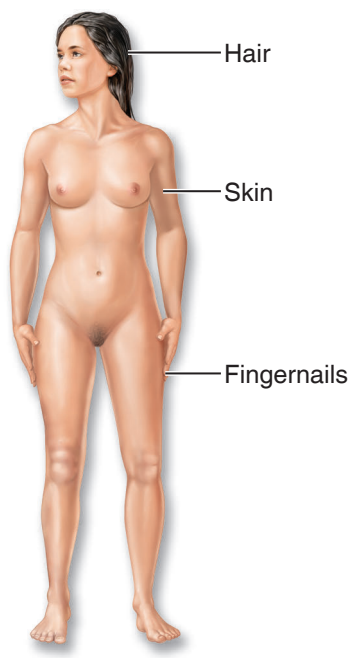
The role of the **lymphatic system** complements that of the cardiovascular system. Its organs include lymphatic vessels, lymph nodes, and other lymphoid organs such as the spleen and tonsils (Figure 1.2g). When fluid is leaked into tissues from the blood, lymphatic vessels return it to the bloodstream so that there is enough blood to continuously circulate through the body. The lymph nodes and other lymphoid organs help to cleanse the blood and house white blood cells involved in immunity.

### Respiratory System

The job of the **respiratory system** is to keep the body supplied with oxygen and to remove carbon dioxide. The respiratory system consists of the nasal passages, pharynx, larynx, trachea, bronchi, and lungs (Figure 1.2h). Within the lungs are tiny air sacs, called alveoli. Gases are exchanged with the blood through the thin walls of these alveoli.

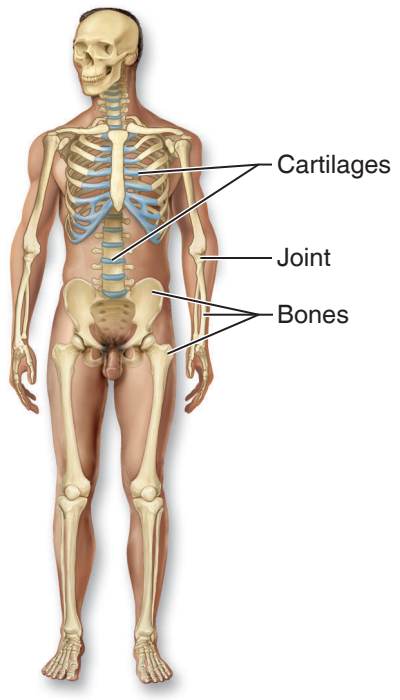
### Digestive System

The **digestive system** is basically a tube running through the body from mouth to anus. The organs of the digestive system include the oral cavity (mouth), esophagus, stomach, small and large intestines, and rectum plus a number of accessory organs (liver, salivary glands, pancreas, and others) (Figure 1.2i). Their role is to break down food and deliver the resulting nutrients to the blood for dispersal to body cells. The breakdown activities that begin in the mouth are completed in the small intestine. From that point on, the major function of the digestive system is to absorb nutrients and reabsorb water. The



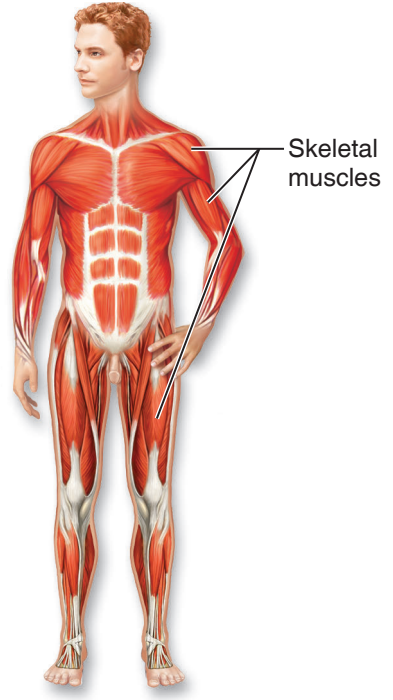
**(a) Integumentary System**

Forms the external body covering; protects deeper tissue from injury; synthesizes vitamin D; location of sensory receptors (pain, pressure, etc.) and sweat and oil glands.



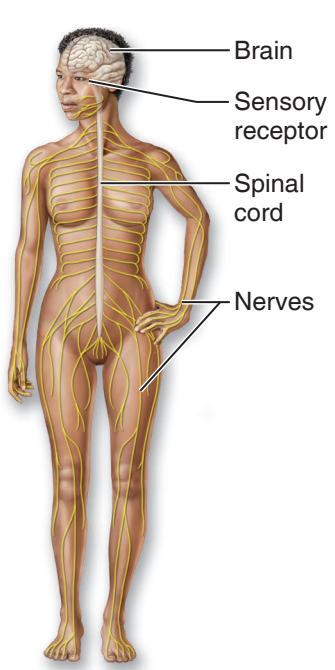
**(b) Skeletal System**

Protects and supports body organs; provides a framework the muscles use to cause movement; blood cells are formed within bones; stores minerals.



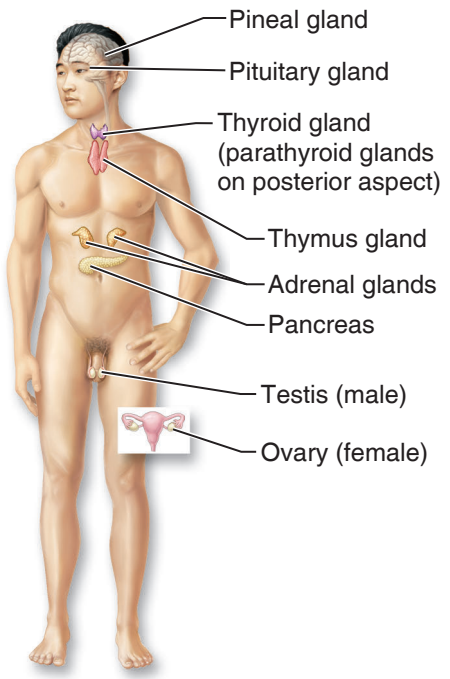
**(c) Muscular System**

Allows manipulation of the environment, locomotion, and facial expression; maintains posture; produces heat.



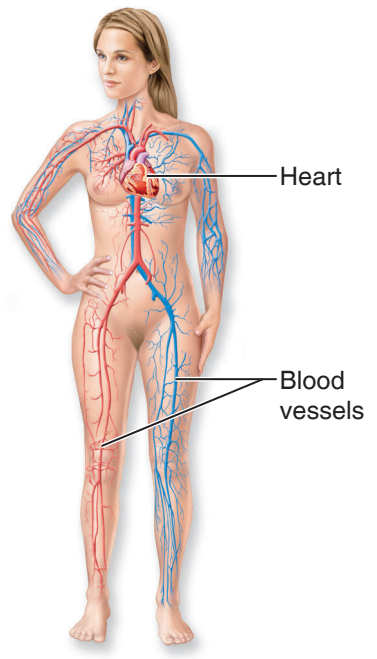
**(d) Nervous System**

Fast-acting control system of the body; responds to internal and external changes by activating appropriate muscles and glands.



**(e) Endocrine System**

Glands secrete hormones that regulate processes such as growth, reproduction, and nutrient use by body cells.

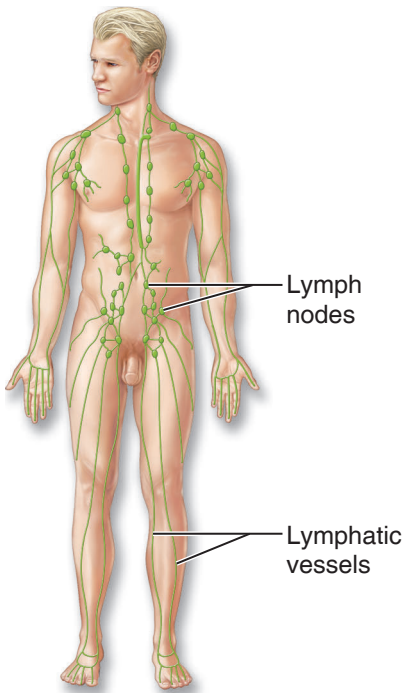


**(f) Cardiovascular System**

Blood vessels transport blood, which carries oxygen, nutrients, hormones, carbon dioxide, wastes, etc.; the heart pumps blood.

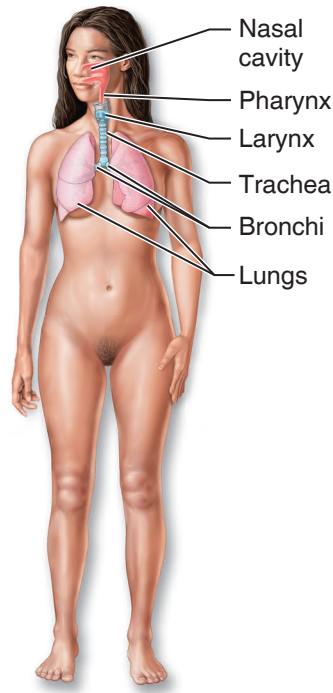
**Figure 1.2** The body's organ systems.

*(Figure continues on page 28.)*



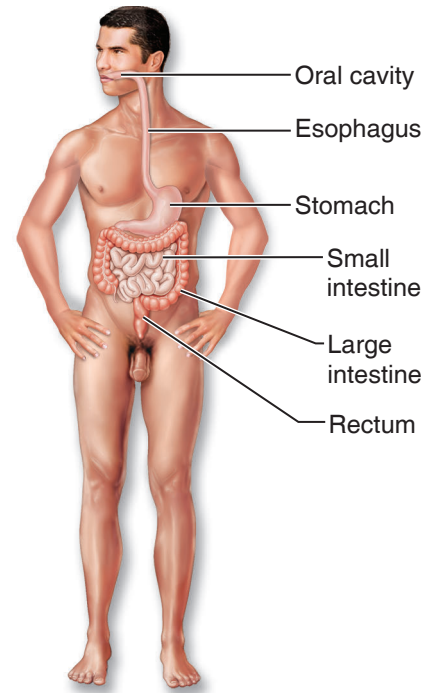
### (g) Lymphatic System

Picks up fluid leaked from blood vessels and returns it to blood; disposes of debris in the lymphatic stream; houses white blood cells involved in immunity.



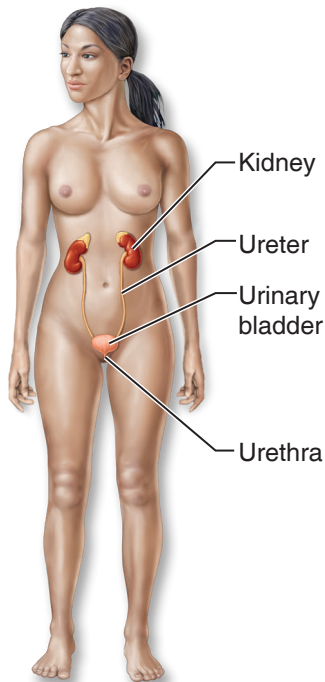
### (h) Respiratory System

Keeps blood constantly supplied with oxygen and removes carbon dioxide; gas exchange occurs through the walls of the air sacs of the lungs.



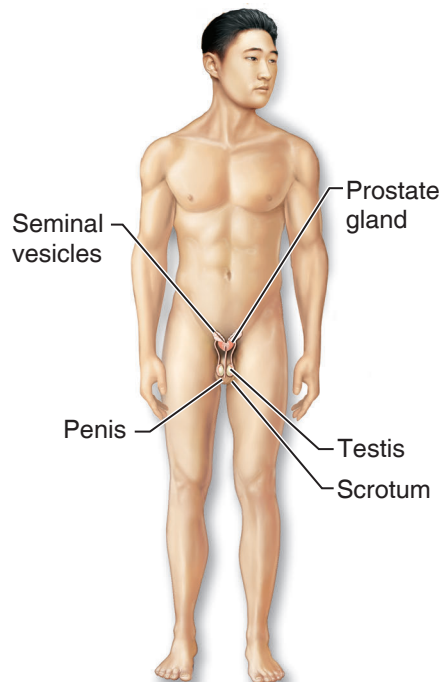
### (i) Digestive System

Breaks food down into absorbable nutrients that enter the blood for distribution to body cells; indigestible foodstuffs are eliminated as feces.



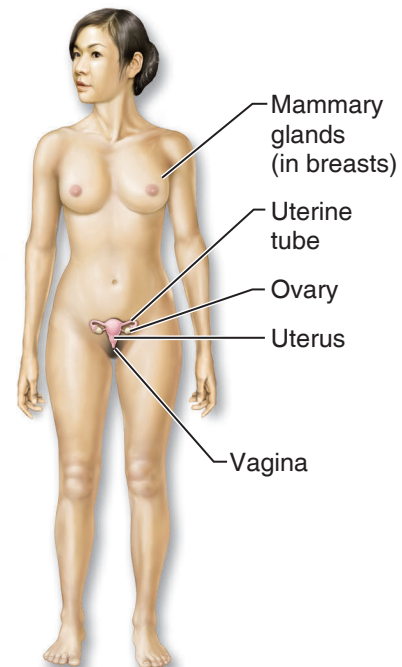
### (j) Urinary System

Eliminates nitrogen-containing wastes from the body; regulates water, electrolyte, and acid-base balance of the blood.



### (k) Male Reproductive System (l) Female Reproductive System

Overall function of the reproductive system is production of offspring. Testes produce sperm and male sex hormone; ducts and glands aid in delivery of viable sperm to the female reproductive tract. Ovaries produce eggs and female sex hormones; remaining structures serve as sites for fertilization and development of the fetus. Mammary glands of female breasts produce milk to nourish the newborn.



**Figure 1.2 (continued)** The body's organ systems.

undigested food that remains in the tract leaves the body through the anus as feces. The liver is considered a digestive organ because the bile it produces helps to break down fats. The pancreas, which delivers digestive enzymes to the small intestine, has both endocrine and digestive functions.

### Urinary System

A normal part of healthy body function is the production of waste by-products, which must be disposed of. One type of waste contains nitrogen (examples are urea and uric acid), which results when the body cells break down proteins and nucleic acids, which are genetic information molecules. The **urinary system** removes the nitrogen-containing wastes from the blood and flushes them from the body in *urine*. This system, often called the *excretory system*, is composed of the kidneys, ureters, bladder, and urethra (Figure 1.2j). Other important functions of this system include maintaining the body's water and salt (electrolyte) balance, regulating the acid-base balance of the blood, and helping to regulate normal blood pressure.

### Reproductive System

The role of the **reproductive system** is to produce offspring. The male testes produce sperm. Other male reproductive system structures are the scrotum, penis, accessory glands, and the duct system, which carries sperm to the outside of the body (Figure 1.2k). The female ovaries produce eggs, or ova; the female duct system consists of the uterine tubes, uterus, and vagina (Figure 1.2l). The uterus provides the site for the development of the fetus (immature infant) once fertilization has occurred.

#### Did You Get It?

- At which level of structural organization is the stomach? At which level is a glucose molecule?
- Which organ system includes the trachea, lungs, nasal cavity, and bronchi?
- Which system functions to remove wastes and help regulate blood pressure?

For answers, see Appendix A.

## 1.3 Maintaining Life

### Learning Objectives

- List eight functions that humans must perform to maintain life.
- List the five survival needs of the human body.

### 1.3a Necessary Life Functions

Now that we have introduced the structural levels composing the human body, a question naturally follows: What does this highly organized human body do? Like all complex animals, human beings maintain their boundaries, move, respond to environmental changes, take in and digest nutrients, carry out metabolism, dispose of wastes, reproduce themselves, and grow.

Organ systems do not work in isolation; instead, they work together to promote the well-being of the entire body (Figure 1.3, p. 30). Because this theme is emphasized throughout this text, it is worthwhile to identify the most important organ systems contributing to each of the necessary life functions. Also, as you study this figure, you may want to refer to the more detailed descriptions of the organ systems just provided (pp. 26–29 and in Figure 1.2).

#### Maintaining Boundaries

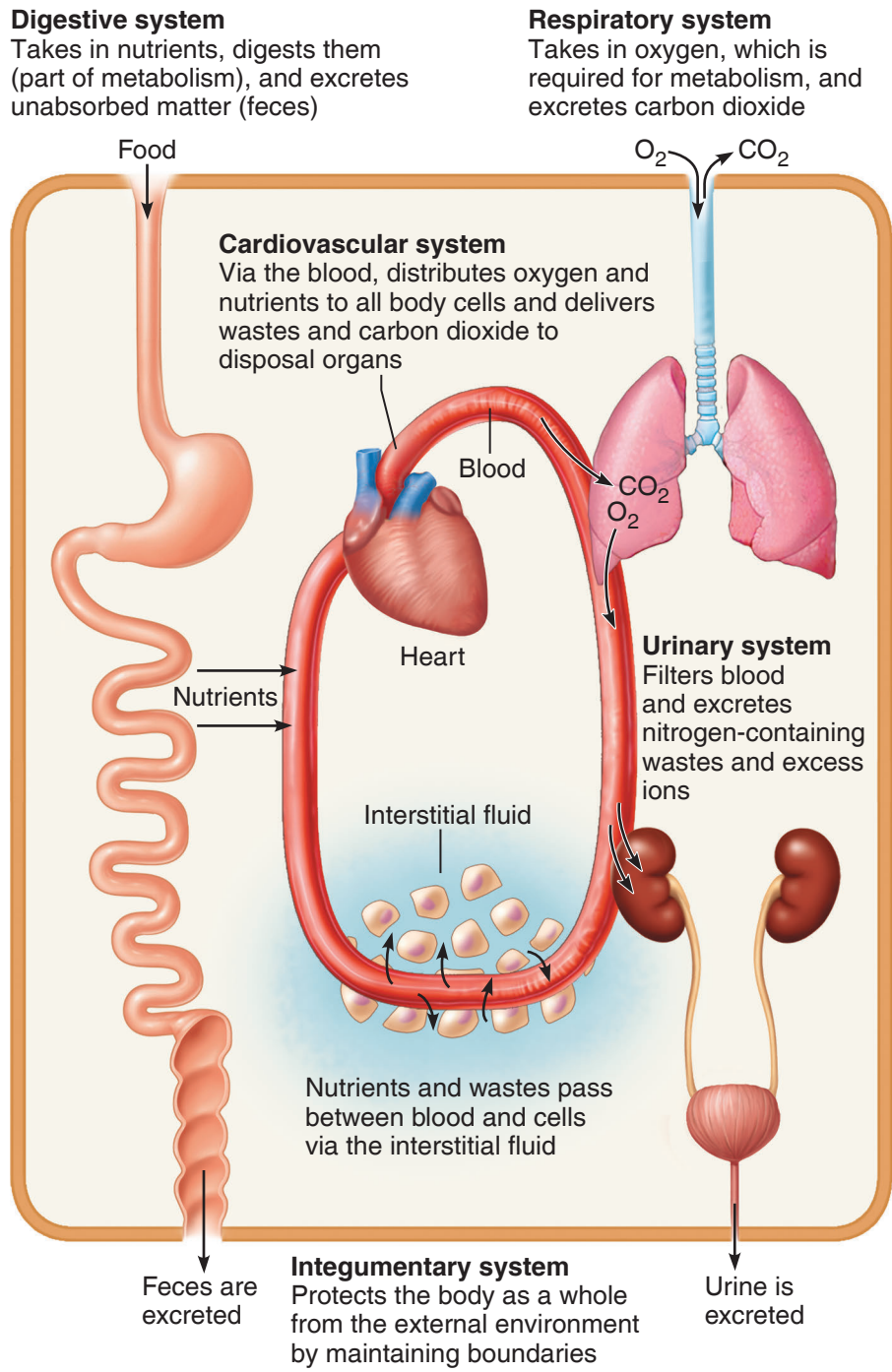
Every living organism must be able to maintain its boundaries so that its “inside” remains distinct from its “outside.” Every cell of the human body is surrounded by an external membrane that separates its contents from the outside interstitial fluid (fluid between cells) and allows entry of needed substances while generally preventing entry of potentially damaging or unnecessary substances. The body as a whole is also enclosed by the integumentary system, or skin. The integumentary system protects internal organs from drying out (which would be fatal), from pathogens, and from the damaging effects of heat, sunlight, and an unbelievable number of chemical substances in the external environment.

