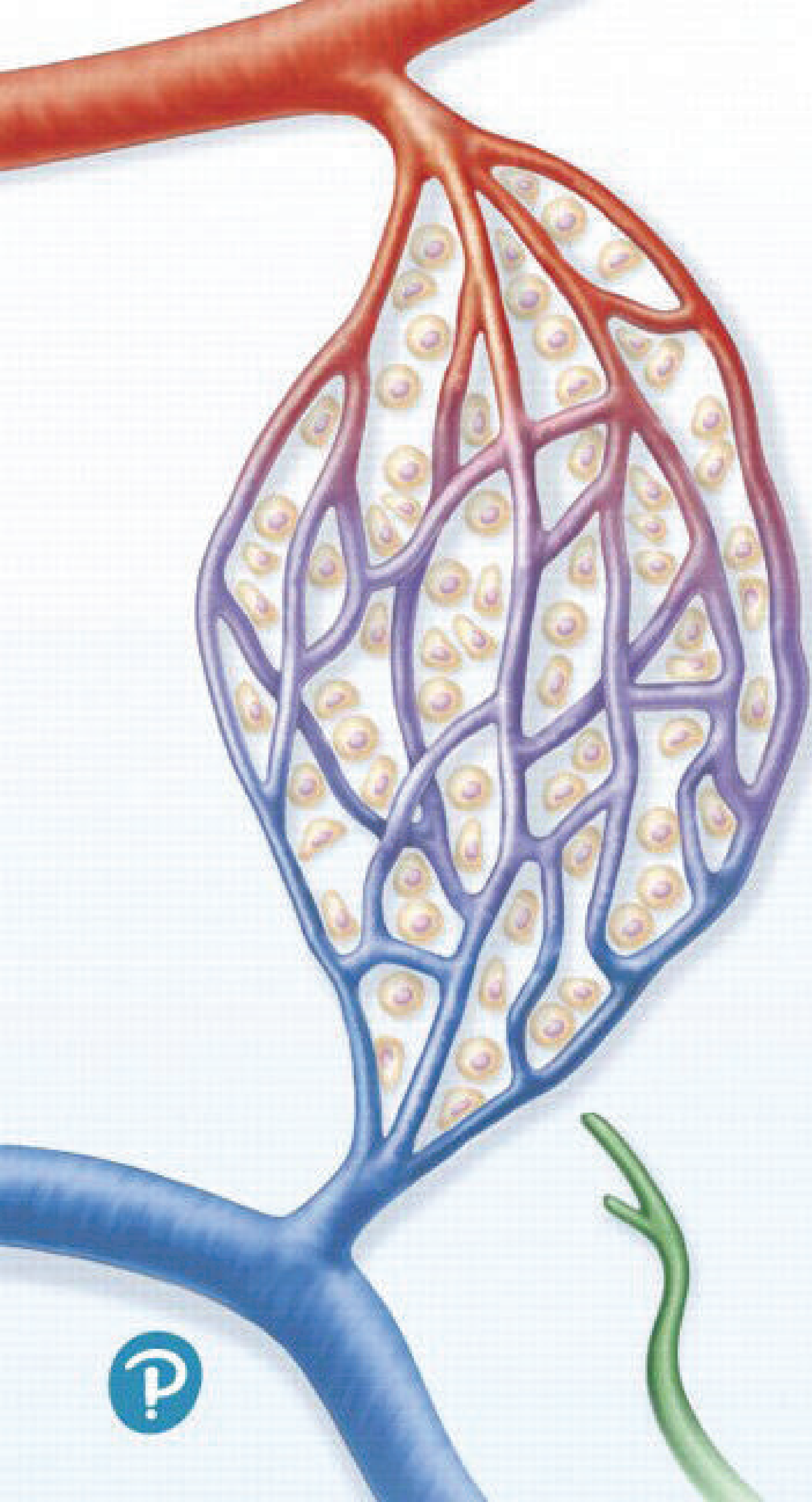
SEVENTH EDITION

Anatomy & Physiology



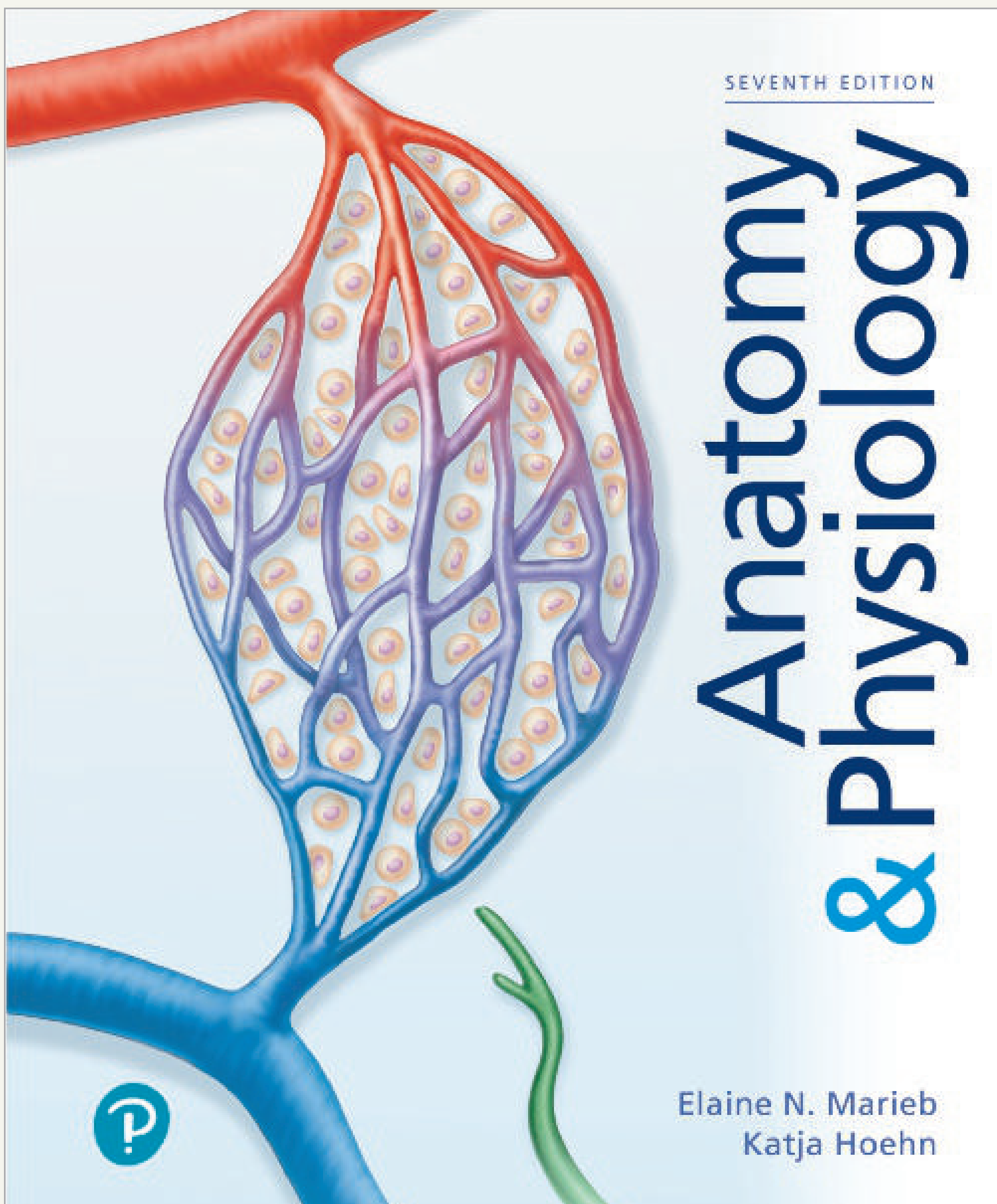
Elaine N. Marieb
Katja Hoehn

Brief Contents

This streamlined edition focuses on core concepts and allows instructors to expand on broader topics such as pregnancy, development, and genetics outside of reading assignments from the text. Discussions about Special Senses are included in Chapter 13

A Streamlined Option for Success in A&P *and Beyond...*

The streamlined edition of Elaine Marieb and Katja Hoehn's best-selling A&P text and media program motivates and supports both novice learners and expert students. Each carefully paced chapter guides you in advancing from lower-level memorizing of terminology to applying knowledge in clinical scenarios, to practicing the critical thinking and problem-solving skills required for entry to nursing, allied health, and exercise science programs.



Pearson

Identify “Big Picture” Concepts Before Exploring Details

Before you look up details within a chapter, turn to the first page of the chapter and read the numbered list of **Key Concepts** that summarize the “big ideas” in the chapter. **Learning Outcomes** will give you a preview of essential information to study within each chapter section. Updated **Career Connection Videos** feature health care professionals who describe how the chapter content relates to their everyday work.

8 Joints

CAREER CONNECTION VIDEO

Learn how the chapter content is used in a real health care setting. Go to https://goo.gl/88srfV

KEY CONCEPTS

The graceful movements of ballet dancers and the rough-and-tumble grapplings of football players demonstrate the great variety of motion allowed by **joints**, or **articulations**—the sites where two or more bones meet. Our joints have two fundamental functions: They give our skeleton mobility, and they hold it together, sometimes playing a protective role in the process.

8.1 Joints are classified into three structural and three functional categories

Learning Outcomes

- **Define joint or articulation.**
- **Classify joints by structure and by function.**

Joints are classified by structure and by function. The *structural classification* focuses on the material binding the bones together and whether or not a joint cavity is present. Structurally, there are *fibrous*, *cartilaginous*, and *synovial joints* (**Table 8.1**). Only synovial joints have a joint cavity.

The *functional classification* is based on the amount of movement allowed at the joint. On this basis, there are **synarthroses** (sin″ar-thro′sēz; *syn* = together, *arthro* = joint), which are immovable joints; **amphiarthroses** (am″fe-ar-thro′sēz; *amphi* = on both sides), slightly movable joints; and **diarthroses** (di″ar-thro′sēz; *dia* = through, apart), or freely movable joints. Freely movable joints predominate in the appendicular skeleton (limbs). Immovable and slightly movable joints are largely restricted to the axial skeleton. This localization of functional joint types makes sense because the less movable the joint, the more stable it is likely to be.

In general, fibrous joints are immovable, and synovial joints are freely movable. However, cartilaginous joints have both rigid and slightly movable examples. Since the structural categories are more clear-cut, we will use the structural classification in this discussion, indicating functional properties where appropriate.

Check Your Understanding

1. What functional joint class contains the least-mobile joints?
2. How are joint mobility and stability related?

For answers, see Answers Appendix.

8.2 In fibrous joints, the bones are connected by fibrous tissue

Learning Outcome

- **Describe the general structure of fibrous joints. Name and give an example of each of the three common types of fibrous joints.**

In **fibrous joints**, the bones are joined by the collagen fibers of connective tissue. No joint cavity is present. The amount of movement allowed depends on the length of the connective tissue fibers. Most fibrous joints are immovable, although a few are slightly movable. The three types of fibrous joints are *sutures*, *syndesmoses*, and *gomphoses*.

Sutures

Sutures, literally “seams,” occur only between bones of the skull (**Figure 8.1a**). The wavy articulating bone edges interlock, and the junction is completely filled by a minimal amount of very short connective tissue fibers that are continuous with the periosteum (◀ p. 154). The result is nearly rigid splices that knit the bones together, yet allow the skull to expand as the brain grows during youth. During middle age, the fibrous tissue ossifies and the skull bones fuse into a single unit. At this stage, the closed sutures are more precisely called **synostoses** (sin″os-to′sēz), literally, “bony junctions.” Because movement of the cranial bones would damage the brain, the immovable nature of sutures is a protective adaptation.

Syndesmoses

In **syndesmoses** (sin″des-mo′sēz), the bones are connected exclusively by *ligaments* (*syndesmos* = ligament), cords or

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Pace Yourself:
Learn & Review the Basics

Sebaceous Glands

The **sebaceous glands** (se-ba′shus; "greasy"), or *oil glands* (Figure 5.9a), are simple branched alveolar glands that are found all over the body except in the thick skin of the palms and soles. They are small on the body trunk and limbs, but quite large on the face, neck, and upper chest. These glands secrete an oily substance called **sebum** (se′bum). The central cells of the alveoli accumulate oily lipids until they become so engorged that they burst, so functionally these glands are *holocrine glands* (◀ p. 111). The accumulated lipids and cell fragments constitute sebum.

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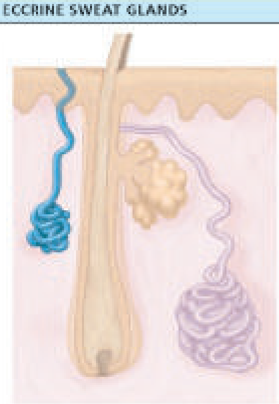
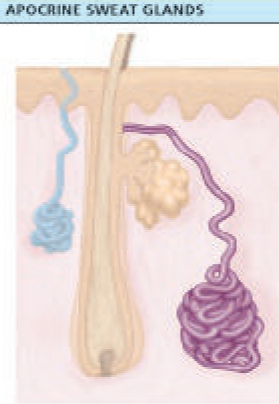
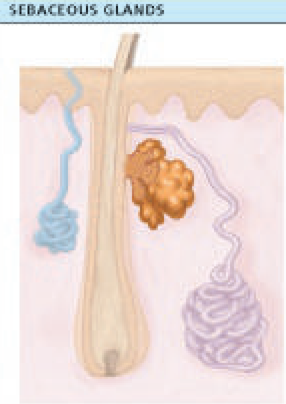
NEW! Text Recall icons guide you to review specific pages where a concept was first introduced.

EXPANDED! Summary Tables present key information and serve as well-organized, time-saving study tools. **13 NEW Summary Tables** have been added to the Seventh Edition.

Table 5.1 Summary of Cutaneous Glands

	ECCRINE SWEAT GLANDS	APOCRINE SWEAT GLANDS	SEBACEOUS GLANDS
			
Functions	• Temperature control • Some antibacterial properties	May act as sexual scent glands	• Lubricate skin and hair • Help prevent water loss • Antibacterial properties
Type of Secretion	Hypotonic filtrate of blood plasma	Filtrate of blood plasma with added proteins and fatty substances	Sebum (an oily secretion)
Method of Secretion	Merocrine (exocytosis)	Merocrine (exocytosis)	Holocrine
Secretion Exits Duct At	Skin surface	Usually upper part of hair follicle; rarely, skin surface	Usually upper part of hair follicle; sometimes, skin surface
Body Location	Everywhere, but especially palms, soles, forehead	Mostly axillary and anogenital regions	Everywhere *except* palms and soles

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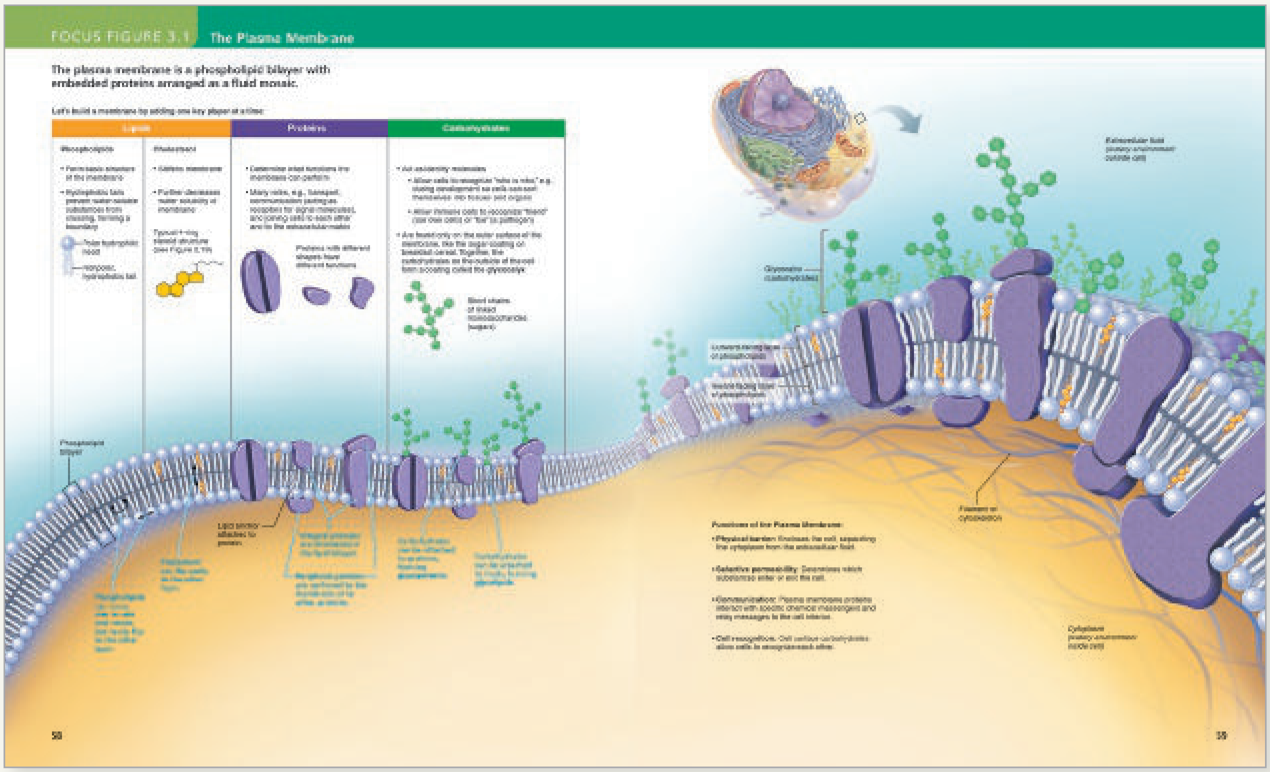
Study the Figures as You Read the Text

EXPANDED! 5 new Focus Figures (for a total of 24) walk you through complex processes using exceptionally clear, easy-to-follow illustrations with integrated text explanations.

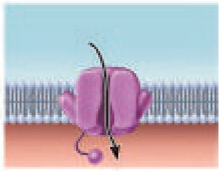


pp. 58-59

- **Chemically gated ion channels** are opened by chemical messengers (e.g., neurotransmitters). This class of ion channel creates small local changes in the membrane potential (as we will see shortly). Receptors for acetylcholine are an example of this class. An **ACh receptor** is a single protein in the plasma membrane that is both a receptor and an ion channel.

Chemically gated ion channel

- **Voltage-gated ion channels** open or close in response to changes in membrane potential. They underlie all action potentials. In skeletal muscle fibers, the initial change in membrane potential is created by chemically gated channels. In other words, chemically gated ion channels cause a small local *depolarization* (a decrease in the membrane potential) that then triggers the voltage-gated ion channels to create an action potential.



Voltage-gated ion channel

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EXPANDED! Dozens of unique In-Line Figures are strategically placed within the text to visually reinforce the text discussion.

Apply Your Knowledge to a Range & Variety of Questions

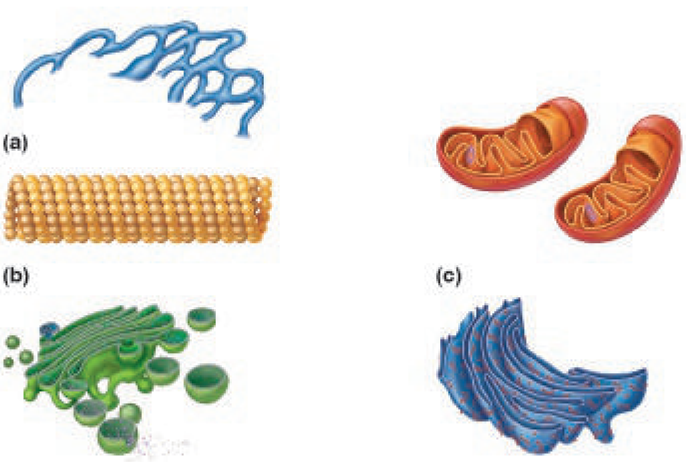
Check Your Understanding

18. Compare the functions of lysosomes and peroxisomes.

19. How are microtubules and microfilaments related functionally?

20. Name each of the organelles. Match the organelle(s) with the applicable statement(s). Answers may be used more than once.

__ (1) Moves organelles within cell using motor proteins
__ (2) Contains its own DNA
__, __, __ (3) Has cisterns
__ (4) Major site of ATP synthesis
__ (5) Site of steroid hormone synthesis
__ (6) Has *cis* and *trans* faces



(a) (b) (c) (d) (e)

21. APPLY Consider a plasma membrane glycoprotein. Describe the protein's path through the cell to the plasma membrane starting with its synthesis on the ribosome.

For answers, see Answers Appendix.

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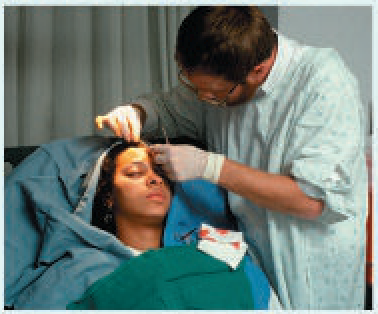
NEW! A greater **variety and range of self-assessment questions** have been added to the **Check Your Understanding** sections within each chapter and include **Apply, Predict, What If?, Draw,** and **Make Connections.** Dozens of new **visual questions** ask you to label structures or interpret visual information.

UPDATED! Clinical Case Studies are provided at the end of most chapters and challenge you to apply your knowledge to realistic clinical scenario questions.

NEW! Each Clinical Case Study includes **"NCLEX-Style" questions** for practice with the kinds of challenge questions that you will eventually encounter on a licensing exam. Your instructor can also assign **new NCLEX-Style questions** in Mastering A&P.

CLINICAL CASE STUDY

21-Year-Old Female with Deep Lacerations



While riding her bike to campus, 21-year-old Liliana Rose was struck by a car. Examination in the Emergency Department reveals several injuries. Relative to her integumentary system, the following comments are noted on her chart:

- Epidermal abrasions of the right lateral upper arm and anterior shoulder.
- A deep, 2-cm laceration extending vertically on right lateral cheek and a horizontal 1-cm laceration on the temple.
- Cyanosis is apparent in her nail beds and lips.

