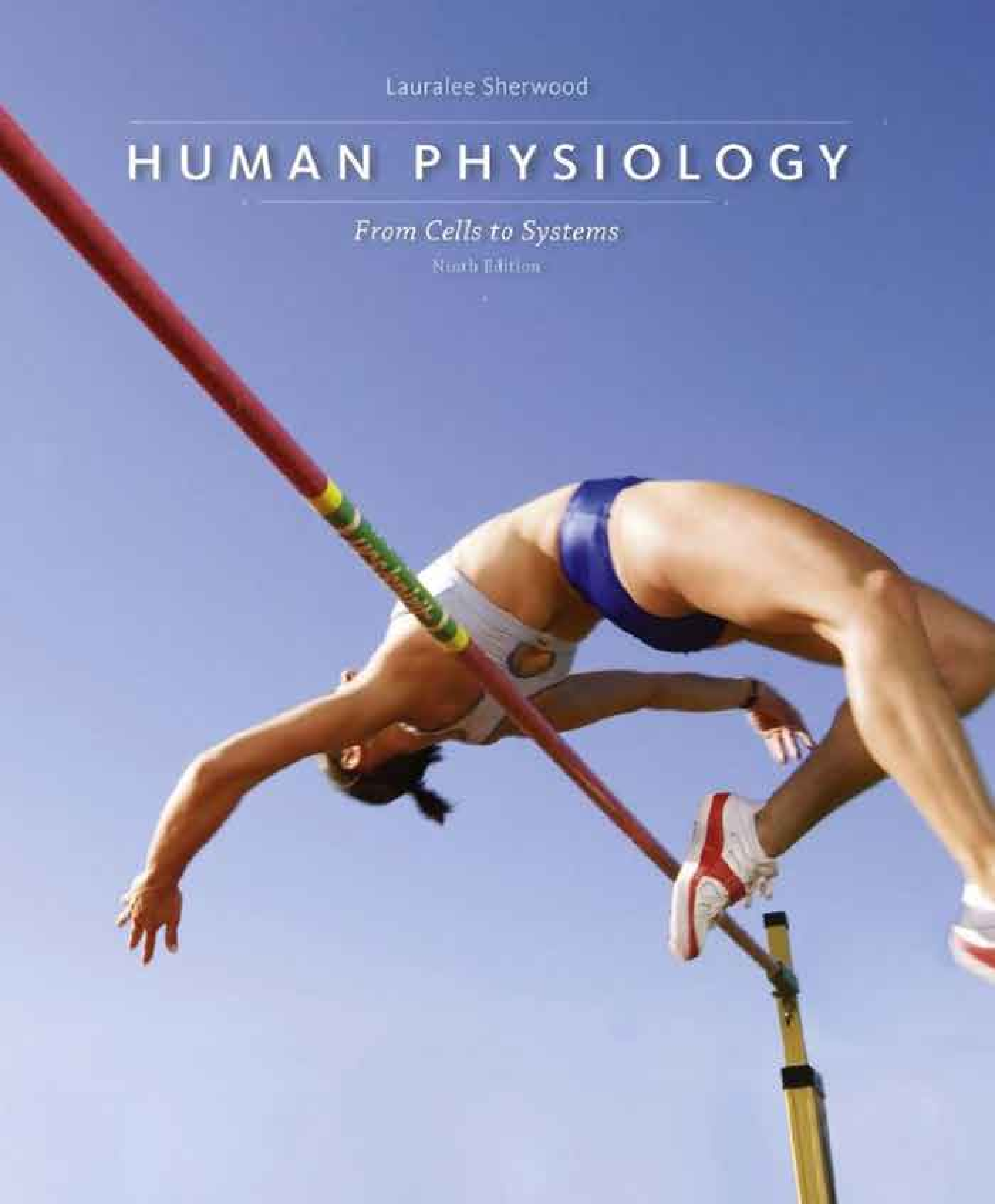
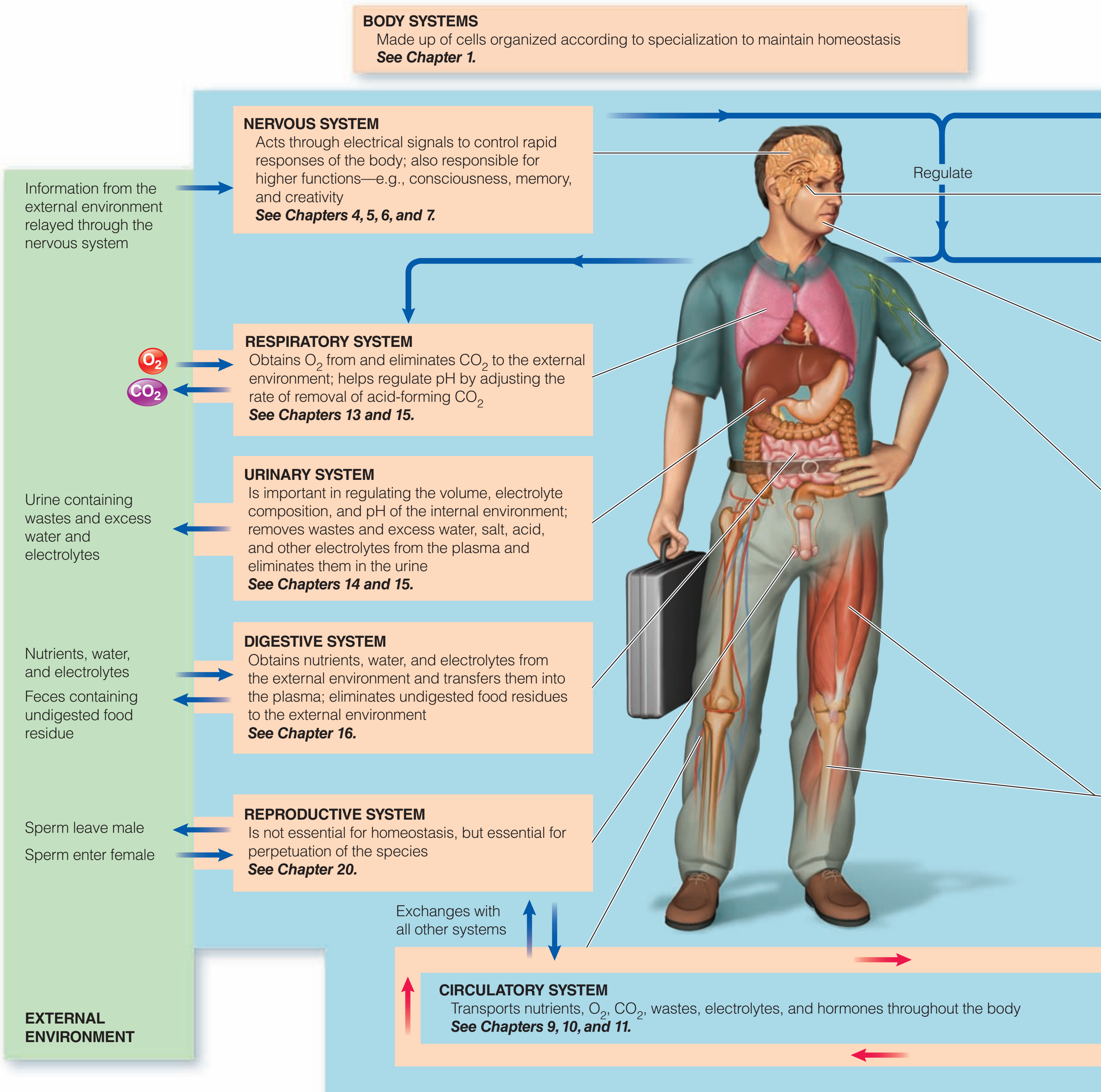
Lauralee Sherwood