#### Movement

**Movement** includes all the activities promoted by the muscular system, such as propelling ourselves from one place to another (by walking, swimming, and so forth) and manipulating the external environment with our fingers. The skeletal system provides the bones that the muscles pull on as they work. Movement also occurs when substances such as blood, foodstuffs, air, and urine are propelled through the internal organs of the cardiovascular, digestive, respiratory, and urinary systems, respectively.

#### Responsiveness

**Responsiveness**, or **irritability**, is the ability to sense changes (stimuli) in the environment and then to react to them. For example, if you accidentally



**Figure 1.3** Examples of interrelationships among organ systems that illustrate life functions.

touch a hot pan, you involuntarily pull your hand away from the painful stimulus (the pan). You do not need to think about it—it just happens! Likewise, when the amount of carbon dioxide in your blood rises to a dangerously high level, your breathing rate speeds up to blow off the excess carbon dioxide.

Because nerve cells are highly irritable and can communicate rapidly with each other via electrical

impulses, the nervous system bears the major responsibility for responsiveness. However, all body cells are responsive to some extent.

**Digestion**

**Digestion** is the process of breaking down ingested food into simple molecules that can then be absorbed into the blood. The nutrient-rich blood is

then distributed to all body cells by the cardiovascular system, where body cells use these simple molecules for energy and raw materials.

### Metabolism

**Metabolism** is a broad term that refers to all chemical reactions that occur within the body and all of its cells. It includes breaking down complex substances into simpler building blocks (as in digestion), making larger structures from smaller ones, and using nutrients and oxygen to produce molecules of *adenosine triphosphate (ATP)*, the energy-rich molecules that power cellular activities. Metabolism depends on the digestive and respiratory systems to make nutrients and oxygen available to the blood and on the cardiovascular system to distribute these needed substances throughout the body. Metabolism is regulated chiefly by hormones secreted by the glands of the endocrine system.

### Excretion

**Excretion** is the process of removing *excreta* (ek-skre'tah), or wastes, from the body. Several organ systems participate in excretion. For example, the digestive system rids the body of indigestible food residues in feces, the urinary system disposes of nitrogen-containing metabolic wastes in urine, and the skin disposes of various waste products as components of sweat.

### Reproduction

**Reproduction**, the production of offspring, can occur on the cellular or organismal level. In cellular reproduction, the original cell divides, producing two identical daughter cells that may then be used for body growth or repair. Reproduction of the human organism is the task of the organs of the reproductive system, which produce sperm and eggs. When a sperm unites with an egg, a fertilized egg forms, which then develops into a baby within the mother's body. The function of the reproductive system is regulated very precisely by hormones of the endocrine system.

### Growth

*Growth* can be an increase in cell size or an increase in body size that is usually accomplished by an increase in the number of cells. For growth to occur, cell-constructing activities must occur at a faster rate than cell-destroying ones. Hormones released by the endocrine system play a major role in directing growth.

## 1.3b Survival Needs

The goal of nearly all body systems is to maintain life. However, life is extraordinarily fragile and requires that several factors be available. These factors, which we will call *survival needs*, include nutrients (food), oxygen, water, and appropriate temperature and atmospheric pressure.

**Nutrients**, which the body takes in through food, contain the chemicals used for energy and cell building. *Carbohydrates* are the major energy-providing fuel for body cells. *Proteins* and, to a lesser extent, *fats* are essential for building cell structures. Fats also cushion body organs and provide reserve fuel. *Minerals* and *vitamins* are required for the chemical reactions that go on in cells and for oxygen transport in the blood.

All the nutrients in the world are useless unless **oxygen** is also available. Because the chemical reactions that release energy from foods require oxygen, human cells can survive for only a few minutes without it. It is made available to the blood and body cells by the cooperative efforts of the respiratory and cardiovascular systems.

*Water* accounts for 60 to 80 percent of body weight, depending on the age of the individual. It is the single most abundant chemical substance in the body and provides the fluid base for body secretions and excretions. We obtain water chiefly from ingested foods or liquids, and we lose it by evaporation from the lungs and skin and in body excretions.

If chemical reactions are to continue at life-sustaining levels, **normal body temperature** must be maintained. If body temperature drops below 37°C (98.6°F), metabolic reactions become slower and slower and finally stop. If body temperature is too high, chemical reactions proceed too rapidly, and body proteins begin to break down. At either extreme, death occurs. Most body heat is generated by the activity of the skeletal muscles and dissipated via blood circulating close to the skin surface or by the evaporation of sweat.

The force exerted on the surface of the body by the weight of air is referred to as **atmospheric pressure**. Breathing and the exchange of oxygen and carbon dioxide in the lungs depend on appropriate atmospheric pressure. At high altitudes, where the air is thin and atmospheric pressure is lower, gas exchange may be too slow to support cellular metabolism.

## Medical Imaging: Illuminating the Body

**I**maging procedures are important diagnostic tools that are either minimally invasive or not invasive at all. By bombarding the body with different forms of energy, medical imaging techniques can reveal the structure of internal organs, show blood flow in real time, and even determine the density of bone.

Until about 60 years ago, the magical but murky X-ray was the only means of peering into a living body without performing surgery.

Two examples of low-dose X-ray procedures are mammography and bone densitometry. A **mammogram** is used to identify changes in breast tissue, including dense masses or calcifications; see photo (a). **Bone densitometry** detects the amount of calcium and minerals stored in bone and is the major diagnostic test for osteoporosis.

The 1950s saw the birth of **ultrasound imaging (ultrasonography)**,

which has some distinct advantages over other imaging techniques. The equipment employs high-frequency sound waves (ultrasound) as its energy source. The body is probed with pulses of sound waves, which cause echoes when reflected and scattered by body tissues. The echoes are analyzed by computer to construct visual images of body organs, much like sonar is used to map the ocean floor. Even though ultrasound is the safest imaging technique available, health care providers should limit patients' exposure to the lowest level that will be effective. The long-term effects of ultrasound exposure are not known.

Perhaps the best known of these newer imaging devices is **computed tomography (CT)**, a refined version of X-ray that eliminates the confusion resulting from images of overlapping structures. A CT scanner takes "pictures" of a thin slice of the body. Different tissues absorb the radiation in

varying amounts. The device's computer translates this information into a detailed image of the body region scanned; see photo (b). CT scans are at the forefront in evaluating most problems that affect the brain and abdomen, and their clarity has all but eliminated exploratory surgery. Special ultrafast CT scanners have produced a technique called **dynamic spatial reconstruction (DSR)**, which provides three-dimensional images of body organs from any angle. It also allows organ movements and changes in internal volumes to be observed at normal speed, in slow motion, and at a specific moment in time. The greatest value of DSR has been to visualize the heart beating and blood flowing through blood vessels.

**Positron emission tomography (PET)** requires an injection of short-lived radioisotopes that have been tagged to biological molecules (such as glucose) in order to view metabolic

The mere presence of these survival factors is not sufficient to maintain life. They must be present in appropriate amounts as well; excesses and deficits may be equally harmful. For example, the food ingested must be of high quality and in proper amounts; otherwise, nutritional disease, obesity, or starvation is likely.

### Did You Get It?

- In addition to being able to metabolize, grow, digest food, and excrete wastes, what other functions must an organism perform if it is to survive?
- Oxygen is a survival need. Why is it so important? In which life function does oxygen participate directly?

For answers, see Appendix A.

## 1.4 The Language of Anatomy

### Learning Objectives

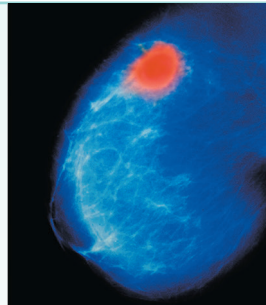
- ✓ Verbally describe or demonstrate the anatomical position.
- ✓ Use proper anatomical terminology to describe body directions, surfaces, and body planes.
- ✓ Locate the major body cavities, and list the chief organs in each cavity.

Learning about the body is exciting, but it can be difficult to maintain our interest when we are faced with all the new terminology of anatomy and physiology. Let's face it: You can't just pick up an anatomy and physiology book and read it as if it were a novel. Unfortunately, confusion is inevitable without specialized terminology. For example, if you are looking at a ball, "above" always means the area over the top of the ball. Other directional terms can also be used consistently because the ball is a sphere. All

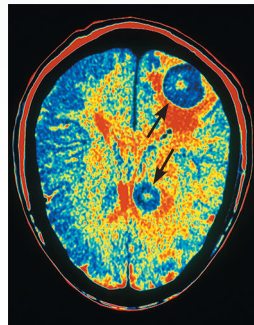


processes. As the radioisotopes are absorbed by the most active brain cells, high-energy gamma rays are produced, which a computer then analyzes to generate a picture of the brain's biochemical activity in vivid colors. PET's greatest clinical value has been its ability to provide insights into brain activity in real time, particularly in people affected by mental illness, Alzheimer's disease, and epilepsy.

A different technique is **magnetic resonance imaging (MRI)**, which uses magnetic fields up to 60,000 times stronger than Earth's to pry information from body tissues. Hydrogen molecules spin like tops in the magnetic field, and their energy is enhanced by the pres-



(a) Mammogram showing breast cancer.



(b) CT scan showing brain tumors (indicated by black arrows).

ence of radio waves. When the radio waves are turned off, energy is released and translated by a computer into a visual image (see Figure 1.5, p. 37). MRI is immensely popular because it can do many things a CT scan cannot. Dense structures do not show up in MRI, so bones of the skull and/or vertebral column do not impair the view of *soft tissues*, such as the brain or intervertebral discs, the cartilage pads between vertebrae.

A variation of MRI called **functional magnetic resonance imaging (fMRI)** allows tracking of blood flow into the brain in real time. Before 1992, PET was the only way to match brain activity to disease. With no need for injections of radio-

isotopes, fMRI provides a less invasive alternative. Despite its advantages, the powerful magnets of the MRI can pose risks. For example, metal objects, such as implanted pacemakers and loose tooth fillings, can be "sucked" through the body. Also, the long-term health risks of exposure to strong magnetic fields are not clear.

### The Essentials

- Medical imaging procedures are minimally invasive or noninvasive.
- The most common imaging techniques include X-ray, CT, MRI, and ultrasound.
- All of these except ultrasound expose patients to ionizing radiation in some form.
- Modern imaging techniques use computer software to build and manipulate three-dimensional images for better visualization of body structures and irregularities.

sides and surfaces are equal. The human body, of course, has many protrusions and bends. Thus, the question becomes: Above what? To prevent misunderstanding, anatomists use a set of terms that allow body structures to be located and identified clearly with just a few words. We present and explain this language of anatomy next.

## 1.4a Anatomical Position

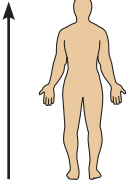
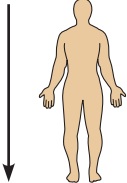


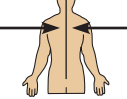
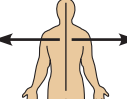

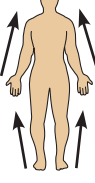
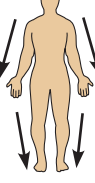


To accurately describe body parts and position, we must have an initial reference point and use directional terms. To avoid confusion, we always assume that the body is in a standard position called **anatomical position**. It is important to understand this position because most body terminology used in this text refers to this body positioning *regardless* of the position the body happens to be in. In anatomical position, the body is erect with the feet parallel and the arms hanging at the sides with the palms facing forward. Stand up now, and

assume the anatomical position. Notice that it is similar to "standing at attention" but is less comfortable because the palms are held unnaturally forward (with thumbs pointing away from the body) rather than hanging cupped toward the thighs.

## 1.4b Directional Terms

**Directional terms** allow medical personnel and anatomists to explain exactly where one body structure is in relation to another. For example, we can describe the relationship between the ears and the nose informally by saying, "The ears are located on each side of the head to the right and left of the nose." In anatomical terminology, this condenses to, "The ears are lateral to the nose." Using anatomical terminology saves words and, once learned, is much clearer. Commonly used directional terms are defined and illustrated in **Table 1.1**. Although many of these terms are also used in everyday conversation, keep in mind that their anatomical meanings are very precise.

**Table 1.1 Orientation and Directional Terms**

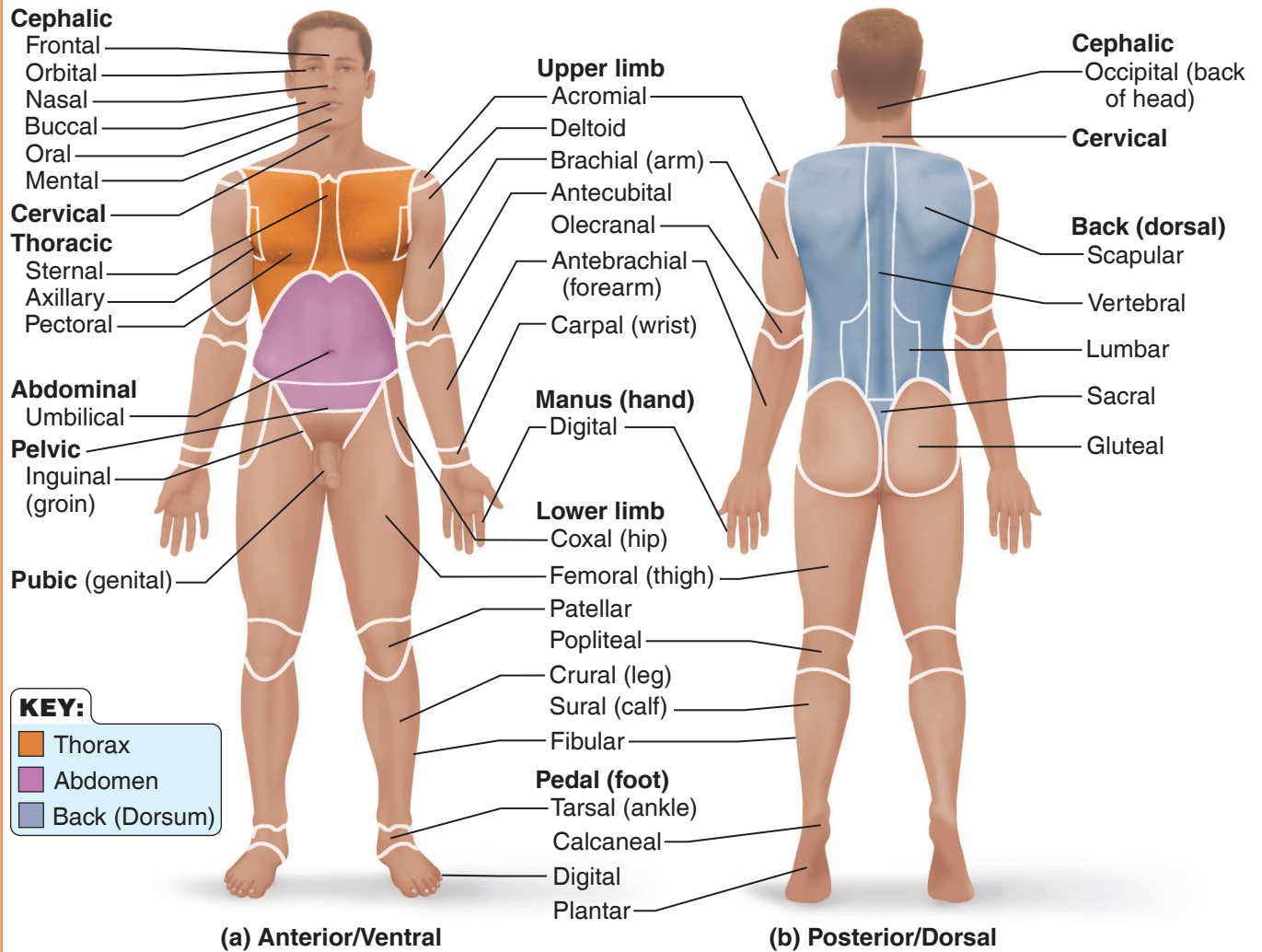
Term	Definition	Illustration	Example
<b>Superior</b> (cranial or cephalic)	Toward the head end or upper part of a structure or the body; above		The forehead is superior to the nose.
<b>Inferior</b> (caudal)*	Away from the head end or toward the lower part of a structure or the body; below		The navel is inferior to the breastbone.
<b>Anterior</b> (ventral)†	Toward or at the front of the body; in front of		The breastbone is anterior to the spine.
<b>Posterior</b> (dorsal)†	Toward or at the backside of the body; behind		The heart is posterior to the breastbone.
<b>Medial</b>	Toward or at the midline of the body; on the inner side of		The heart is medial to the arm.
<b>Lateral</b>	Away from the midline of the body; on the outer side of		The arms are lateral to the chest.
<b>Intermediate</b>	Between a more medial and a more lateral structure		The collarbone is intermediate between the breastbone and the shoulder.
<b>Proximal</b>	Close to the origin of the body part or the point of attachment of a limb to the body trunk		The elbow is proximal to the wrist (meaning that the elbow is closer to the shoulder or attachment point of the arm than the wrist is).
<b>Distal</b>	Farther from the origin of a body part or the point of attachment of a limb to the body trunk		The knee is distal to the thigh.
<b>Superficial</b> (external)	Toward or at the body surface		The skin is superficial to the skeleton.
<b>Deep</b> (internal)	Away from the body surface; more internal		The lungs are deep to the rib cage.

\*The term caudal, literally "toward the tail," is synonymous with inferior only to the inferior end of the spine.

†*Anterior* and *ventral* are synonymous in humans, but not in four-legged animals. *Ventral* refers to an animal's "belly," making it the inferior surface. Likewise, posterior and dorsal surfaces are the same in humans, but *dorsal* refers to an animal's back, making it the superior surface.



Study this figure for a moment to answer these two questions. Where would you hurt if you (1) pulled a groin muscle or (2) cracked a bone in your olecranal area?



**Figure 1.4** The anatomical position and regional terms. This figure shows terms used to designate specific body areas. **(a)** Anterior view. **(b)** Posterior view. The heels are raised slightly to show the inferior plantar surface (sole) of the foot, which is actually on the inferior surface of the body.

Before continuing, check your understanding of what you have read in the table. Complete each of the following statements with the correct anatomical term.

The wrist is \_\_\_\_\_ to the hand.