The lacerated areas are cleaned, sutured (stitched), and bandaged by the emergency room (ER) personnel.

1. **+ NCLEX-STYLE** Liliana's epidermal layer has been damaged. Which statement best explains the significance of this damage?
   - **a.** It's not significant, because the cells in the epidermis are already dead.
   - **b.** It's significant because cells in the epidermis give rise to all the cells in all the different skin layers.
   - **c.** It's significant because disrupting the epidermis will cause severe, sometimes life-threatening bleeding.
   - **d.** It's significant because the cells of the epidermis protect against evaporative water loss, UV radiation, and infection.

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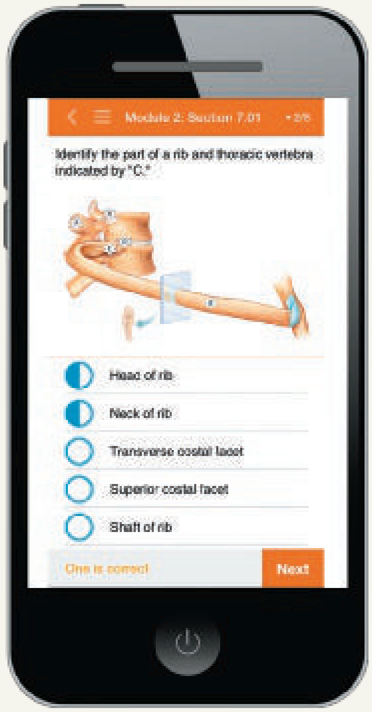
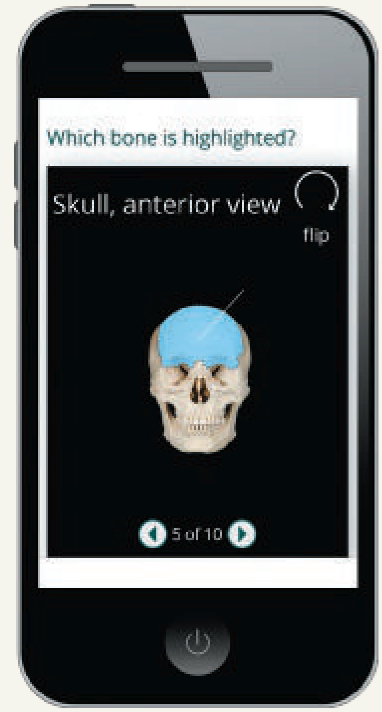
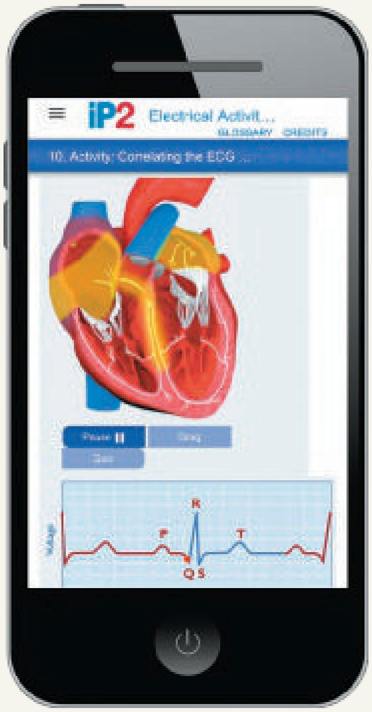
Flexible and Mobile Study and Practice with Mastering A&P



Dynamic Study Modules use cognitive science to help students study course topics by adapting to their performance in real time. Customized feedback provides just-in-time remediation, improving student confidence. Instructors can assign from over 3,000 questions organized by chapter and module. Over 70% of students cite DSMs as their favorite study tool and a main reason for success in the course.

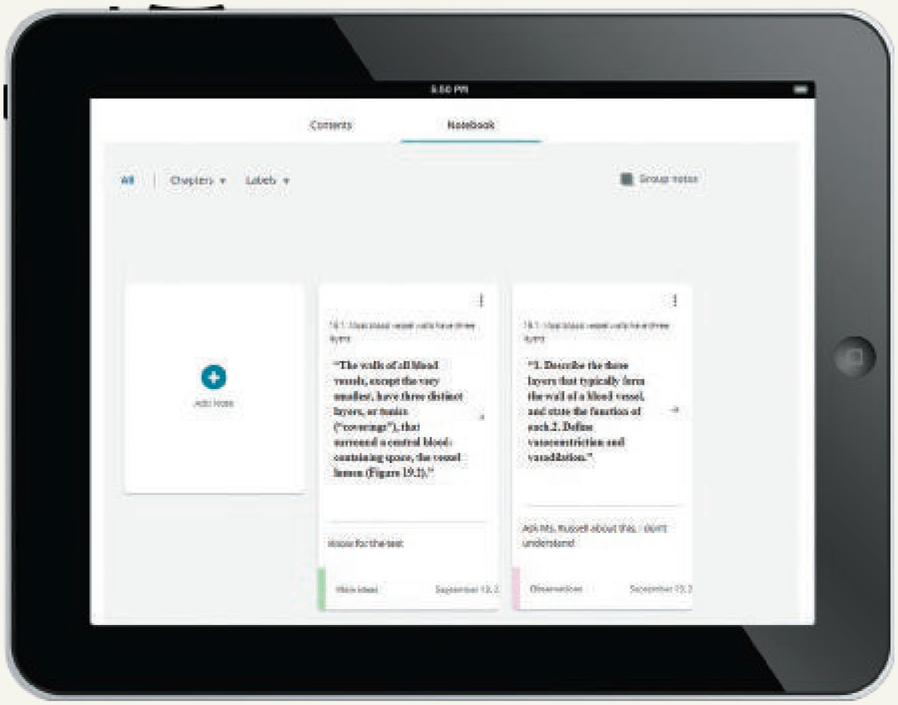


NEW! PAL 3.1 Mobile, Customizable Flashcards allow students to create a personalized, mobile-friendly deck of flashcards and quizzes using images from the virtual Practice Anatomy Lab 3.1. Students can use the checklist to filter down to the images referenced in the course. For optimal viewing, access the flashcards on a mobile device using Mastering login credentials.



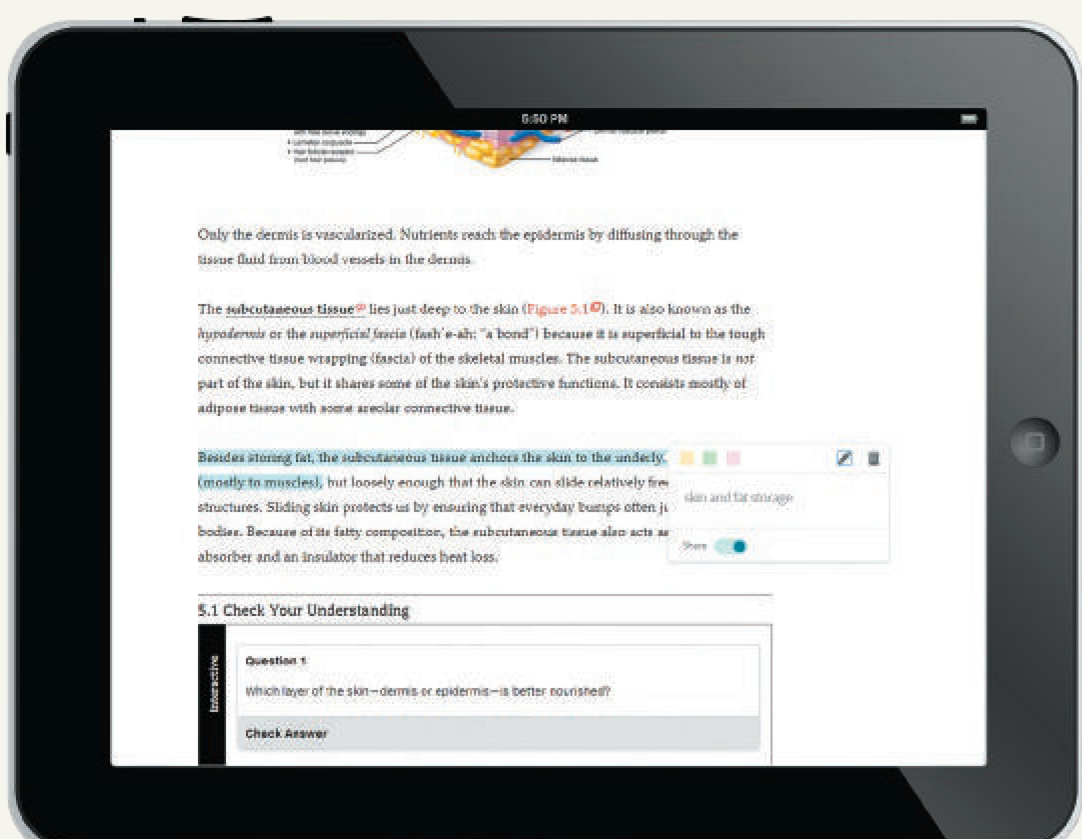
EXPANDED! Interactive Physiology 2.0 Coaching Activities teach complex physiological processes using exceptionally clear animations, interactive tutorials, games, and quizzes. IP 2.0 features new graphics, quicker navigation, and a mobile-ready design. New topics include Generation of an Action Potential, Glomerular Filtration, and the Neuromuscular Junctions. IP 2.0 can be assigned in Mastering A&P and accessed in the Study Area.

Personalize Your Mastering A&P eText



Students can personalize their eText by **creating highlights** with meaningful labels and notes, concentrating their focus on what they need to study. The **NEW! customizable Notebook** allows students to filter, arrange, and group their notes in a way that makes sense to them.

NEW! Instructors can create notes in their own notebook and choose to share them with students, effectively creating a study guide and encouraging students to read and discover areas for further understanding. Instructor notes will always show up in blue in the student notebook.



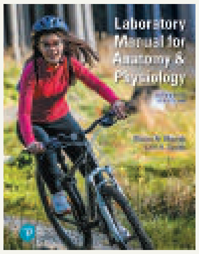
Additional Support for Instructors and Students

Mastering A&P™ is the teaching and learning platform that empowers you to reach every student. By combining trusted author content with digital tools developed to engage students and emulate the office-hour experience, Mastering personalizes learning and improves results for each student. Built for and directly tied to the text, Mastering A&P enables an extension of learning, allowing students a platform to practice, learn, and apply outside of the classroom. Highlights of the new assignments include:

- **NEW! Building Vocabulary Coaching Activities** give students practice learning and using word roots in context while learning new A&P terms.
- **NEW! Focus Figure "Mini-Animation" Coaching Activities** bring the 5 new Focus Figures to life and include assessment questions.
- **IMPROVED! Concept Map Coaching Activities** support the concept maps in the text without requiring students to submit their own concept map for grading.
- **NEW! NCLEX-Style Questions** give students practice with the kinds of questions that will eventually appear on a licensing exam.

The Mastering A&P™ Instructor Resources Area for the Seventh Edition includes:

- **Customizable PowerPoint lecture outlines and images** provide a springboard for lecture prep.
- **All of the figures, photos, and tables from the text** are available in JPEG and Power Point formats, in labeled and unlabeled versions, and with customizable labels and leader lines.
- **Test bank** provides thousands of customizable questions across Bloom's Taxonomy levels. Each question is tagged to chapter learning outcomes that can also be tracked within Mastering A&P assessments. Available in Microsoft Word and Test Gen formats.
- **Animations and videos** bring A&P concepts to life and include A&P Flix 3-D Animations.
- **A comprehensive Instructor Guide to Text and Media,** co-authored by Elaine Marieb and Laura Steele, includes a detailed teaching outline for each chapter, along with a wealth of activities, examples, and analogies that have been thoroughly class-tested with thousands of students.



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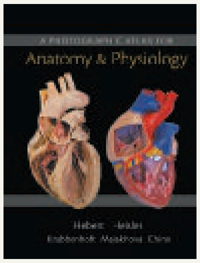

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Anatomy & Physiology

SEVENTH EDITION

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Pearson

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About the Authors

We dedicate this work to our students both present and past, who always inspire us to "push the envelope."

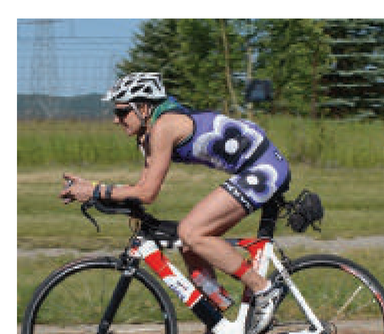
Elaine N. Marieb

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 developed a desire 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 publications are known.

Dr. Marieb has given generously to provide opportunities for students to further their education. She funds the E.N. Marieb Science Research Awards at Mount Holyoke College, which promotes research by undergraduate science majors, and has underwritten renovation of the biology labs in Clapp Laboratory at that college. Dr. Marieb also contributes to the University of Massachusetts at Amherst, where she provided funding for reconstruction and instrumentation of a cutting-edge cytology research laboratory. Recognizing the severe national shortage of nursing faculty, she underwrites the Nursing Scholars of the Future Grant Program at the university.

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

Katja Hoehn



Dr. Katja Hoehn is a professor in the Department of Biology at Mount Royal University in Calgary, Canada. Dr. Hoehn's first love is teaching. Her teaching excellence has been recognized by several awards during her 24 years at Mount Royal University. These include a PanCanadian Educational Technology Faculty Award (1999), a Teaching Excellence Award from the Students' Association of Mount Royal (2001), and the Mount Royal Distinguished Faculty Teaching Award (2004).

Dr. Hoehn received her M.D. (with Distinction) from the University of Saskatchewan, and her Ph.D. in Pharmacology from Dalhousie University. In 1991, the Dalhousie Medical Research Foundation presented her with the Max Forman (Jr.) Prize for excellence in medical research. During her Ph.D. and postdoctoral studies, she also pursued her passion for teaching by presenting guest lectures to first- and second-year medical students at Dalhousie University and at the University of Calgary.

Dr. Hoehn has been a contributor to several books, written numerous research papers in Neuroscience and Pharmacology, and has co-authored the previous four editions of this textbook. For many years, she has also reviewed and authored electronic media that accompanies Pearson anatomy and physiology books.

Following Dr. Marieb's example, Dr. Hoehn provides financial support for students in the form of a scholarship that she established in 2006 for nursing students at Mount Royal University.

Dr. Hoehn is also actively involved in the Human Anatomy and Physiology Society (HAPS) and is a member of the American Association of Anatomists. When not teaching, she likes to spend time outdoors with her husband and two sons. She also enjoys competing in long-course triathlons, and playing Irish flute down at the local pub.

Preface

Today's students have access to an enormous amount of information about anatomy and physiology. As educators, our biggest challenge is to help students focus on mastering the basic concepts of this field. Providing this firm foundation will help students to become lifelong learners who can critically evaluate new information, connect that information to the foundation they have already established, and apply it in a clinical setting. How can we help students build a strong foundation in anatomy and physiology? We believe that this new edition of our textbook will help learners by building on the strengths of previous editions while using new and innovative ways to help students visualize connections between various concepts.

Unifying Themes

Three unifying themes that have helped to organize and set the tone of this textbook continue to be valid and are retained in this edition. These themes are:

Interrelationships of body organ systems. This theme emphasizes the fact that nearly all regulatory mechanisms have interactions with several organ systems. The respiratory system, for example, cannot carry out its role of gas exchange in the body if there are problems with the cardiovascular system that prevent the normal delivery of blood throughout the body. The Make Connections questions throughout the book help students connect new information to old information and think of the body as a community of dynamic parts instead of a number of independent units.

Homeostasis. Homeostasis is the normal and most desirable condition of the body. Its loss is always associated with past or present pathology. This theme is not included to emphasize pathological conditions, but rather to illustrate what happens in the body "when things go wrong" and homeostasis is lost. Whenever students see a red balance beam symbol accompanied by an associated clinical topic, their understanding of how the body works to stay in balance is reinforced.

Complementarity of structure and function. This theme encourages students to understand the structure of some body part (ranging from a molecule to an organ) in order to understand the function of that structure. For example, muscle cells can produce movement because they are contractile cells.

New to the Seventh Edition

New and augmented elements aim to help learners in the following ways.

To help students make connections between new and previously learned material. In order for students to master new concepts, they must link these new concepts with concepts they already understand. In this edition, we help them do this by adding:

- **Text recall icons (◀).** These icons direct the student back to the specific pages where a concept was first introduced.
- **Make Connections questions.** We've added more of this type of question to the Check Your Understanding review questions that follow each module within a chapter. To answer these questions, the student must employ concepts learned previously (most often in previous chapters).
- **New kinds of higher-level questions.** Each chapter now has at least five higher-level questions that require students to think more deeply, pulling together strands from multiple concepts. These questions are clearly identified as APPLY, DRAW, PREDICT, MAKE CONNECTIONS, and WHAT IF? questions.
- **New summary tables.** Students have told us that they want more summary tables. In response, 13 new summary tables (two with illustrations) have been added in order to help students see the big picture.

To enhance students' visual literacy. Anatomy is and has always been taught principally through images. Increasingly, however, physiological data is also represented as images, whether it be molecular interactions or graphical descriptions of processes. Throughout their future health care careers, students will need to be able to understand and interpret information presented visually. In this edition, we help them do this by:

- **Adding new Focus figures.** Focus figures are illustrations that use a "big picture" layout and dramatic art to guide the student through difficult physiological processes in a step-by-step way. Our previous Focus figures have been a hit with both students and instructors. In response to requests for additional Focus figures, we are pleased to present five new two-page features.
- **Adding DRAW questions in each chapter.** Students often think that they understand an illustration simply by looking at it, but to truly comprehend an illustration and cement its concepts requires a more active learning approach. For this reason we now include at least one higher-level review question within each chapter that requires a student either to draw an illustration or to add to an existing diagram.
- **Adding questions about illustrations.** To help students practice their visual literacy skills, we have added 43 new Check Your Understanding questions that include an illustration as part of the question. Some of these are as simple as labeling exercises, but many require more advanced interpretation.
- **Updating art to improve its teaching effectiveness.** As always, this is a major part of the revision. Today's students are accustomed to seeing sophisticated photorealistically rendered images. However, many students are not adept at extracting, and thinking critically about, the relevant information contained in such illustrations. With this in mind we continue to refine and update our illustrations as students' needs change, improving their ability to teach important concepts. In many cases we have added blue "instructor's voice" text within the figure to guide a student through it, replacing much of the more remote figure legend. In addition, new photos were painstakingly chosen and labeled to enhance the learning process.
- **Adding new illustrations to existing tables and adding new illustrated tables.** Students find illustrated tables particularly effective because they provide a visual cue that helps them remember a topic. In this edition, we have added illustrations to two tables and added two new illustrated tables.
- **Adding in-line figures.** These are small (less than a half-column wide) illustrations or photos strategically located within the text that discuss the concept they illustrate. This edition now has 31 such in-line figures, most of them newly added.

To help students clinically apply what they have learned

- **Updated Homeostatic Imbalance features.** Many of the Homeostatic Imbalance features have been updated and relevant photos have been added to some. All have been reviewed for accuracy and relevancy. In addition, the updated book design makes these features stand out more clearly.
- **Updated Clinical Case Studies in most chapters, with added new ✚ NCLEX-STYLE questions.** The end-of-chapter review questions, which are now organized into three levels of difficulty based on Bloom's Taxonomy categories, culminate in a clinical case study that allows students to apply some of the concepts they have learned to a clinical scenario. These case studies have been extensively revised and each case study has two questions that are similar in style to those in the NCLEX exam.
- **New clinically relevant photos.** We have added or updated a number of photos that have clinical relevance (procedures, conditions, etc.) that will help students apply what they are reading to real-life situations and to their future careers.

In this edition, certain chapters have received the bulk of our attention and have been more heavily revised. As you can see in the Highlights of New Content (below), these are Chapters 2–4, 9, and 26.

As in the previous edition, we have taken painstaking care to ensure that almost all the text and the associated art are covered on the same two-page spread. Although this sounds like a simple goal, it actually takes a great deal of work and has not usually been achieved by other textbooks. We make this effort because it is invaluable to student learning to not have to flip pages back and forth between art and text. Finally, you will notice the appearance of new icons referencing Mastering A&P® interspersed within the text. This guides students to go to the relevant on-line activities to supplement their learning.

Other Highlights of New Content

Chapter 1 The Human Body: An Orientation

- New Figure 1.1 illustrates complementarity of structure and function.
- New Homeostatic Imbalance features about hiatal hernias and about "wrong site surgery."

Chapter 2 Chemistry Comes Alive

- New Homeostatic Imbalance feature about patient's pH predicting outcome of CPR.
- New figures illustrate triglyceride structure (2.16); the difference between saturated and unsaturated fatty acids (2.17); phospholipids (2.18); and protein functions (2.20).
- Revised Figures 2.6 (formation of ionic bonds) and 2.12 (dissociation of salt in water) teach more effectively.
- New summary tables reinforce information about chemical bonds (Table 2.2) and about macromolecules and their monomers and polymers (Table 2.5).

Chapter 3 Cells: The Living Units

- Added Focus Figure 3.1 about the plasma membrane, and reorganized accompanying text.
- Reorganized text about passive membrane transport for improved clarity; updated and reorganized discussion of autophagy and apoptosis.
- Updated information about Tay-Sachs disease.
- New micrographs show micro- and intermediate filaments (Figure 3.20).

- Improved teaching effectiveness of Figures 3.5 (diffusion), 3.17 (processing and distribution of newly synthesized proteins), and 3.30 (stages of transcription).
- New information about telomeres in cancer cells.
- New Homeostatic Imbalance feature about progeria.

Chapter 4 Tissue: The Living Fabric

- New images of cilia show the difference between transmission and scanning electron microscopy (Figure 4.2).
- New in-line figure illustrates apical and basal surfaces of epithelial cells.
- Revised art for epithelial and connective tissue for clarity (Figures 4.4 and 4.11).
- New Figure 4.5 shows how exocrine and endocrine glands differ, and new Figure 4.10 gives an overview of the classification of connective tissue.