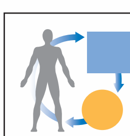
HUMAN PHYSIOLOGY

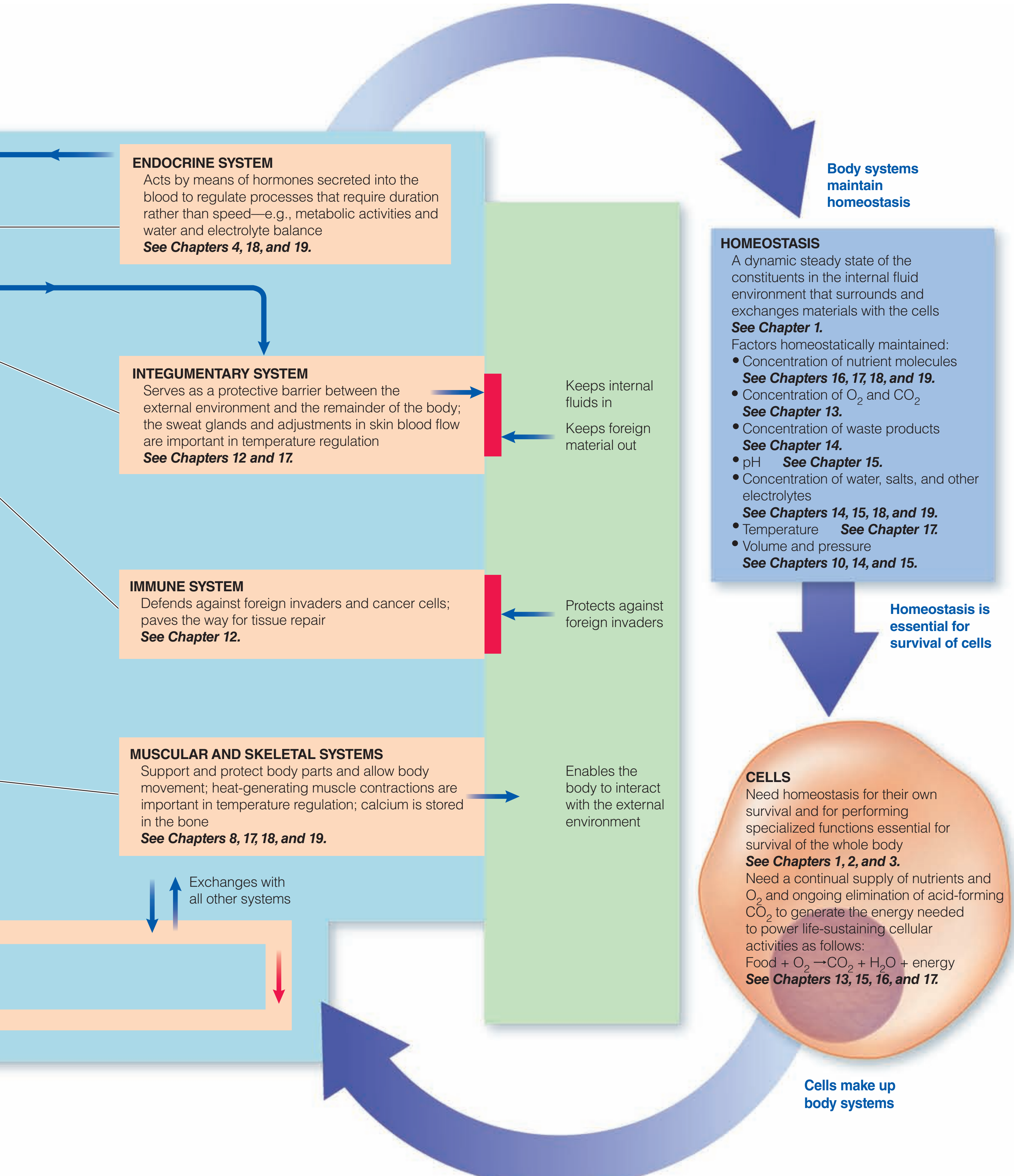
From Cells to Systems

Ninth Edition






This pictorial homeostatic model is developed in Chapter 1 to show you the relationship among cells, systems, and homeostasis (maintenance of relatively stable conditions in the internal fluid environment that surrounds the cells). The accompanying icon marks special sections at the beginning and end of each chapter that focus on how the topic of the chapter contributes to homeostasis. Together these features will give you a better perspective on homeostasis and the interdependency of body systems.