The breastbone is \_\_\_\_\_ to the spine.

The brain is \_\_\_\_\_ to the spinal cord.

The thumb is \_\_\_\_\_ to the fingers. (Be careful here. Remember the anatomical position.)



(1) Your inguinal region. (2) Your posterior elbow region.

### 1.4c Regional Terms

There are many visible landmarks on the surface of the body. Once you know their proper anatomical names, you can be specific in referring to different regions of the body.

#### Anterior Body Landmarks

Look at **Figure 1.4a** to find the following body regions. Once you have identified all the anterior body landmarks, cover the labels that describe what

the structures are. Then go through the list again, pointing out these areas on your own body.

- **abdominal** (ab-dom'ĩ-nal): anterior body trunk inferior to ribs
- **acromial** (ah-kro'me-ul): point of shoulder
- **antebrachial** (an'te-bra'ke-al): forearm
- **antecubital** (an'te-ku'bĩ-tal): anterior surface of elbow
- **axillary** (ak'sĩ-lar'e): armpit
- **brachial** (bra'ke-al): arm
- **buccal** (buk'al): cheek area
- **carpal** (kar'pal): wrist
- **cervical** (ser'vĩ-kal): neck region
- **coxal** (kok'sal): hip
- **crural** (kroo'ral): anterior leg; the shin
- **deltoid** (del'toyd): curve of shoulder formed by large deltoid muscle
- **digital** (dij'ĩ-tal): fingers, toes
- **femoral** (fem'or-al): thigh (applies to both anterior and posterior)
- **fibular** (fib'u-lar): lateral part of leg
- **frontal** (frun'tal): forehead
- **inguinal** (in'gwĩ-nal): area where thigh meets body trunk; groin
- **mental** (men'tul): chin
- **nasal** (na'zul): nose area
- **oral** (o'ral): mouth
- **orbital** (or'bĩ-tal): eye area
- **patellar** (pah-tel'er): anterior knee
- **pectoral** (pek'to-ral): relating to, or occurring in or on, the chest
- **pelvic** (pel'vik): area overlying the pelvis anteriorly
- **pubic** (pyu'bik): genital region
- **sternal** (ster'nul): breastbone area
- **tarsal** (tar'sal): ankle region
- **thoracic** (tho-ras'ik): area between the neck and abdomen, supported by the ribs, sternum and costal cartilages; chest
- **umbilical** (um-bil'ĩ-kal): navel

### Posterior Body Landmarks

Identify the following body regions in Figure 1.4b, and then locate them on yourself without referring to this text.

- **calcaneal** (kal-ka'ne-ul): heel of foot
- **cephalic** (seh-fã'lik): head
- **femoral** (fem'or-al): thigh
- **gluteal** (gloo'te-al): buttock
- **lumbar** (lum'bar): area of back between ribs and hips; the loin
- **occipital** (ok-sip'ĩ-tal): posterior surface of head or base of skull
- **olecranal** (ol-eh-kra'nel): posterior surface of elbow
- **popliteal** (pop-lit'e-al): posterior knee area
- **sacral** (sa'krul): area between hips at base of spine
- **scapular** (skap'u-lar): shoulder blade region
- **sural** (soo'ral): the posterior surface of leg; the calf
- **vertebral** (ver'tẽ-bral): area of spinal column

The **plantar** region, or the sole of the foot, actually on the inferior body surface, is illustrated with the posterior body landmarks (see Figure 1.4b).

### Did You Get It?

8. What is the anatomical position, and why is it important that an anatomy student understand it?
9. The axillary and the acromial areas are both in the general area of the shoulder. To what specific body area does each of these terms apply?
10. Use anatomical language to describe the location of a cut to the back of your left forearm.

For answers, see Appendix A.

### 1.4d Body Planes and Sections

When preparing to look at the internal structures of the body, medical students make a **section**, or cut. When the section is made through the body wall or through an organ, it is made along an imaginary line called a **plane**. Because the body is three-dimensional, we can refer to three types of planes or sections that lie at right angles to one another (**Figure 1.5**).

Q

Which section type would separate the two eyes?



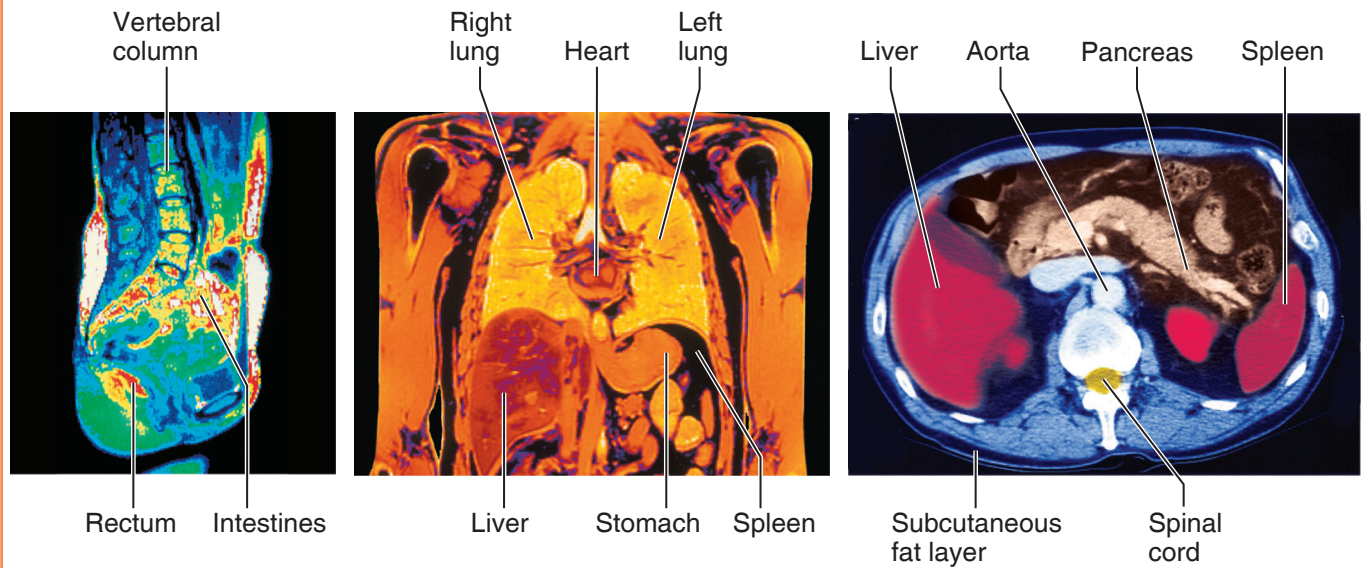
(a) Median (midsagittal)



(b) Frontal (coronal) plane



(c) Transverse plane



**Figure 1.5** The planes of the body—median, frontal, and transverse—with corresponding MRI scans. Note that the planes are shown on a body in anatomical position.

A **sagittal** (saj'ī-tal) **section** is a cut along the lengthwise, or longitudinal, plane of the body, dividing the body into right and left parts. If the cut is

down the median plane of the body and the right and left parts are equal in size, it is called a **median (midsagittal) section**. All other sagittal sections are parasagittal sections (*para* = near).

A

A midsagittal section would separate the two eyes.

1

A **frontal section** is a cut along a lengthwise plane that divides the body (or an organ) into anterior and posterior parts. It is also called a **coronal** (ko-ro'nal, "crown") **section**.

A **transverse section** is a cut along a horizontal plane, dividing the body or organ into superior and inferior parts. It is also called a **cross section**.

Sectioning a body or one of its organs along different planes often results in very different views. For example, a transverse section of the body trunk at the level of the kidneys would show kidney structure in cross section very nicely; a frontal section of the body trunk would show a different view of kidney anatomy; and a midsagittal section would miss the kidneys completely. Information on body organ positioning can be gained by taking magnetic resonance imaging (MRI) scans along different body planes (see Figure 1.5). MRI scans are described further in "A Closer Look" (pp. 32–33).

## 1.4e Body Cavities

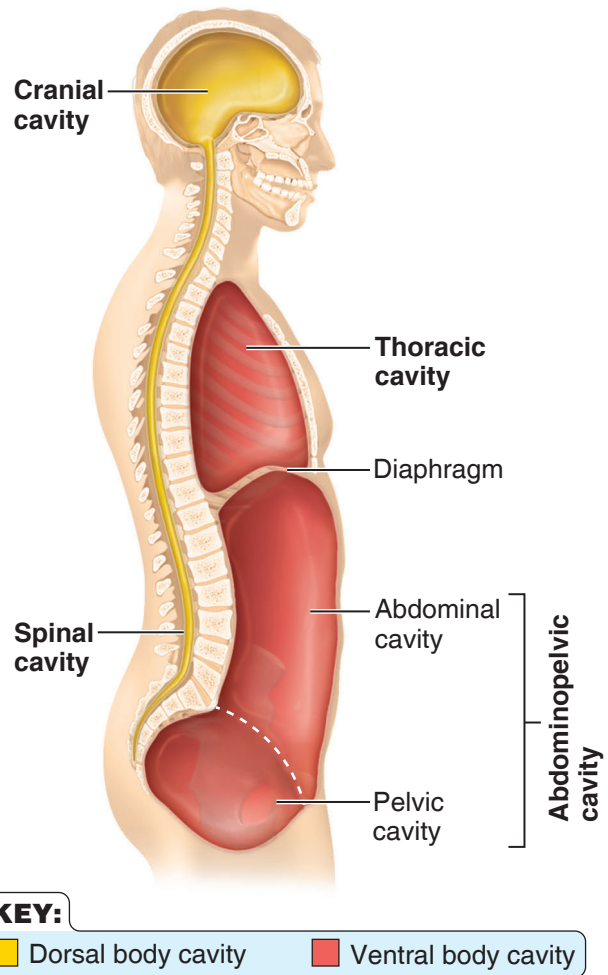
Anatomy and physiology textbooks typically describe two sets of internal body cavities, called the *dorsal* and *ventral body cavities*, that provide different degrees of protection to the organs within them (Figure 1.6). Because these cavities differ in their mode of embryological development and in their lining membranes, many anatomy reference books do not identify the dorsal, or neural, body cavity as an internal body cavity. However, the idea of two major sets of internal body cavities is a useful learning concept, so we will continue to use it here.

### Dorsal Body Cavity

The **dorsal body cavity** has two subdivisions, which are continuous with each other. The **cranial cavity** is the space inside the bony skull. The brain is well protected because it occupies the cranial cavity. The **spinal cavity** extends from the cranial cavity to the end of the spinal cord. The spinal cord, which is a continuation of the brain, is protected by the bony vertebrae, which surround the spinal cavity and form the spine.

### Ventral Body Cavity

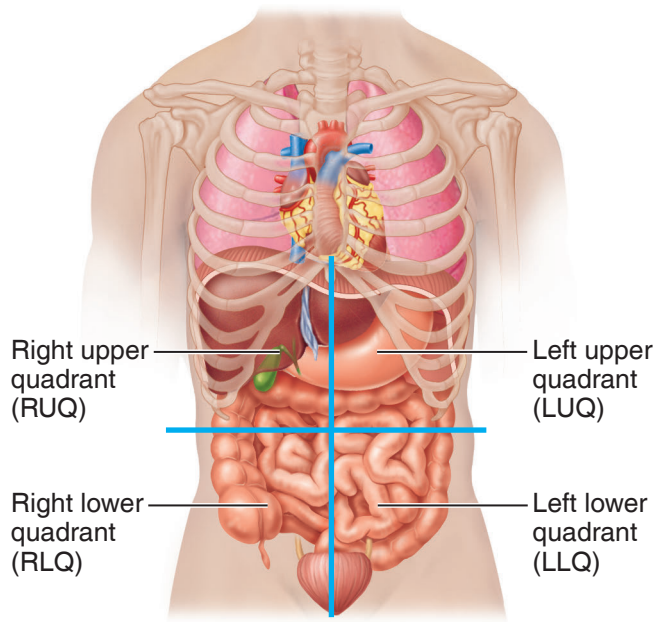
The **ventral body cavity** is much larger than the dorsal cavity. It contains all the structures within the chest and abdomen, that is, the organs in those regions. Like the dorsal cavity, the ventral body cavity is subdivided. The superior **thoracic cavity** is separated from the rest of the ventral cavity by a



**Figure 1.6 Body cavities.** Notice the angular relationship between the abdominal and pelvic cavities.

dome-shaped muscle, the **diaphragm** (di'ah-fram). The organs in the thoracic cavity (lungs, heart, and others) are protected by the rib cage. A central region called the **mediastinum** (me'de-as-ti'num) separates the lungs into right and left cavities in the thoracic cavity. The mediastinum itself houses the heart, trachea, and several other visceral organs.

The cavity inferior to the diaphragm is the **abdominopelvic** (ab-dom'i-no-pel'vik) **cavity**. Some prefer to subdivide it into a superior **abdominal cavity** containing the stomach, liver, intestines, and other organs, and an inferior **pelvic cavity** containing the reproductive organs, bladder, and rectum. However, there is no actual physical structure dividing the abdominopelvic cavity. The pelvic cavity is not immediately inferior to the abdominal cavity, but rather tips away from the abdominal cavity in the posterior direction (see Figure 1.6).



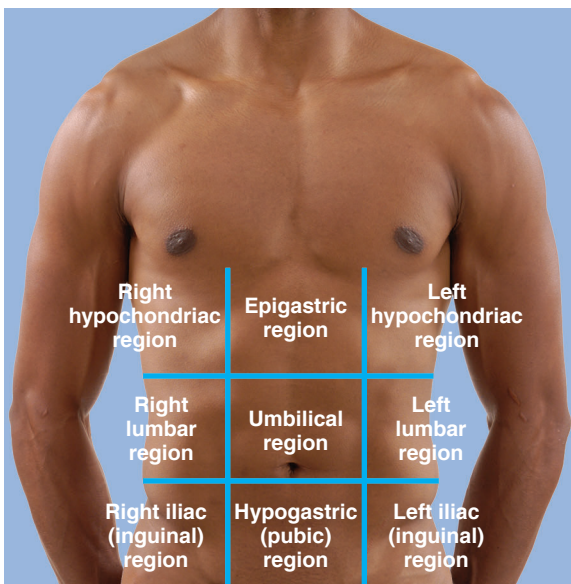
**Figure 1.7 The four abdominopelvic quadrants.** In this scheme used by medical personnel, the abdominopelvic cavity is divided into four quadrants by two planes.

When the body is subjected to physical trauma (as often happens in an automobile accident, for example), the most vulnerable abdominopelvic organs are those within the abdominal cavity. The reason is that the abdominal cavity walls are formed only of trunk muscles and are not reinforced by bone. The pelvic organs receive some protection from the bony pelvis in which they reside.

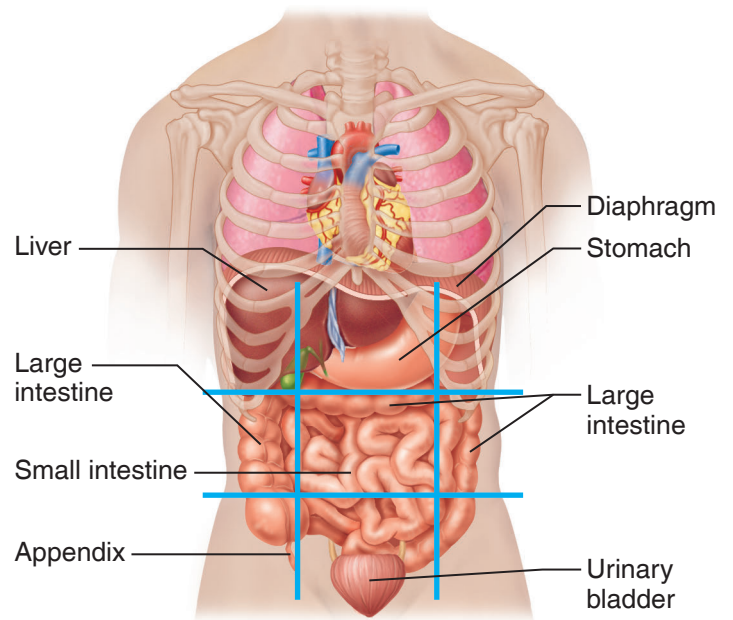
Because the abdominopelvic cavity is quite large and contains many organs, it helps to divide it up into smaller areas for study. A scheme commonly used by medical personnel divides the abdominopelvic cavity into four more or less equal regions called *quadrants*. The quadrants are named according to their relative locations with respect to anatomical position—that is, right upper quadrant (RUQ), right lower quadrant (RLQ), left upper quadrant (LUQ), and left lower quadrant (LLQ) (**Figure 1.7**).

Another system, used mainly by anatomists, divides the abdominopelvic cavity into nine separate *regions* by four planes (**Figure 1.8a**). As you locate these regions, notice the organs they contain (Figure 1.8b).

- The **umbilical region** is the centermost region, deep to and surrounding the umbilicus (navel).



**(a) Nine regions delineated by four planes**



**(b) Anterior view of the nine regions showing the superficial organs**

**Figure 1.8 The nine abdominopelvic regions.** The abdominopelvic cavity is divided into nine regions by four planes in this

scheme used mostly by anatomists. In (a), the superior transverse plane is just superior to the ribs; the inferior transverse plane is just superior to

the hip bones; and the parasagittal planes lie just medial to the nipples.

- The **epigastric** (ep"i-gas'trik) **region** is located superior to the umbilical region (*epi* = upon, above; *gastric* = stomach).
- The **hypogastric (pubic) region** is inferior to the umbilical region (*hypo* = below).
- The **right iliac (inguinal) region** and **left iliac (inguinal) region** are lateral to the hypogastric region (*iliac* = superior part of the hip bone).
- The **right lumbar region** and **left lumbar region** lie lateral to the umbilical region (*lumbus* = loins) and spinal column between the bottom ribs and the hip bones; see Figure 1.4b).
- The **right hypochondriac** (hi"po-kon'dre-ak) **region** and **left hypochondriac region** are lateral to the epigastric region and contain the lower ribs (*chondro* = cartilage).

### Other Body Cavities

In addition to the large closed body cavities, there are several smaller body cavities. Most are in the head and open to the body exterior.

- **Oral cavity** and **digestive cavity**. The oral cavity, or the mouth, contains the teeth and tongue. This cavity is part of and continuous with the digestive organs, which open to the exterior at the anus.
- **Nasal cavity**. Located within and posterior to the nose, the nasal cavity is part of the respiratory system.
- **Orbital cavities**. The orbital cavities (orbits) in the skull house the eyes and present them in an anterior position.
- **Middle ear cavities**. The middle ear cavities carved into the skull lie just medial to the eardrums. These cavities contain tiny bones that transmit sound vibrations to the hearing receptors in the inner ears.

### Did You Get It?

11. If you were dissecting a cadaver and wanted to separate the thoracic cavity from the abdominal cavity, which type of section would you make?
12. Which of the following organs are in the abdominopelvic cavity: spinal cord, small intestine, uterus, heart?
13. Joe went to the emergency room, where he complained of severe pains in the lower right quadrant of his abdomen. What might be his problem?

For answers, see Appendix A.

## 1.5 Homeostasis

### Learning Objectives

- ✓ Define *homeostasis*, and explain its importance.
- ✓ Define *negative feedback*, and describe its role in maintaining homeostasis and normal body function.