Chapter 5 The Integumentary System

- New illustrated summary table comparing cutaneous glands (Table 5.1).
- Revised Figures 5.3 and 5.4 for better teaching effectiveness.
- Updated information about skin color and disease states.
- Updated Homeostatic Imbalance features about hirsutism and about hair loss.
- New Homeostatic Imbalance feature about nail changes with disease.
- Updated statistics for and treatment of melanoma, with new photo (Figure 5.11c).

Chapter 6 Bones and Skeletal Tissues

- New summary Table 6.1 compares cartilage and bone tissue.
- New photos of an osteoclast (Figure 6.7); of a femur in longitudinal section to show compact and spongy bone (Figure 6.3); and of a section of a flat bone (skull bone) (Figure 6.4 top).
- Extensive revision of Figure 6.12, which teaches bone growth at epiphyseal plates, including new X ray to show epiphyseal plates, and new photomicrograph of epiphyseal cartilage.
- Updated information about bone remodeling, hormonal regulation of bone growth, and osteoporosis.

Chapter 7 The Skeleton

- New drawings to illustrate the location of the true and false pelves, and the pelvic inlet and outlet (Figure 7.33).
- Updated Homeostatic Imbalance feature about pes planus (flat feet)
- New photo of bimalleolar fracture (Figure 7.35).

Chapter 8 Joints

- New Homeostatic Imbalance feature about shoulder dislocations.
- New Table 8.3 summarizes movements at synovial joints.
- Revised Figure 8.4 (bursae and tendon sheaths).

Chapter 9 Muscles and Muscle Tissue

- New "Background and Overview" section begins the discussion of the mechanisms of excitation and contraction of skeletal muscle, including a new "big picture" overview in Figure 9.7.
- New introduction to ion channels with art helps students understand skeletal muscle excitation and contraction.
- Reorganized discussions of graded muscle contractions and of smooth muscle, including new Figure 9.24 showing calcium sources for smooth muscle contraction.
- Updated discussion of muscle fatigue.
- Updated Homeostatic Imbalance feature on Duchenne muscular dystrophy.

Chapter 10 The Muscular System

- Revised art about levers for clarity (Figures 10.2 and 10.3).
- New cadaver dissection photos show dissection of muscles of the anterior neck and throat, superficial muscles of the thorax and shoulder in posterior view, and posterior muscles of the thigh and hip (Figures 10.9, 10.14, and 10.21).
- New photo illustrates thumb movements.

Chapter 11 Fundamentals of the Nervous System and Nervous Tissue

- New Focus Figure 11.4 illustrates postsynaptic potentials and their summation.
- Improved teaching effectiveness of Figure 11.12 (coding of action potentials for stimulus intensity) and Figure 11.19 (illustrating a reflex).

Chapter 12 The Central Nervous System

- New Figure 12.26 and revised text teach more effectively about the blood brain barrier.
- New Figure 12.30 shows spinal cord segment location in relation to vertebral column.
- New Table 12.2 summarizes spinal cord cross-sectional anatomy.
- Updated Homeostatic Imbalance features about hypothalamic disorders and about narcolepsy and insomnia, including new use of orexin receptor antagonists to treat insomnia.
- New type of MRI photo shows fiber tracts in brain and spinal cord.

Chapter 13 The Peripheral Nervous System and Reflex Activity

- Revised Figure 13.4 (the lacrimal apparatus) for better teaching effectiveness.
- New photo of fundus of retina (Figure 13.9).
- New images illustrating the results of damage to the ulnar and radial nerves.
- New summary table of nerve plexuses (Table 13.9).
- New Homeostatic Imbalance feature about an abnormal plantar reflex (Babinski's sign)
- Redrawn Figure 13.44 illustrating crossed-extensor reflex for improved student understanding.
- New drawings of nerves of cervical, brachial, lumbar, and sacral plexuses show their position in relationship to the vertebrae (and hip bone in some cases) (Figures 13.36–13.39).

Chapter 14 The Autonomic Nervous System

- New Figure 14.8 shows sympathetic innervation of the adrenal medulla.
- Clarified section about visceral sensory neurons.
- New photo illustrates Raynaud's disease.
- Revised Figure 14.5 on the sympathetic trunk for better teaching effectiveness.

Chapter 15 The Endocrine System

- New Table 15.1 compares the endocrine and nervous systems.
- New Focus Figure 15.2 describes short- and long-term stress responses.
- Figures 15.5 (effects of growth hormone) and 15.9 (synthesis of thyroid hormone) revised for clarity.
- Updated information about diabetes mellitus, Addison's disease, and thyroid deficiency in childhood.

Chapter 16 Blood

- Updated information about anticoagulant medications.
- New photo shows petechiae resulting from thrombocytopenia (Figure 16.16).

Chapter 17 The Cardiovascular System: The Heart

- New Focus Figure 17.2 teaches students how to understand the cardiac cycle, with accompanying text reorganized.
- New photo shows an individual having an ECG (Figure 17.16).

Chapter 18 The Cardiovascular System: Blood Vessels

- New "drinking straw" analogy and art to explain resistance.
- New Figure 18.4 shows the structure of most capillary beds according to current understanding, and new text describes those capillary beds.
- Revised Figure 18.6 on proportions of blood volume throughout the vascular tree for greater teaching effectiveness.
- New illustration of cerebral arterial circle (circle of Willis) (Figure 18.24).

Chapter 19 The Lymphatic System and Lymphoid Organs and Tissues

- New illustrated Table 19.1 summarizes key characteristics of the major lymphoid organs.
- Revised Figure 19.9 with orientation diagrams helps students locate Peyer's patches (aggregated lymphoid nodules).
- Updated information about lymphatic drainage of the CNS.

Chapter 20 The Immune System: Innate and Adaptive Body Defenses

- New Focus Figure 20.1 gives an example of a primary immune response and summarizes innate and adaptive defenses.
- New illustrated Table 20.8 summarizes the components of adaptive immunity and complements the new Focus figure.
- New photo of a macrophage engulfing bacteria.
- Revised Figure 20.4 and text on inflammation, Figure 20.6 on complement activation, and Figure 20.11 on clonal selection of a B cell for greater teaching effectiveness.

Chapter 21 The Respiratory System

- New Figure 21.1 illustrates the four respiratory processes.
- Added section about sleep apnea.
- New scanning electron micrographs of emphysematous and normal lung tissue (Figure 21.22).
- Updated statistics about lung cancer and trends in asthma prevalence.

Chapter 22 The Digestive System

- New Figure 22.25 teaches the enterohepatic circulation of bile salts, and new Figure 22.30 shows the macroscopic anatomy of the small intestine.
- Improved teaching effectiveness of Figures 22.7 (neural reflex pathways in the gastrointestinal tract) and 22.16 (microscopic anatomy of the stomach).
- Added Homeostatic Imbalance features about dry mouth (xerostomia) and about tooth decay in primary teeth.
- Updated Homeostatic Imbalance feature about acute appendicitis to state that surgery is no longer always the first choice of treatment.

Chapter 23 Nutrition, Metabolism, and Energy Balance

- New Figure 23.24 shows the size and composition of various lipoproteins.
- Improved teaching effectiveness of Figures 23.21 (insulin effects during the postabsorptive stage).
- Updated Homeostatic Imbalance feature with mechanism of cell death in frostbite.
- Updated nutritional information about lipids, and updated statistics about the prevalence of obesity in adults and children and about the prevalence of diabetes mellitus.

Chapter 24 The Urinary System

- New Figure 24.18 shows the medullary osmotic gradient and interstitial fluid osmolalities in the renal cortex and medulla.
- New Table 24.1 summarizes the regulation of glomerular filtration rate.
- Improved teaching effectiveness of Figures 24.9 (blood vessels of the renal cortex), 24.12 (the filtration membrane), 24.15 (routes for tubular reabsorption), and 24.16 (tubular reabsorption of water and nutrients).
- New pyelogram shows anatomy of kidneys, ureters, and urinary bladder (Figure 24.23).
- Added Homeostatic Imbalance feature about renal trauma.
- Updated Homeostatic Imbalance feature about kidney stones.

Chapter 25 Fluid, Electrolyte, and Acid-Base Balance

- New Figure 25.12 summarizes the body's chemical buffers.
- Improved teaching effectiveness of Figures 25.1 (major fluid compartments of the body), 25.2 (electrolyte composition of blood plasma, interstitial fluid, and intracellular fluid), and 25.7 (disturbances in water balance).
- Clarified definitions of sensible and insensible water loss.

Chapter 26 The Reproductive System

- This chapter has been extensively updated, revised, and reorganized. Almost every figure has been reconceptualized and several new figures have been added. These changes have been made for better teaching effectiveness.
- New opening module now compares male and female reproductive system anatomy and physiology and highlights common features, allowing students to make connections more easily. Homologous structures, patterns of hormone release, and meiosis are included in this section.
- New Figure 26.1 illustrates the basic pattern of interactions along the hypothalamic-pituitary-gonadal (HPG) axis in both males and females.
- The section about meiosis has been extensively rewritten to help increase student understanding. New in-line figures help introduce the basic terminology and some of the concepts before meiosis is discussed in detail.
- A new big-picture overview of meiosis introduces the major events before the details of each step are presented.
- Figures 26.22 (events of oogenesis) and 26.24 (regulation of the ovarian cycle) are extensively revised and updated for increased teaching effectiveness and accuracy.

Acknowledgments

Producing a new edition of this book is an enormous undertaking. Let us take you through the steps and introduce you to the people behind the scenes that have helped make this book what it is. Every new edition begins with a revision plan. We'd like to thank all of the students and instructors who have provided the feedback (gathered by our editorial team) that forms the basis of this plan. Once this plan was in place, Barbara Price (our text Development Editor) scoured each chapter. This was Barbara's first exposure to the book and her fresh eyes on the text found opportunities to further clarify the presentation. In addition, she noted places where additional chunking of the text (such as bulleted lists) would help the students. Her excellent work has made this text better. We incorporated her ideas, and reviewer feedback, together with our own updates and ideas for reorganization of the text and art. Thanks to Patricia Bowne for contributing to the Clinical Case Studies and Wendy Mercier for reviewing all of the Case Studies. We also very much appreciate the help of Karen Dougherty, who used her expertise as a physician and educator to review all of the Homeostatic Imbalance features and help us revise and update them.

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At the same time the text was in revision, the art program was going through a similar process. This book would not be what it is without the help of Laura Southworth, our superb Art Development Editor. Laura's creativity, attention to detail, and her sense of what will teach well and what won't have helped us immensely. She has worked tirelessly to make our Focus figures and other art even better. Finding good, usable photos is never easy, and we are grateful for the hard work of Kristin Piljay (Photo Researcher). It was also a pleasure to work with Jean Lake again, who expertly juggled the administrative aspects of the art program and kept us all on track. This team ensured that the artists at Imagineering had all the information they needed to produce beautiful final art products.

As the manuscript made the transition from Editorial to Production, Michelle Mangelli (wearing a different hat—this one as the Production and Design Manager) took over again. As head honcho and skilled handler of all aspects of production, everyone answered to her from this point on. Kudos to our excellent production coordinator, Karen Gulliver, who did much of the hands-on handling, routing, and scheduling of the manuscript. We'd also like to thank Martha Ghent (Proofreader), Betsy Dietrich (Art Proofreader), Sallie Steele (Indexer), Alicia Elliot (Project Manager at Imagineering), and Spi Global (Compositor). Izak Paul meticulously read every chapter for scientific accuracy, and we are very grateful for his careful work. Thanks also to Gary Hespenheide for his stunning design work on the cover, chapter opening pages, and the text.

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Kudos to our entire team. We feel we have once again prepared a superb textbook. We hope you agree.

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We really would appreciate hearing from you concerning your opinion—suggestions and constructive criticisms—of this text. It is this type of feedback that will help us in the next revision and underlies the continued improvement of this text.

Elaine Marieb

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Contents

UNIT 5 Continuity

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1 The Human Body: An Orientation

CAREER CONNECTION VIDEO

Learn how the chapter content is used in a real health care setting. Go to https://goo.gl/88srfV

KEY CONCEPTS

Welcome to the study of one of the most fascinating subjects possible—your own body. Such a study is not only highly personal, but timely as well. We get news of some medical advance almost daily. To appreciate emerging discoveries in molecular genetics, to understand new techniques for detecting and treating disease, and to make use of published facts on how to stay healthy, you'll find it helps to learn about the workings of your body. If you are preparing for a career in the health sciences, the study of anatomy and physiology has added rewards because it provides the essential foundation for your clinical experiences.

In this chapter we define and contrast anatomy and physiology and discuss how the human body is organized. Then we review needs and processes common to all living organisms. Three essential concepts—*the complementarity of structure and function, the hierarchy of structural organization,* and *homeostasis*—will unify and form the bedrock for your study of the human body. And finally you'll learn the language of anatomy—terminology that anatomists use to describe the body and its parts.

1.1 Form (anatomy) determines function (physiology)

Learning Outcomes

- **Define anatomy and physiology and describe their subdivisions.**
- **Explain the principle of complementarity.**

Two complementary branches of science—anatomy and physiology—provide the concepts that help us to understand the human body. **Anatomy** studies the *structure* of body parts and their relationships to one another. Anatomy has a certain appeal because it is concrete. Body structures can be seen, felt, and examined closely. You don't need to imagine what they look like.

Physiology concerns the *function* of the body, in other words, how the body parts work and carry out their life-sustaining activities. When all is said and done, physiology is explainable only in terms of the underlying anatomy.

For simplicity, when we refer to body structures and physiological values (body temperature, heart rate, and the like), we will assume that we are talking about a healthy young *reference man* weighing about 155 lb [70 kilograms (kg)] or a healthy young *reference woman* weighing about 125 lb (57 kg).

Although we use the reference values and common directional and regional terms to refer to all human bodies, you know from observing the faces and body shapes of people around you that we humans differ in our external anatomy. The same kind of variability holds for internal organs as well. In one person, for example, a nerve or blood vessel may be somewhat out of place, or a small muscle may be missing. Nonetheless, well over 90% of all structures present in any human body match the textbook descriptions. We seldom see extreme anatomical variations because they are incompatible with life.

Topics of Anatomy

Anatomy is a broad field with many subdivisions, each providing enough information to be a course in itself. **Gross**, or **macroscopic**, **anatomy** is the study of large body structures visible to the naked eye, such as the heart, lungs, and kidneys. Indeed, the term *anatomy* (from Greek, meaning "to cut apart") relates most closely to gross anatomy because in such studies preserved animals or their organs are dissected (cut up) to be examined.

Gross anatomy can be approached in different ways.

- In **regional anatomy**, all the structures (muscles, bones, blood vessels, nerves, etc.) in a particular region of the body, such as the abdomen or leg, are examined at the same time.
- In **systemic anatomy** (sis-tem′ik),* body structure is studied system by system. For example, when studying the cardiovascular system, you would examine the heart and the blood vessels of the entire body.

* For the pronunciation guide rules, see the first page of the glossary in the back of the book.

- Another subdivision of gross anatomy is **surface anatomy**, the study of internal structures as they relate to the overlying skin surface. You use surface anatomy when you identify the bulging muscles beneath a bodybuilder's skin, and clinicians use it to locate appropriate blood vessels in which to feel pulses and draw blood.

Microscopic anatomy deals with structures too small to be seen with the naked eye. For most such studies, exceedingly thin slices of body tissues are stained and mounted on glass slides to be examined under the microscope. Subdivisions of microscopic anatomy include **cytology** (si-tol′o-je), which considers the cells of the body, and **histology** (his-tol′o-je), the study of tissues.

Developmental anatomy traces structural changes that occur throughout the life span. **Embryology** (em″bre-ol′o-je), a subdivision of developmental anatomy, concerns developmental changes that occur before birth.

Some highly specialized branches of anatomy are used primarily for medical diagnosis and scientific research. For example, *pathological anatomy* studies structural changes caused by disease. *Radiographic anatomy* studies internal structures as visualized by X-ray images or specialized scanning procedures.

Studying Anatomy

One essential tool for studying anatomy is a mastery of anatomical terminology. Other tools are observation, manipulation, and, in a living person, *palpation* (feeling organs with your hands) and *auscultation* (listening to organ sounds with a stethoscope). A simple example illustrates how some of these tools work together in an anatomical study.

Let's assume that your topic is freely movable joints of the body. In the laboratory, you will be able to *observe* an animal joint, noting how its parts fit together. You can work the joint (*manipulate* it) to determine its range of motion. Using *anatomical terminology*, you can name its parts and describe how they are related so that other students (and your instructor) will have no trouble understanding you. The list of word roots (at the back of the book) and the glossary will help you with this special vocabulary.

Although you will make most of your observations with the naked eye or with the help of a microscope, medical technology has developed a number of sophisticated tools that can peer into the body without disrupting it.

Topics of Physiology

Like anatomy, physiology has many subdivisions. Most of them consider the operation of specific organ systems. For example, **renal physiology** concerns kidney function and urine production. **Neurophysiology** explains the workings of the nervous system. **Cardiovascular physiology** examines the operation of the heart and blood vessels. While anatomy provides us with a static image of the body's architecture, physiology reveals the body's dynamic and animated workings.

Physiology often focuses on events at the cellular or molecular level. This is because the body's abilities depend on those of its individual cells, and cells' abilities ultimately depend on the chemical reactions that go on within them. Physiology also rests on principles of physics, which help to explain electrical currents, blood pressure, and the way muscles use bones to cause body movements, among other things. We present basic chemical and physical principles in Chapter 2 and throughout the book as needed to explain physiological topics.

Complementarity of Structure and Function

Although it is possible to study anatomy and physiology individually, they are really inseparable because function always reflects structure. That is, what a structure can do depends on its specific form. This key concept is called the **principle of complementarity of structure and function**.

For example, bones can support and protect body organs because they contain hard mineral deposits. Blood flows in one direction through the heart because the heart has valves that prevent backflow. Another example is how the various shapes of our teeth reflect their different actions, as shown in **Figure 1.1**. Throughout this book, we accompany a description of a structure's anatomy with an explanation of its function, and we emphasize structural characteristics contributing to that function.

Check Your Understanding

1. In what way does physiology depend on anatomy?
2. Would you be studying anatomy or physiology if you investigated how muscles shorten? If you explored the location of the lungs in the body?
3. APPLY Use the word root definitions located at the back of this book to define each of the following terms: gastritis, leukocyte, nephropathy.

For answers, see Answers Appendix.

1.2 The body's organization ranges from atoms to the entire organism

Learning Outcomes

- **Name the different levels of structural organization that make up the human body, and explain their relationships.**
- **List the 11 organ systems of the body, identify their components, and briefly explain the major function(s) of each system.**

The human body has many levels of structural organization (**Figure 1.2**, p. 4). The simplest level of the structural hierarchy is the **chemical level**, which we study in Chapter 2. At this level, *atoms*, tiny building blocks of matter, combine to form *molecules* such as water and proteins. Molecules, in turn, associate in specific ways to form *organelles* that are the basic components of cells. *Cells* are the smallest units of living things. We examine the **cellular level** in Chapter 3. All cells share some common functions, but individual cells vary widely in size and shape, reflecting their unique functions in the body.

The simplest living creatures are single cells, but in complex organisms such as human beings, the hierarchy continues on

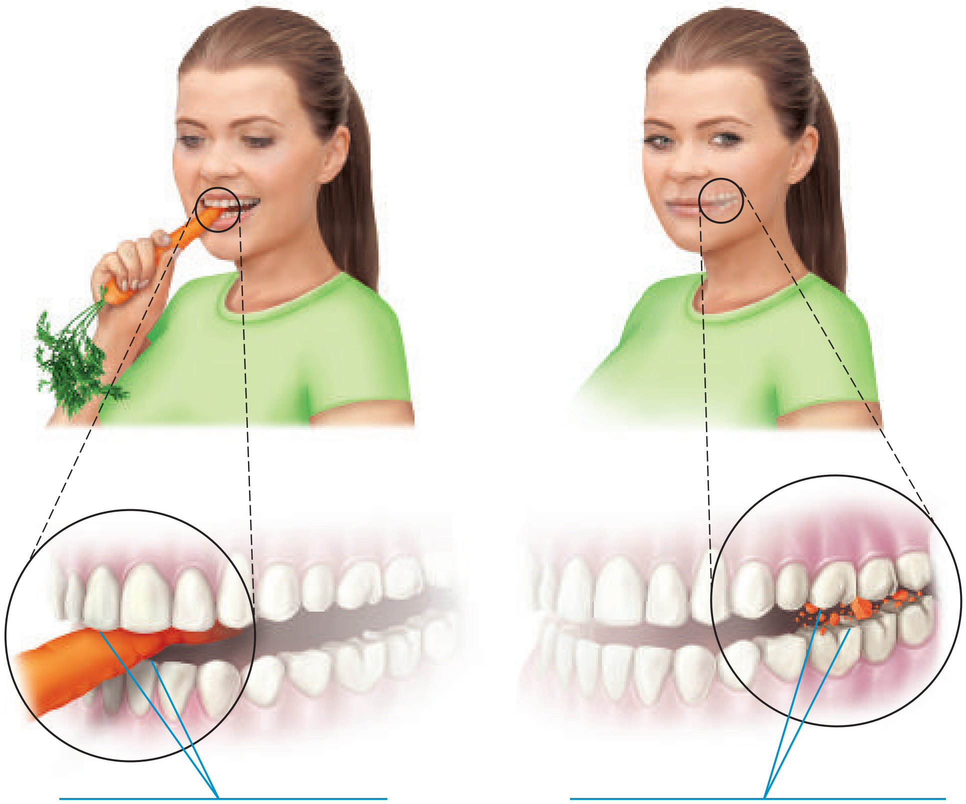


Figure 1.1 Complementarity of structure and function.

to the **tissue level**. *Tissues* are groups of similar cells that have a common function. The four basic tissue types in the human body are epithelial tissue, muscle tissue, connective tissue, and nervous tissue.

Each tissue type has a characteristic role in the body, which we explore in Chapter 4. Briefly, epithelial tissue covers the body surface and lines its cavities. Muscle tissue provides movement. Connective tissue supports and protects body organs. Nervous tissue provides a means of rapid internal communication by transmitting electrical impulses.