ENDOCRINE SYSTEM
Acts by means of hormones secreted into the blood to regulate processes that require duration rather than speed—e.g., metabolic activities and water and electrolyte balance
See Chapters 4, 18, and 19.
INTEGUMENTARY SYSTEM
Serves as a protective barrier between the external environment and the remainder of the body; the sweat glands and adjustments in skin blood flow are important in temperature regulation
See Chapters 12 and 17.
Keeps internal fluids in
Keeps foreign material out
IMMUNE SYSTEM
Defends against foreign invaders and cancer cells; paves the way for tissue repair
See Chapter 12.
Protects against foreign invaders
MUSCULAR AND SKELETAL SYSTEMS
Support and protect body parts and allow body movement; heat-generating muscle contractions are important in temperature regulation; calcium is stored in the bone
See Chapters 8, 17, 18, and 19.
Enables the body to interact with the external environment
Exchanges with all other systems
Body systems maintain homeostasis
HOMEOSTASIS
A dynamic steady state of the constituents in the internal fluid environment that surrounds and exchanges materials with the cells
See Chapter 1.
Factors homeostatically maintained:
• Concentration of nutrient molecules
See Chapters 16, 17, 18, and 19.
• Concentration of O_2 and CO_2
See Chapter 13.
• Concentration of waste products
See Chapter 14.
• pH See Chapter 15.
• Concentration of water, salts, and other electrolytes
See Chapters 14, 15, 18, and 19.
• Temperature See Chapter 17.
• Volume and pressure
See Chapters 10, 14, and 15.
Homeostasis is essential for survival of cells
CELLS
Need homeostasis for their own survival and for performing specialized functions essential for survival of the whole body
See Chapters 1, 2, and 3.
Need a continual supply of nutrients and O_2 and ongoing elimination of acid-forming CO_2 to generate the energy needed to power life-sustaining cellular activities as follows:
Food + O_2 → CO_2 + H_2O + energy
See Chapters 13, 15, 16, and 17.
Cells make up body systems

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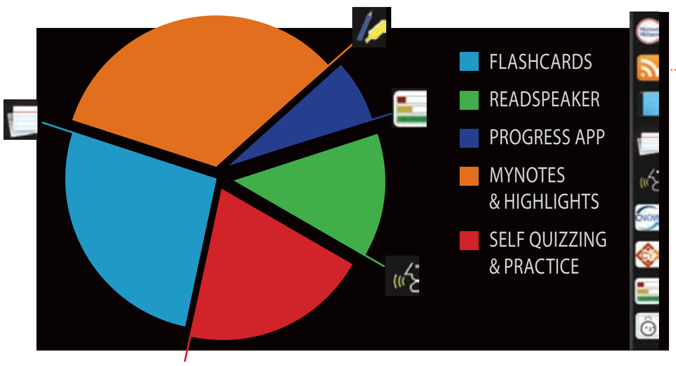

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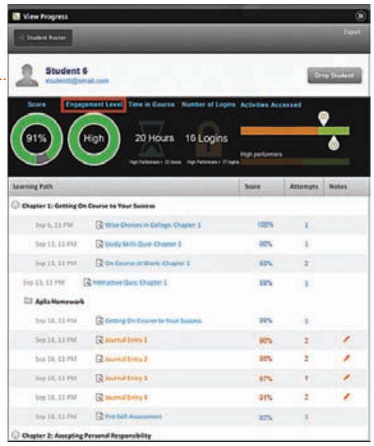

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9TH Edition

Human Physiology

From Cells to Systems

Lauralee Sherwood

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***Human Physiology: From Cells to Systems,* Ninth Edition**

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With love to my family,
for all that they do for me
and all that they mean to me:

My husband,
Peter Marshall

My daughters and sons-in-law,
Melinda and Mark Marple
Allison Tadros and Bill Krantz

My grandchildren,
Lindsay Marple
Emily Marple
Alexander Tadros
Lauren Krantz

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Preface

Goals, Philosophy, and Theme

I am constantly awestruck at the miraculous intricacies and efficiency of body function. No machine can perform even a portion of natural body function as effectively. My goal in writing physiology textbooks is not only to help students learn about how the body works, but also to share my enthusiasm for the subject matter. Most of us, even infants, have a natural curiosity about how our bodies work. When babies first discover they can control their hands, they are fascinated and spend many hours manipulating them in front of their faces. By capitalizing on students' natural curiosity about themselves, I try to make physiology a subject they can enjoy learning.

Even the most tantalizing subject can be difficult to comprehend if not effectively presented, however. Therefore, this book has a logical, understandable format with an emphasis on how each concept is an integral part of the entire subject. Too often, students view the components of a physiology course as isolated entities; by understanding how each component depends on the others, a student can appreciate the integrated functioning of the human body. The text focuses on the mechanisms of body function from cells to systems and is organized around the central theme of *homeostasis*—how the body meets changing demands while maintaining the internal constancy necessary for all cells and organs to function. The text is written in simple, straightforward language, and every effort has been made to ensure smooth reading through good transitions, commonsense reasoning, and integration of ideas throughout.

This text is designed for undergraduate students preparing for health-related careers, but its approach and depth also are appropriate for other undergraduates. Because this book is intended as an introduction and, for most students, may be their only exposure to a formal physiology text, all aspects of physiology receive broad coverage, yet depth, where needed, is not sacrificed. The scope of this text has been limited by judicious selection of pertinent content that a student can reasonably be expected to assimilate in a one-semester physiology course. Materials were selected for inclusion on a "need to know" basis, so the book is not cluttered with unnecessary detail. Instead, content is restricted to relevant information needed to understand basic physiological concepts and to serve as a foundation for future careers in the health professions. Some controversial ideas and hypotheses are presented to illustrate that physiology is a dynamic, changing discipline.

To keep pace with today's rapid advances in the health sciences, students in the health professions must be able to draw on their conceptual understanding of physiology instead of merely recalling isolated facts that soon may be out of date. Therefore, this text is designed to promote understanding of the basic principles and concepts of physiology rather than memorization of details.

In consideration of the clinical orientation of most students, research methodologies and data are not emphasized, although the material is based on up-to-date evidence. New information based on recent discoveries has been included throughout. Students can be assured of the timeliness and accuracy of the material presented. To make room for new, applicable information, I have carefully trimmed content while clarifying, modifying, and simplifying as needed to make this edition fresh, reader-friendly, and current.

Because the function of an organ depends on the organ's construction, enough relevant anatomy is integrated within the text to make the inseparable relation between form and function meaningful.

Hallmark Features and Learning Aids

Implementing the homeostasis theme

Homeostasis is the first word in this text, in the caption for the chapter opener photo for Chapter 1, "Introduction to Physiology and Homeostasis," indicative of the importance placed on homeostasis (see p. 1).

Each chapter begins with **Homeostasis Highlights,** an opening feature that emphasizes the big picture of how the content to come plays a part in homeostasis and functionally fits in with the body as a whole. As an example, see *Homeostasis Highlights* for Chapter 8, "Muscle Physiology," p. 251.

At the close of each chapter, **Homeostasis: Chapter in Perspective** points out specific ways in which the topic covered in the chapter contributes to homeostasis, returning the reader to this central theme, no matter how far the content appears to be removed from playing a role in maintaining internal constancy, as exemplified by *Homeostasis: Chapter in Perspective* for Chapter 3, "The Plasma Membrane and Membrane Potential," p. 84.