When you really think about the fact that your body contains trillions of cells in nearly constant activity, and that remarkably little usually goes wrong with it, you begin to appreciate what a marvelous organism your body really is. The word **homeostasis** (ho"me-o-sta'sis) describes the body's ability to maintain relatively stable internal conditions even though the outside world is continuously changing. Although the literal translation of *homeostasis* is "unchanging" (*homeo* = the same; *stasis* = standing still), the term does not really mean an unchanging state. Instead, it indicates a *dynamic* state of equilibrium, or a balance in which internal conditions change and vary but always within relatively narrow limits.

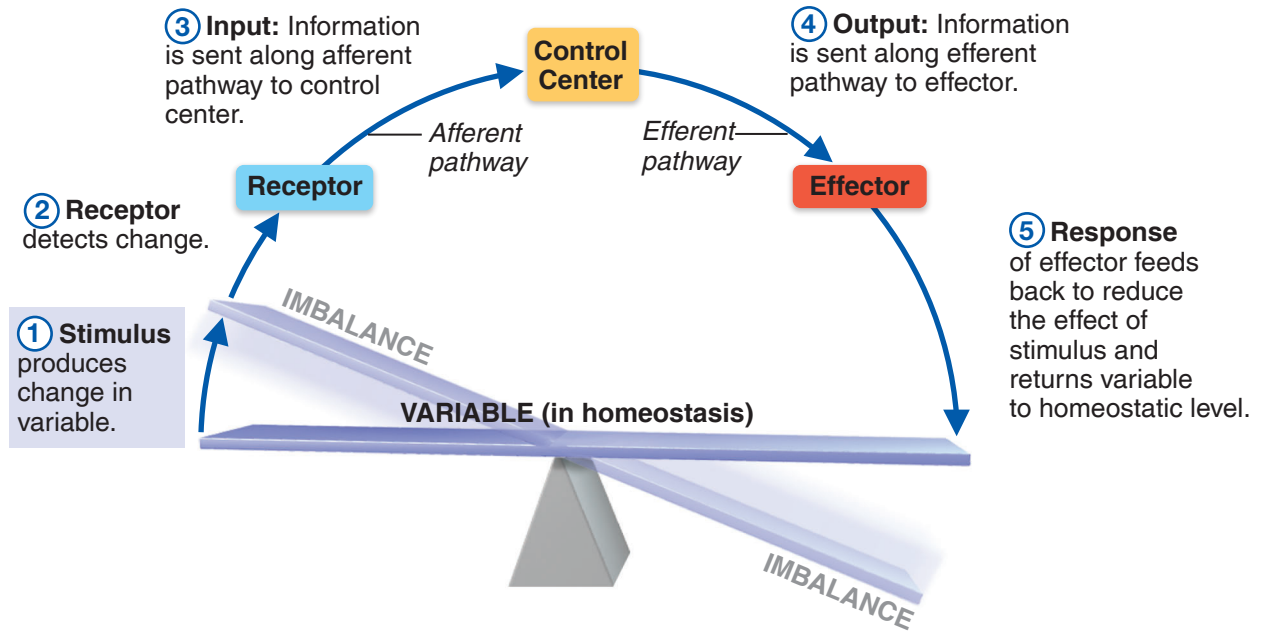
In general, the body demonstrates homeostasis when its needs are being adequately met and it is functioning smoothly. Virtually every organ system plays a role in maintaining the constancy of the internal environment. Adequate blood levels of vital nutrients must be continuously present, and heart activity and blood pressure must be constantly monitored and adjusted so that the blood is propelled with adequate force to reach all body tissues. Additionally, wastes must not be allowed to accumulate, and body temperature must be precisely controlled.

Communication within the body is essential for homeostasis and is accomplished chiefly by the nervous and endocrine systems, which use electrical signals delivered by nerves or bloodborne hormones, respectively, as information carriers. The details of how these two regulating systems operate are the subjects of later chapters, but we explain the basic characteristics of the neural and hormonal control systems that promote homeostasis here.

### 1.5a Components of Homeostatic Control Systems

Regardless of the factor or event being regulated (this is called the *variable*), all homeostatic control mechanisms have at least three components: a *receptor*, *control center*, and *effector* (Figure 1.9). The **receptor** is a type of sensor that monitors and responds to changes in the environment. It responds to such changes, called *stimuli*, by sending information (input) to the second component, the control center.

**Q** If this control system were regulating room temperature, what apparatus would be the effector?



**Figure 1.9** The elements of a homeostatic control system. Interaction between the receptor, control center, and effector is essential for normal operation of the system. This example shows negative feedback.

Information flows from the receptor to the control center along the *afferent pathway*. (It may help to remember that information traveling along the *afferent pathway approaches* the control center.)

The **control center** determines the level (set point) at which a variable is to be maintained. This component analyzes the information it receives and then determines the appropriate response or course of action.

The third component, the **effector**, provides the means for the control center's response (output) to the stimulus. Information flows from the control center to the effector along the *efferent pathway*. (*Efferent* information *exits* the control center.) The results of the response then *feed back* to influence the stimulus (the original change), either by reducing the amount of change (negative feedback), so that the whole control mechanism is shut off; or by increasing the amount of change (positive feedback), so that the reaction continues at an even faster rate.

### 1.5b Feedback Mechanisms

Most homeostatic control mechanisms are **negative feedback** mechanisms, as indicated in Figure 1.9. In such systems, the net effect of the response to the stimulus is to either shut off the original stimulus or reduce its intensity. A good example of a nonbiological negative feedback system is a home heating system connected to a thermostat. In this situation, the thermostat contains both the receptor and the control center. If the thermostat is set at 20°C (68°F), the heating system (effector) will be triggered ON when the house temperature drops below that setting. As the furnace produces heat, the air is warmed. When the temperature reaches 20°C or slightly higher, the thermostat sends a signal to shut off the furnace. Your body "thermostat" operates in a similar way to regulate body temperature. Other negative feedback mechanisms regulate heart rate, blood pressure, breathing rate, the release of hormones, and blood levels of glucose (blood sugar), oxygen, carbon dioxide, and minerals.

**Positive feedback** mechanisms are rare in the body because they tend to increase the original disturbance (stimulus) and to push the variable *farther* from its original value. Typically these mechanisms

**A** The heat-generating furnace or oil burner.

control infrequent events that occur explosively and do not require continuous adjustments. Blood clotting and the birth of a baby are the most familiar examples of positive feedback mechanisms.

### Homeostatic Imbalance 1.1

Homeostasis is so important that most disease can be regarded as being the result of its disturbance, a condition called **homeostatic imbalance**. As we age, our body organs become less efficient, and our internal conditions become less and less stable. These events place us at an increasing risk for illness and produce the changes we associate with aging.

We provide examples of homeostatic imbalances throughout this text to enhance your understanding of normal physiological mechanisms.

### Did You Get It?

- When we say that the body demonstrates homeostasis, do we mean that conditions in the body are unchanging? Explain your answer.
- When we begin to become dehydrated, we usually get thirsty, which causes us to drink liquids. Is the thirst sensation part of a negative or a positive feedback control system? Defend your choice.

For answers, see Appendix A.

## Summary



Listen to the story of this chapter in a brief summary at **Mastering A&P > Study Area > Author Narrated Audio Summaries**

### 1.1 An Overview of Anatomy and Physiology (pp. 23–24)

- Anatomy**—the study of structure
- Physiology**—the study of how a structure functions or works
- Structure determines what functions are possible

### 1.2 Levels of Structural Organization (pp. 24–29)

- Six levels of structural organization: **atoms** and molecules, **cells**, **tissues**, **organs**, **organ systems**, and the **organism**
- Eleven organ systems: **integumentary system**, **skeletal system**, **muscular system**, **nervous system**, **endocrine system**, **cardiovascular system**, **lymphatic system**, **respiratory system**, **digestive system**, **urinary system**, and **reproductive system**

### 1.3 Maintaining Life (pp. 29–32)

- Necessary life functions: maintaining boundaries, **movement**, **responsiveness**, **digestion**, **metabolism**, **excretion**, **reproduction**, and growth
- Items required for survival: **nutrients**, **oxygen**, water, **normal body temperature**, and normal **atmospheric pressure**

### 1.4 The Language of Anatomy (pp. 32–40)

- Anatomical terminology assumes that the body is in anatomical position
  - Anatomical position**—body stands erect, palms facing forward

### 1.4b. Directional terms often occur in pairs

- Superior** (toward the head): **inferior** (toward the tail)
- Anterior** (toward the front of the body): **posterior** (toward the rear or back of the body)
- Medial** (toward the midline of the body): **lateral** (away from the midline of the body)
- Proximal** (closer to the trunk): **distal** (farther from the trunk)
- Superficial** (at or close to the body surface): **deep** (below or away from the body surface)

### 1.4c. Regional terms are visible landmarks on the body surface (see Figure 1.4, p. 35)

### 1.4d. Body planes and sections

- A **sagittal section** separates the body into right and left parts
  - A **midsagittal section** separates the body into equal right and left parts
- A **frontal section** separates the body into anterior and posterior parts
- A **transverse section** separates the body into superior and inferior parts

### 1.4e. Body cavities

- Dorsal body cavity**: well protected by bone; includes **cranial cavity** (brain) and **spinal cavity** (spinal cord)
- Ventral body cavity**: protected only by trunk muscles; includes **thoracic cavity** (heart and lungs) and **abdominopelvic cavity** (digestive, urinary, and reproductive organs)

- Other small body cavities: **oral cavity**, **nasal cavity**, **orbital cavity**, and **middle ear cavity**

### 1.5 Homeostasis (pp. 40–42)

**1.5a.** Body functions interact to maintain **homeostasis**, a relatively stable internal environment

- **Homeostatic imbalance** leads to illness
- All homeostatic control mechanisms include a **receptor**, which responds to environmental

changes (stimuli); a **control center**, which assesses changes and stimulates an **effector**, which produces a response to the environmental change

**1.5b.** Most homeostatic control systems are negative feedback systems

- **Negative feedback** systems act to reduce or stop the initial stimulus
- **Positive feedback** systems act to increase the initial stimulus

## Review Questions

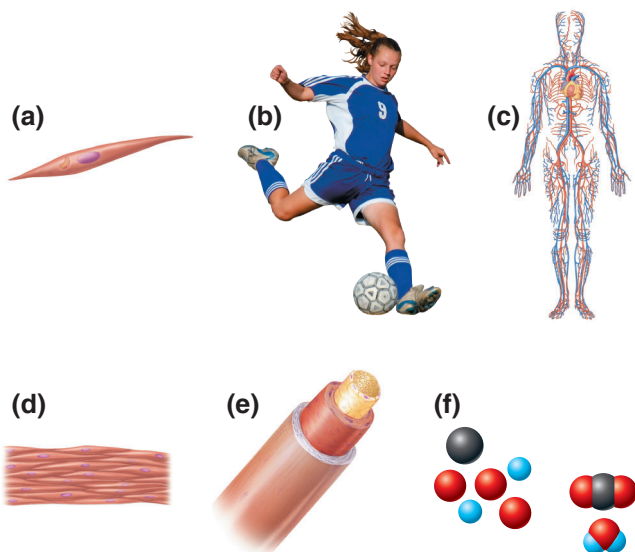


Access more practice questions at **Mastering A&P** > Study Area > Study by Chapter

### Multiple Choice

More than one choice may apply.

1. Which level of organization consists of groups of cells with similar structures and functions?



2. Which is *not* essential to survival?

- a. Water
- b. Oxygen
- c. Gravity
- d. Atmospheric pressure
- e. Nutrients

3. Using the terms listed below, fill in the blank with the proper term.

anterior superior medial proximal superficial  
posterior inferior lateral distal deep

The heart is located \_\_\_\_\_ to the diaphragm.

The muscles are \_\_\_\_\_ to the bone.

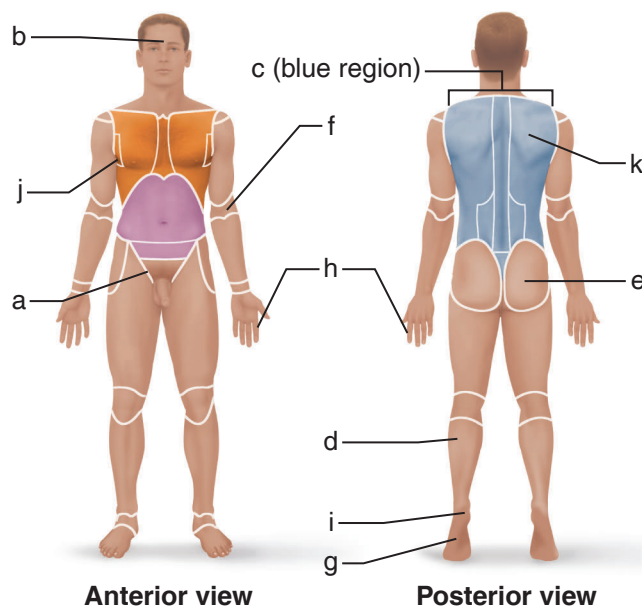
The shoulder is \_\_\_\_\_ to the elbow.

In anatomical position, the thumb is \_\_\_\_\_ to the index finger.

The vertebral region is \_\_\_\_\_ to the scapular region.

The gluteal region is located on the \_\_\_\_\_ surface of the body.

4. Match each anatomical region shown in the image with the anatomical term that describes it.



\_\_\_ 1. digital

\_\_\_ 2. dorsal

\_\_\_ 3. gluteal

\_\_\_ 4. inguinal

\_\_\_ 5. plantar

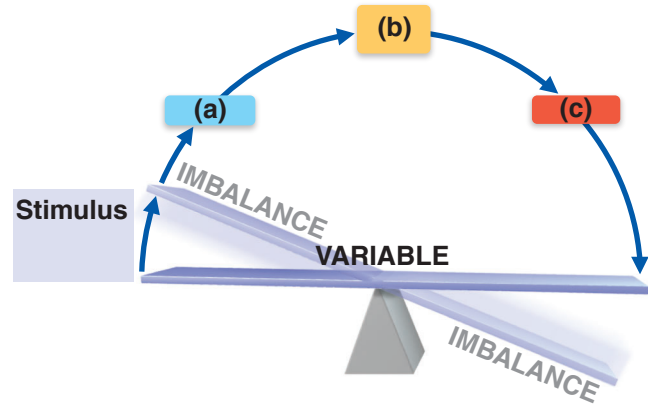
\_\_\_ 6. frontal

\_\_\_ 7. calcaneal

\_\_\_ 8. sural

\_\_\_ 9. antecubital

5. Anatomical terms that apply to the backside of the body in the anatomical position include
  - a. ventral and anterior.
  - b. back and rear.
  - c. posterior and dorsal.
  - d. head and lateral.
6. A neurosurgeon orders a spinal tap for a patient. Into what body cavity will the needle be inserted?
  - a. Ventral
  - b. Thoracic
  - c. Dorsal
  - d. Cranial
  - e. Pelvic
7. Which of the following body regions are subdivisions of the abdominopelvic cavity?
  - a. Thoracic
  - b. Epigastric
  - c. Hypogastric
  - d. Right hypochondriac
  - e. Spinal
8. Which component of homeostatic control is responsible for the following? See the figure.
  1. Sends signal to effector.
  2. Sends signal to control center.
  3. Receives signal of environmental change.
  4. In negative feedback, reduces original stimulus.



### Short Answer Essay

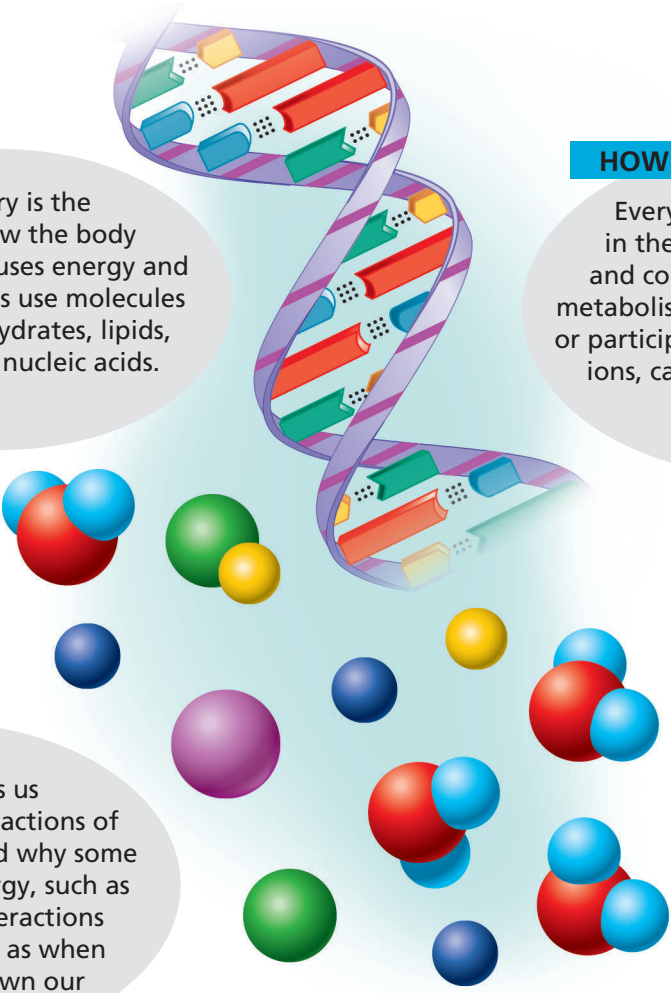
9. Define *anatomy* and *physiology*.
10. List the 11 organ systems of the body, briefly describe the function of each, and then name two organs in each system.
11. Which regions of the body do the following body landmarks refer to—acromial, crural, inguinal, popliteal, and sural?
12. Which of the following organ systems—digestive, respiratory, reproductive, circulatory, urinary, or muscular—are found in *both* subdivisions of the ventral body cavity? Which are found in the thoracic cavity only? In the abdominopelvic cavity only?
13. Explain the meaning of *homeostasis* as applied to the living organism.
14. What is the consequence of loss of homeostasis, or homeostatic imbalance?



## Critical Thinking and Clinical Application Questions

15. A diagnostic radiographer told John that she was going to take an image of his calcaneal region. What part of his body was she referring to? Later, a nurse told him that she was going to give him an injection containing pain killers in his gluteal region. Did he take off his shirt or his pants to get the injection? When John next saw a physiotherapist, the therapist noticed John had tenderness and swelling in the tarsal region. What part of his body was tender and swollen?
16. Jennifer fell off her motorcycle and tore a nerve in her axillary region. She also tore ligaments in her cervical and scapular regions and broke the only bone of her right brachial region. Explain where each of her injuries is located.
17. Students of an anatomy class are preparing to dissect a body to reach the heart. In which cavity is the heart located, and how can they gain access to it?
18. Parathyroid hormone (PTH) is secreted in response to a drop in the calcium level in the blood. The secretion of PTH is regulated by a negative feedback mechanism. What can you expect to happen to the calcium blood level as increased amounts of PTH are secreted, and why?
19. Tom likes to discuss medical matters with his doctor. Since Tom has fever quite often, he wants to know what might happen if a person's body temperature deviates grossly from the normal. What would be the doctor's response?