An *organ* is a discrete structure composed of at least two tissue types (four is more common) that performs a specific function for the body. The liver, the brain, and a blood vessel are very different from the stomach, but each is an organ. You can think of each organ of the body as a specialized functional center responsible for a necessary activity that no other organ can perform.

At the **organ level**, extremely complex functions become possible. Let's take the stomach for an example. Its lining is an epithelium that produces digestive juices. The bulk of its wall is muscle, which churns and mixes stomach contents (food). Its connective tissue reinforces the soft muscular walls. Its nerve fibers increase digestive activity by stimulating the muscle to contract more vigorously and the glands to secrete more digestive juices.

The next level of organization is the **organ system level**. Organs that work together to accomplish a common purpose make up an *organ system*. For example, the heart and blood vessels of the cardiovascular system circulate blood continuously to carry oxygen and nutrients to all body cells. Besides the cardiovascular system, the other organ systems of the body are the integumentary, skeletal, muscular, nervous, endocrine, lymphatic, respiratory, digestive, urinary, and reproductive systems. (Note that the immune system is closely associated with the lymphatic system.) Look ahead to Figure 1.4 on pp. 6–7 for an overview of the 11 organ systems.

The highest level of organization is the *organism*, the living human being. The **organismal level** represents the sum total of all structural levels working together to keep us alive.

Check Your Understanding

4. What level of structural organization is typical of a cytologist's field of study?

5. What is the correct structural order for the following terms: tissue, organism, organ, cell?

For answers, see Answers Appendix.

1.3 What are the requirements for life?

Learning Outcomes

- **List the functional characteristics necessary to maintain life in humans.**
- **List the survival needs of the body.**

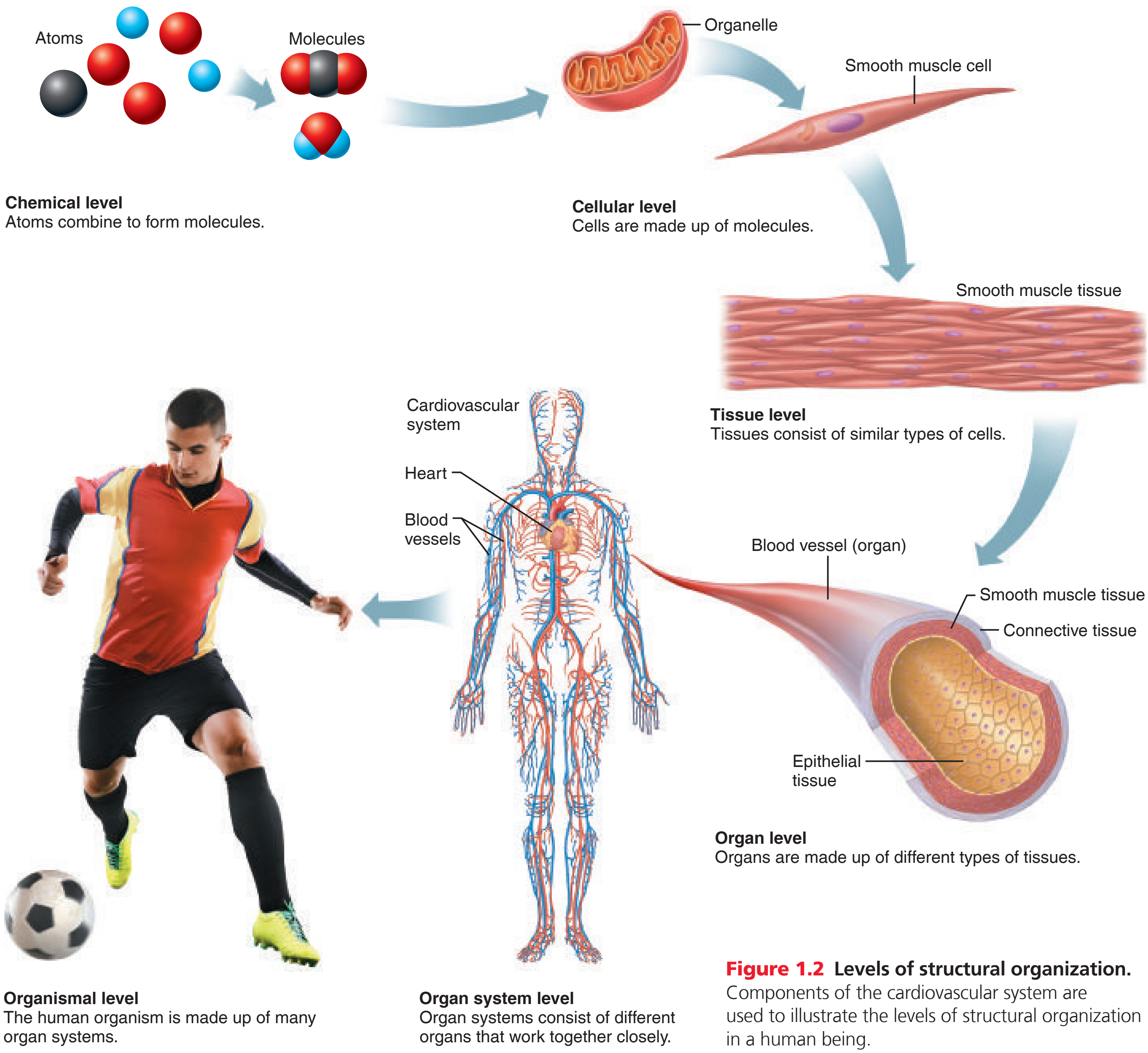


Figure 1.2 Levels of structural organization. Components of the cardiovascular system are used to illustrate the levels of structural organization in a human being.

Necessary Life Functions

Now that you know the structural levels of the human body, the question that naturally follows is: What does this highly organized human body do?

Like all complex animals, humans maintain their boundaries, move, respond to environmental changes, take in and digest nutrients, carry out metabolism, dispose of wastes, reproduce themselves, and grow. We will introduce these necessary life functions here and discuss them in more detail in later chapters.

We cannot emphasize too strongly that all body cells are interdependent. This interdependence is due to the fact that humans are multicellular organisms and our vital body functions are parceled out among different organ systems. Organ systems, in turn, work cooperatively to promote the well-being of the entire body. **Figure 1.3** identifies some of the organ systems making major contributions to necessary life functions. Also, as you read this section, check **Figure 1.4** on pp. 6–7 for more detailed descriptions of the body's organ systems.

Maintaining Boundaries

Every living organism must **maintain its boundaries** so that its internal environment (its inside) remains distinct from the external environment (its outside). In single-celled organisms, the external boundary is a limiting membrane that encloses its contents and lets in needed substances while restricting entry of potentially

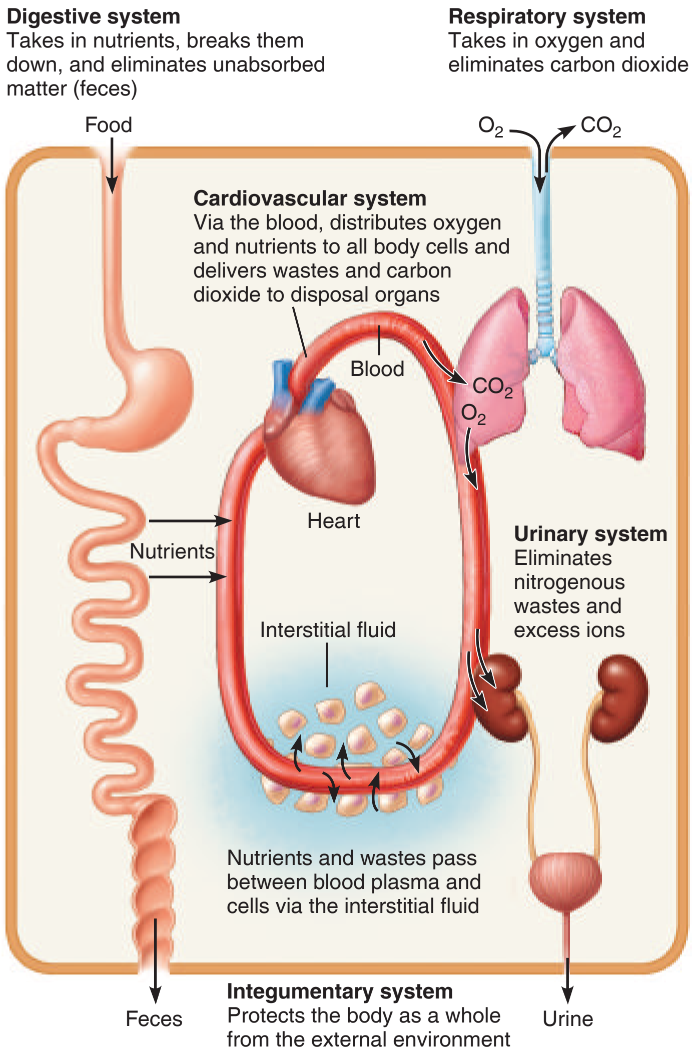


Figure 1.3 Examples of interrelationships among body organ systems.

damaging or unnecessary substances. Similarly, all body cells are surrounded by a selectively permeable *plasma membrane*.

The plasma membrane separates the *intracellular fluid* inside cells from the *extracellular fluid* outside. Part of the extracellular fluid (blood *plasma*) is enclosed in blood vessels. The remainder, the *interstitial fluid*, surrounds and bathes all of our cells (see Figure 1.3).

Another important boundary, the integumentary system, or skin, encloses the body as a whole (Figure 1.4a). This system protects our internal organs from drying out (a fatal change), infection, and the damaging effects of heat, sunlight, and an unbelievable number of chemicals in the external environment.

Movement

Movement includes the activities promoted by the muscular system, such as propelling ourselves from one place to another by running or swimming, and manipulating the external environment with our nimble fingers (Figure 1.4c). The skeletal system provides the bony framework that the muscles pull on as they work (Figure 1.4b). Movement also occurs when substances such as blood, foodstuffs, and urine are propelled through internal organs of the cardiovascular, digestive, and urinary systems, respectively. On the cellular level, the muscle cell's ability to move by shortening is more precisely called **contractility**.

Responsiveness

Responsiveness, or **excitability**, is the ability to sense changes (stimuli) in the environment and then respond to them. For example, if you cut your hand on broken glass, a *withdrawal reflex* occurs—you involuntarily pull your hand away from the painful stimulus (the broken glass). You don't have to think about it—it just happens! Likewise, when carbon dioxide in your blood rises to dangerously high levels, chemical sensors respond by sending messages to brain centers controlling respiration, and you breathe more rapidly.

Because nerve cells are highly excitable and communicate rapidly with each other via electrical impulses, the nervous system is most involved with responsiveness (Figure 1.4d). However, all body cells are excitable to some extent.

Digestion

Digestion is the breaking down of ingested foodstuffs to simple molecules that can be absorbed into the blood. The nutrient-rich blood is then distributed to all body cells by the cardiovascular system. In a simple, one-celled organism such as an amoeba, the cell itself is the "digestion factory," but in the multicellular human body, the digestive system performs this function for the entire body (Figure 1.4i).

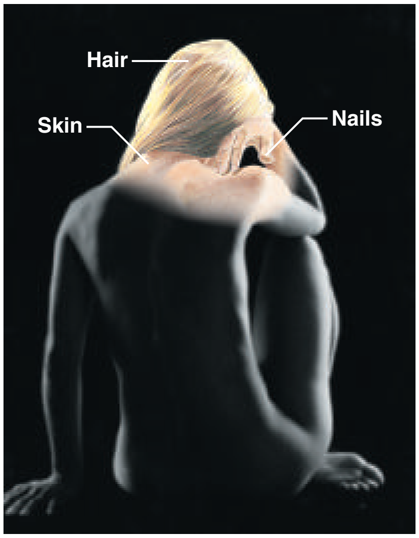
Metabolism

Metabolism (mĕ-tab′o-lizm; "a state of change") is a broad term that includes all chemical reactions that occur within body cells. It includes breaking down substances into simpler building blocks (the process of *catabolism*), synthesizing more complex substances from simpler building blocks (*anabolism*), and using nutrients and oxygen to produce (via *cellular respiration*) 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 them throughout the body (Figure 1.4i, h, and f, respectively). Metabolism is regulated largely by hormones secreted by endocrine system glands (Figure 1.4e).

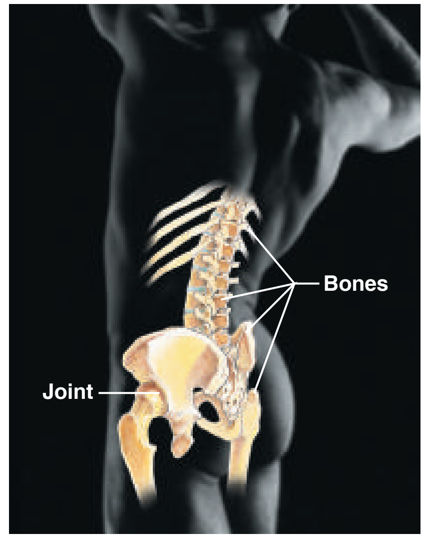
Excretion

Excretion is the process of removing wastes, or *excreta* (ek-skre′tah), from the body. If the body is to operate as we expect it to, it must get rid of nonuseful substances produced during digestion and metabolism.

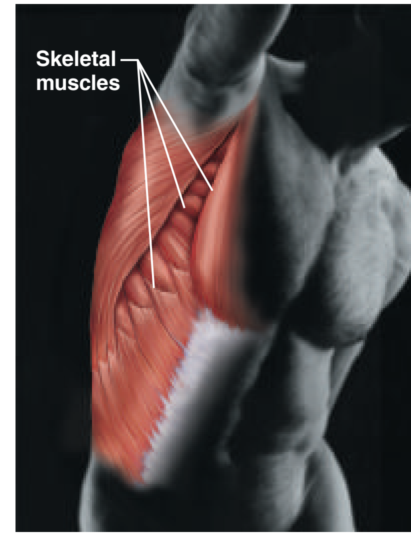
Several organ systems participate in excretion. For example, the digestive system rids the body of indigestible food residues in feces, and the urinary system disposes of nitrogen-containing metabolic wastes, such as urea, in urine (Figure 1.4i and j). Carbon dioxide, a by-product of cellular respiration, is carried in the blood to the lungs, where it leaves the body in exhaled air (Figure 1.4h).



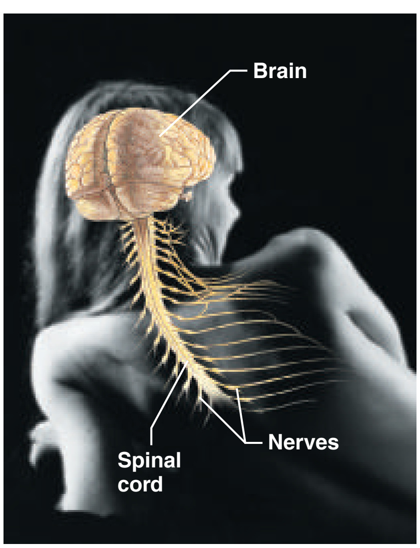
(a) Integumentary System
Forms the external body covering, and protects deeper tissues from injury. Synthesizes vitamin D, and houses cutaneous (pain, pressure, etc.) receptors, and sweat and oil glands.



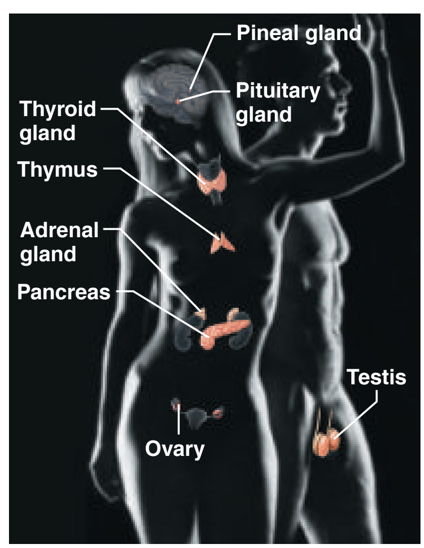
(b) Skeletal System
Protects and supports body organs, and provides a framework the muscles use to cause movement. Blood cells are formed within bones. Bones store minerals.



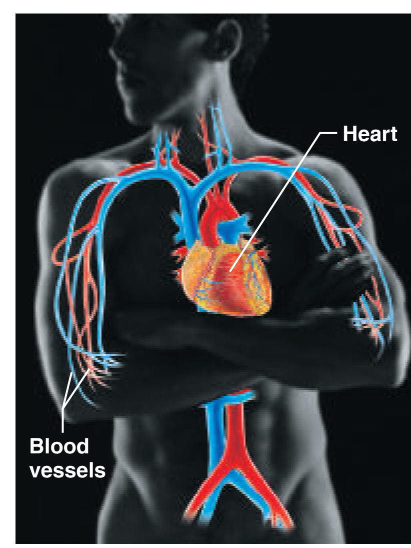
(c) Muscular System
Allows manipulation of the environment, locomotion, and facial expression. Maintains posture, and produces heat.



(d) Nervous System
As the fast-acting control system of the body, it 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 (metabolism) by body cells.

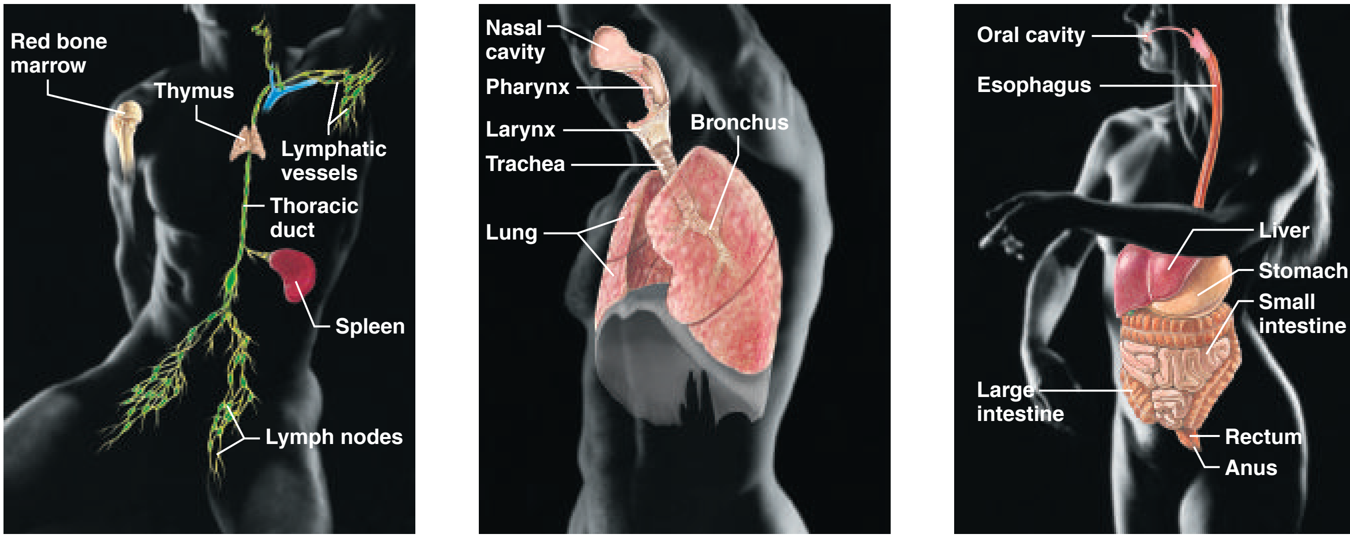


(f) Cardiovascular System
Blood vessels transport blood, which carries oxygen, carbon dioxide, nutrients, wastes, etc. The heart pumps blood.

Figure 1.4 The body's organ systems and their major functions.

Reproduction

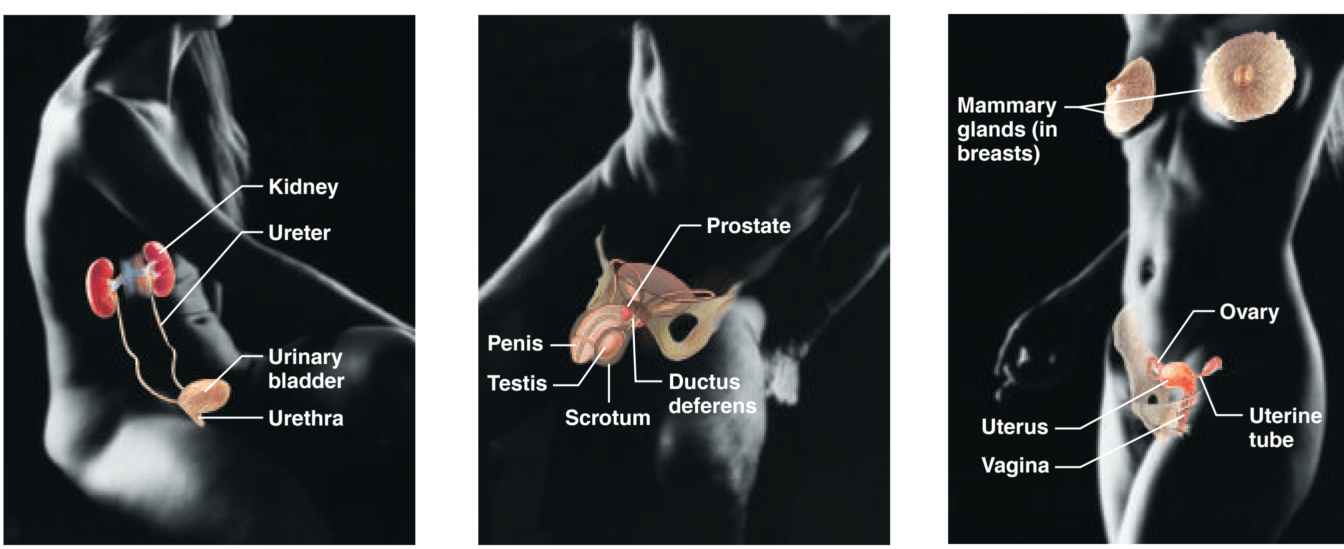
Reproduction occurs at the cellular and the organismal level. In cellular reproduction, the original cell divides, producing two identical daughter cells that may then be used for body growth or repair. Reproduction of the human organism, or making a whole new person, is the major task of the reproductive system. When a sperm unites with an egg, a fertilized egg forms and develops into a baby within the mother's body. The reproductive system is directly responsible for producing offspring, but its function is exquisitely regulated by hormones of the endocrine system (Figure 1.4e).