A unique, easy-to-follow, pictorial homeostatic model showing the relationship among cells, systems, and homeostasis is developed in the introductory chapter (see pp. 14–15) and presented on the inside front cover as a quick reference.

These opening and closing features and the homeostatic model work together to facilitate students' comprehension of the interactions and interdependency of body systems, even though each system is discussed separately.

Chapter openers

The chapter openers consist of three key components: an eye-catching, informative photo relevant to the chapter; *Chapter at a Glance,* a concise list of contents; and the brief *Homeostasis Highlights* narrative that orients the readers to the homeostatic aspects of the material that follows. Check out the chapter opener for Chapter 13, "The Respiratory System," on p. 445 as an example.

Pedagogical illustrations

Anatomic illustrations, schematic representations, step-by-step descriptions within process-oriented figures, photographs, tables, and graphs complement and reinforce the written material.

Widespread use of integrated descriptions within figures, including numerous **process-oriented figures with incorporated step-by-step descriptions**, allows visually oriented students to review processes through figures. Check out Figure 5-17, p. 161; Figure 8-11, p. 260; and Figure 11-11, p. 396, for examples.

Flow diagrams are used extensively to help students integrate the written information. In the flow diagrams, lighter and darker shades of the same color denote a decrease or increase in a controlled variable, such as blood pressure or the concentration of blood glucose. Physical entities, such as body structures and chemicals, are distinguished visually from actions. Icons of physical entities are incorporated into the flow diagrams. See Figure 15-4, p. 545; Figure 16-12, p. 592; and Figure 20-9, p. 729, for examples.

Most chapters feature one or more **showcase figures**, which are art-enhanced, visually appealing, broad-based foundation figures that draw students' attention to key structural and functional components relevant to the chapter. Examples include the following:

- Figure 2-1, A diagram of cell structures visible under an electron microscope, p. 23
- Figure 14-1, The urinary system, p. 493
- Figure 19-7, Anatomy of and hormonal secretion by the adrenal glands, p. 672

Also, integrated **color-coded figure/table combinations** help students better visualize what part of the body is responsible for what activities. For example, anatomic depiction of the brain is integrated with a table of the functions of the major brain components, with each component shown in the same color in the figure and the table (see Table 5-1, pp. 144–145).

A unique feature of this book is that people depicted in the various illustrations are realistic representatives of a cross-section of humanity. Sensitivity to various races, sexes, and ages should enable all students to identify with the material being presented.

Analogies

Many analogies and frequent references to everyday experiences are included to help students relate to the physiology concepts presented. These useful tools have been drawn in large part from my more than four decades of teaching experience. Knowing which areas are likely to give students the most difficulty, I have tried to develop links that help them relate the new material to something with which they are already familiar. As examples, the lymphatic system as an accessory drainage route for interstitial fluid is compared to a storm sewer that picks up and carries away excess rainwater so that it does not accumulate and flood an area (p. 358); and the effect of sildenafil (Viagra) is likened to pushing a pedal on a piano not causing a note to be played but prolonging a played note (p. 734).

Pathophysiology and clinical coverage

Another effective way to keep students' interest is to help them realize they are learning worthwhile and applicable material. Because many students using this text will have health-related careers, frequent references to pathophysiology and clinical physiology demonstrate the content's relevance to their professional goals. Clinical Note icons flag clinically relevant material, which is integrated throughout the text.

Boxed features

Two types of boxed features are incorporated within the chapters. Concepts, Challenges, and Controversies boxes expose students to high-interest information on such diverse topics as new technologies involving "seeing" with the tongue or the ear (see p. 210); historical highlights, for example, development of vaccinations (see p. 422); body responses to different environments such as those encountered in mountain climbing and deep-sea diving (see pp. 480–481); and in-depth discussions regarding common diseases such as Alzheimer's disease (see pp. 164–165).

A Closer Look at Exercise Physiology boxes are included for three reasons: increasing national awareness of the importance of physical fitness, increasing recognition of the value of prescribed therapeutic exercise programs for a variety of conditions, and growing career opportunities related to fitness and exercise. As an example, see the exercise physiology box on p. 542 regarding the importance of acclimatization to exercising in the heat.

Major section heads and feedforward statements as subsection titles

Major section heads and subsections logically break up large concepts into smaller, manageable chunks. Instead of traditional short topic titles for each subsection (for example, "Glial cells"), feedforward statements alert students to the main point of the subsection to come (for example, "Glial cells support the interneurons physically, metabolically, and functionally"). As an added bonus, the listing of these headings in the **Contents** at the beginning of the book serves as a set of objectives for each chapter.

Key terms and word derivations

Key terms are defined as they appear in the text. Because physiology is laden with new vocabulary words, many of which are rather intimidating at first glance, word derivations are provided to enhance understanding of new words.

Review and self-evaluation tools in the text

Students are provided opportunities to review and are encouraged to assess their comprehension in a variety of ways.

Check Your Understanding Questions Questions at the end of each major section serve as study breaks for students to test their knowledge before starting the next section. These questions are different than the questions that cover the same content at the end of the chapter. Many of these section questions involve doing something other than copying an answer from a text description, such as drawing and labeling, preparing a chart, predicting based on information provided, and so on. In response to positive feedback regarding the usefulness of this pedagogical tool, which was introduced in the last edition, I have added nearly 100 new Check Your Understanding questions to this edition, bringing them to a total of about 350.

NEW! Figure Focus Questions Designed to check and promote student comprehension, focus questions have been added to specific figures throughout the text. To answer these critical thinking questions correctly, the reader must analyze, interpret, infer, and apply the content of 120 key figures. Check out examples of these new questions in Figures 13-20 and 13-21, p. 467; Figure 14-27, p. 525; and Figure 19-2, p. 667.

NEW! Blooms-Based Organization of Review Exercises The Review Exercises at the end of each chapter are now organized into categories using the educational tool *Bloom's Taxonomy of Learning Domains* as a guide. Questions are grouped in a hierarchy from lower- to higher-order levels as follows:

- **Reviewing Terms and Facts:** The objective-type questions in this exercise are intended for students to self-test their basic knowledge of the chapter by recalling terms and facts.
- **Understanding Concepts:** With this level, students demonstrate their understanding of the concepts presented by describing, explaining, comparing, stating main ideas, and so on in their own words.
- **Solving Quantitative Exercises:** These problem-solving exercises provide students with an opportunity to practice calculations that enhance their understanding of complex relationships.
- **Applying Clinical Reasoning:** This mini case history challenges students to apply acquired knowledge to a patient's specific symptoms, a situation relevant to the health-profession career goals of most students using this textbook.
- **Thinking at a Higher Level:** This section features thought-provoking problems that encourage students to analyze, synthesize, reorganize, or apply in a different way what they have learned in the chapter.