# 2 Basic Chemistry



**WHAT**

Chemistry is the basis for how the body transforms and uses energy and for how our cells use molecules such as carbohydrates, lipids, proteins, and nucleic acids.

**HOW**

Everything that happens in the body, from signaling and communication to energy metabolism requires the movement or participation of chemicals such as ions, carbohydrates, lipids, and proteins.

**WHY**

Chemistry helps us understand the interactions of different molecules and why some interactions store energy, such as in fat, and other interactions release energy, such as when enzymes break down our food.

Instructors may assign a related “Building Vocabulary” activity using **Mastering A&P**

Many short courses in anatomy and physiology lack the time to consider chemistry as a topic. So why include it here? The answer is simple: Your entire body is made up of chemicals—thousands of them—continuously interacting with one another at an incredible pace.

Chemical reactions underlie all body processes—movement, digestion, the pumping of your heart, and even your thoughts. In this chapter we present the basics of chemistry and biochemistry (the chemistry of living systems), providing the background you will need to understand body functions (physiology).

## 2.1 Concepts of Matter and Energy

### Learning Objectives

- ✓ Differentiate matter from energy.
- ✓ List four major energy forms, and provide one example of how each is used in the body.

### 2.1a Matter

**Matter** is the “stuff” of the universe. With some exceptions, it can be seen, smelled, and felt. More precisely, matter is anything that occupies space and has mass. *Weight* is a measure of gravity pulling on

mass. Chemistry studies the nature of matter—how its building blocks are put together and how they interact.

Matter exists in solid, liquid, and gaseous states, all of which are found in the human body. *Solids*, such as bones and teeth, have a definite shape and volume. *Liquids* have a definite volume, but they conform to the shape of their container. Examples of body liquids are blood plasma and the interstitial fluid that bathes all body cells. *Gases* have neither a definite shape nor a definite volume. The air we breathe is a mixture of gases.

Matter may be changed both physically and chemically. *Physical changes* do not alter the basic nature of a substance. Examples include changes in state, such as ice melting to water and food being cut into smaller pieces. *Chemical changes* do alter the composition of the substance—often substantially. Fermenting grapes to make wine and the digestion of food in the body are examples of chemical changes.

## 2.1b Energy

In contrast to matter, **energy** has no mass and does not take up space. It can be measured only by its effects on matter. We commonly define energy as the ability to do work or to put matter into motion. When energy is actually doing work (moving objects), we refer to it as **kinetic** (kĭ-neh'tik) **energy**. Kinetic energy is displayed in the constant movement of the tiniest particles of matter (atoms) as well as in larger objects, such as a bouncing ball. When energy is inactive or stored (as in the batteries of an unused toy), we call it **potential energy**. All forms of energy exhibit both kinetic and potential work capacities.

All living things are built of matter, and to grow and function they require a continuous supply of energy. Thus, matter is the substance, and energy is the mover of the substance. Because this is so, let's take a brief detour to introduce the forms of energy the body uses as it does its work.

### Forms of Energy

- **Chemical energy** is stored in the bonds of chemical substances. When the bonds are broken, the (potential) stored energy is unleashed and becomes kinetic energy (energy in action). For example, when gasoline molecules are broken apart in your automobile engine, the energy released powers your car. Similarly, the chemical

energy harvested from the foods we eat fuels all body activities.

- **Electrical energy** results from the movement of charged particles. In your house, electrical energy is the flow of subatomic particles called electrons along the wiring. In your body, an electrical current is generated when charged particles (called *ions*) move across cell membranes. The nervous system uses electrical currents called *nerve impulses* to transmit messages from one part of the body to another.
- **Mechanical energy** is energy *directly* involved in moving matter. When you pedal a bicycle, your legs provide the mechanical energy that turns the wheels. We can take this example one step further back: As the muscles in your legs shorten (contract), they pull on your bones, causing your limbs to move (so that you can pedal the bike).
- **Radiant energy** travels in waves; that is, it is the energy of the electromagnetic spectrum, which includes X rays, infrared radiation (heat energy), visible light, radio, and ultraviolet (UV) waves. Light energy, which stimulates the retinas of your eyes, is important in vision. UV waves cause sunburn, but they also stimulate our bodies to make vitamin D.

### Energy Form Conversions

With a few exceptions, energy is easily converted from one form to another. For example, chemical energy (from gasoline) that powers the motor of a speedboat is converted into the mechanical energy of the whirling propeller that allows the boat to skim across the water. In the body, chemical energy from food is trapped in the bonds of a high-energy chemical called **ATP (adenosine triphosphate)**, and ATP's energy may ultimately be transformed into the electrical energy of a nerve impulse or the mechanical energy of contracting muscles.

Energy conversions are not very efficient, and some of the initial energy supply is always "lost" to the environment as heat (thermal energy). It is not really lost, because energy cannot be created or destroyed, but the part given off as heat is *unusable*. You can easily demonstrate this principle by putting your finger close to a lightbulb that has been lit for an hour or so. Notice that some of the electrical energy reaching the bulb is producing heat instead of light. Likewise, all energy conversions in the body

liberate heat. This heat makes us warm-blooded animals and contributes to our relatively high body temperature, which has an important influence on body function. For example, when matter is heated, its particles begin to move more quickly; that is, their kinetic energy (energy of motion) increases. This is important to the chemical reactions that occur in the body because, up to a point, the higher the temperature, the faster those reactions occur.

### Did You Get It?

1. Matter and energy—how are they interrelated?
2. What form of energy is used to transmit messages from one part of the body to another? What form of energy fuels cellular processes?
3. What type of energy is available when we are still? When we are exercising?
4. What does it mean when we say that some energy is “lost” every time energy changes from one form to another in the body?

For answers, see Appendix A.

## 2.2 Composition of Matter

### 2.2a Elements and Atoms

#### Learning Objectives

- ✓ Define *element*, and list the four elements that form the bulk of body matter.
- ✓ Explain how elements and atoms are related.

All matter is composed of a limited number of substances called **elements**, unique substances that cannot be broken down into simpler substances by ordinary chemical methods. Examples of elements include many commonly known substances, such as oxygen, silver, gold, copper, and iron.

So far, 118 elements have been identified with certainty. Ninety-two of these occur in nature; the rest are made artificially in accelerator devices. A complete listing of the elements appears in the **periodic table**, an odd-shaped checkerboard (see Appendix C) that appears in chemistry classrooms the world over. Four of these elements—carbon, oxygen, hydrogen, and nitrogen—make up about 96 percent of the weight of the human body. Besides these four elements, several others are present in small or trace amounts. The most abundant elements found in the body and their major roles are listed in **Table 2.1**, p. 48.

Each element is composed of very similar particles, or building blocks, called **atoms**. Because all elements are unique, the atoms of each element differ from those of all other elements. We designate each element by a one- or two-letter shorthand name called an **atomic symbol**. In most cases, the atomic symbol is simply the first or first two letters of the element’s name. For example, C stands for carbon, O for oxygen, and Ca for calcium. In a few cases, the atomic symbol is taken from the Latin name for the element. For instance, Na (from the Latin word *natrium*) indicates sodium, and K (from *kalium*) potassium.

### 2.2b Atomic Structure

#### Learning Objective

- ✓ List the subatomic particles, and describe their relative masses, charges, and positions in the atom.

#### The Basic Atomic Subparticles

The word *atom* comes from the Greek word meaning “incapable of being divided,” and historically this idea of an atom was accepted as a scientific truth. According to this notion, you could theoretically divide a pure element, such as a block of gold, into smaller and smaller particles until you got down to the individual atoms, at which point you could subdivide no further. We now know that atoms, although indescribably small, are clusters of even smaller components called **subatomic particles**, which include *protons*, *neutrons*, and *electrons*. Even so, the old idea of atomic indivisibility is still very useful because an atom loses the unique properties of its element when it is split into its component particles.

An atom’s subatomic particles differ in their mass, electrical charge, and position within the atom (**Table 2.2**, p. 49). **Protons ( $p^+$ )** have a positive charge, whereas **neutrons ( $n^0$ )** are uncharged, or neutral. Protons and neutrons are heavy particles and have approximately the same mass (1 atomic mass unit, or amu). The tiny **electrons ( $e^-$ )** bear a negative charge equal in strength to the positive charge of the protons, but their mass is so small that it is usually designated as 0 amu.

The electrical charge of a particle is a measure of its ability to attract or repel other charged particles. Particles with the same type of charge (+ to + or – to –) repel each other, but particles with

**Table 2.1 Common Elements Making Up the Human Body**

Element	Atomic symbol	Percentage of body mass	Role
<b>Major (96.1%)</b>			
Oxygen	O	65.0	A major component of both organic and inorganic molecules; as a gas, essential to the oxidation of glucose and other food fuels, during which cellular energy (ATP) is produced.
Carbon	C	18.5	The primary element in all organic molecules, including carbohydrates, lipids, proteins, and nucleic acids.
Hydrogen	H	9.5	A component of all organic molecules; as an ion (a charged atom), it influences the pH of body fluids.
Nitrogen	N	3.2	A component of proteins and nucleic acids (genetic material).
<b>Lesser (3.9%)</b>			
Calcium	Ca	1.5	Found as a salt in bones and teeth; in ionic form, required for muscle contraction, neural transmission, and blood clotting.
Phosphorus	P	1.0	Present as a salt, in combination with calcium, in bones and teeth; also present in nucleic acids and many proteins; forms part of the high-energy compound ATP.
Potassium	K	0.4	In its ionic form, the major intracellular cation; necessary for the conduction of nerve impulses and for muscle contraction.
Sulfur	S	0.3	A component of proteins (particularly contractile proteins of muscle).
Sodium	Na	0.2	As an ion, the major extracellular cation; important for water balance, conduction of nerve impulses, and muscle contraction.
Chlorine	Cl	0.2	In ionic (chloride) form, the most abundant extracellular anion.
Magnesium	Mg	0.1	Present in bone; also an important cofactor for enzyme activity in a number of metabolic reactions.
Iodine	I	0.1	Needed to make functional thyroid hormones.
Iron	Fe	0.1	A component of the functional hemoglobin molecule (which transports oxygen within red blood cells) and some enzymes.
<b>Trace (less than 0.01%)*</b>			
Chromium (Cr), Cobalt (Co), Copper (Cu), Fluorine (F), Manganese (Mn), Molybdenum (Mo), Selenium (Se), Silicon (Si), Tin (Sn), Vanadium (V), Zinc (Zn)			

\*Referred to as the *trace elements* because they are required in very small amounts; many are found as part of enzymes or are required for enzyme activation.

opposite charges (+ to –) attract each other. Neutral particles are neither attracted to nor repelled by charged particles.

Because all atoms are electrically neutral, the number of protons an atom has must be balanced by its number of electrons (the + and – charges will

then cancel the effect of each other). Thus, helium has two protons and two electrons, and iron has 26 protons and 26 electrons. For any atom, the number of protons and electrons is always equal. Atoms that have gained or lost electrons are called *ions* and no longer have equal numbers of protons and electrons.

Table 2.2 Subatomic Particles

Particle	Position in atom	Mass (amu)	Charge
Proton ( $p^+$ )	Nucleus	1	+
Neutron ( $n^0$ )	Nucleus	1	0
Electron ( $e^-$ )	Orbits around the nucleus	1/2000*	-

\*The mass of an electron is so small, that we will ignore it and assume a mass of 0 amu.

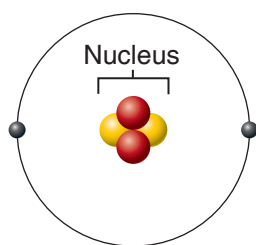
### Planetary and Orbital Models of an Atom

The **planetary model** of an atom portrays the atom as a miniature solar system (Figure 2.1a) in which the protons and neutrons are clustered at the center of the atom in the **atomic nucleus**. Because the nucleus contains all the heavy particles, it is fantastically dense and positively charged. The tiny electrons orbit around the nucleus in fixed, generally circular orbits, like planets around the sun. But we can never determine the exact location of electrons at a particular time because they jump around following unknown paths. So, instead of speaking of specific orbits, chemists talk about *orbitals*—regions around the nucleus in which electrons are *likely* to

be found. The **orbital model** depicts the general location of electrons outside the nucleus as a haze of negative charge referred to as the *electron cloud* (Figure 2.1b). Regions where electrons are most likely to be found are shown by denser shading rather than by orbit lines.

Notice that in both models, the electrons have the run of nearly the entire volume of the atom. Electrons also determine an atom's chemical behavior (that is, its ability to bond with other atoms). Though now considered outdated, the planetary model is simple and easy to understand and use. Most of the descriptions of atomic structure in this text use that model.

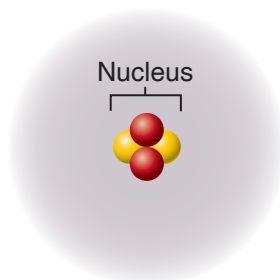
Hydrogen is the simplest atom, with just one proton and one electron. You can visualize the hydrogen atom by imagining it as a sphere with its diameter equal to the length of a football field. The nucleus could then be represented by a lead ball the size of a gumdrop in the exact center of the sphere and the lone electron pictured as a fly buzzing about unpredictably within the sphere. This mental picture should remind you that most of the volume of an atom is empty space, and most of the mass is in the central nucleus.



Helium atom

2 protons ( $p^+$ )  
2 neutrons ( $n^0$ )  
2 electrons ( $e^-$ )

(a) Planetary model







Helium atom

2 protons ( $p^+$ )  
2 neutrons ( $n^0$ )  
2 electrons ( $e^-$ )

(b) Orbital model

#### KEY:

 Proton	 Electron
 Neutron	 Electron cloud

**Figure 2.1 The structure of an atom.** The dense central nucleus contains the protons and neutrons. (a) In the planetary model of an atom, the electrons move around the nucleus in fixed orbits. (b) In the orbital model, electrons are shown as a cloud of negative charge.

#### Did You Get It?

- Which four elements make up the bulk of living matter?
- How is an atom related to an element?

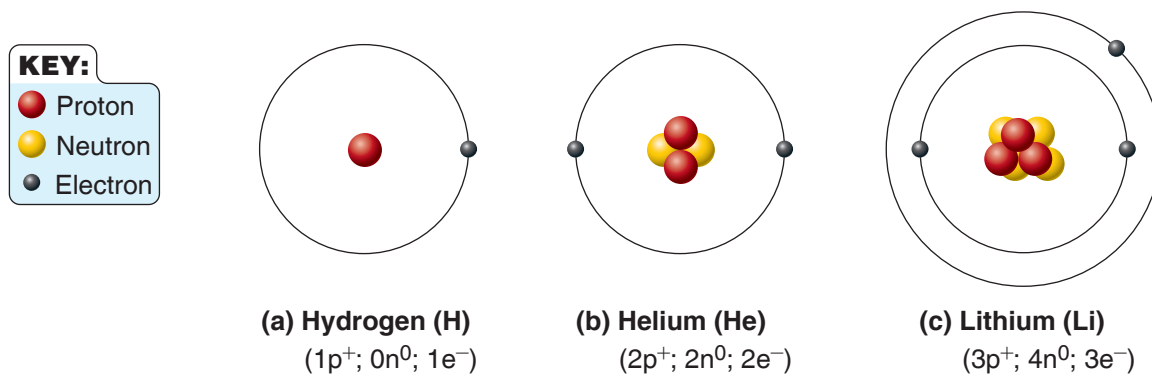
For answers, see Appendix A.

## 2.2c Identifying Elements

### Learning Objective

- Define *radioisotope*, and describe briefly how radioisotopes are used in diagnosing and treating disease.

All protons are alike, regardless of the atom being considered. The same is true of all neutrons and all



**Figure 2.2** Atomic structure of the three smallest atoms.

electrons. So what determines the unique properties of each element? The answer is that atoms of different elements are composed of *different numbers* of protons, neutrons, and electrons.

The simplest and smallest atom, hydrogen, has one proton, one electron, and no neutrons (**Figure 2.2**). Next is the helium atom, with two protons, two neutrons, and two orbiting electrons. Lithium follows with three protons, four neutrons, and three electrons. If we continue this step-by-step listing of subatomic particles, we could describe all known atoms by adding one proton and one electron at each step. The number of neutrons is not as easy to pin down, but light atoms tend to have equal numbers of protons and neutrons, whereas in larger atoms neutrons outnumber protons. However, all we really need to know to identify a particular element is its *atomic number*, *atomic mass number*, and *atomic weight*. Taken together, these indicators provide a fairly complete picture of each element.

### Atomic Number

Each element is given a number, called its **atomic number**, that is equal to the number of protons its atoms contain. Atoms of each element contain a different number of protons from the atoms of any other element; hence, its atomic number is unique. Because the number of protons is always equal to the number of electrons, the atomic number *indirectly* also tells us the number of electrons that atom contains.

### Atomic Mass Number

The **atomic mass number** (or just **mass number**) of any atom is the sum of the masses of all the

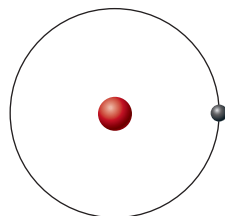
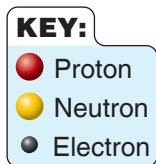
protons and neutrons contained in its nucleus. (Remember, the mass of an electron is so small that we ignore it.) Because hydrogen has one proton and no neutrons in its nucleus, its atomic number and mass number are the same: 1. Helium, with two protons and two neutrons, has a mass number of 4. The mass number is written as a superscript to the left of the atomic symbol (see the examples in **Figure 2.3**).

### Atomic Weight and Isotopes

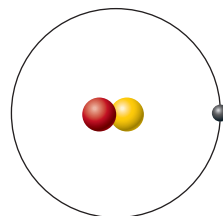
At first glance, it seems that the **atomic weight** of an atom should be equal to its atomic mass. This would be so if there were only one type of atom representing each element. However, the atoms of almost all elements exhibit two or more structural variations; these varieties are called **isotopes** (i'sō-tōps). Isotopes have the same number of protons and electrons but vary in the number of *neutrons* they contain. Thus, the isotopes of an element have the same atomic number but different atomic masses. Because all of an element's isotopes have the same number of electrons (and electrons determine bonding properties), their chemical properties are *exactly* the same. As a general rule, the atomic weight of any element is approximately equal to the mass number of its most abundant isotope. For example, as we said before, hydrogen has an atomic number of 1, but it also has isotopes with atomic masses of 1, 2 (called *deuterium*), and 3 (called *tritium*) (see **Figure 2.3**). Its atomic weight is 1.008, which reveals that its lightest isotope is present in much greater amounts in our world than its  $^2\text{H}$  or  $^3\text{H}$  forms. (The atomic numbers, mass numbers, and atomic weights for elements commonly found in the body are provided in **Table 2.3**).

Q

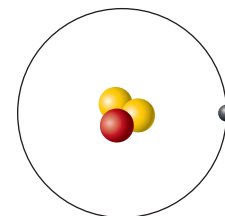
Which of these isotopes is the heaviest?