(g) Lymphatic System/Immunity
Picks up fluid leaked from blood vessels and returns it to blood. Disposes of debris in the lymphatic stream. Houses white blood cells (lymphocytes) involved in immunity. The immune response mounts the attack against foreign substances within the body.

(h) Respiratory System
Keeps blood constantly supplied with oxygen and removes carbon dioxide. These exchanges occur through the walls of the air sacs of the lungs.

(i) Digestive System
Breaks down food into absorbable units that enter the blood for distribution to body cells. Indigestible foodstuffs are eliminated as feces.



(j) Urinary System
Eliminates nitrogenous wastes from the body. Regulates water, electrolyte, and acid-base balance of the blood.

(k) Male Reproductive System **(l) Female Reproductive System**
Overall function is production of offspring. Testes produce sperm and male sex hormone, and male ducts and glands aid in delivery of sperm to the female reproductive tract. Ovaries produce eggs and female sex hormones. The remaining female structures serve as sites for fertilization and development of the fetus. Mammary glands of female breasts produce milk to nourish the newborn.

Figure 1.4 *(continued)*

Because males produce sperm and females produce eggs (ova), there is a division of labor in reproduction, and the reproductive organs of males and females are different (Figure 1.4k, l). Additionally, the female's reproductive structures provide the site for fertilization of eggs by sperm, and then protect and nurture the developing fetus until birth.

Growth

Growth is an increase in size of a body part or the organism as a whole. It is usually accomplished by increasing the number of cells. However, individual cells also increase in size when not dividing. For true growth to occur, constructive activities must occur at a faster rate than destructive ones.

1

Survival Needs

The ultimate goal of all body systems is to maintain life. However, life is extraordinarily fragile and requires several factors. These **survival needs** include nutrients (food), oxygen, water, and appropriate temperature and atmospheric pressure.

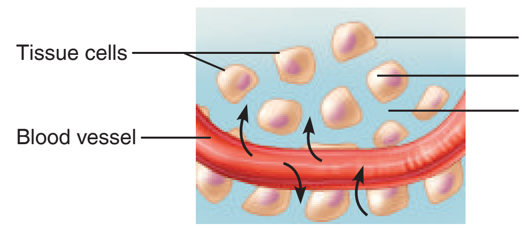
- **Nutrients. Nutrients**, taken in via the diet, contain the chemical substances used for energy and cell building. Most plant-derived foods are rich in carbohydrates, vitamins, and minerals, whereas most animal foods are richer in proteins and fats.

  Carbohydrates are the major energy fuel for body cells. Proteins, and to a lesser extent fats, are essential for building cell structures. Fats also provide a reserve of energy-rich fuel. Selected minerals and vitamins are required for the chemical reactions that go on in cells and for oxygen transport in the blood. The mineral calcium helps to make bones hard and is required for blood clotting.
- **Oxygen.** All the nutrients in the world are useless unless **oxygen** is also available. Because the chemical reactions that release energy from foods are *oxidative* reactions that require oxygen, human cells can survive for only a few minutes without oxygen. Approximately 20% of the air we breathe is oxygen. The cooperative efforts of the respiratory and cardiovascular systems make oxygen available to the blood and body cells.
- **Water. Water** accounts for 50–60% of our body weight and is the single most abundant chemical substance in the body. It provides the watery environment necessary for chemical reactions and the fluid base for body secretions and excretions. We obtain water from ingested foods and liquids. We lose it from the body by evaporation from the lungs and skin and in body excretions.
- **Normal body temperature.** If chemical reactions are to continue at life-sustaining rates, **normal body temperature** must be maintained. As body temperature drops below 37°C (98.6°F), metabolic reactions become slower and slower, and finally stop. When body temperature is too high, chemical reactions occur at a frantic pace and body systems stop functioning. At either extreme, death occurs. The activity of the muscular system generates most body heat.
- **Appropriate atmospheric pressure. Atmospheric pressure** is the force that air exerts on the surface of the body. Breathing and gas exchange in the lungs depend on *appropriate* atmospheric pressure. At high altitudes, where atmospheric pressure is lower and the air is thin, gas exchange may be inadequate to support cellular metabolism.

The mere presence of these survival factors is not sufficient to sustain life. They must be present in the proper amounts. Too much and too little may be equally harmful. For example, oxygen is essential, but excessive amounts are toxic to body cells. Similarly, the food we eat must be of high quality and in proper amounts. Otherwise, nutritional disease, obesity, or starvation is likely. Also, while the needs listed here are the most crucial, they do not even begin to encompass all of the body's needs. For example, we can live without gravity if we must, but the quality of life suffers.

Check Your Understanding

6. What separates living beings from nonliving objects?
7. What name is given to all chemical reactions that occur within body cells?
8. The image below shows tissue cells and part of a blood vessel. The cells' nutrients and wastes are exchanged across an important boundary between two fluid compartments. Name the boundary (a) and the fluid in the compartments (b and c). Be specific.



For answers, see Answers Appendix.

1.4 Homeostasis is maintained by negative feedback

Learning Outcomes

- **Define homeostasis and explain its significance.**
- **Describe how negative and positive feedback maintain body homeostasis.**
- **Describe the relationship between homeostatic imbalance and disease.**

When you 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 machine your body is. Walter Cannon, an American physiologist of the early twentieth century, spoke of the "wisdom of the body," and he coined the word **homeostasis** (ho″me-o-sta′sis) to describe its ability to maintain relatively stable internal conditions even though the outside world changes continuously.

Although the literal translation of homeostasis is "unchanging," the term does not really mean a static, or unchanging, state. Rather, it indicates a *dynamic* state of equilibrium, or a balance, in which internal conditions vary, but always within relatively narrow limits. In general, the body is in homeostasis when its needs are adequately met and it is functioning smoothly.

Maintaining homeostasis is more complicated than it appears at first glance. 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 to all body tissues. Also, wastes must not be allowed to accumulate, and body temperature must be precisely controlled. A wide variety of chemical, thermal, and neural factors act and interact in complex ways—sometimes helping and sometimes hindering the body as it works to maintain its "steady rudder."

Homeostatic Control

Communication within the body is essential for homeostasis. Communication is accomplished chiefly by the nervous and

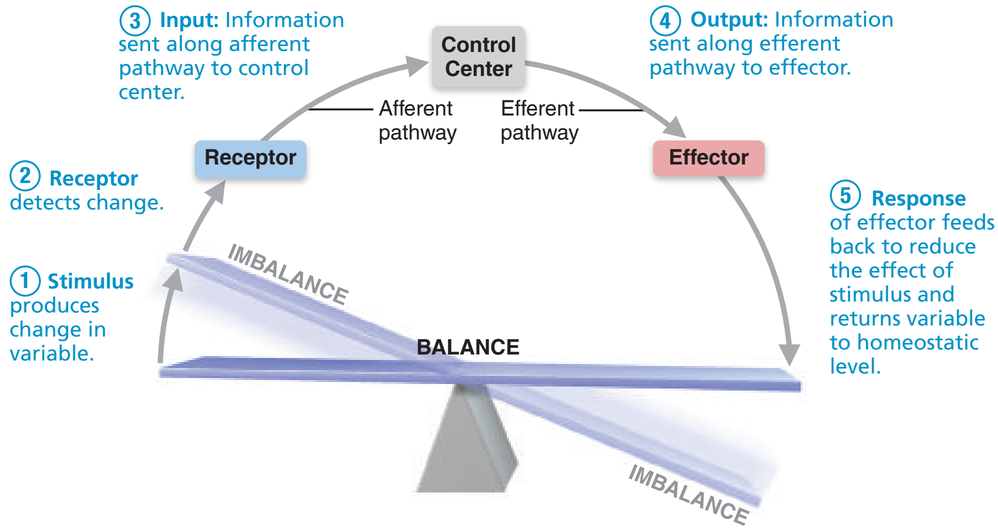


Figure 1.5 Interactions among the elements of a homeostatic control system maintain stable internal conditions.

endocrine systems, which use neural electrical impulses or bloodborne hormones, respectively, as information carriers. We cover the details of how these two great regulating systems operate in later chapters, but here we explain the basic characteristics of control systems that promote homeostasis.

The **variable** is the factor or event being regulated. All homeostatic control mechanisms are processes involving at least three components that work together to regulate the variable (**Figure 1.5**).

1. The **receptor** is the first component. It is a sensor that monitors the environment. It responds to *stimuli* (changes) by sending information (input) along the *afferent pathway* to the second component, the *control center*.
2. The **control center** determines the *set point*, which is the level (or range of levels) at which a variable is to be maintained. It analyzes the input it receives by comparing it to the set point and determines the appropriate response. Information (output) then flows from the control center along the *efferent pathway* to the third component, the *effector*. (To help you remember the difference between "afferent" and "efferent," note that information traveling along the afferent pathway *approaches* the control center and efferent information *exits* from the control center.)
3. The **effector** carries out the control center's response to the stimulus. The results of the response then *feed back* to influence the effect of the stimulus, either reducing it so that the whole control process is shut off, or enhancing it so that the whole process continues at an even faster rate.

Negative Feedback Mechanisms

Most homeostatic control mechanisms are **negative feedback mechanisms**. In these systems, the output shuts off the original effect of the stimulus or reduces its intensity. These mechanisms cause the variable to change in a direction *opposite* to that of the initial change, returning it to its "ideal" value.

Let's start with an example of a nonbiological negative feedback system: a home heating system connected to a temperature-sensing thermostat. The thermostat houses both the receptor (thermometer) and the control center. If the thermostat is set at 20°C (68°F), the heating system (effector) is triggered ON when the house temperature drops below that setting. As the furnace produces heat and warms the air, the temperature rises, and when it reaches 20°C or slightly higher, the thermostat triggers the furnace OFF. This process results in a cycling of the furnace between "ON" and "OFF" so that the temperature in the house stays very near the desired temperature. Your body "thermostat," located in a part of your brain called the hypothalamus, operates in a similar fashion (**Figure 1.6**, p. 10).

Regulation of body temperature is only one of the many ways the nervous system maintains the constancy of the internal environment. Another type of neural control mechanism is seen in the *withdrawal reflex* mentioned earlier, in which the hand is jerked away from a painful stimulus such as broken glass.

The endocrine system is equally important in maintaining homeostasis. A good example of a hormonal negative feedback mechanism is the control of blood sugar (glucose) by insulin. As blood sugar rises, receptors in the body sense this change, and the pancreas (the control center) secretes insulin into the blood. This change in turn prompts body cells to absorb more glucose, removing it from the bloodstream. As blood sugar falls, the stimulus for insulin release ends.

The body's ability to regulate its internal environment is fundamental. All negative feedback mechanisms have the same goal: preventing severe changes within the body. Body temperature and blood sugar are only two of the variables that need to be regulated. There are many! Other negative feedback mechanisms regulate heart rate, blood pressure, the rate and depth of breathing, and blood levels of oxygen, carbon dioxide, and minerals.

Positive Feedback Mechanisms

In **positive feedback mechanisms**, the initial response enhances the original stimulus so that further responses are even greater. This feedback mechanism is "positive" because the change that results proceeds in the *same* direction as the initial change, causing the variable to deviate further and further from its original value or range.

In contrast to negative feedback controls, which maintain some physiological function or keep blood chemicals within narrow ranges, positive feedback mechanisms usually control infrequent events that do not require continuous adjustments. Typically, they set off a linked sequence of events. Once initiated, the results of each reaction feed into the next like a series

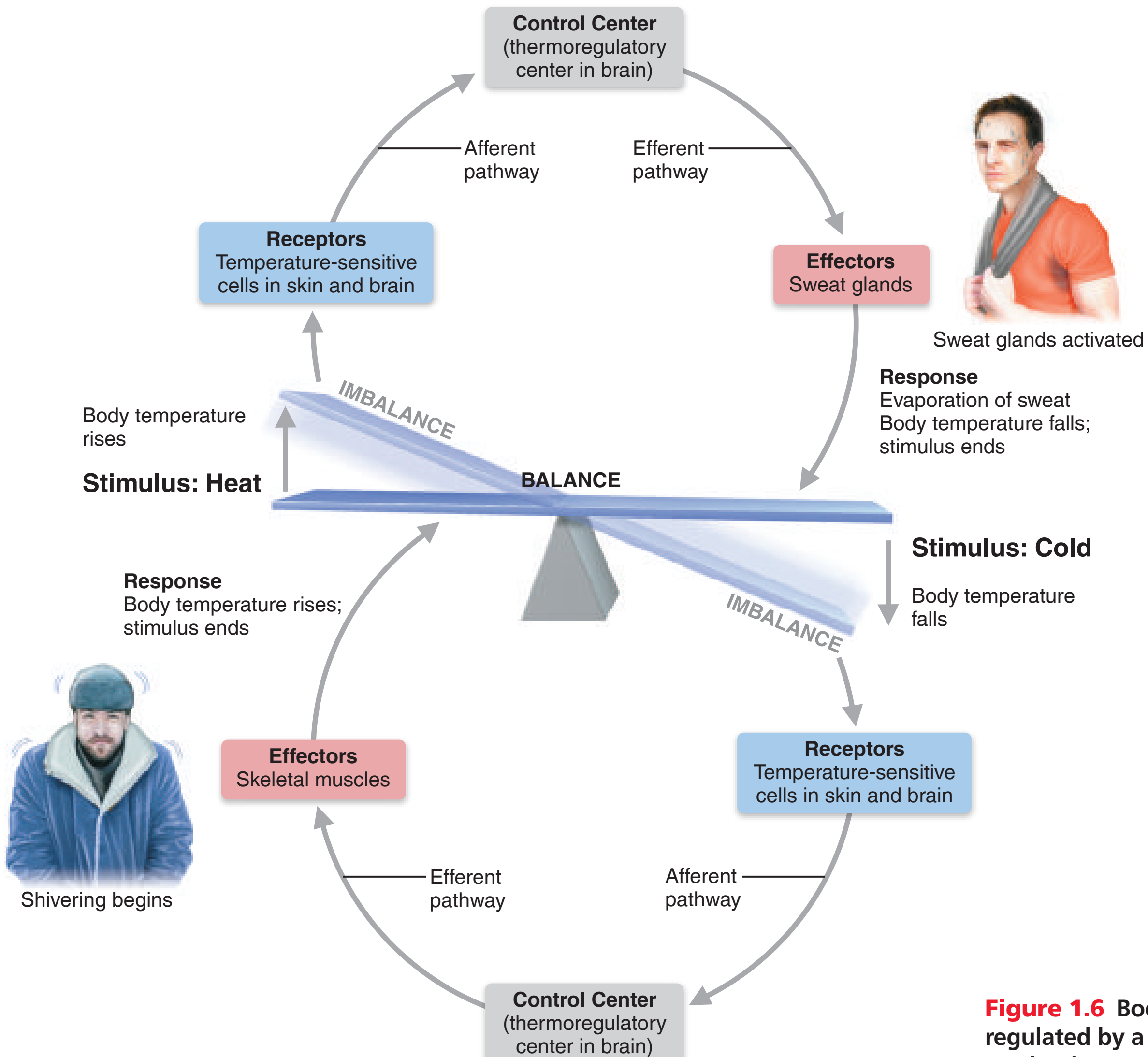


Figure 1.6 Body temperature is regulated by a negative feedback mechanism.

of waterfalls on a river. Because of these characteristics, positive feedback mechanisms are often referred to as *cascades* (from the Italian word meaning "to fall") that amplify the original stimulus. Two familiar examples are the enhancement of labor contractions during birth and blood clotting.

In one example of a positive feedback mechanism, oxytocin, a hypothalamic hormone, intensifies labor contractions during the birth of a baby. Oxytocin causes the contractions to become both more frequent and more powerful. The increased contractions cause more oxytocin to be released, which causes more contractions, and so on until the baby is born. The birth ends the stimulus for oxytocin release and shuts off the positive feedback mechanism.

Blood clotting is a normal response to a break in the wall of a blood vessel and is an excellent example of an important body function controlled by positive feedback. Once a vessel has been damaged, blood elements called platelets immediately begin to cling to the injured site and release chemicals that attract more platelets. This rapidly growing pileup of platelets temporarily "plugs" the tear and initiates the sequence of events that finally forms a clot (**Figure 1.7**).

Positive feedback mechanisms are likely to race out of control, so they are rarely used to promote the moment-to-moment well-being of the body. Some positive feedback mechanisms, including this one, may have only local effects. For example, blood clotting is accelerated in injured vessels, but does not normally spread to the entire circulation.

Homeostatic Imbalance

Homeostasis is so important that most disease can be regarded as a result of its disturbance, a condition called **homeostatic imbalance**. As we age, our body's control systems become less efficient, and our internal environment becomes less and less stable. These events increase our risk for illness and produce the changes we associate with aging.

Another important source of homeostatic imbalance occurs when the usual negative feedback mechanisms are overwhelmed and destructive positive feedback mechanisms take over. Some instances of heart failure reflect this phenomenon.

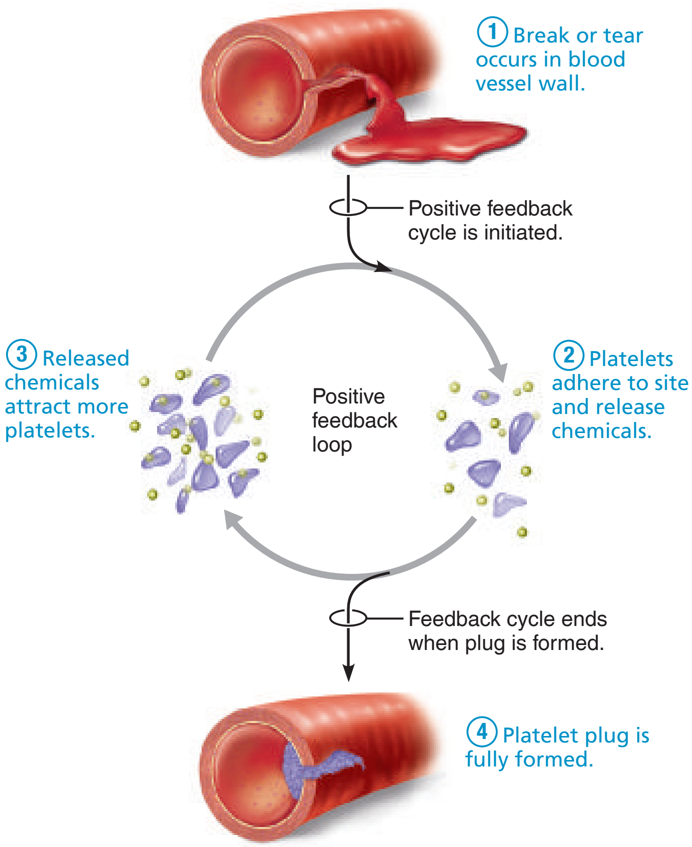


Figure 1.7 A positive feedback mechanism regulates formation of a platelet plug.

Examples of homeostatic imbalance appear throughout this book to enhance your understanding of normal physiological mechanisms. This symbol introduces the homeostatic imbalance sections and alerts you to the fact that we are describing an abnormal condition. Each Homeostatic Imbalance section is numbered to correspond with critical thinking questions available in the Study Area of **Mastering A&P**—visit the website to find Homeostatic Imbalance questions and other helpful study tools.

Check Your Understanding

9. What process allows us to adjust to either extreme heat or extreme cold?

10. Why is the control system shown in Figure 1.7 called a positive feedback mechanism? What event ends it?

11. APPLY When we begin to get dehydrated, we usually get thirsty, which causes us to drink fluids. Is thirst part of a negative or a positive feedback control system? Explain your choice.

For answers, see Answers Appendix.

1.5 Anatomical terms describe body directions, regions, and planes

Learning Outcomes

- **Describe the anatomical position.**
- **Use correct anatomical terms to describe body directions, regions, and body planes or sections.**

Most of us are naturally curious about our bodies, but our interest sometimes dwindles when we are confronted with the terminology of anatomy and physiology. Let's face it—you can't just pick up an anatomy and physiology book and read it as though it were a novel. Unfortunately, confusion is likely without precise, specialized terminology. To prevent misunderstanding, anatomists use universally accepted terms to identify body structures precisely and with a minimum of words. We present and explain the language of anatomy next.

Anatomical Position and Directional Terms

To describe body parts and position accurately, we need an initial reference point, and we must indicate direction. The anatomical reference point is a standard body position called the **anatomical position**. In the anatomical position, the body is erect with feet slightly apart. This position is easy to remember because it resembles "standing at attention," except that the palms face forward and the thumbs point away from the body. You can see the anatomical position in **Figure 1.8a**, p. 12 and **Table 1.1** (top) on p. 13.

It is essential to understand the anatomical position because most of the directional terms used in this book refer to the body *as if it were in this position, regardless of its actual position*. Another point to remember is that the terms "right" and "left" refer to those sides of the person or the cadaver being viewed—not those of the observer.

Directional terms allow us to explain where one body structure is in relation to another. For example, we could describe the relationship between the ears and the nose by stating, "The ears are located on each side of the head to the right and left of the nose." Using anatomical terminology, this becomes "The ears are lateral to the nose." Using anatomical terms saves words and is less ambiguous.

Commonly used orientation and directional terms are defined and illustrated in Table 1.1. Many of these terms are also used in everyday conversation, but remember as you study them that their anatomical meanings are very precise.

Regional Terms

The two fundamental divisions of our body are its *axial* and *appendicular* (ap″en-dik′u-lar) parts. The **axial part**, which makes up the main *axis* of our body, includes the head, neck, and trunk. The **appendicular part** consists of the *appendages*, or *limbs*, which are attached to the body's axis. **Regional terms** used to designate specific areas within these major body divisions are indicated in Figure 1.8.