Answers and explanations for these exercises are available in an appendix and online as described in the next section.

Study Cards A tear-out study card is available for each chapter. Each study card presents the major points of the chapter in concise, section-by-section bulleted lists, including cross-references for page numbers, figures, and tables. Students can carry these handy chapter summaries instead of the book to conveniently review key concepts for exams. The tear-out design lets students more efficiently review material even with the book in hand because they can see the written summary and visual information side-by-side without having to flip pages back and forth. This feature enables students to easily review main concepts before moving on.

Appendixes and glossary

Most undergraduate physiology texts have a chapter on chemistry, yet physiology instructors rarely teach basic chemistry concepts. Knowledge of chemistry beyond that introduced in secondary schools is not required for understanding this text. Therefore, I provide instead ***Appendix A,* A Review of Chemical Principles,** as a handy reference for students who need a brief review of basic chemistry concepts that apply to physiology. The following additional review materials are available online at **www.cengagebrain.com** *Storage, Replication, and Expression of Genetic Information* and *Principles of Quantitative Reasoning*.

***Appendix B,* Text References to Exercise Physiology,** provides an index of all relevant content on this topic.

***Appendix C,* Answers,** provides answers to all objective learning activities, including in-chapter *Check Your Understanding* questions and *Figure Focus* questions and end-of-chapter *Reviewing Terms and Facts,* solutions to the *Solving Quantitative Exercises,* and explanations for *Applying Clinical Reasoning* and *Thinking at a Higher Level* exercises. Answers to *Understanding Concepts* questions can be found at **www.cengagebrain.com.**

The **Glossary,** which offers a way to review the meaning of key terminology, includes phonetic pronunciations of the entries.

Organization

There is no ideal organization of physiologic processes into a logical sequence. In the sequence I chose, most chapters build on material presented in immediately preceding chapters, yet each chapter is designed to stand on its own, allowing the instructor flexibility in curriculum design. This flexibility is facilitated by cross-references to related material in other chapters. The cross-references let students quickly refresh their memory of material already learned or proceed, if desired, to a more in-depth coverage of a particular topic.

The general flow is from introductory background information to cells to excitable tissue (nerve and muscle) to organ systems, with logical transitions from one chapter to the next. For example, Chapter 8, "Muscle Physiology," ends with a discussion of cardiac (heart) muscle, which is carried forward in Chapter 9, "Cardiac Physiology." Even topics that seem unrelated in sequence, such as Chapter 12, "Body Defenses," and Chapter 13, "The Respiratory System," are linked together, in this case by ending Chapter 12 with a discussion of respiratory defense mechanisms.

Several organizational features warrant specific mention. The most difficult decision in organizing this text was placement of the endocrine material. There is merit in placing the chapters on the nervous and the endocrine (hormone-secreting) systems in close proximity because they are the body's two major regulatory systems. However, discussing details of the endocrine system immediately after the nervous system would disrupt the logical flow of material related to excitable tissue. In addition, the endocrine system cannot be covered in the depth its importance warrants if it is discussed before students have the background to understand this system's roles in maintaining homeostasis.

My solution to this dilemma is Chapter 4, "Principles of Neural and Hormonal Communication." This chapter introduces the underlying mechanisms of neural and hormonal action before the nervous system and specific hormones are mentioned in later chapters. It contrasts how nerve cells and endocrine cells communicate with other cells in carrying out their regulatory actions. Building on the different modes of action of nerve and endocrine cells, the last section of this chapter compares, in a general way, how the nervous and endocrine systems differ as regulatory systems. Chapter 5 then begins with the nervous system, providing a good link between Chapters 4 and 5. Chapters 5, 6, and 7 are devoted to the nervous system. Specific hormones are introduced in appropriate chapters, such as hormonal control of the heart and blood vessels in maintaining blood pressure in Chapters 9 and 10 and hormonal control of the kidneys in maintaining fluid balance in Chapters 14 and 15. The body's processing of absorbed energy-rich nutrient molecules is largely under endocrine control, providing a link from digestion (Chapter 16) and energy balance (Chapter 17) to the endocrine system (Chapters 18 and 19). These endocrine chapters pull together the source, functions, and control of specific endocrine secretions and serve as a summarizing and unifying capstone for homeostatic body function. Finally, building on the hormones that control the gonads (testes and ovaries) introduced in the endocrine chapters, the last chapter, Chapter 20, diverges from the theme of homeostasis to focus on reproductive physiology.

Besides the novel handling of hormones and the endocrine system, other organizational features are unique to this book. For example, unlike other physiology texts, the skin is covered in the chapter on defense mechanisms of the body (Chapter 12), in consideration of the skin's recently recognized immune functions. Bone is also covered more extensively in the endocrine chapter than in most undergraduate physiology texts, especially with regard to hormonal control of bone growth and bone's dynamic role in calcium metabolism.

Although there is a rationale for covering the various aspects of physiology in the order given here, it is by no means the only logical way of presenting the topics. Because each chapter is able to stand on its own, especially with the cross-references provided, instructors can vary the sequence of presentation at their discretion. Some chapters may even be omitted, depending on the students' needs and interests and the time constraints of the course. For example, a cursory explanation of the defense role of the leukocytes appears in Chapter 11 on blood, so an instructor can choose to omit the more detailed explanations of immune defense in Chapter 12.

New to the Ninth Edition

This edition has a new look, new pedagogical features, updates, and numerous revisions to make the book as current, relevant, and accessible to students as possible. Every aspect of the text has been upgraded as the following examples illustrate. For a detailed list of all changes, contact your Cengage Learning sales representative.

New look

Not only does this edition have fresh colors but the pages are more visually interesting because of creative wrapping of some of the written material around the art for a contemporary look instead of just being wrapped with a traditional, single 90-degree corner. See pp. 111, 245, and 413 for examples.

New self-check pedagogical tools

Already mentioned, new to this edition are several new or revised self-check features, including the new *Figure Focus* questions, more *Check Your Understanding* questions, and new organization of the end-of-chapter *Review Exercises* into hierarchical learning levels.