Hydrogen ( ${}^1\text{H}$ )  
( $1\text{p}^+$ ;  $0\text{n}^0$ ;  $1\text{e}^-$ )



Deuterium ( ${}^2\text{H}$ )  
( $1\text{p}^+$ ;  $1\text{n}^0$ ;  $1\text{e}^-$ )



Tritium ( ${}^3\text{H}$ )  
( $1\text{p}^+$ ;  $2\text{n}^0$ ;  $1\text{e}^-$ )

**Figure 2.3** Isotopes of hydrogen. Isotopes differ in their numbers of neutrons.

The heavier isotopes of certain atoms are unstable and tend to release energy in order to become more stable; such isotopes are called **radioisotopes**. Why this process occurs is very complex, but apparently the “glue” that holds the atomic nuclei together is weaker in the heavier isotopes. This process of spontaneous atomic decay, which is called

**radioactivity**, can be compared to a tiny sustained explosion. All types of radioactive decay involve the ejection of particles (*alpha* or *beta particles*) or electromagnetic energy (*gamma rays*) from the atom’s nucleus and are damaging to living cells. Emission of alpha particles has the least penetrating power; gamma radiation has the most. Contrary to what

**Table 2.3** Atomic Structures of the Most Abundant Elements in the Body

Element	Symbol	Atomic number (# of p)	Mass number (# of p + n)	Atomic weight	Electrons in valence shell
Calcium	Ca	20	40	40.078	2
Carbon	C	6	12	12.011	4
Chlorine	Cl	17	35	35.453	7
Hydrogen	H	1	1	1.008	1
Iodine	I	53	127	126.905	7
Iron	Fe	26	56	55.847	2
Magnesium	Mg	12	24	24.305	2
Nitrogen	N	7	14	14.007	5
Oxygen	O	8	16	15.999	6
Phosphorus	P	15	31	30.974	5
Sodium	Na	11	23	22.989	1
Sulfur	S	16	32	32.064	6

A

Tritium.

some believe, ionizing radiation does not damage the atoms in its path directly. Instead, it sends electrons flying, like a bowling ball through pins, all along its path. It is these electrons that do the damage.

Radioisotopes are used in minute amounts to tag biological molecules so that they can be followed, or traced, through the body and are valuable tools for medical diagnosis and treatment. For example, PET scans, which use radioisotopes, are discussed in “A Closer Look” (pp. 32–33). A radioisotope of iodine can be used to scan the thyroid gland of a patient suspected of having a thyroid tumor. Additionally, radium, cobalt, and certain other radioisotopes are used to destroy localized cancers.

### Did You Get It?

- An atom has five neutrons, four protons, and four electrons. What is its atomic number? What is its atomic mass number?
- What name is given to an unstable atom that has either more or fewer neutrons than its typical number?

For answers, see Appendix A.

## 2.3 Molecules and Compounds

### Learning Objective

- Define *molecule*, and explain how molecules are related to compounds.

When two or more atoms combine chemically, **molecules** are formed. If two or more atoms of the same element bond, or become chemically linked together, a molecule of that element is produced. For

example, when two hydrogen atoms bond, a molecule of hydrogen gas is formed:



In this example of a chemical reaction, the *reactants* (the atoms taking part in the reaction) are indicated by their atomic symbols, and the *product* (the molecule formed) is indicated by a *molecular formula* that shows its atomic makeup. The chemical reaction is shown as a *chemical equation*.

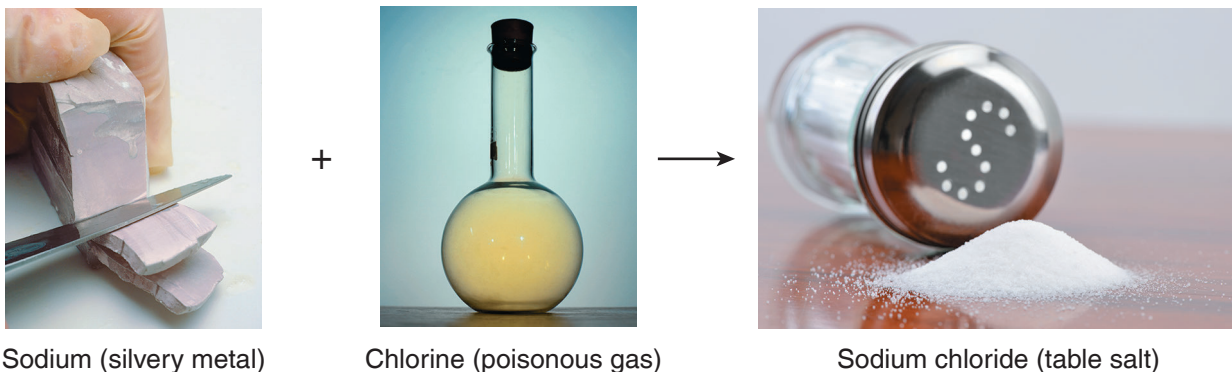
When two or more *different* atoms bind together to form a molecule, the molecule is more specifically referred to as a molecule of a **compound**. For example, four hydrogen atoms and one carbon atom can interact chemically to form methane:



Thus, a molecule of methane is a compound, but a molecule of hydrogen gas is not—it is instead called *molecular hydrogen*.

Compounds always have properties quite different from those of the atoms making them up, and it would be next to impossible to determine the atoms making up a compound without analyzing it chemically. Sodium chloride is an excellent example of the difference in properties between a compound and its constituent atoms (**Figure 2.4**). Sodium is a silvery white metal, and chlorine in its molecular state is a poisonous green gas used to make bleach. However, sodium chloride is table salt, a white

\*Notice that when the number of atoms is written as a subscript, it indicates that the atoms are joined by a chemical bond. Thus, 2H represents two separate atoms, but H<sub>2</sub> indicates that the two hydrogen atoms are bound together to form a molecule. The atomic symbol by itself represents one atom.



**Figure 2.4** Properties of a compound differ from those of its atoms.

crystalline solid that we sprinkle on our food. Notice that just as an atom is the smallest particle of an element that still retains that element's properties, a molecule is the smallest particle of a compound that still retains the properties of that compound. If you break the bonds between the atoms of the compound, properties of the atoms, rather than those of the compound, will be exhibited.

### Did You Get It?

9. What is the meaning of the term *molecule*?
10. How does a molecular substance differ from a molecule of a compound?

For answers, see Appendix A.

## 2.4 Chemical Bonds and Chemical Reactions

### Learning Objectives

- ✓ Recognize that chemical reactions involve the interaction of electrons to make and break chemical bonds.
- ✓ Differentiate between ionic, polar covalent, and nonpolar covalent bonds, and describe the importance of hydrogen bonds.
- ✓ Contrast synthesis, decomposition, and exchange reactions.

**Chemical reactions** occur whenever atoms combine with or dissociate from other atoms. When atoms unite chemically, chemical bonds are formed.

### 2.4a Bond Formation

A **chemical bond** is not an actual physical structure, like a pair of handcuffs linking two people together. Instead, it is an energy relationship that involves interactions between the electrons of the reacting atoms. Let's consider the role electrons play in forming bonds.

#### Role of Electrons

The orbits, or generally fixed regions of space that electrons occupy around the nucleus (see Figure 2.2), are called **electron shells**, or **energy levels**. The maximum number of electron shells in any atom known so far is seven, and these are numbered 1 to 7 from the nucleus outward. The electrons closest to the nucleus are those most strongly attracted to its positive charge, and those farther away are less

securely held. As a result, the more distant electrons are likely to interact with other atoms. Put more simply, the electron shell furthest from the nucleus is also the first part of the atom any other atom will come into contact with prior to reacting or bonding.

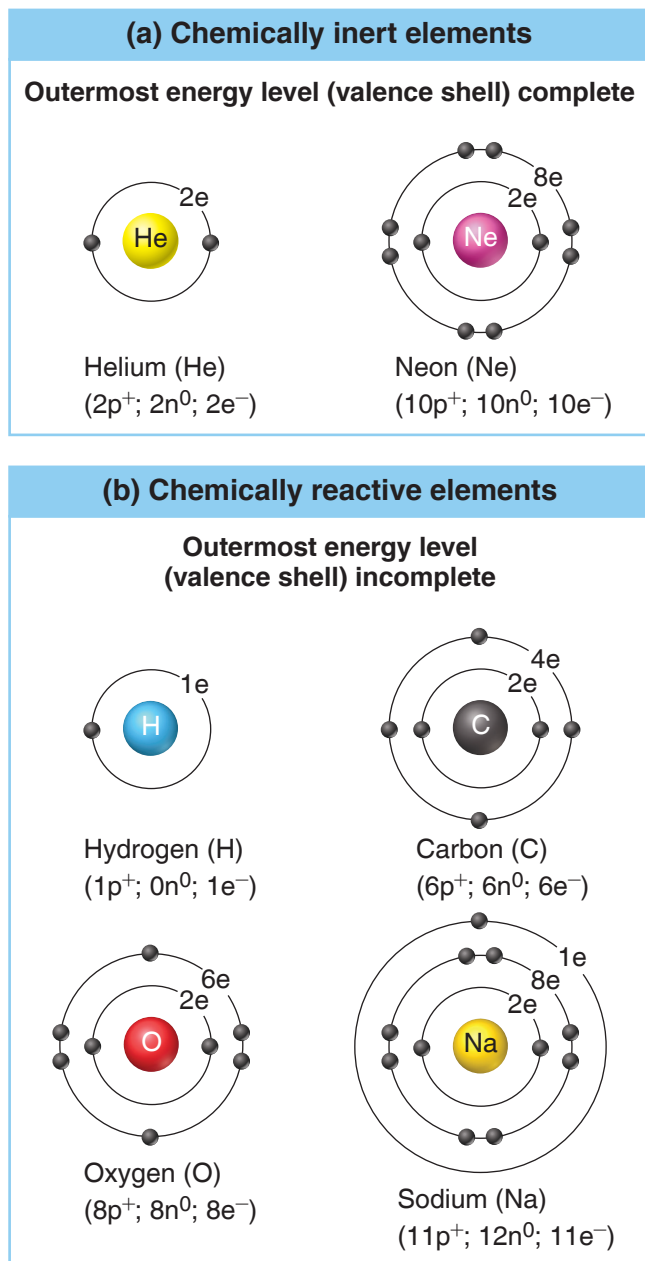
There is an upper limit to the number of electrons that each electron shell can hold. Shell 1, closest to the nucleus, is small and can accommodate only 2 electrons. Shell 2 holds a maximum of 8. Shell 3 can accommodate up to 18 electrons. Subsequent shells hold larger and larger numbers of electrons. In most (but not all) cases, the shells tend to be filled consecutively.

The only electrons that are important to bonding behavior are those in the atom's outermost shell. This shell is called the **valence shell**, and its *valence electrons* determine the chemical behavior of the atom. As a general rule, the electrons of inner shells do not take part in bonding.

The key to chemical reactivity is referred to as the *rule of eights*: In the absence of a full valence shell, atoms interact in such a way that they will have eight electrons in their valence shell. The first electron shell represents an exception to this rule, because it is "full" when it has two electrons. When the valence shell of an atom contains eight electrons, the atom is completely stable and is chemically inactive (inert). When the valence shell contains fewer than eight electrons, an atom will tend to gain, lose, or share electrons with other atoms to reach a stable state. When any of these events occurs, chemical bonds are formed. (Examples of chemically inert and reactive elements are shown in Figure 2.5, p. 54). As you might guess, atoms must approach each other very closely for their electrons to interact in a chemical bond—in fact, their outermost electron shells must overlap.

#### Types of Chemical Bonds

**Ionic Bonds** **Ionic** (i-on'ik) **bonds** form when electrons are completely transferred from one atom to another. Atoms are electrically neutral, but when they gain or lose electrons during bonding, their positive and negative charges are no longer balanced, and charged particles, called **ions**, result. When an atom gains an electron, it acquires a net negative charge because it now has more electrons than protons. Negatively charged ions are more specifically called *anions*, and they are indicated by a minus sign after the atomic symbol, such as  $\text{Cl}^-$  for the chloride ion. When atoms lose an electron, they become



**Figure 2.5** Chemically inert and reactive elements.

To simplify the diagrams, each atomic nucleus is shown as a circle with the atom's symbol in it; protons and neutrons are not shown.

positively charged ions, *cations*, because they now possess more protons than electrons. Cations are represented by their atomic symbol with a plus sign, such as H<sup>+</sup> for the hydrogen ion (it may help you to remember that a cation is positively charged by thinking of its "t" as a plus [+ ] sign). Both anions and cations result when an ionic bond is formed.

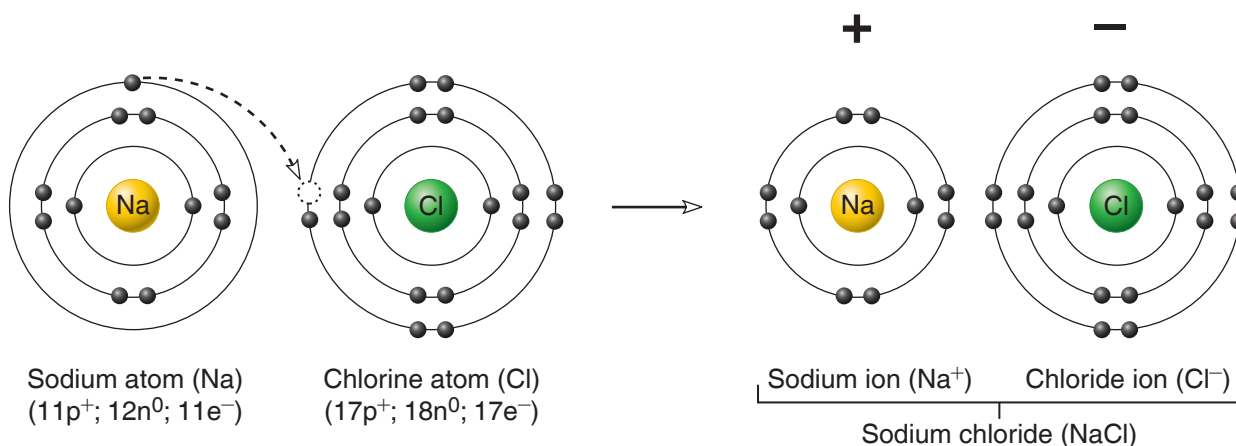
Because opposite charges attract, the newly created ions tend to stay close together.

The formation of sodium chloride (NaCl), common table salt, provides a good example of ionic bonding. Sodium's valence shell contains only one electron and so is incomplete (Figure 2.6). However, if this single electron is "lost" to another atom, shell 2, which contains eight electrons, becomes the valence shell; thus sodium becomes a cation (Na<sup>+</sup>) and achieves stability. Chlorine needs only one electron to fill its valence shell, and it is much easier to gain one electron (forming Cl<sup>-</sup>) than it is to "give away" seven. Thus, the ideal situation is for sodium to donate its valence electron to chlorine, which is exactly what happens. Sodium chloride and most other compounds formed by ionic bonding fall into the general category of inorganic chemicals called *salts*.

**Covalent Bonds** Electrons do not have to be completely lost or gained for atoms to become stable. Instead, they can be shared in such a way that each atom is able to fill its valence shell at least part of the time.

Molecules in which atoms share valence electrons are called *covalent molecules*, and their bonds are **covalent bonds** (*co* = with; *valent* = having power). For example, hydrogen, with its single electron, can become stable if it fills its valence shell (energy level 1) by sharing a pair of electrons—its own and one from another atom. A hydrogen atom can share an electron pair with another hydrogen atom to form a molecule of hydrogen gas (Figure 2.7a, p. 56). The shared electron pair orbits the whole molecule and satisfies the stability needs of both hydrogen atoms. Likewise, two oxygen atoms, each with six valence electrons, can share two pairs of electrons (form double bonds) with each other (Figure 2.7b) to form a molecule of oxygen gas (O<sub>2</sub>).

A hydrogen atom may also share its electron with an atom of a different element. Carbon has four valence electrons but needs eight to achieve stability. When methane gas (CH<sub>4</sub>) is formed, carbon shares four electrons with four hydrogen atoms (each bond includes one electron from each atom to form a pair of electrons; Figure 2.7c). Because the shared electrons orbit and "belong to" the whole molecule, each atom has a full valence shell enough of the time to satisfy its stability needs.



**Figure 2.6 Formation of an ionic bond.** Both sodium and chlorine atoms are chemically reactive because their valence shells are incompletely filled. Sodium gains stability by losing one electron, whereas chlorine becomes stable by gaining one electron. After electron transfer, sodium becomes a sodium ion (Na<sup>+</sup>), and chlorine becomes a chloride ion (Cl<sup>-</sup>). The oppositely charged ions attract each other.

In the covalent molecules described thus far, electrons have been shared *equally* between the atoms of the molecule. Such molecules are called *nonpolar covalent molecules*. However, electrons are not shared equally in all cases. When covalent bonds are made, the molecule formed always has a definite three-dimensional shape. A molecule's shape plays a major role in determining just what other molecules (or atoms) it can interact with; the shape may also result in unequal electron-pair sharing. The following two examples illustrate this principle.

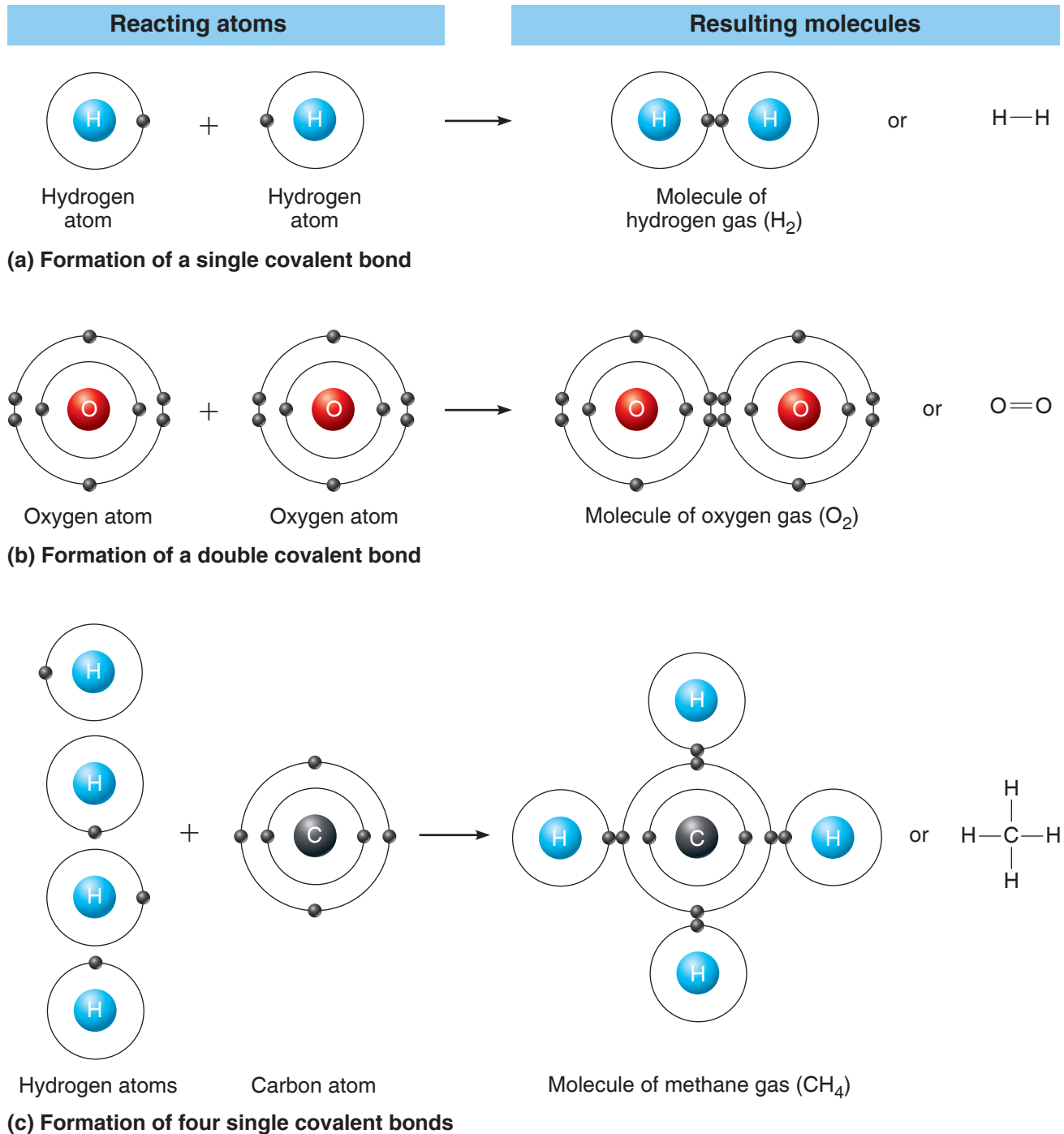
Carbon dioxide (CO<sub>2</sub>) is formed when a carbon atom shares its four valence electrons with two oxygen atoms. Oxygen is a very "electron-hungry" atom, so it attracts the shared electrons much more strongly than does carbon. However, because the carbon dioxide molecule is linear (O=C=O), the electron-pulling power of one oxygen atom is offset by that of the other, like a tug-of-war at a standoff between equally strong teams (Figure 2.8a, p. 57). As a result, the electron pairs are shared equally and orbit the entire molecule, and carbon dioxide is a *nonpolar molecule*.