Body Planes and Sections

For anatomical studies, the body is often cut, or *sectioned*, along a flat surface called a *plane*. The most frequently used body planes are *sagittal*, *frontal*, and *transverse* planes, which lie at right angles to one another (**Figure 1.9**, p. 14). A section is named for the plane along which it is cut. Thus, a cut along a sagittal plane produces a sagittal section.

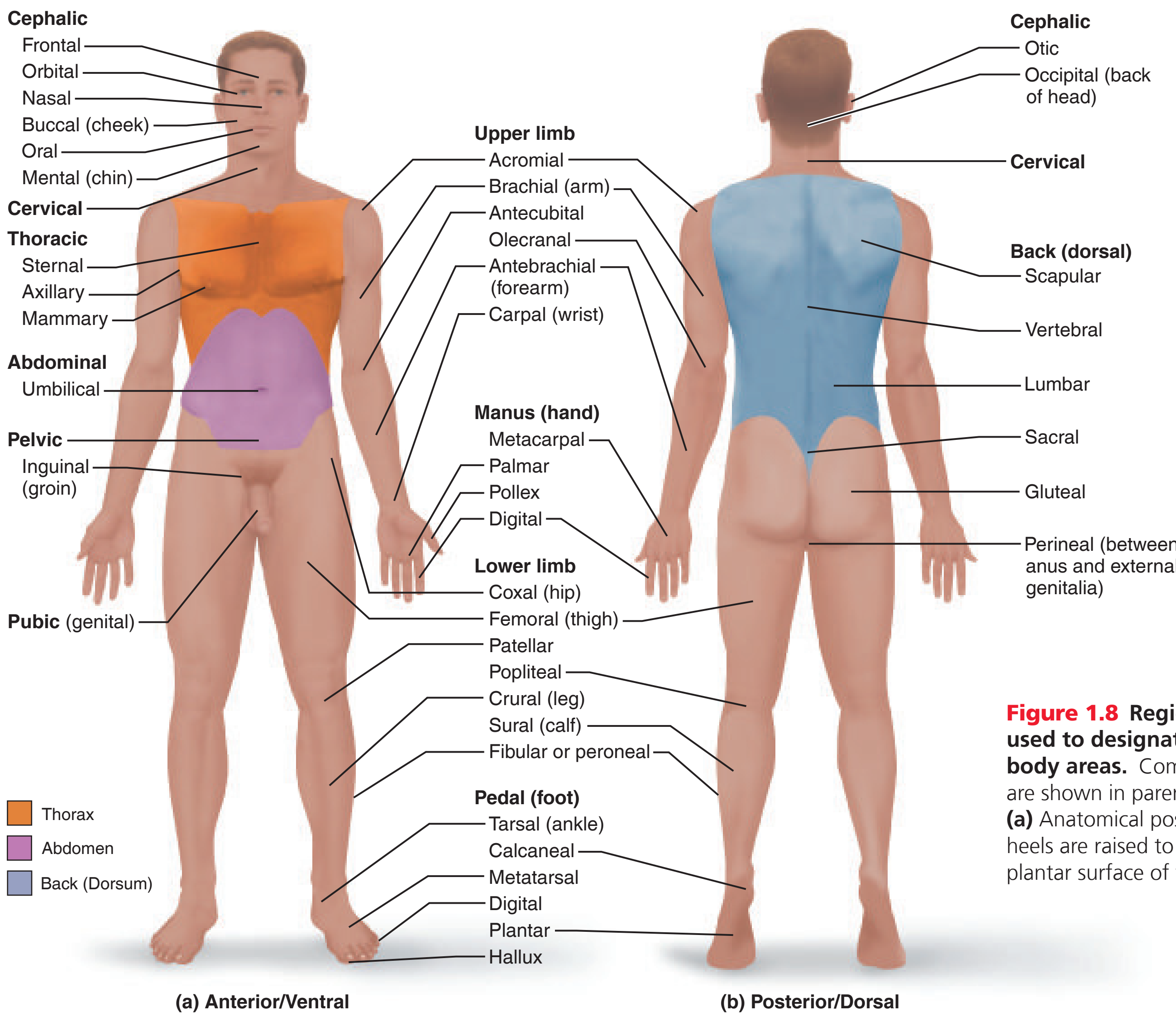


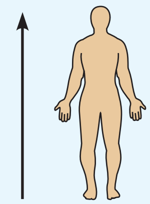
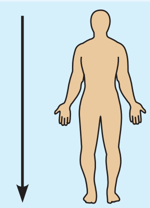
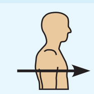
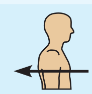
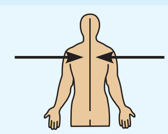
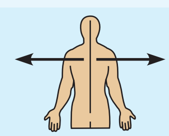
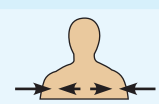
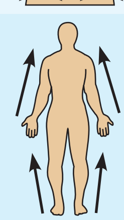
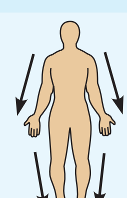
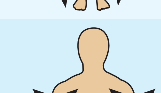
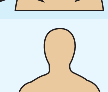
Figure 1.8 Regional terms used to designate specific body areas. Common terms are shown in parentheses. **(a)** Anatomical position. **(b)** The heels are raised to show the plantar surface of the foot.

- A **sagittal plane** (saj′ĭ-tal; "arrow") is a vertical plane that divides the body into right and left parts. A sagittal plane that lies exactly in the midline is the **median plane**, or **midsagittal plane** (Figure 1.9a). All other sagittal planes, offset from the midline, are **parasagittal planes** (*para* = near).
- **Frontal planes**, like sagittal planes, lie vertically. Frontal planes, however, divide the body into anterior and posterior parts (Figure 1.9b). A frontal plane is also called a **coronal plane** (kŏ-ro′nal; "crown").
- A **transverse**, or **horizontal**, **plane** runs horizontally from right to left, dividing the body into superior and inferior parts (Figure 1.9c). Of course, many different transverse planes exist, at every possible level from head to foot. A transverse section is also called a **cross section**.
- **Oblique sections** are cuts made diagonally between the horizontal and the vertical planes. Because oblique sections are often confusing and difficult to interpret, they are seldom used.

Figure 1.9 includes examples of magnetic resonance imaging (MRI) scans that correspond to the three sections shown in the figure. Clinically, the ability to interpret sections made through the body, especially transverse sections, is important. Additionally, certain medical imaging devices produce sectional images rather than three-dimensional images.

It takes practice to determine an object's overall shape from sectioned material. Sectioning the body or an organ 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. With experience, you will gradually learn to relate two-dimensional sections to three-dimensional shapes.

Table 1.1 Orientation and Directional Terms

TERM	DEFINITION	EXAMPLE	
Superior (cranial)	Toward the head end or upper part of a structure or the body; above		The head is superior to the abdomen.
Inferior (caudal)	Away from the head end or toward the lower part of a structure or the body; below		The navel is inferior to the chin.
Anterior (ventral)*	Toward or at the front of the body; in front of		The breastbone is anterior to the spine.
Posterior (dorsal)*	Toward or at the back of the body; behind		The heart is posterior to the breastbone.
Medial	Toward or at the midline of the body; on the inner side of		The heart is medial to the arm.
Lateral	Away from the midline of the body; on the outer side of		The arms are lateral to the chest.
Intermediate	Between a more medial and a more lateral structure		The collarbone is intermediate between the breastbone and shoulder.
Proximal	Closer 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.
Distal	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.
Superficial (external)	Toward or at the body surface		The skin is superficial to the skeletal muscles.
Deep (internal)	Away from the body surface; more internal		The lungs are deep to the skin.

*The terms *ventral* and *anterior* are synonymous in humans, but this is not the case in four-legged animals. *Anterior* refers to the leading portion of the body (abdominal surface in humans, head in a cat), but *ventral* specifically refers to the "belly" of a vertebrate animal, so it is the inferior surface of four-legged animals. Likewise, although the dorsal and posterior surfaces are the same in humans, the term *dorsal* specifically refers to an animal's back (as in the dorsal fin of a shark). Thus, the dorsal surface of four-legged animals is their superior surface.

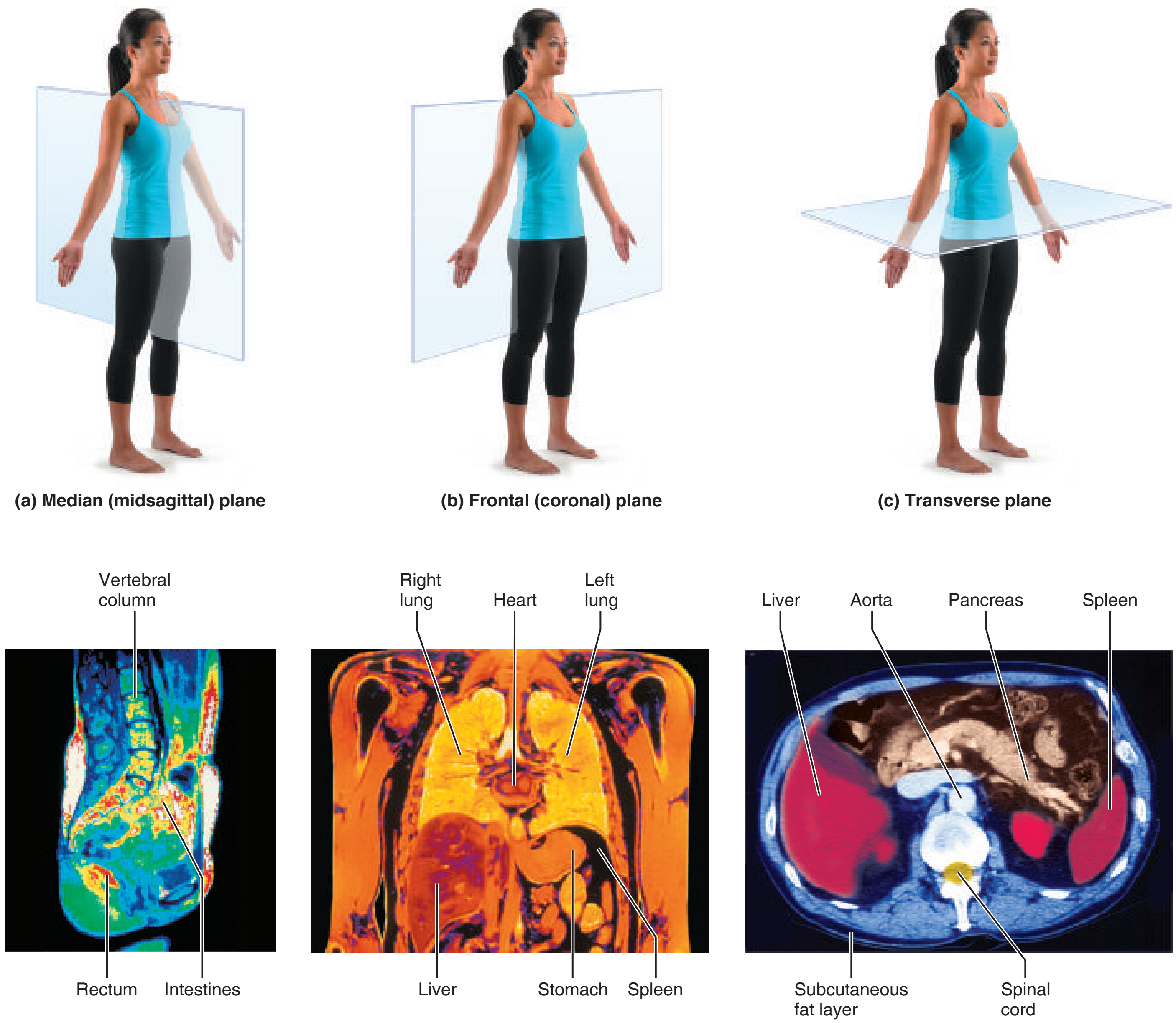


Figure 1.9 **Planes of the body with corresponding magnetic resonance imaging (MRI) scans.**

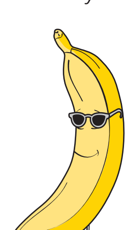
Check Your Understanding

12. What is the anatomical position? Why is it important that *you* learn this position?

13. The axillary and acromial regions are both in the general area of the shoulder. Where specifically is each located?

14. What type of cut would separate the brain into anterior and posterior parts?

15. DRAW Draw the outline that you would get if you made midsagittal, coronal, and transverse sections of the banana at the right.



For answers, see Answers Appendix.

1.6 Many internal organs lie in membrane-lined body cavities

Learning Outcomes

- **Locate and name the major body cavities and their subdivisions and associated membranes, and list the major organs contained within them.**
- **Name the four quadrants or nine regions of the abdominopelvic cavity and list the organs they contain.**

Anatomy and physiology textbooks typically describe two sets of internal body cavities called the dorsal and ventral body cavities. These cavities are closed to the outside and provide different degrees of protection to the organs within them. Because these two cavities differ in their mode of embryonic development and their lining membranes, the dorsal body cavity is not recognized as such in many anatomical references. However, the idea of two sets of internal body cavities is a useful learning concept and we use it here.

Dorsal Body Cavity

The **dorsal body cavity**, which protects the fragile nervous system organs, has two subdivisions (**Figure 1.10**, gold areas). The **cranial cavity**, in the skull, encases the brain. The **vertebral**, or **spinal**, **cavity**, which runs within the bony vertebral column, encloses the delicate spinal cord. The spinal cord is essentially a continuation of the brain, and the cranial and spinal cavities are continuous with one another. Both the brain and the spinal cord are covered by membranes called meninges.

Ventral Body Cavity

The more anterior and larger of the closed body cavities is the **ventral body cavity** (Figure 1.10, deep-red areas). Like the dorsal cavity, it has two major subdivisions, the *thoracic cavity* and the *abdominopelvic cavity*. The ventral body cavity houses internal organs collectively called the **viscera** (vis′er-ah; *viscus* = an organ in a body cavity), or visceral organs.

The superior subdivision, the **thoracic cavity** (tho-ras′ik), is surrounded by the ribs and muscles of the chest. The thoracic cavity is further subdivided into lateral **pleural cavities** (ploo′ral), each enveloping a lung, and the medial **mediastinum** (me″de-ah-sti′num). The mediastinum contains the **pericardial cavity** (per″ĭ-kar′de-al), which encloses the heart, and it also surrounds the remaining thoracic organs (esophagus, trachea, and others).

The thoracic cavity is separated from the more inferior **abdominopelvic cavity** (ab-dom′ĭ-no-pel′vic) by the diaphragm, a dome-shaped muscle important in breathing. The abdominopelvic cavity, as its name suggests, has two parts. However, these regions are not physically separated by a muscular or membrane wall. Its superior portion, the **abdominal cavity**, contains the stomach, intestines, spleen, liver, and other organs. The inferior part, the **pelvic cavity**, lies in the bony pelvis and contains the urinary bladder, some reproductive organs, and the rectum. The abdominal and pelvic cavities are not aligned with each other. Instead, the bowl-shaped pelvis tips away from the perpendicular as shown in Figure 1.10a. 1

HOMEOSTATIC IMBALANCE 1.1 — **CLINICAL**

Each body cavity is uniquely suited to house its contents. Problems arise when a structure strays into a neighboring cavity. A *hiatal hernia* occurs when part of the stomach slides through the diaphragm into the thoracic cavity, allowing stomach acid to cause heartburn (which is actually irritation of the esophagus, not the heart). Severe cases may require surgical repair.

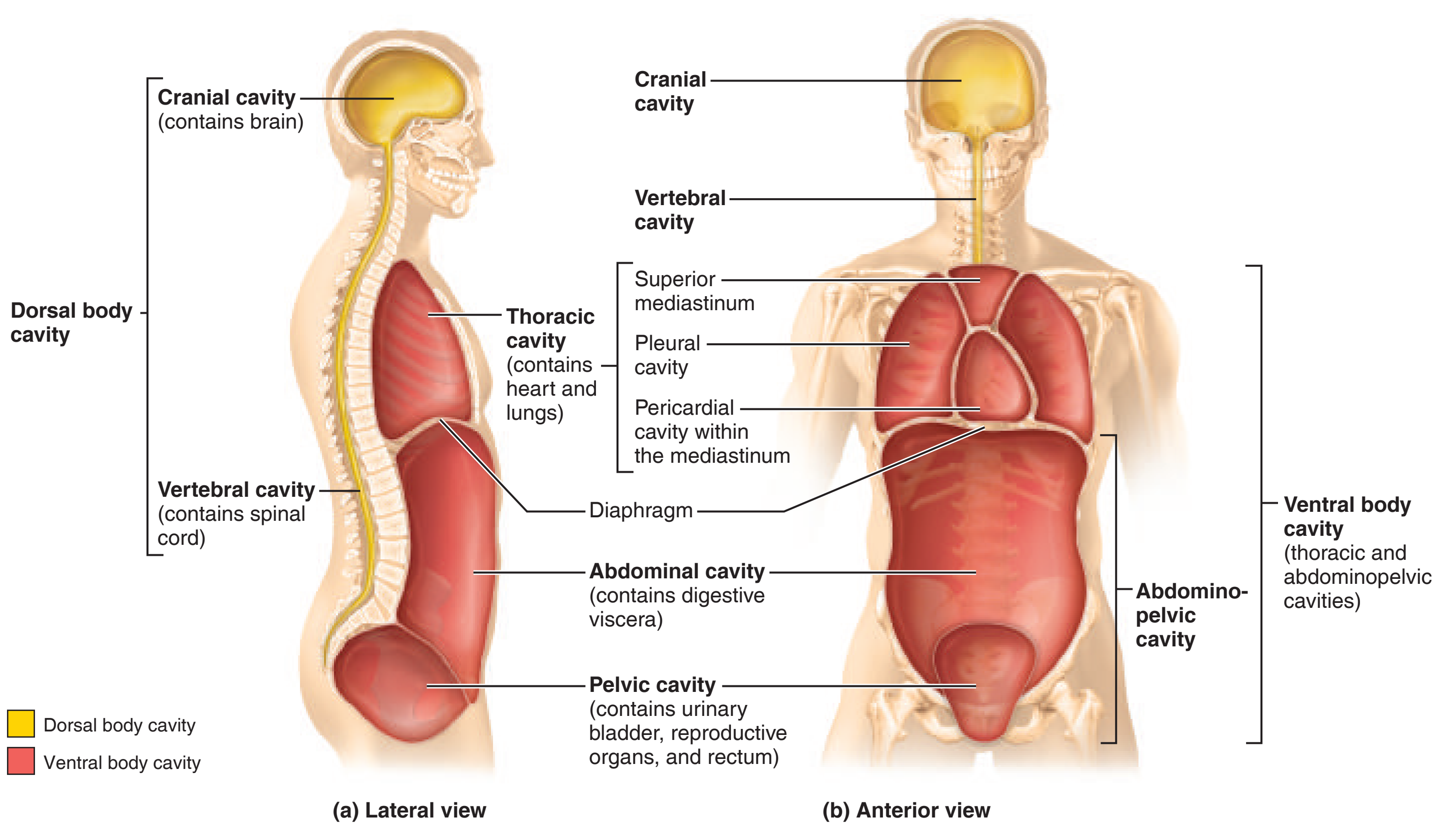
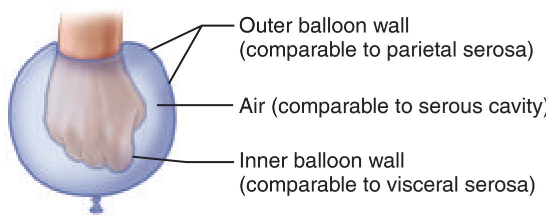
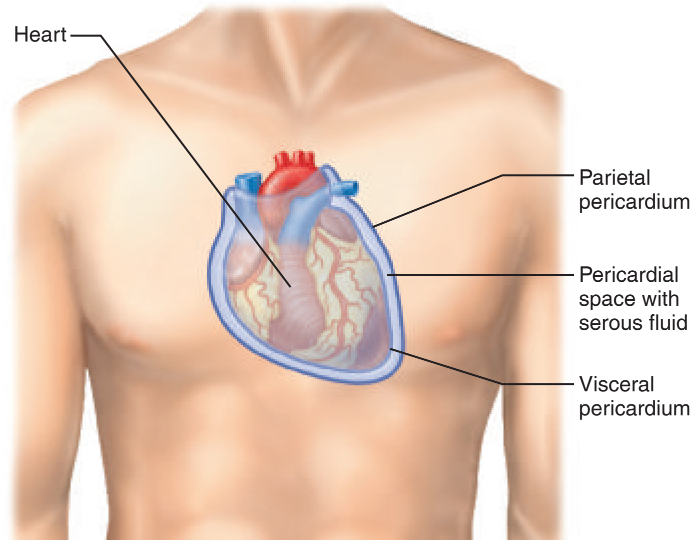


Figure 1.10 Dorsal and ventral body cavities and their subdivisions.



(a) A fist thrust into a flaccid balloon demonstrates the relationship between the parietal and visceral serous membrane layers.



(b) The serosae associated with the heart.

Figure 1.11 Serous membrane relationships.

Membranes in the Ventral Body Cavity

The walls of the ventral body cavity and the outer surfaces of the organs it contains are covered by a thin, double-layered membrane, the **serosa** (se-ro′sah), or **serous membrane**. The part of the membrane lining the cavity walls is called the **parietal serosa** (pah-ri′ĕ-tal; *parie* = wall). It folds in on itself to form the **visceral serosa**, covering the organs in the cavity.

You can visualize the relationship between the serosal layers by pushing your fist into a limp balloon (**Figure 1.11a**). The part of the balloon that clings to your fist can be compared to the visceral serosa clinging to an organ's external surface. The outer wall of the balloon represents the parietal serosa that lines the walls of the cavity. (However, unlike the balloon, the parietal serosa is never exposed but is always fused to the cavity wall.) In the body, the serous membranes are separated not by air but by a thin layer of lubricating fluid, called **serous fluid**, which is secreted by both membranes. Although there is a potential space between the two membranes, the barely present, slitlike *serous cavity* is filled with serous fluid.