New and revised figures

New Art The following exemplify first-time illustrations added in this edition:

- Figure 5-9, Layers of the cerebral cortex, p. 147
- Figure 10-11, Major local chemical and physical means of controlling arteriolar caliber, p. 347
- Figure 16-11, Mechanism of $NaHCO_3$ secretion, p. 591

Revised Art Examples of extensively revised, newly conceptualized, or reorganized figures include the following:

- Figure 8-1, Characteristics of three types of muscle, p. 252
- Figure 10-26, Skeletal muscle pump enhancing venous return and countering effect of gravity on venous pressure, p. 363
- Figure 16-5, Oropharyngeal and esophageal stages of swallowing, p. 577

New Photos More than 50 new photos and replacement photos are incorporated throughout the text, including replacing 45% of the chapter opener photos. For instance, see Chapter 5 opener, a diffusion resonance image (dMRI) scan of the white matter pathways of the brain, p. 133. The following are other examples of content not shown in photos in previous editions:

- Figure 4-7, A micrograph of dendritic spines incorporated into Anatomy of the most common type of neuron, p. 95
- Figure 6-37, A scanning electron micrograph of the tip links between adjacent stereocilia, incorporated into The role of stereocilia in sound transduction, p. 218
- Table 16-3, A scanning electron micrograph of stomach lining showing gastric pits, incorporated into an integrated figure/table featuring The stomach mucosa and the gastric glands, p. 583

New tables

More new tables that group and consolidate information for easier learning have been added to this edition than ever before, as the following samples demonstrate:

- Table 4-2, Major Neurotransmitters, p. 107
- Table 8-3, Motor Control by CNS, p. 280
- Table 20-4, Stages of Follicular Development, p. 743

New boxed features

Several old boxes have been retired and two new boxes regarding timely, relevant content have been added: (1) *The Ups (Causes) and Downs (Treatments) of Hypertension*, in consideration of the fact that one third of all adults in the United States have hypertension (see pp. 372–373); and (2) *Still a Big Question: Why Do We Age?*, which focuses on the current theories of aging, in view of the increased graying of America as baby boomers are reaching old age (see pp. 678–679).

New, updated content

Recent discoveries and hot topics have been incorporated throughout as the following examples illustrate:

- In Chapter 2, inserted a discussion and figure of proteasomes breaking down ubiquinated proteins into recyclable building blocks (p. 27)
- Among the numerous new topics in Chapter 5 is the glymphatic system, a recently identified glia substitute for the lymphatic system in the brain (p. 137)
- Added a comparison of the trichromatic theory and the opponent-process theory of color vision in Chapter 6 (p. 205)
- In Chapter 9, expanded presentation of cardiac autorhythmicity to include both the membrane clock mechanism and the Ca^{2+} mechanism (together, the coupled-clock system) responsible for the pacemaker potential (p. 304)
- Introduced in Chapter 12 newly identified immune cells (innate lymphoid cells [ILCs] and innate response activator [IRA] B cells) that straddle the innate and adaptive immune systems (p. 415)
- Significantly expanded coverage of the microbiota and microbiome in Chapter 16 in light of a torrent of new findings in this hot area of science (pp. 613–614)
- In Chapter 17, updated discussion of brown fat in view of recent studies suggesting that irisin, a newly discovered chemical mediator released from exercising muscles, may promote "browning" of white adipose tissue by stimulating synthesis of uncoupling proteins in mitochondria of white fat cells (p. 632)
- Augmented coverage of the underlying molecular mechanism responsible for the suprachiasmatic nucleus's circadian oscillations in Chapter 18 by adding the interactions of PER and CRY with CLOCK and BMAL-1 (see p. 660)
- Updated discussion of islets of Langerhans in Chapter 19 to include secretion of amylin in addition to insulin by the beta cells and secretion of ghrelin by newly found epsilon cells (pp. 692 and 689)
- Expanded coverage of clinically related issues, such as adding a new discussion of concussions and chronic traumatic encephalopathy (p. 172)

Reorganization

Although the focus of each chapter remains the same as previous editions, I moved some content between and within chapters for better grouping of material, as follows:

- Moved the discussion of eicosanoids from Chapter 20 (in association with male accessory sex gland secretions) to Chapter 4, the chapter devoted primarily to neural and hormonal communication and signal transduction. Eicosanoids and cytokines are now more appropriately grouped together and presented in a new section entitled *Introduction to Paracrine Communication* (pp. 118–120)
- Transferred introduction of the JAK/STAT pathway from Chapter 18, where it was treated more as an aside in the discussion of signal transduction by growth hormone and prolactin, to Chapter 4, where the topic more logically fits in with coverage of other means of signal transduction (pp. 116–117)
- Rearranged and grouped together the material within Chapter 5 related to brain waves and the electroencephalogram for better flow and improved clarity (pp. 168–169)
- Based on reviewer input, relocated presentation of specific somatic reflexes, namely the stretch reflex, withdrawal reflex, and crossed extensor reflex, from Chapter 5, Central Nervous System, where these reflexes were covered in conjunction with the spinal cord, to Chapter 8, Muscle Physiology, where they are now included in the section on Control of Motor Movement (pp. 282, 284–286)

Clearer, more concise coverage

I look at every edition for opportunities to make the writing as clear, concise, well-organized, and relevant for readers as possible. By careful tightening, I was able to shave 22 pages from the text while retaining all essential content and adding more beneficial learning tools and updated content, a win-win for readers.

New and Enhanced Technology for Instructors and Students

NEW! MindTap for Human Physiology

MindTap is a personalized, fully digital learning platform of authoritative content, assignments, and services that engages students with interactivity while also offering instructors their choice in the configuration of coursework and enhancement of the curriculum via Web-based applications known as MindApps. MindApps range from ReadSpeaker (which reads the text out loud to students) to Kaltura (allowing you to insert inline video and audio into your curriculum). MindTap is well beyond an eBook, a homework solution, a digital supplement, a resource center Web site, a course delivery platform, or a Learning Management System. It is the first in a new category—the Personal Learning Experience. MindTap for *Human Physiology* includes an integrated study guide, homework, and clinical case studies, among other valuable learning tools.

NEW! Aplia for Human Physiology

Aplia for *Human Physiology* helps students learn and understand key concepts via focused assignments and active learning opportunities that include randomized, automatically graded questions, exceptional text interaction, and detailed explanations. With Aplia, students move away from just memorizing facts toward a more conceptual understanding of the course materials, In addition, Aplia has a full course management system that can be used independently or in conjunction with other course management systems such as MindTap, D2L, or Blackboard.

NEW! Virtual Physiology Labs 2.0

Virtual Physiology Labs enable students to conduct experiments online without expensive equipment. By acquiring data, performing experiments, and using that data to explain physiology concepts, students become involved in the scientific process—they don't just watch or read about it.

Resources for Instructors

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This manual, which may be required by the instructor in courses that have a laboratory component, contains a variety of exercises that reinforce concepts covered in *Human Physiology: From Cells to Systems*, Ninth Edition. These laboratory experiences increase students' understanding of the subject matter in a straightforward manner, with thorough directions to guide them through the process and relevant questions for reviewing, explaining, and applying results.