A water molecule (H<sub>2</sub>O) is formed when two hydrogen atoms bind covalently to a single oxygen atom. Each hydrogen atom shares an electron pair with the oxygen atom, and again the oxygen has the stronger electron-attracting ability. But in this case, the molecule formed is V-shaped (H—O—H). The

two hydrogen atoms are located at one end of the molecule, and the oxygen atom is at the other (Figure 2.8b); consequently, the electron pairs are not shared equally. This arrangement allows them to spend more time in the vicinity of the oxygen atom. Because electrons are negatively charged, that end of the molecule becomes slightly more negative (indicated by δ<sup>-</sup>, the Greek letter delta with a minus sign) and the hydrogen end becomes slightly more positive (indicated by δ<sup>+</sup>). In other words, a *polar molecule*, a molecule with two charged *poles*, is formed.

Polar molecules orient themselves toward other polar molecules or charged particles (ions, proteins, and others), and they play an important role in chemical reactions that occur in body cells. Because different types of body tissues can consist of up to 80 percent water, the fact that water is a polar molecule is particularly significant.

**Hydrogen Bonds** Hydrogen bonds are extremely weak bonds formed when a hydrogen atom bound to one "electron-hungry" nitrogen or oxygen atom is attracted by another such atom, and the hydrogen atom forms a "bridge" between them. Electrons are not involved in hydrogen bonds, as they are in ionic and covalent bonds. Hydrogen bonding is common between water molecules (Figure 2.9a, p. 57) and is reflected in water's surface tension. The surface tension of water causes it to "ball up," or form spheres at the surface. This tension allows some insects, such



**Figure 2.7 Formation of covalent bonds.** (a) Formation of a single covalent bond\* between two hydrogen atoms forms a molecule of hydrogen gas. (b) Formation of a molecule of oxygen gas. Each oxygen

atom shares two electron pairs with its partner; thus, a double covalent bond is formed. (c) Formation of a molecule of methane. A carbon atom shares four electron pairs with four hydrogen atoms. In the structural

formulas of the molecules shown at the far right, each pair of shared electrons is indicated by a single line connecting the sharing atoms.

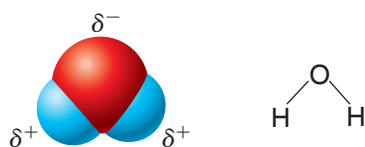
\*Note that in each covalent bond formed, each participating atom donates one electron to the partnership. Thus, each individual covalent bond includes a pair of electrons (2) being shared by both atoms.



Which molecule—(a) or (b)—is a polar molecule?

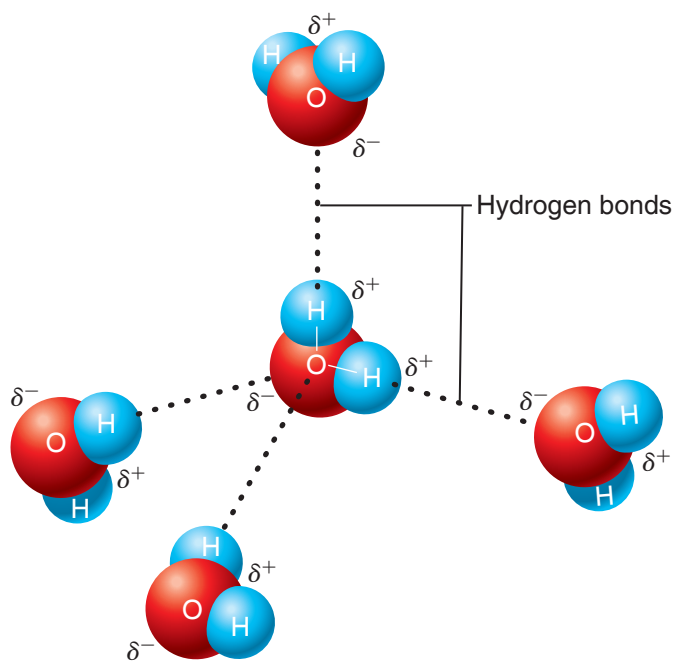


(a) Carbon dioxide ( $\text{CO}_2$ )



(b) Water ( $\text{H}_2\text{O}$ )

**Figure 2.8** Molecular models illustrating the three-dimensional structure of carbon dioxide and water molecules.



(a)

**Figure 2.9** Hydrogen bonding between polar water molecules.

(a) The slightly positive ends of the water molecules (indicated by  $\delta^+$ )

become aligned with the slightly negative ends (indicated by  $\delta^-$ ) of other water molecules. (b) Water's high surface tension, a result of the

combined strength of its hydrogen bonds, allows a water strider to walk on a pond without breaking the surface.

as water striders, to walk on water as long as they tread lightly (Figure 2.9b).

Hydrogen bonds are also important *intramolecular bonds*; that is, they help to bind different parts of the *same* molecule together into a special three-dimensional shape. These rather fragile bonds are very important in helping to maintain the structure of both protein molecules, which are essential functional molecules and body-building materials, and DNA, the genetic information molecule.

## 2.4b Patterns of Chemical Reactions

Chemical reactions involve the making or breaking of bonds between atoms. The total number of atoms remains the same, but the atoms appear in new combinations. Most chemical reactions have one of the three recognizable patterns we describe next.

### Synthesis Reactions

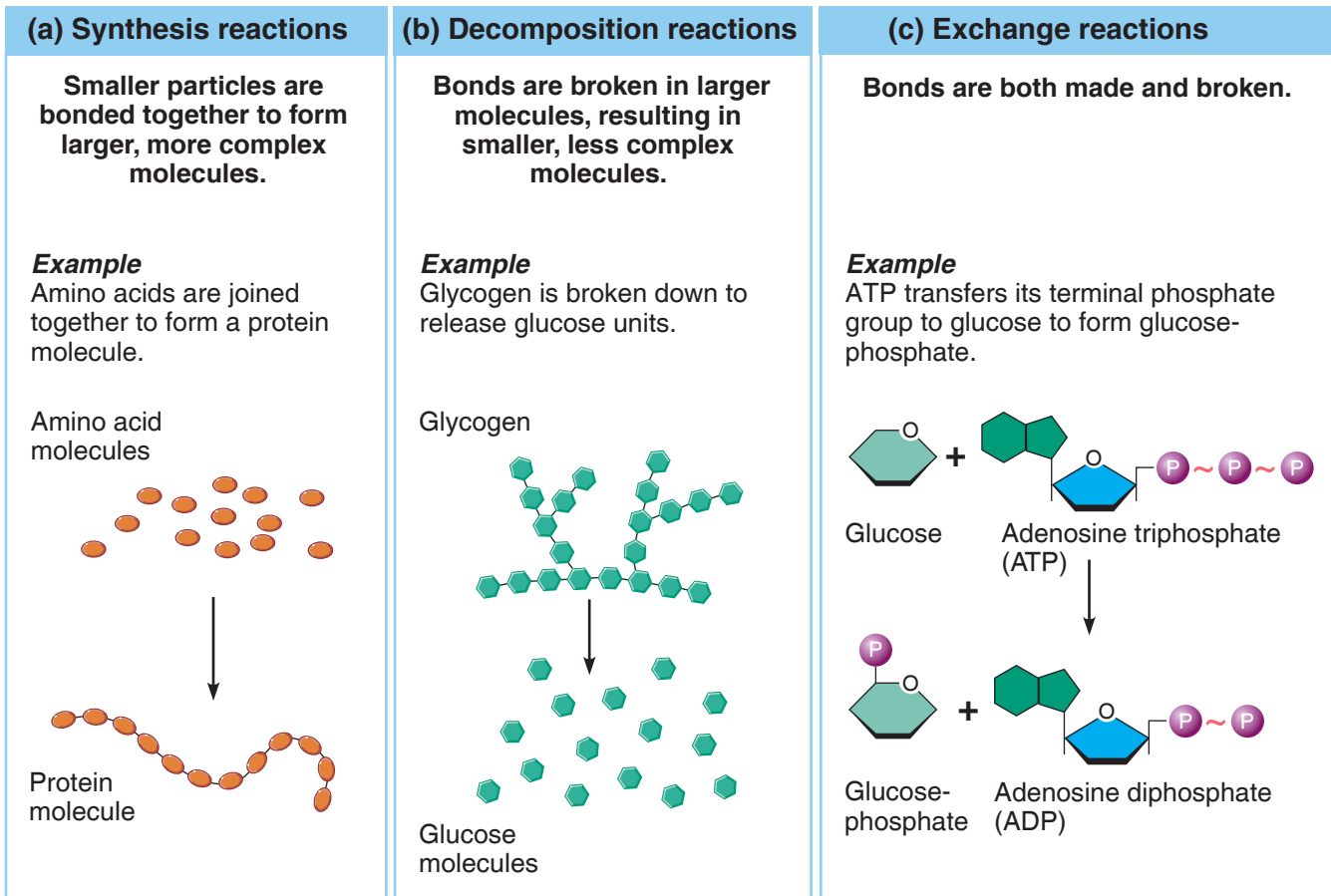
**Synthesis reactions** occur when two or more atoms or molecules combine to form a larger,



(b)

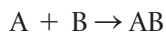


Water is a polar molecule.



**Figure 2.10** Patterns of chemical reactions.

more complex molecule, which can be simply represented as

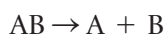


Synthesis reactions always involve bond formation. Because energy must be absorbed to make bonds, synthesis reactions are energy-storing reactions.

Synthesis reactions underlie all anabolic (building) activities that occur in body cells. They are particularly important for growth and for repair of worn-out or damaged tissues. The formation of a protein molecule by the joining of *amino acids* (protein building blocks) into long chains is a synthesis reaction (**Figure 2.10a**).

### Decomposition Reactions

**Decomposition reactions** occur when a molecule is broken down into smaller molecules, atoms, or ions and can be indicated by



Essentially, decomposition reactions are synthesis reactions in reverse. Bonds are always broken, and the products of these reactions are smaller and simpler than the original molecules. As bonds are broken, chemical energy is released.

Decomposition reactions underlie all catabolic (destructive) processes that occur in body cells; that is, they are reactions that break down molecules. Examples include the digestion of foods into their building blocks and the breakdown of glycogen (a large carbohydrate molecule stored in the liver) to release glucose (**Figure 2.10b**) when the blood sugar level starts to decline.

### Exchange Reactions

**Exchange reactions** involve simultaneous synthesis and decomposition reactions; in other words, bonds are both made and broken. During exchange reactions, a switch is made between molecule parts (changing partners, so to speak), and different

**Table 2.4 Factors Increasing the Rate of Chemical Reactions**

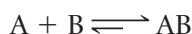
Factor	Mechanism to increase the number of collisions
↑ temperature	↑ the kinetic energy of the molecules, which in turn move more rapidly and collide more forcefully.
↑ concentration of reacting particles	↑ the number of collisions because reacting particles are crowded together.
↓ particle size	Smaller particles have more kinetic energy and move faster than larger ones, hence they take part in more collisions.
Presence of catalysts	↓ the amount of energy the molecules need to interact by holding the reactants in the proper positions to interact (see p. 72).

molecules are made. Thus, an exchange reaction can be generally indicated as

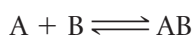


An exchange reaction occurs, for example, when ATP reacts with glucose and transfers its end phosphate group (its full name is *adenosine triphosphate*; *tri-* = three) to glucose, forming glucose-phosphate (Figure 2.10c). At the same time, the ATP becomes ADP, adenosine diphosphate (*di-* = two). This important reaction, which occurs whenever glucose enters a body cell, traps glucose inside the cell.

Most chemical reactions are reversible. If chemical bonds can be made, they can be broken, and vice versa. Reversibility is indicated by a double arrow in a chemical equation. When the arrows differ in length, the longer arrow indicates the more rapid reaction or the major direction in which the reaction is proceeding. For example, in the reaction



the reaction going to the right is occurring more rapidly, so over time AB will accumulate while A and B will decrease in amount. If the arrows are of equal length, the reaction is at chemical equilibrium. Thus, in



for each molecule of AB made, a molecule of AB is breaking down to release A and B.

### Factors Influencing the Rate of Chemical Reactions

As mentioned earlier, for the atoms forming molecules to react chemically, their outermost electron shells must overlap. In fact, for them to get close enough for this to happen, the particles must collide

forcefully. Remember also that atoms move constantly because of their kinetic energy—this is what drives collisions between particles. Several factors, including temperature, concentration of the particles, and size of the particles, influence the kinetic energy and, hence, the speed of the particles and the force of collisions (Table 2.4).

### Did You Get It?

- How do ionic bonds differ from covalent bonds?
- What kind of bond forms between water molecules?
- Which reaction type (see Figure 2.10) occurs when fats are digested in your small intestine?
- How can you indicate that a chemical reaction is reversible?

For answers, see Appendix A.

## 2.5 Biochemistry: The Chemical Composition of Living Matter

### Learning Objective

- ✓ Distinguish organic from inorganic compounds.

All chemicals found in the body fall into one of two major classes of molecules: either inorganic or organic compounds. The class of the compound is determined solely by the presence or absence of carbon. Except for a few so far unexplainable exceptions (such as carbon dioxide gas [CO<sub>2</sub>] and carbon monoxide [CO]), **inorganic compounds** lack carbon and tend to be small, simple molecules. Examples of inorganic compounds found in the body are *water*, *salts*, and many (but not all)

*acids* and *bases*. **Organic compounds** contain carbon. The important organic compounds in the body are *carbohydrates*, *lipids*, *proteins*, and *nucleic acids*. All organic compounds are fairly (or very) large covalent molecules.

Inorganic and organic compounds are equally essential for life. Trying to determine which is more valuable can be compared to trying to decide whether the ignition system or the engine is more essential to the operation of a car.

## 2.5a Inorganic Compounds

### Learning Objectives

- ✔ Explain the importance of water to body homeostasis, and provide several examples of the roles of water.
- ✔ List several salts (or their ions) vitally important to body functioning.
- ✔ Differentiate a salt, an acid, and a base.
- ✔ Explain the concept of pH, and state the pH of blood.

### Water

Water is the most abundant inorganic compound in the body. It accounts for about two-thirds of body weight. Among the properties that make water so vital are the following:

- **High heat capacity.** Water has a *high heat capacity*; that is, it absorbs and releases large amounts of heat before its temperature changes. Thus, it prevents the sudden changes in body temperature that might otherwise result from intense sun exposure, chilling winter winds, or internal events (such as vigorous muscle activity) that liberate large amounts of heat.
- **Polarity/solvent properties.** Water is an excellent solvent because of its polarity; indeed, it is often called the “universal solvent.” A *solvent* is a liquid or gas in which smaller amounts of other substances, called *solutes* (which may be gases, liquids, or solids), can be dissolved or suspended. The resulting mixture is called a *solution* when the solute particles are exceedingly tiny, and a *suspension* when the solute particles are fairly large. Translucent mixtures with solute particles of intermediate size are called *colloids*.

Small reactive chemicals—such as salts, acids, and bases—dissolve easily in water and become evenly distributed. Molecules cannot react chemically unless they are in solution, so virtually all

chemical reactions that occur in the body depend on water’s solvent properties.

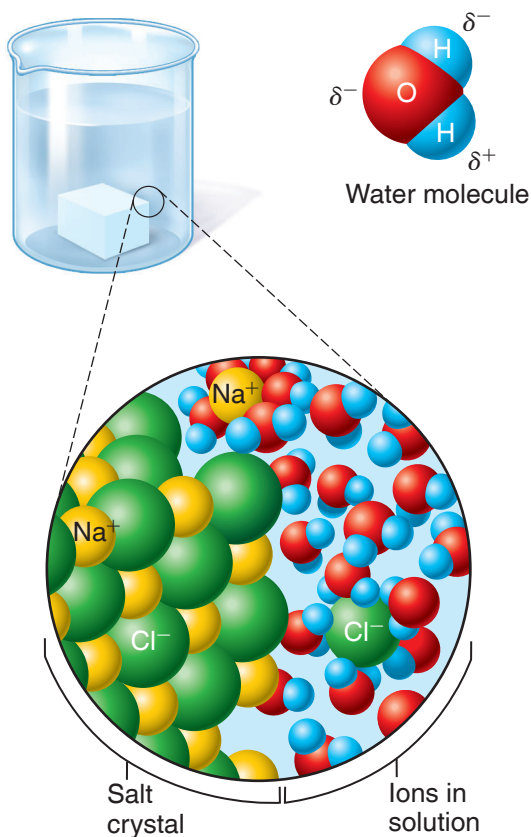
Because nutrients, respiratory gases (oxygen and carbon dioxide), and wastes can dissolve in water, water can act as a transport and exchange medium in the body. For example, all these substances are carried around the body in blood plasma (the liquid part of blood that is mostly made up of water) and are exchanged between the blood and body cells by passing through the water-based interstitial fluid that bathes cells. Specialized molecules that lubricate the body, such as mucus and synovial fluid, also use water as their solvent. Synovial fluid “oils” the ends of bones as they move within joint cavities.

- **Chemical reactivity.** Water is an important *reactant* in some types of chemical reactions. For example, to digest foods or break down biological molecules, water molecules are added to the bonds of the larger molecules in order to break them. Such reactions are called *hydrolysis reactions*, a term that specifically recognizes this role of water (*hydro* = water; *lys* = splitting).
- **Cushioning.** Water also serves a protective function. In cerebrospinal fluid, water forms a cushion around the brain that helps to protect it from physical trauma. Amniotic fluid, which surrounds a developing fetus within the mother’s body, plays a similar role in protecting the fetus.