The slippery serous fluid allows the organs to slide without friction across the cavity walls and one another as they carry out their routine functions. This freedom of movement is especially important for mobile organs such as the pumping heart and the churning stomach.

The serous membranes are named for the specific cavity and organs with which they are associated. For example, as shown in Figure 1.11b, the *parietal pericardium* lines the pericardial cavity and folds back as the *visceral pericardium*, which covers the heart. Likewise, the *parietal pleurae* (ploo′re) line the walls of the thoracic cavity, and the *visceral pleurae* cover the lungs. The *parietal peritoneum* (per″ĭ-to-ne′um) is associated with the walls of the abdominopelvic cavity, while the *visceral peritoneum* covers most of the organs within that cavity. (The pleural and peritoneal serosae are illustrated in Figure 4.14c on p. 127.)

HOMEOSTATIC IMBALANCE 1.2 **CLINICAL**

When serous membranes are inflamed, their normally smooth surfaces become roughened. This roughness causes the membranes to stick together and drag across one another. Excruciating pain results, as anyone who has experienced *pleurisy* (inflammation of the pleurae) or *peritonitis* (inflammation of the peritoneums) knows.

Abdominopelvic Regions and Quadrants

Because the abdominopelvic cavity is large and contains several organs, it helps to divide it into smaller areas for study. Medical personnel usually use a simple scheme to locate the abdominopelvic cavity organs (**Figure 1.12**). In this scheme, a transverse and a median plane pass through the umbilicus at right angles. The four resulting quadrants are named according to their positions from the subject's point of view: the **right upper quadrant (RUQ)**, **left upper quadrant**

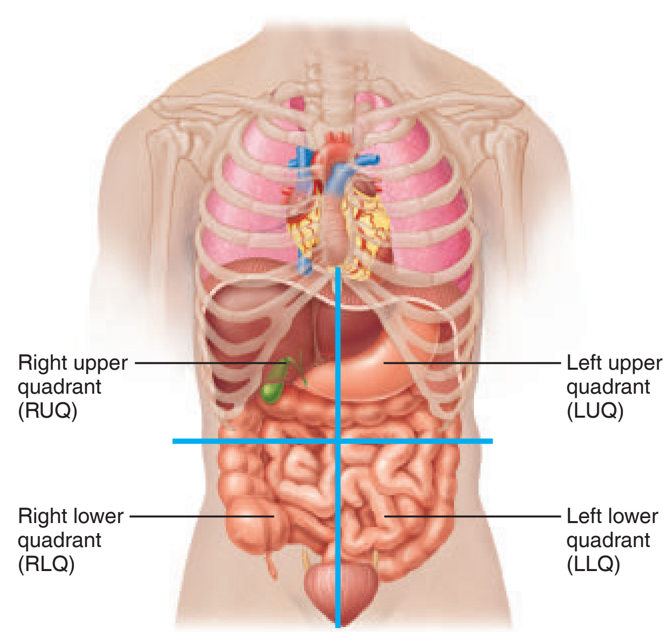
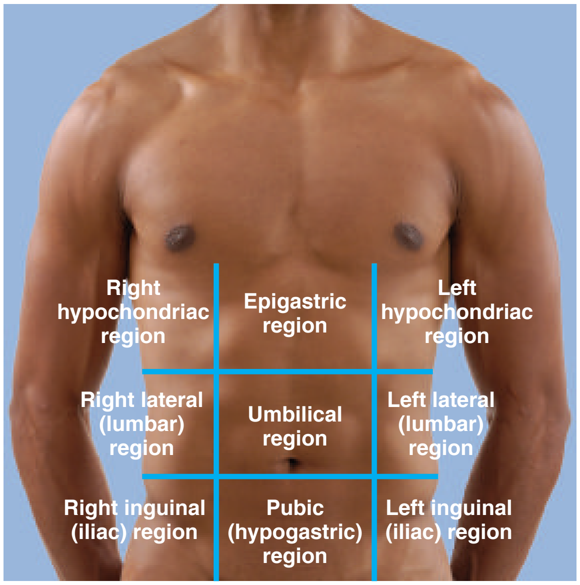
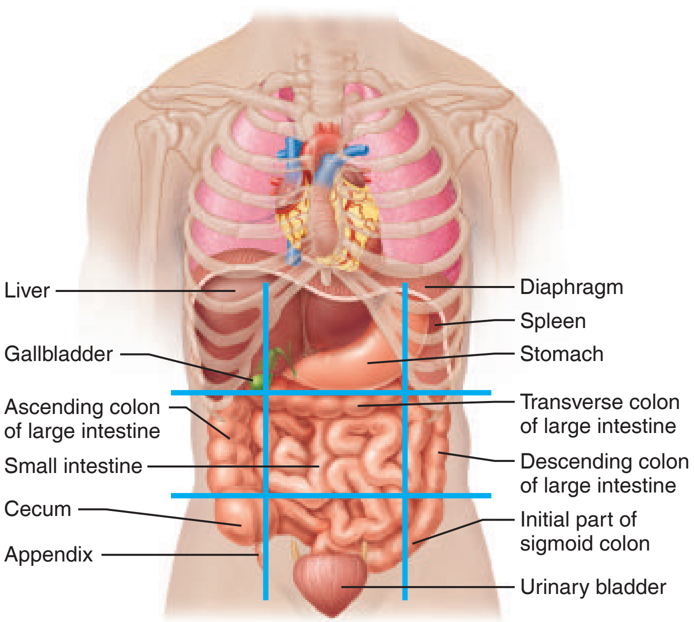


Figure 1.12 The four abdominopelvic quadrants. In this scheme, the abdominopelvic cavity is divided into four quadrants by two planes.



(a) Nine regions delineated by four planes



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

Figure 1.13 The nine abdominopelvic regions. The superior transverse plane is just inferior to the ribs; the inferior transverse plane is just superior to the hip bones; and the parasagittal planes lie just medial to the nipples.

(LUQ), **right lower quadrant (RLQ)**, and **left lower quadrant (LLQ)**.

Another division method, used primarily by anatomists, uses two transverse and two parasagittal planes. These planes, positioned like a tic-tac-toe grid on the abdomen, divide the cavity into nine regions (**Figure 1.13**):

- The **umbilical region** is the centermost region deep to and surrounding the umbilicus (navel).
- The **epigastric region** is located superior to the umbilical region (*epi* = upon, above; *gastri* = belly).
- The **pubic (hypogastric) region** is located inferior to the umbilical region (*hypo* = below).
- The **right** and **left inguinal**, or **iliac**, **regions** (ing′gwĭ-nal) are located lateral to the hypogastric region (*iliac* = superior part of the hip bone).
- The **right** and **left lateral (lumbar) regions** lie lateral to the umbilical region (*lumbus* = loin).
- The **right** and **left hypochondriac regions** lie lateral to the epigastric region and deep to the ribs (*chondro* = cartilage).

1

HOMEOSTATIC IMBALANCE 1.3 — CLINICAL

You may have seen news stories about "wrong site surgery" and wondered how such serious mistakes can happen. Critical errors, including amputation, may result from confusion about right versus left or poor understanding of terminology. As you master the terminology of anatomy, you are helping to eliminate these blunders.

Other Body Cavities

In addition to the large closed body cavities, there are several smaller body cavities. Most of these are in the head and most open to the body exterior. Figure 1.8 provides the terms that will help you locate all but the last two cavities mentioned here.

- **Oral and digestive cavities.** The oral cavity, commonly called the mouth, contains the teeth and tongue. This cavity is part of and continuous with the cavity of the digestive organs, which opens to the body exterior at the anus.
- **Nasal cavity.** Located within and posterior to the nose, the nasal cavity is part of the respiratory system passageways.
- **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 in 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.
- **Synovial cavities.** Synovial (sĭ-no′ve-al) cavities are joint cavities. They are enclosed within fibrous capsules that surround freely movable joints of the body (such as the elbow and knee joints). Like the serous membranes, membranes lining synovial cavities secrete a lubricating fluid that reduces friction as the bones move across one another.

Check Your Understanding

16. Of the uterus, small intestine, spinal cord, and heart, which is/are in the dorsal body cavity?

17. APPLY When you rub your cold hands together, the friction between them results in heat that warms your hands. Why doesn't warming friction result during movements of the heart, lungs, and digestive organs?

18. PREDICT 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 Answers Appendix.

REVIEW QUESTIONS

To access additional practice questions using your smartphone, tablet, or computer: **Mastering A&P** > Study Area > Practice Tests & Quizzes

(Some multiple choice questions have more than one correct answer. Select the best answer or answers from the choices given.)

Level 1 Remember/Understand

1. The correct sequence of levels forming the structural hierarchy is:
(a) organ, organ system, cellular, chemical, tissue, organismal
(b) chemical, cellular, tissue, organismal, organ, organ system
(c) chemical, cellular, tissue, organ, organ system, organismal
(d) organismal, organ system, organ, tissue, cellular, chemical

2. The structural and functional unit of life is **(a)** a cell, **(b)** an organ, **(c)** the organism, **(d)** a molecule.

3. Which of the following is a *major* functional characteristic of all organisms? **(a)** movement, **(b)** growth, **(c)** metabolism, **(d)** responsiveness, **(e)** all of these.

4. Two of these organ systems bear the *major* responsibility for ensuring homeostasis of the internal environment. Which two? **(a)** nervous system, **(b)** digestive system, **(c)** cardiovascular system, **(d)** endocrine system, **(e)** reproductive system.

5. In (a)–(e), a directional term [e.g., distal in (a)] is followed by terms indicating different body structures or locations (e.g., the elbow/the wrist). In each case, choose the structure or organ that matches the given directional term. **(a)** distal: the elbow/the wrist, **(b)** lateral: the hip bone/the umbilicus, **(c)** superior: the nose/the chin, **(d)** anterior: the toes/the heel, **(e)** superficial: the scalp/the skull

6. Which ventral cavity subdivision has no bony protection? **(a)** thoracic cavity, **(b)** abdominal cavity, **(c)** pelvic cavity.

7. Terms that apply to the backside of the body in the anatomical position include: **(a)** ventral; anterior, **(b)** back; rear, **(c)** posterior; dorsal, **(d)** medial; lateral

8. According to the principle of complementarity, how does anatomy relate to physiology?

9. Construct a table that lists the 11 systems of the body, names two organs of each system (if appropriate), and describes the overall or major function of each system.

10. List and describe briefly five external factors that must be present or provided to sustain life.

11. Define homeostasis.

12. Define plane and section.

13. Provide the anatomical term that correctly names each of the following body regions: **(a)** arm, **(b)** thigh, **(c)** chest, **(d)** fingers and toes, **(e)** anterior aspect of the knee.

14. **(a)** Make a diagram showing the nine abdominopelvic regions, and name each region. Name two organs (or parts of organs) that could be located in each of the named regions. **(b)** Make a similar sketch illustrating how the abdominopelvic cavity may be divided into quadrants, and name each quadrant.

Level 2 Apply/Analyze

15. Assume that the body has been sectioned along three planes: **(1)** a median plane, **(2)** a frontal plane, and **(3)** a transverse plane made at the level of each of the organs listed below. Which organs would be visible in only one or two of these three cases? **(a)** urinary bladder, **(b)** brain, **(c)** lungs, **(d)** kidneys, **(e)** small intestine, **(f)** heart.

16. Relate each of the following conditions or statements to either the dorsal body cavity or the ventral body cavity.
(a) surrounded by the bony skull and the vertebral column
(b) includes the thoracic and abdominopelvic cavities
(c) contains the brain and spinal cord
(d) contains the heart, lungs, and digestive organs

17. Which of the following relationships is *incorrect*?
(a) visceral peritoneum/outer surface of small intestine
(b) parietal pericardium/outer surface of heart
(c) parietal pleura/wall of thoracic cavity

18. Compare and contrast the operation of negative and positive feedback mechanisms in maintaining homeostasis. Provide two examples of variables controlled by negative feedback mechanisms and one example of a process regulated by a positive feedback mechanism.

19. Why is an understanding of the anatomical position important?

20. Use as many directional terms as you can to describe the relationship between the elbow's olecranal region and your palm.

21. At the clinic, Harry was told that blood would be drawn from his antecubital region. What body part was Harry asked to hold out? Later, the nurse came in and gave Harry a shot of penicillin in the area just distal to his acromial region. Did Harry take off his shirt or drop his pants to receive the injection? Before Harry left, the nurse noticed that Harry had a nasty bruise on his gluteal region. What part of his body was black and blue?

22. Calcium levels in Mr. Gallariani's blood are dropping to dangerously low levels. The hormone PTH is released and soon blood calcium levels begin to rise. Shortly after, PTH release slows. Is this an example of a positive or negative feedback mechanism? What is the initial stimulus? What is the result?

23. Mr. Harvey, a computer programmer, has been complaining of numbness and pain in his right hand. The nurse practitioner diagnosed his problem as carpal tunnel syndrome and prescribed use of a splint. Where will Mr. Harvey apply the splint?

Level 3 Evaluate/Synthesize

24. Aiden has been suffering agonizing pain with each breath and has been informed by the physician that he has pleurisy. **(a)** Specifically, what membranes are involved in this condition? **(b)** What is their usual role in the body? **(c)** Explain why Aiden's condition is so painful.

2 Chemistry Comes Alive

CAREER CONNECTION VIDEO

Learn how the chapter content is used in a real health care setting. Go to https://goo.gl/88srfV

KEY CONCEPTS

Why study chemistry in an anatomy and physiology course? The answer is simple. Your entire body is made up of chemicals, thousands of them, continuously interacting with one another at an incredible pace. Although it is possible to study anatomy without much reference to chemistry, chemical reactions underlie all physiological processes—movement, digestion, the pumping of your heart, and even your thoughts. This chapter presents the basic chemistry and biochemistry (the chemistry of living material) you need to understand body functions.

PART 1
BASIC CHEMISTRY

2.1 Matter is the stuff of the universe and energy moves matter

Learning Outcomes

- **Differentiate between matter and energy and between potential energy and kinetic energy.**
- **Describe the major energy forms.**

Matter

Matter is the "stuff" of the universe. More precisely, **matter** is anything that occupies space and has mass. With some exceptions, it can be seen, smelled, and felt.

We usually consider mass to be the same as weight. However, this statement is not quite accurate. The *mass* of an object is equal to the actual amount of matter in the object, and it remains constant wherever the object is. In contrast, weight varies with gravity. So while your mass is the same at sea level and on a mountaintop, you weigh just slightly less on that mountaintop. The science of chemistry studies the nature of matter, especially how its building blocks are put together and interact.

States of Matter

Matter exists in *solid*, *liquid*, and *gaseous states*. Examples of each state are found in the human body. Solids, like bones and teeth, have a definite shape and volume. Liquids such as blood plasma have a definite volume, but they conform to the shape of their container. Gases have neither a definite shape nor a definite volume. The air we breathe is a gas.

2

Energy

Compared with matter, energy is less tangible. It has no mass, does not take up space, and we can measure it only by its effects on matter. **Energy** is defined as the capacity to do work, or to put matter into motion. The greater the work done, the more energy is used doing it. A baseball player who has just hit the ball over the fence uses much more energy than a batter who bunts the ball back to the pitcher.

Kinetic versus Potential Energy

Energy exists in two states, and each can be transformed to the other. **Kinetic energy** (ki-net′ik) is energy in action. We see evidence of kinetic energy in the constant movement of the tiniest particles of matter (atoms) as well as in larger objects (a bouncing ball). Kinetic energy does work by moving objects, which in turn can do work by moving or pushing on other objects. For example, a push on a swinging door sets it into motion.

Potential energy is stored energy, that is, inactive energy that has the *potential*, or capability, to do work but is not presently doing so. The batteries in an unused toy have potential energy, as does water confined behind a dam. Your leg muscles have potential energy when you sit still on the couch. When potential energy is released, it becomes kinetic energy and so is capable of doing work. For example, dammed water becomes a rushing torrent when the dam is opened, and that rushing torrent can move a turbine at a hydroelectric plant and charge a battery.

Matter and energy are inseparable. Matter is the substance, and energy is the mover of the substance. All living things are composed of matter and they all require energy to grow and function. The release and use of energy by living systems gives us the elusive quality we call life. Now let's consider the forms of energy used by the body as it does its work.

Forms of Energy

- **Chemical energy** is the form stored in the bonds of chemical substances. When chemical reactions occur that rearrange the atoms of the chemicals in a certain way, the potential energy is unleashed and becomes kinetic energy, or energy in action.

  For example, some of the energy in the foods you eat is eventually converted into the kinetic energy of your moving arm. However, food fuels cannot be used to energize body activities directly. Instead, some of the food energy is captured temporarily in the bonds of a chemical called *adenosine triphosphate* (*ATP*; ah-den′o-sēn tri″fos′fāt). Later, ATP's bonds are broken and the stored energy is released as needed to do cellular work. Chemical energy in the form of ATP is the most useful form of energy in living systems because it is used to run almost all functional processes.
- **Electrical energy** results from the movement of charged particles. In your home, electrical energy is found in the flow of electrons along the household wiring. In your body, electrical currents are generated when charged particles (*ions*) move along or across cell membranes. The nervous system uses electrical currents, called *nerve impulses* (or *action potentials*), to transmit messages from one part of the body to another. Electrical currents traveling across the heart stimulate it to contract (beat) and pump blood. (This is why a strong electrical shock, which interferes with such currents, can cause death.)
- **Mechanical energy** is energy *directly* involved in moving matter. When you ride a bicycle, your legs provide the mechanical energy that moves the pedals.
- **Radiant energy**, or **electromagnetic radiation** (e-lek″tro-mag-net′ik), is energy that travels in waves. These waves, which vary in length, are collectively called the *electromagnetic spectrum*. They include radio waves, microwaves, infrared waves, visible light, ultraviolet waves, and X rays. Light energy, which stimulates the retinas of our eyes, is important in vision. Ultraviolet waves cause sunburn, but they also stimulate your body to make vitamin D.

Converting Forms of Energy

With few exceptions, energy is easily converted from one form to another. For example, the chemical energy (in gasoline) that powers the motor of a speedboat is converted into the mechanical energy of the whirling propeller that makes the boat skim across the water.

Energy conversions are quite inefficient. Some of the initial energy supply is always "lost" to the environment as heat. It is not really lost because energy cannot be created or destroyed, but that portion given off as heat is at least partly *unusable*. It is easy to demonstrate this principle. Electrical energy is converted into light energy in a lightbulb. But if you touch a lit bulb, you will soon discover that some of the electrical energy is producing heat instead.

Likewise, all energy conversions in the body liberate heat. This heat helps to maintain our relatively high body temperature, which influences body functioning. For example, when matter is heated, the kinetic energy of its particles increases and they begin to move more quickly. The higher the temperature, the faster the body's chemical reactions occur. We will learn more about this later.

Check Your Understanding

1. What form of energy is found in the food we eat?
2. What form of energy is used to transmit messages from one part of the body to another?
3. What type of energy is available when we are still? When we are exercising?

For answers, see Answers Appendix.

2.2 The properties of an element depend on the structure of its atoms

Learning Outcomes

- **Define chemical element and list the four elements that form the bulk of body matter.**

- **Define atom. List the subatomic particles, and describe their relative masses, charges, and positions in the atom.**
- **Define atomic number, atomic mass, atomic weight, isotope, and radioisotope.**

All matter is composed of **elements**, unique substances that cannot be broken down into simpler substances by ordinary chemical methods. Among the well-known elements are oxygen, carbon, gold, silver, copper, and iron.

At present, 118 elements are recognized. Of these, 92 occur in nature. The rest are made artificially in particle accelerator devices.

Four elements—carbon, oxygen, hydrogen, and nitrogen—make up about 96% of body weight, and 20 others are present in the body, some in trace amounts. **Table 2.1** lists those of importance to the body. An oddly shaped checkerboard called the **periodic table** provides a listing of the known elements and helps to explain the properties of each element.

Each element is composed of essentially identical particles or building blocks, called **atoms**. The smallest atoms are less than 0.1 nanometer (nm) in diameter, and the largest are only about five times as large. [1 nm = 0.000000001 (or 10^{-9}) meter (m), or 40 billionths of an inch!]

Table 2.1 Common Elements Composing the Human Body*

ELEMENT	ATOMIC SYMBOL	APPROX. % BODY MASS†	FUNCTIONS
Major (96.1%)			
Oxygen	O	65.0	A component of both organic (carbon-containing) and inorganic (non-carbon-containing) molecules. As a gas, it is needed for the production of cellular energy (ATP).
Carbon	C	18.5	A component of all organic molecules, which include carbohydrates, lipids (fats and oils), proteins, and nucleic acids.
Hydrogen	H	9.5	A component of all organic molecules. As an ion (proton), it influences the pH of body fluids.
Nitrogen	N	3.2	A component of proteins and nucleic acids (genetic material).
Lesser (3.9%)			
Calcium	Ca	1.5	Found as a salt in bones and teeth. Its ionic (Ca^{2+}) form is required for muscle contraction, conduction of nerve impulses, and blood clotting.
Phosphorus	P	1.0	Part of calcium phosphate salts in bones and teeth. Also present in nucleic acids, and as part of ATP and phospholipids.
Potassium	K	0.4	Its ion (K^+) is the major positive ion (cation) in cells. Necessary for conduction of nerve impulses and muscle contraction.
Sulfur	S	0.3	Component of proteins, particularly muscle proteins.
Sodium	Na	0.2	As an ion (Na^+), sodium is the major positive ion found in extracellular fluids (fluids outside of cells). Important for water balance, conduction of nerve impulses, and muscle contraction.
Chlorine	Cl	0.2	Its ion (chloride, Cl^-) is the most abundant negative ion (anion) in extracellular fluids.
Magnesium	Mg	0.1	Present in bone. Also an important cofactor in a number of metabolic reactions.
Iodine	I	0.1	Needed to make functional thyroid hormones.
Iron	Fe	0.1	Component of hemoglobin (which transports oxygen within red blood cells) and some enzymes.
Trace (less than 0.01%)			
Chromium (Cr); cobalt (Co); copper (Cu); fluorine (F); manganese (Mn); molybdenum (Mo); selenium (Se); silicon (Si); tin (Sn); vanadium (V); zinc (Zn)			
These elements are referred to as *trace elements* because they are required in very minute amounts; many are found as part of enzymes or are required for enzyme activation.			