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Thanks to all!

Lauralee Sherwood

Introduction to Physiology and Homeostasis

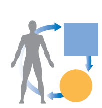
1

Oliver Eltinger/Agefotostock

Homeostasis (maintaining internal consistency) in action. Body temperature is maintained as evaporation of sweat cools the body to counterbalance heat gained through exertion on a hot day, and fluid balance is maintained as thirst encourages fluid intake to offset fluid lost in sweat.

CHAPTER AT A GLANCE

Homeostasis Highlights



Physiology focuses on body functions. This book explores how the various components of the human body function to maintain **homeostasis**, the relatively stable conditions inside the body needed for survival. Each chapter begins with *Homeostasis Highlights* to give you a heads up on how the body part under discussion fits in with the big picture of homeostasis. Each chapter concludes with *Homeostasis: Chapter in Perspective,* which points out specific ways in which the topic covered in the chapter contributes to homeostasis.

1.1 Introduction to Physiology

Look at Figure 1-1. The activities described are a sampling of the body processes that occur all the time just to keep us alive. We usually take these life-sustaining activities for granted and do not really think about "what makes us tick," but that's what physiology is about. **Physiology** is the study of the functions of living things. Specifically, we will focus on how the human body works.

Physiology focuses on mechanisms of action.

Two approaches are used to explain events that occur in the body; one emphasizes the *purpose* of a body process and the other emphasizes the underlying *mechanism* by which this process occurs. In response to the question "Why do I shiver when I am cold?" one answer would be "to help my body warm up, because shivering generates heat." This approach, which explains body functions in terms of meeting a bodily need, emphasizes *why* body processes occur. Physiologists, however, explain *how* processes occur in the body. They view the body as a machine whose mechanisms of action can be explained in terms of cause-and-effect sequences of physical and chemical processes—the same types of processes that occur throughout the universe. A physiologist's explanation of shivering is that when temperature-sensitive nerve cells detect a fall in body temperature, they signal the area in the brain responsible for temperature regulation. In response, this brain area activates nerve pathways that ultimately bring about involuntary, oscillating muscle contractions (that is, shivering).

Structure and function are inseparable.

Physiology is closely related to **anatomy**, the study of the structure of the body. Physiological mechanisms are made possible by the structural design and relationships of the various body parts that carry out each of these functions. Just as the functioning of an automobile depends on the shapes, organization, and interactions of its various parts, the structure and function of the human body are inseparable. Therefore, as we tell the story of how the body works, we provide sufficient anatomic background for you to understand the function of the body part being discussed.

Some structure–function relationships are obvious. For example, the heart is well designed to receive and pump blood, the teeth to tear and grind food, and the hingelike elbow joint to permit bending of the arm. In other situations, the interdependence of form and function is more subtle but equally important. Consider the interface between air and blood in the lungs as an example: The respiratory airways, which carry air from the outside into the lungs, branch extensively when they reach the lungs. Tiny air sacs cluster at the ends of the huge number of airway branches. The branching is so extensive that the lungs contain about 300 million air sacs. Similarly, the vessels carrying blood into the lungs branch extensively and form dense networks of small vessels that encircle each air sac (see Figure 13-2, p. 448). Because of this structural relationship, the total surface area forming an interface between the air in the air sacs and the blood in the small vessels is about the size of one side of a volleyball court. This tremendous interface is crucial for the lungs' ability to efficiently carry out their function: the transfer of needed oxygen (O_2) from the air into the blood and the unloading of the waste product carbon dioxide (CO_2) from the blood into the air. The greater the surface area available for these exchanges, the faster O_2 and CO_2 can move between the air and the blood. This large functional interface packaged within the confines of your lungs is possible only because both the air-containing and blood-containing components of the lungs branch extensively.

Check Your Understanding 1.1

1. Define *physiology*.
2. The nutrient-absorbing intestinal cells have a multitude of fingerlike projections in contact with the digested food (see Figure 16-20, p. 602). Based on your knowledge of structure–function relationships, explain the functional advantage of this structural feature. (Answers are in Appendix C.)

1.2 Levels of Organization in the Body

We now turn to how the body is structurally organized into a total functional unit, from the chemical level to the whole body (Figure 1-2). These levels of organization make possible life as we know it.

The chemical level: Various atoms and molecules make up the body.

Like all matter, both living and nonliving, the human body is a combination of specific *atoms,* which are the smallest building blocks of matter. The most common atoms in the body—oxygen, carbon, hydrogen, and nitrogen—make up approximately 96% of the total body chemistry. These common atoms and a few others combine to form the *molecules* of life, such as proteins, carbohydrates, fats, and nucleic acids (genetic material, such as deoxyribonucleic acid, or DNA). These important atoms and molecules are the inanimate raw ingredients from which all living things arise. (See Appendix A for a review of this chemical level.)

The cellular level: Cells are the basic units of life.

The mere presence of a particular collection of atoms and molecules does not confer the unique characteristics of life. Instead, these nonliving chemical components must be arranged and packaged in precise ways to form a living entity. The **cell**, the fundamental unit of both structure and function in a living being, is the smallest unit capable of carrying out the processes associated with life. Cell physiology is the focus of Chapter 2.