### Salts

A **salt** is an ionic compound containing cations other than the *hydrogen ion* ( $H^+$ ) and anions other than the *hydroxide ion* ( $OH^-$ ). Salts of many metal elements are commonly found in the body, but the most plentiful salts are those containing calcium and phosphorus, found chiefly in bones and teeth. When dissolved in body fluids, salts easily separate into their ions. This process, called *dissociation*, occurs rather easily because the ions have already been formed. All that remains is for the ions to “spread out.” This is accomplished by the polar water molecules, which orient themselves with their slightly negative ends toward the cations and their slightly positive ends toward the anions, thereby overcoming the attraction between them (**Figure 2.11**).

Salts, both in their ionic forms and in combination with other elements, are vital to body functioning. For example, sodium and potassium ions are



**Figure 2.11 Dissociation of salt in water.** The slightly negative ends of the water molecules ( $\delta^-$ ) are attracted to  $\text{Na}^+$ , whereas the slightly positive ends of water molecules ( $\delta^+$ ) orient toward  $\text{Cl}^-$ , causing the ions of the salt crystal to be pulled apart.

essential for nerve impulses, and iron forms part of the hemoglobin molecule that transports oxygen within red blood cells.

Because ions are charged particles, all salts are **electrolytes**—substances that conduct an electrical current in solution. When electrolyte balance is severely disturbed, virtually nothing in the body works. (The functions of the elements found in body salts are summarized in Table 2.1 on p. 48.)

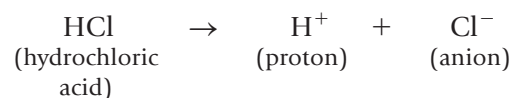
### Acids and Bases

Like salts, acids and bases are electrolytes. That is, they ionize, dissociate in water, and can then conduct an electrical current.

**Characteristics of Acids** **Acids** have a sour taste and can dissolve many metals or “burn” a hole in your rug. Acids can have a devastating effect; for example, consider the damage to sea life, trees, and famous historical monuments caused by the

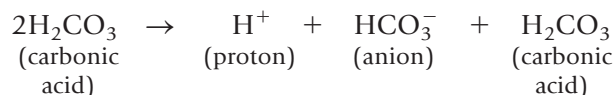
vinegar-like acid rain. But the most useful definition of an acid is that it is a substance that can release *hydrogen ions* ( $\text{H}^+$ ) in detectable amounts. Because a hydrogen ion is a hydrogen nucleus (a “naked proton”), acids are also defined as **proton ( $\text{H}^+$ ) donors**. You may find it useful to think of acids as putting protons “in the game.” As free protons, hydrogen ions can influence the acidity of body fluids.

When acids are dissolved in water, they release hydrogen ions and some anions. The anions are unimportant; it is the release of protons that determines an acid’s effects on the environment. The ionization of hydrochloric acid (an acid produced by stomach cells that aids digestion) is shown in the following equation:

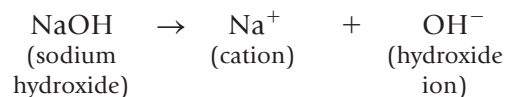


Other acids found or produced in the body include acetic acid (the acidic component of vinegar) and carbonic acid.

Acids that ionize completely and liberate all their protons are called *strong acids*; an example is hydrochloric acid. Acids that ionize incompletely, as do acetic and carbonic acid, are called *weak acids*. For example, when carbonic acid dissolves in water, only some of its molecules ionize to liberate  $\text{H}^+$ .

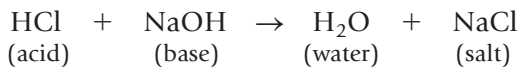


**Characteristics of Bases** **Bases** have a bitter taste, feel slippery, and are **proton ( $\text{H}^+$ ) acceptors**. (You can also think of them as taking protons “out of the game”; when protons are bound to a molecule, they are unable to affect the acidity of body fluids.) Hydroxides are common inorganic bases. Like acids, the hydroxides ionize and dissociate in water; but in this case, the *hydroxide ion* ( $\text{OH}^-$ ) and some cations are released. The ionization of sodium hydroxide ( $\text{NaOH}$ ), commonly known as lye, is shown as



The hydroxide ion is an avid proton ( $\text{H}^+$ ) seeker, and any base containing this ion is considered a strong base. By contrast, *bicarbonate ion* ( $\text{HCO}_3^-$ ), an important base in blood, is a fairly weak base.

**Acids, Bases, and Neutralization** When acids and bases are mixed, they react with each other (in an exchange reaction) to form water and a salt:



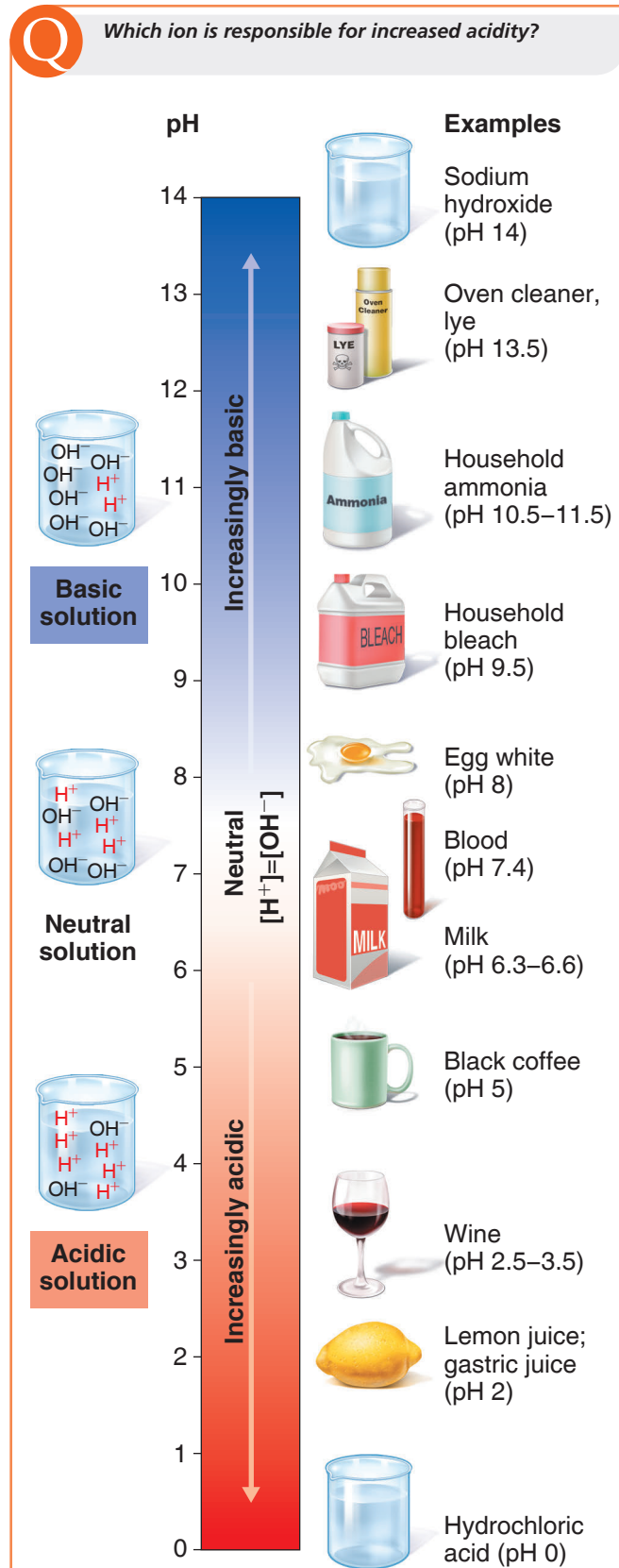
This type of exchange reaction, in which an acid and a base interact, is more specifically called a **neutralization** reaction.

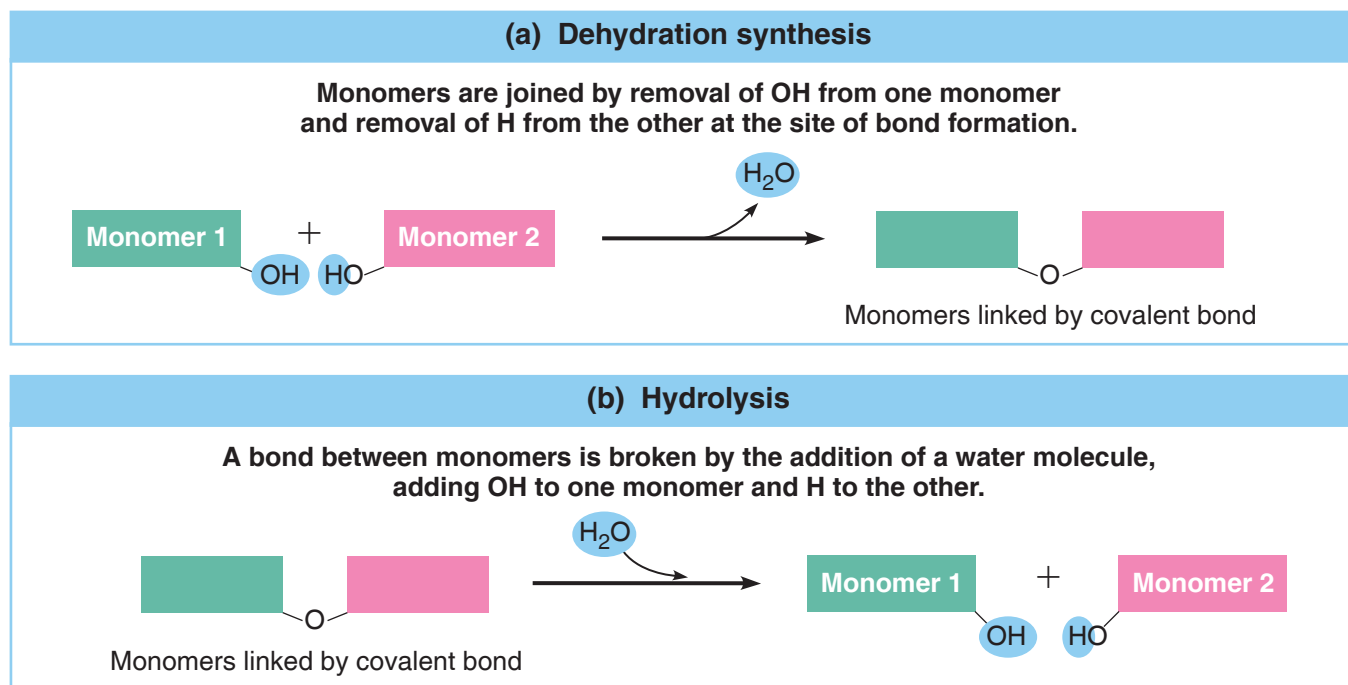
**pH: Acid-Base Concentrations** The relative concentration of hydrogen (and hydroxide) ions in various body fluids is measured in concentration units called **pH** (pe-äch) units. The **pH scale**, which was devised in 1909 by a Danish biochemist (and part-time beer brewer) named Sørensen, is based on the number of protons in solution.

The pH scale runs from 0 to 14 (Figure 2.12), and each successive change of 1 pH unit represents a tenfold change in hydrogen ion concentration. At a pH of 7, the number of hydrogen ions exactly equals the number of hydroxide ions, and the solution is neutral; that is, neither acidic nor basic. Solutions with a pH lower than 7 are acidic: The hydrogen ions outnumber the hydroxide ions. A solution with a pH of 6 has 10 times as many hydrogen ions as a solution with a pH of 7, and a pH of 3 indicates a 10,000-fold ( $10 \times 10 \times 10 \times 10$ ) increase in hydrogen ion concentration from pH 7. Solutions with a pH number higher than 7 are basic, or alkaline, and solutions with a pH of 8 and 12 have 1/10 and 1/100,000 (respectively) the number of hydrogen ions present in a solution with a pH of 7.

Living cells are extraordinarily sensitive to even slight changes in pH. Acid-base balance is carefully regulated by the kidneys, lungs, and a number of chemicals called **buffers** that are present in body fluids. Weak acids and weak bases are important components of the body's buffer systems, which act to maintain pH stability by taking up excess hydrogen or hydroxide ions (see Chapter 15).

**Figure 2.12 The pH scale and pH values of representative substances.** The pH scale is based on the number of hydrogen ions in solution. At a pH of 7, the number of  $\text{H}^+$  = the number of  $\text{OH}^-$ , and the solution is neutral. A solution with a pH below 7 is acidic (more  $\text{H}^+$  than  $\text{OH}^-$ ); above 7, basic, or alkaline (less  $\text{H}^+$  than  $\text{OH}^-$ ).





**Figure 2.13** Dehydration synthesis and hydrolysis of biological molecules.

Biological molecules are formed from their monomers (units) by dehydration synthesis and broken down to their monomers by hydrolysis.

Because blood comes into close contact with nearly every body cell, regulation of blood pH is especially critical. Normally, blood pH varies in a narrow range, from 7.35 to 7.45. When blood pH changes more than a few tenths of a pH unit from these limits, death becomes a distinct possibility. Although we could give hundreds of examples to illustrate this point, we will provide just one very important one: When blood pH begins to dip into the acid range, the amount of life-sustaining oxygen that the hemoglobin in blood can carry to body cells decreases rapidly to dangerously low levels.

### Did You Get It?

15. What property of water prevents rapid changes in body temperature?
16. Which is a proton donor—an acid or a base?
17. Is a pH of 11 acidic or basic? What is the difference in pH between a solution at pH 11 and a solution at pH 5?
18. Biochemistry is “wet” chemistry. What does this statement mean?
19. Salts are electrolytes. What does that mean?

For answers, see Appendix A.

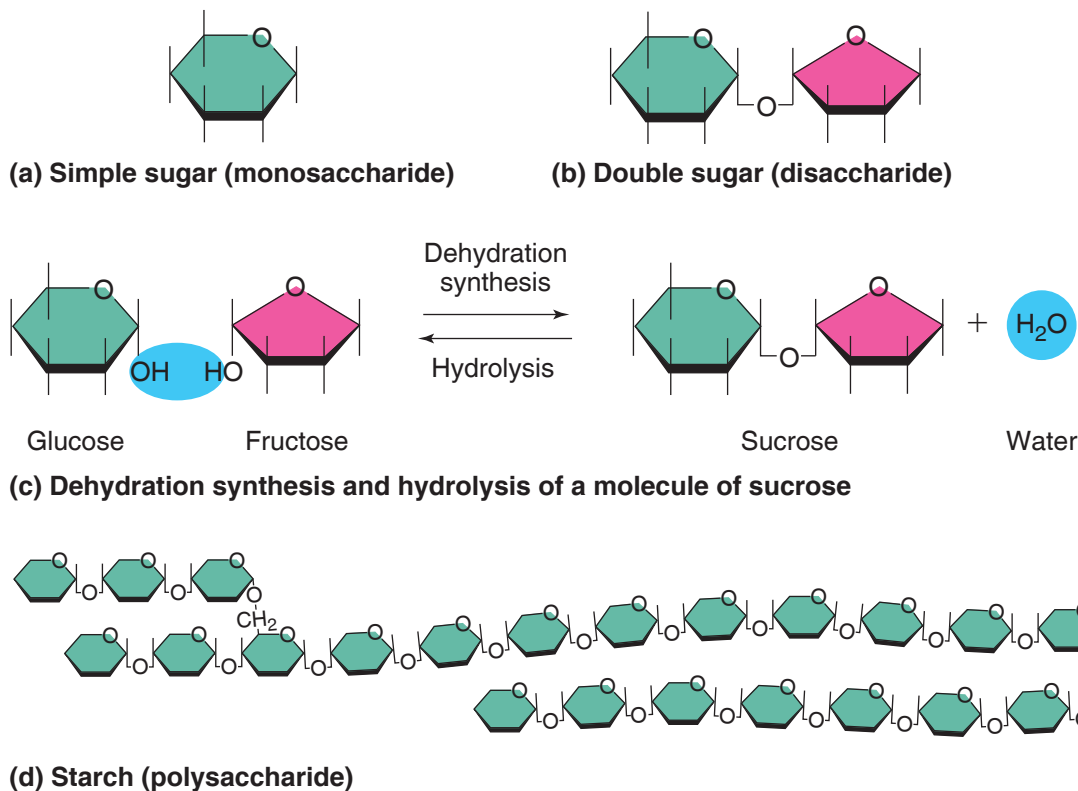
## 2.5b Organic Compounds

### Learning Objectives

- ✓ Explain the role of dehydration synthesis and hydrolysis in formation and breakdown of organic molecules.
- ✓ Compare and contrast carbohydrates and lipids in terms of their building blocks, structures, and functions in the body.

Most organic compounds are very large molecules, but their interactions with other molecules typically involve only small, reactive parts of their structure called *functional groups* (acid groups, amines, and others).

Many organic compounds (carbohydrates and proteins, for example) are polymers. **Polymers** are chainlike molecules made of many similar or repeating units (**monomers**), which are joined together by **dehydration synthesis** (Figure 2.13a). During dehydration synthesis, a hydrogen atom is removed from one monomer and a hydroxyl group (—OH) is removed from the monomer it is to be joined with. A covalent bond then forms, uniting the monomers, and a water molecule is released. This removal of a water molecule (dehydration) at the bond site occurs



**Figure 2.14 Carbohydrates.** (a) The generalized structure of a monosaccharide. (b) and (d) The basic structures of a disaccharide and a polysaccharide, respectively. (c) Formation and breakdown of the disaccharide sucrose by dehydration synthesis and hydrolysis, respectively.

each time a monomer is added to the growing polymer chain (synthesis).

When polymers must be broken down or digested to their monomers, the reverse process, called **hydrolysis**, occurs (Figure 2.13b). As a water molecule is added to each bond, the bond is broken, releasing the monomers. All organic molecules covered in this chapter—carbohydrates, lipids, proteins, and nucleic acids—are formed by dehydration synthesis and broken down by hydrolysis.

## Carbohydrates

**Carbohydrates**, which include sugars and starches, contain carbon, hydrogen, and oxygen. With slight variations, the hydrogen and oxygen atoms appear in the same ratio as in water; that is, two hydrogen atoms to one oxygen atom. This is reflected in the word *carbohydrate*, which means “hydrated carbon,” and in the molecular formulas of sugars. For example, glucose is  $C_6H_{12}O_6$ , and ribose is  $C_5H_{10}O_5$ .

Carbohydrates are classified according to size and solubility in water as monosaccharides, disaccharides, or polysaccharides. Because monosaccharides are joined to form the molecules of the other two groups, they are the structural units, or building blocks, of carbohydrates.

**Monosaccharides** **Monosaccharide** means one (*mono*) sugar (*saccharide*), and thus monosaccharides are also referred to as *simple sugars*. They are single-chain or single-ring structures (meaning the carbon backbone forms either a line or a circle), containing from three to seven carbon atoms (Figure 2.14a).

The most important monosaccharides in the body are glucose, fructose, galactose, ribose, and deoxyribose. **Glucose**, also called *blood sugar*, is the universal cellular fuel. *Fructose* and *galactose* are converted to glucose for use by body cells. *Ribose* and *deoxyribose* form part of the structure of nucleic acids, another group of organic molecules responsible for genetic information.