*A listing of the elements by ascending order of atomic number appears in the periodic table.
†Percentage of "wet" body mass; includes water.

Every element's atoms differ from those of all other elements and give the element its unique physical and chemical properties. *Physical properties* are those we can detect with our senses (such as color and texture) or measure (such as boiling point and freezing point). *Chemical properties* describe the way atoms interact with other atoms (bonding behavior) and account for the facts that iron rusts, animals can digest their food, and so on.

We designate each element by a one- or two-letter chemical shorthand called an **atomic symbol**, usually the first letter(s) 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 example, sodium is indicated by Na, from the Latin word *natrium*.

Structure of Atoms

The word *atom* comes from the Greek word meaning "indivisible." However, we now know that atoms are clusters of even smaller particles called protons, neutrons, and electrons and that even those subatomic particles can be subdivided. Still, the old idea of atomic indivisibility is useful because an atom loses the unique properties of its element when it is split into its subatomic particles.

An atom's subatomic particles differ in mass, electrical charge, and position in the atom. An atom has a central **nucleus** containing protons and neutrons tightly bound together. The nucleus, in turn, is surrounded by orbiting electrons (**Figure 2.1**). **Protons** (p^+) bear a positive electrical charge, and **neutrons** (n^0) are neutral, so the nucleus is positively charged overall. Protons and neutrons are heavy particles and have approximately the same mass, arbitrarily designated as 1 **atomic mass unit** (1 amu). Since all of the heavy subatomic particles are concentrated in the nucleus, the nucleus is fantastically dense, accounting for nearly the entire mass (99.9%) of the atom.

The tiny **electrons** (e^-) bear a negative charge equal in strength to the positive charge of the proton. However, an electron has only about 1/2000 the mass of a proton, and the mass of an electron is usually designated as 0 amu.

All atoms are electrically neutral because the number of protons in an atom is precisely balanced by its number of electrons (the + and − charges will then cancel the effect of each other). For example, hydrogen has one proton and one electron, and iron has 26 protons and 26 electrons. For any atom, the number of protons and electrons is always equal.

The **planetary model** of the atom is a simplified model of atomic structure (Figure 2.1). As you can see, it depicts electrons moving around the nucleus in fixed, generally circular orbits. But we can never determine the exact location of electrons at a particular time because they jump around following unknown trajectories. So, instead of speaking of specific orbits, chemists talk about **orbitals**—regions around the nucleus in which a given electron or electron pair is likely to be found most of the time. This more modern **orbital model** is more useful for predicting the chemical behavior of atoms (Figure 2.1, left). The orbital model depicts *probable* regions of greatest electron density by denser shading (this haze is called the *electron cloud*). However, the planetary model is simpler to depict, so we will use that model in most illustrations of atomic structure in this text.

Hydrogen, with just one proton and one electron, is the simplest atom. You can visualize the spatial relationships in the hydrogen atom by imagining it as a sphere enlarged until its diameter equals the length of a football field. In that case, the nucleus could be represented by a lead ball the size of a gumdrop in the exact center of the sphere. Its lone electron could be pictured as a fly buzzing about unpredictably within the sphere. Though not completely accurate, this mental image demonstrates that most of the volume of an atom is empty space, and nearly all of its mass is concentrated in the central nucleus.

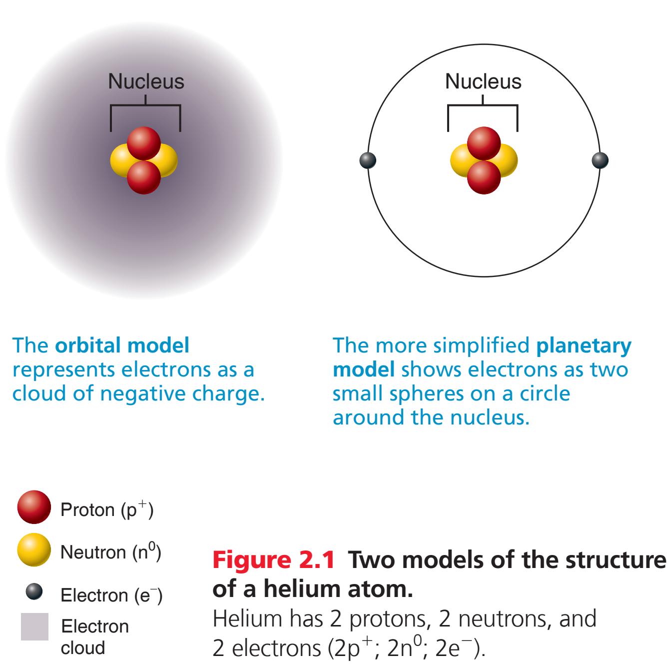


Figure 2.1 Two models of the structure of a helium atom.
Helium has 2 protons, 2 neutrons, and 2 electrons ($2p^+$; $2n^0$; $2e^-$).

Identifying Elements

All protons are alike, regardless of the atom considered. The same is true of all neutrons and all 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 and this determines the chemical and physical properties of each element.

The simplest and smallest atom, hydrogen, has 1 proton, 1 orbiting electron, and no neutrons (**Figure 2.2**). Next in size is the helium atom, with 2 protons, 2 neutrons, and 2 electrons. Lithium follows with 3 protons, 4 neutrons, and 3 electrons. If we continued this step-by-step progression, we would get a graded series of atoms containing from 1 to 118 protons, an equal number of electrons, and a slightly larger number of neutrons at each step.

All we really need to know about a particular element, however, are its atomic number, mass number, and atomic weight. Taken together, these provide a fairly complete picture of each element.

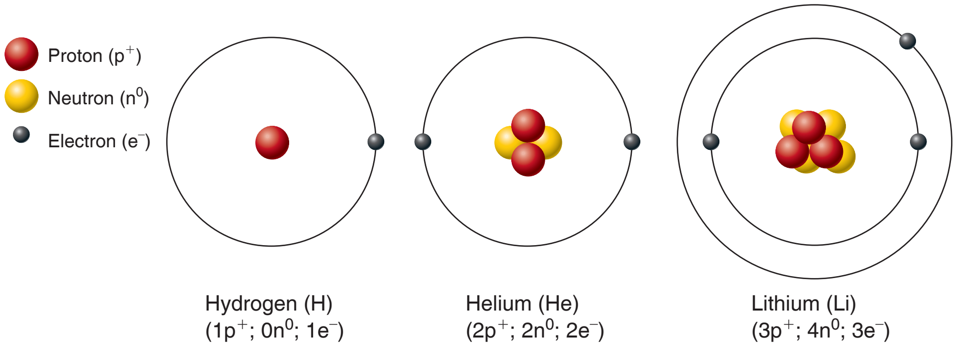


Figure 2.2 Atomic structure of the three smallest atoms.

Atomic Number

The **atomic number** of any atom is equal to the number of protons in its nucleus and is written as a subscript to the left of its atomic symbol. Hydrogen, with one proton, has an atomic number of 1 ($_1$H). Helium, with two protons, has an atomic number of 2 ($_2$He), and so on. The number of protons is always equal to the number of electrons in an atom, so the atomic number *indirectly* tells us the number of electrons in the atom as well. As we will see shortly, this information is important indeed, because electrons determine the chemical behavior of atoms.

Mass Number and Isotopes

The **mass number** of an atom is the sum of the masses of its protons and neutrons. The mass of the electrons is so small that it is ignored. Recall that protons and neutrons have a mass of 1 amu. Hydrogen has only one proton in its nucleus, so its atomic and mass numbers are the same: 1. Helium, with 2 protons and 2 neutrons, has a mass number of 4.

The mass number is usually indicated by a superscript to the left of the atomic symbol. For example, helium is $^4_2$He. This simple notation allows us to deduce the total number and kinds of subatomic particles in any atom because it indicates the number of protons (the atomic number), the number of electrons (equal to the atomic number), and the number of neutrons (mass number minus atomic number). In our example, we can do the subtraction to find that $^4_2$He has two neutrons.

From what we have said so far, it may appear as if each element has one, and only one, type of atom representing it. This is not the case. Nearly all known elements have two or more structural variations called **isotopes** (i′so-tōps; *iso* = same; *topos* = place). Isotopes of an element have the same number of protons and electrons (and so have the same chemical properties), but they differ in the number of neutrons they contain. Earlier, when we said that hydrogen has a mass number of 1, we were speaking of ^{1}H, its most abundant isotope. A few hydrogen atoms have a mass of 2 or 3 amu (atomic mass units), which means that they have 1 proton and, respectively, 1 or 2 neutrons (**Figure 2.3**).

Carbon has several isotopes. The most abundant of these are ^{12}C, ^{13}C, and ^{14}C. Each of the carbon isotopes has six protons (otherwise it would not be carbon), but ^{12}C has six neutrons, ^{13}C has seven, and ^{14}C has eight. Isotopes can also be written with the mass number following the symbol: C-14, for example.

Atomic Weight

You might think that atomic weight should be the same as atomic mass, and this would be so if atomic weight referred to the weight of a single atom. However, **atomic weight** is an average of the weights (mass numbers) of *all* the isotopes of an element, taking into account their relative abundance in nature. As a rule, the atomic weight of an element is approximately equal to the mass number of its most abundant isotope. For example, the atomic weight of hydrogen is 1.008, which reveals that its lightest isotope (^{1}H) is present in much greater amounts in our world than its ^{2}H or ^{3}H forms.

Radioisotopes

The heavier isotopes of many elements are unstable, and their atoms decompose spontaneously into more stable forms. This process of atomic decay is called *radioactivity*, and isotopes that exhibit this behavior are called **radioisotopes** (ra″de-o-i′so-tōps). The disintegration of a radioactive nucleus may be compared to a tiny explosion. It occurs when subatomic *alpha* (α) *particles* (packets of 2p + 2n), *beta* (β) *particles* (electron-like particles), or *gamma* (γ) *rays* (electromagnetic energy) are ejected from the atomic nucleus.

Why does this happen? The answer is complex, but for our purposes, the important point is that the dense nuclear particles are composed of even smaller particles called *quarks* that associate in one way to form protons and in another way to form neutrons. The "glue" that holds these nuclear particles

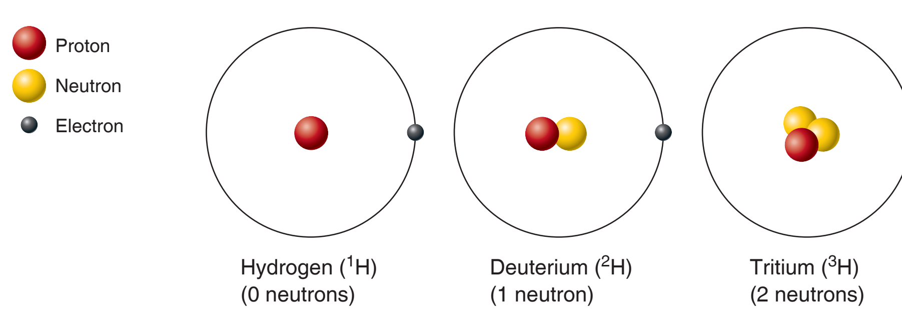


Figure 2.3 Isotopes of hydrogen.

together is weaker in the heavier isotopes. When radioisotopes disintegrate, the element usually transforms to a different element.

Because we can detect radioactivity with scanners, and radioactive isotopes share the same chemistry as their more stable isotopes, radioisotopes are valuable tools for biological research and medicine. Most radioisotopes used in the clinical setting are used for diagnosis, that is, to localize and illuminate damaged or cancerous tissues. For example, iodine-123 is used to determine the size and activity of the thyroid gland and to detect thyroid cancer. PET scans use radioisotopes to probe the workings of molecules deep within our bodies. All radioisotopes, regardless of the purpose for which they are used, damage living tissue, and they all gradually lose their radioactive behavior. The time required for a radioisotope to lose one-half of its activity is called its *half-life*. The half-lives of radioisotopes vary dramatically from hours to thousands of years.

Alpha emission is easily blocked outside the body, but if absorbed, it causes considerable damage. For this reason, alpha particles from decaying inhaled radon gas are second only to smoking as a cause of lung cancer. (Radon, a gas, results naturally from decay of uranium in the ground.) Gamma emission has the greatest penetrating power. Radium-226, cobalt-60, and certain other radioisotopes that decay by gamma emission are used to destroy localized cancers.

Contrary to what some believe, ionizing radiation does not damage organic molecules directly. Instead, it knocks electrons out of other atoms and sends them flying, like bowling balls smashing through pins all along their path. It is the electron's energy and the unstable molecules left behind that do the damage.

Check Your Understanding

4. What two elements besides H and N make up the bulk of living matter?
5. DRAW Draw a planetary model of an atom with a mass number of 7 and an atomic number of 3.
6. WHAT IF Look at the function of iron in Table 2.1 on p. 21. What would be the effect of an iron deficiency on blood?

For answers, see Answers Appendix.

2.3 Atoms bound together form molecules; different molecules can make mixtures

Learning Outcomes

- **Define molecule, and distinguish between a compound and a mixture.**
- **Compare solutions, colloids, and suspensions.**

Molecules and Compounds

Most atoms do not exist in the free state, but instead are chemically combined with other atoms. Such a combination of two or more atoms held together by chemical bonds is called a **molecule**.

If two or more atoms of the *same* element combine, the resulting substance is called a *molecule of that element*. When two hydrogen atoms bond, the product is a molecule of hydrogen gas and is written as H_2. Similarly, when two oxygen atoms combine, a molecule of oxygen gas (O_2) is formed. Sulfur atoms commonly combine to form sulfur molecules containing eight sulfur atoms (S_8).

When two or more *different* kinds of atoms bind, they form molecules of a **compound**. Two hydrogen atoms combine with one oxygen atom to form the compound water (H_2O). Four hydrogen atoms combine with one carbon atom to form the compound methane (CH_4). Notice again that molecules of methane and water are compounds, but molecules of hydrogen gas are not, because compounds always contain atoms of at least two different elements.

Compounds are chemically pure, and all of their molecules are identical. So, just as an atom is the smallest particle of an element that still has the properties of the element, a molecule is the smallest particle of a compound that still has the specific characteristics of the compound. This concept is important because the properties of compounds are usually very different from those of the atoms they contain. Water, for example, is very different from the elements hydrogen and oxygen. Indeed, it is next to impossible to tell what atoms are in a compound without analyzing it chemically.

Mixtures

Mixtures are substances composed of two or more components *physically intermixed*. Most matter in nature exists in the form of mixtures, but there are only three basic types: *solutions*, *colloids*, and *suspensions* (**Figure 2.4**).

Solutions

Solutions are homogeneous mixtures of components that may be gases, liquids, or solids. *Homogeneous* means that the mixture has exactly the same composition or makeup throughout—a sample taken from any part of the mixture has the same composition (in terms of the atoms or molecules it contains) as a sample taken from any other part of the mixture. Examples include the air we breathe (a mixture of gases) and seawater (a mixture of salts, which are solids, and water). The substance present in the greatest amount is called the **solvent** (or dissolving medium). Solvents are usually liquids. Substances present in smaller amounts (dissolved in the solvent) are called **solutes**.

Water is the body's chief solvent. Most solutions in the body are *true solutions* containing gases, liquids, or solids dissolved in water. True solutions are usually transparent. Examples are saline solution [table salt (NaCl) and water], a mixture of glucose and water, and mineral water. The solutes of true solutions are very small, usually in the form of individual atoms and molecules. Consequently, they are not visible to the naked eye, do not settle out, and do not scatter light. In other words, if a beam of light is passed through a true solution, you will not see the path of light.

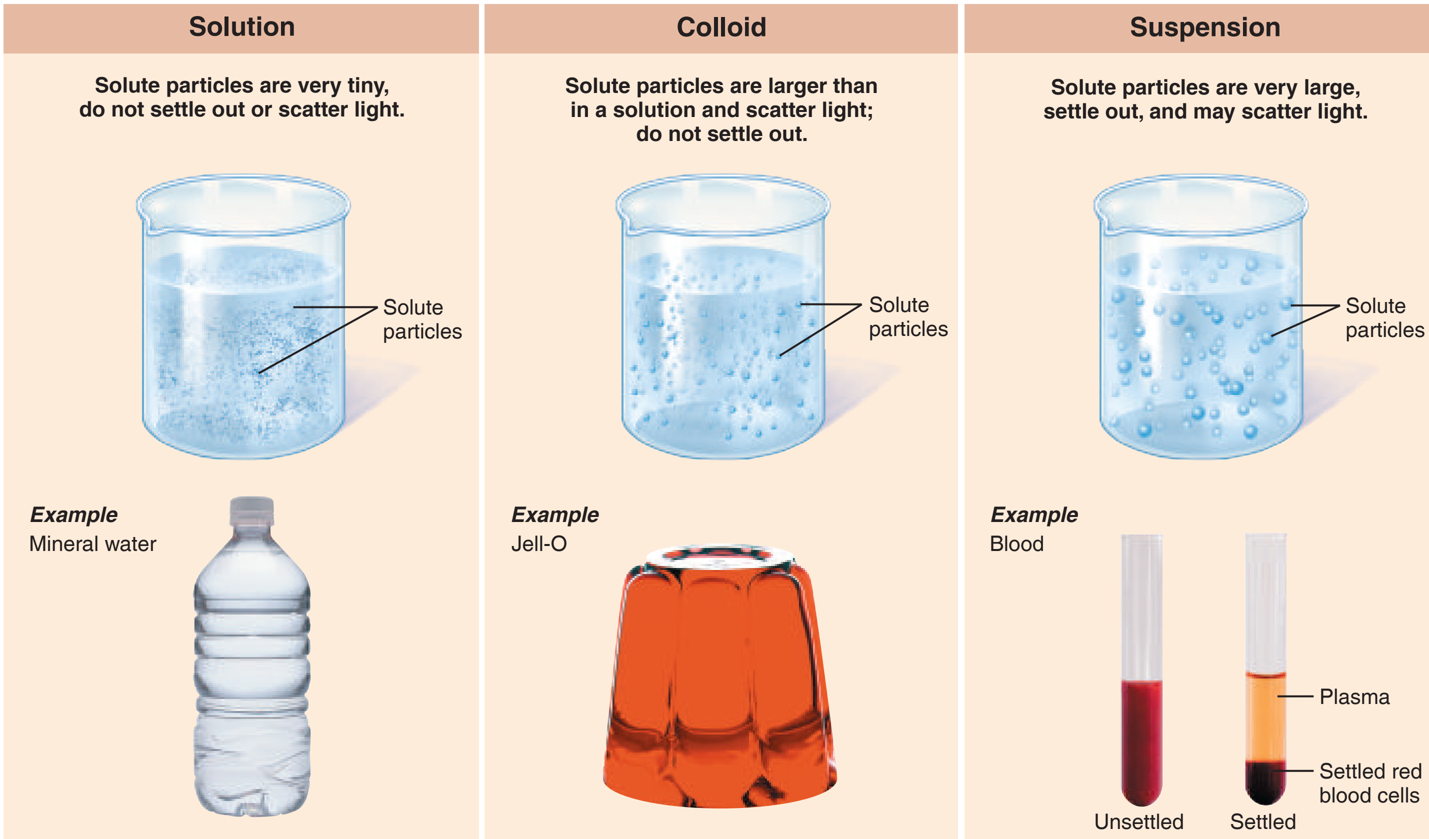


Figure 2.4 **The three basic types of mixtures.**

Concentration of Solutions We describe true solutions in terms of their *concentration*, which may be indicated in various ways. Solutions used in a college laboratory or a hospital are often described in terms of the **percent** (parts per 100 parts) of the solute in the total solution. This designation always refers to the solute percentage, and unless otherwise noted, water is assumed to be the solvent.

Milligrams per deciliter (*mg/dl*) is a concentration measurement commonly used to measure the blood concentration of glucose, cholesterol, and so on. (A deciliter is 100 milliliters or 0.1 liter.)

Still another way to express the concentration of a solution is in terms of its **molarity** (mo-lar′ĭ-te), or moles per liter, indicated by *M*. This method is more complicated but much more useful. To understand molarity, you must understand what a mole is. A **mole** of any element or compound is equal to its atomic weight or **molecular weight** (sum of the atomic weights) in grams. This concept is easier than it seems, as illustrated by the following example.

Glucose is $C_6H_{12}O_6$, which indicates that it has 6 carbon atoms, 12 hydrogen atoms, and 6 oxygen atoms. To compute the molecular weight of glucose, you would look up the atomic weight of each of its atoms in the periodic table and compute its molecular weight as follows:

Atom	Number of Atoms		Atomic Weight		Total Atomic Weight
C	6	×	12.011	=	72.066
H	12	×	1.008	=	12.096
O	6	×	15.999	=	95.994
					180.156

Then, to make a *one-molar* solution of glucose, you would weigh out 180.156 grams (g) of glucose and add enough water to make 1 liter (L) of solution. In short, a one-molar solution (abbreviated 1.0 *M*) of a chemical substance is the molecular weight of the substance in grams in 1 L (1000 milliliters) of solution.

The beauty of using the mole as the basis of preparing solutions is its precision. One mole of any substance always contains exactly the same number of solute particles, that is, 6.02×10^{23}. This number is called **Avogadro's number** (av″o-gad′rōz). So whether you weigh out 1 mole of glucose (180 g) or 1 mole of water (18 g) or 1 mole of methane (16 g), in each case you will have 6.02×10^{23} molecules of that substance.* This allows almost mind-boggling precision to be achieved.

* The important exception to this rule concerns molecules that ionize and break up into charged particles (ions) in water, such as salts, acids, and bases (see pp. 34–35). For example, simple table salt (sodium chloride) breaks up into two types of charged particles. Therefore, in a 1.0 *M* solution of sodium chloride, 2 *moles* of solute particles are actually in solution.