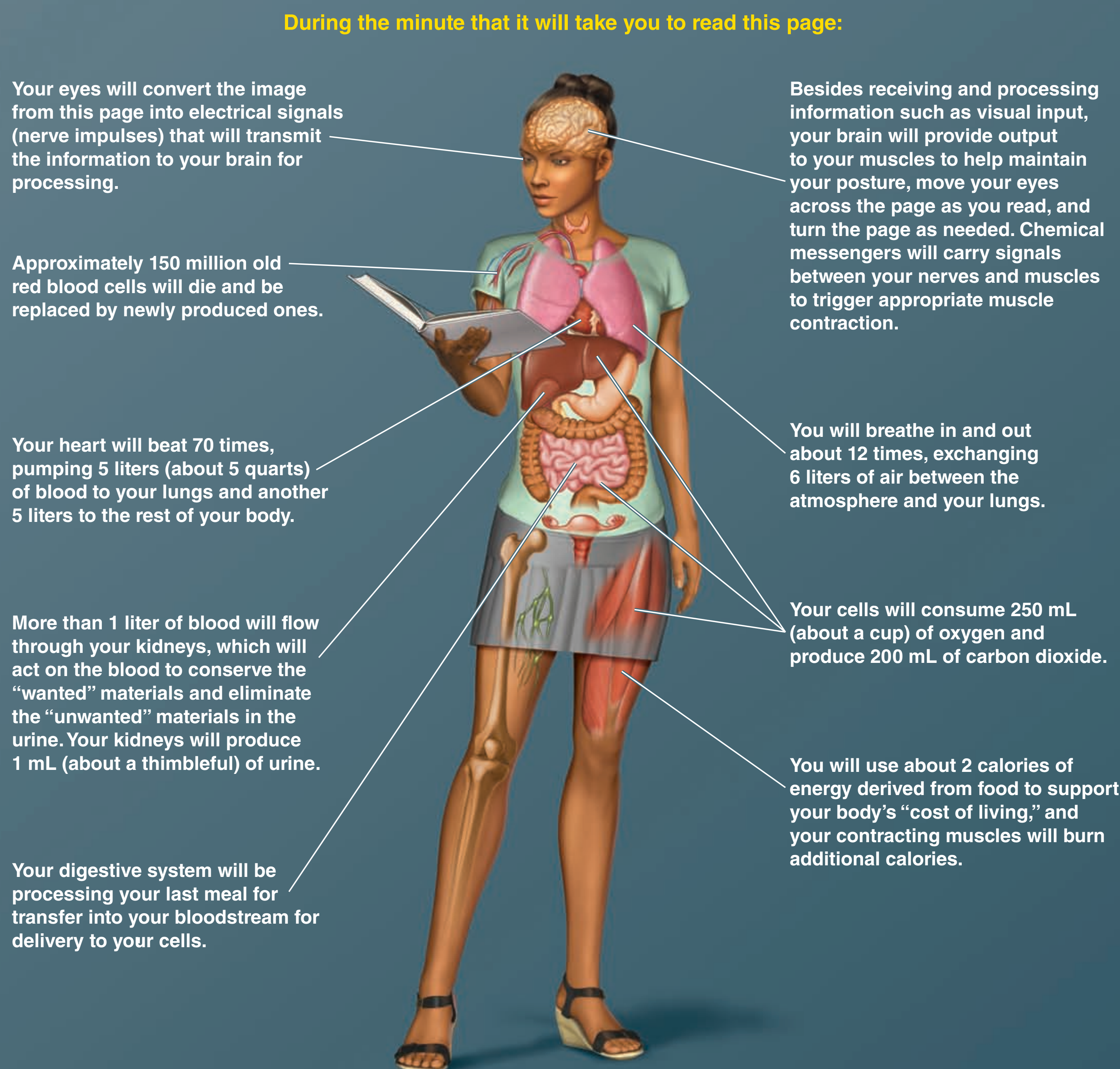


Figure 1-1 A glimpse at your body functions.

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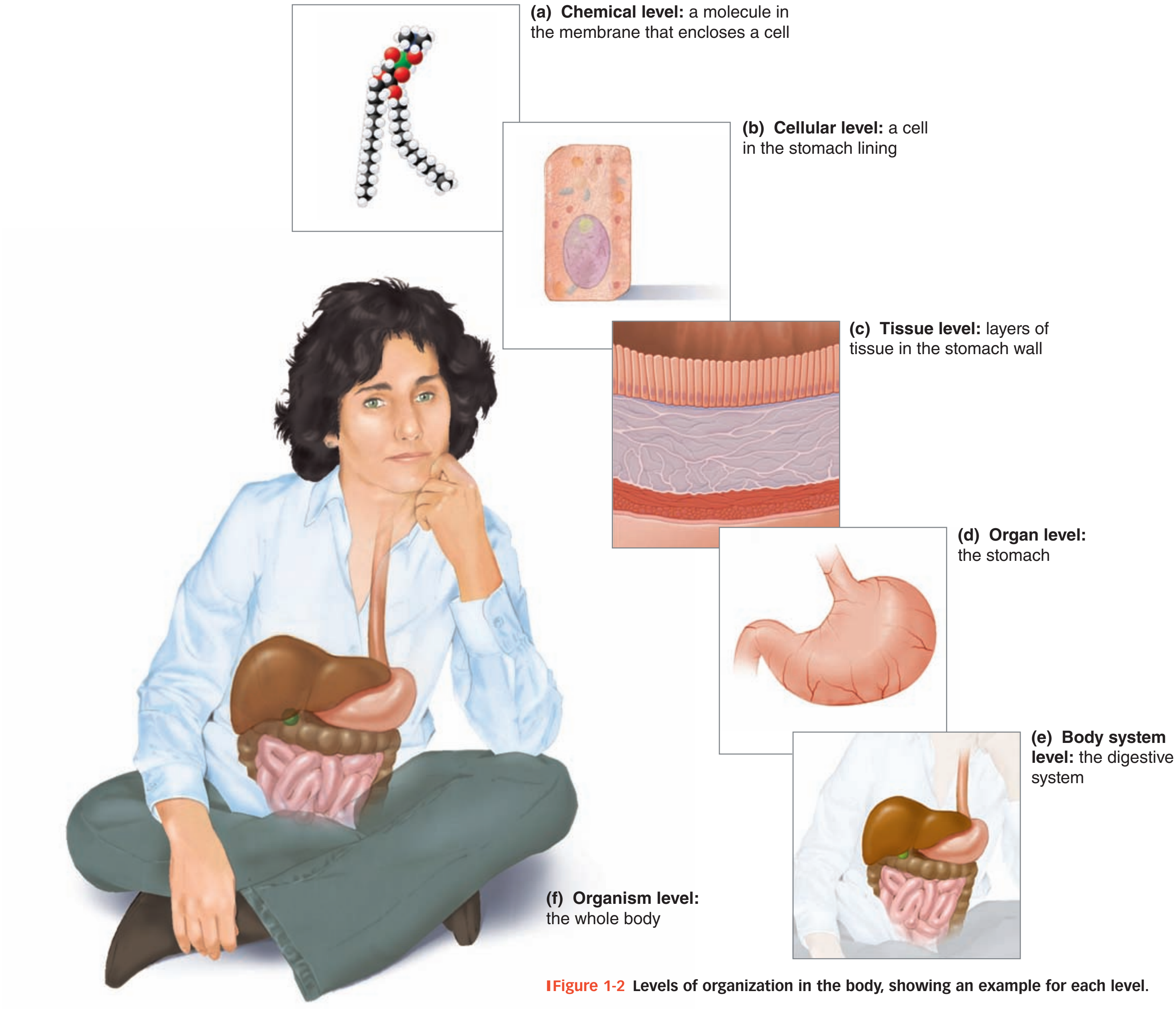


Figure 1-2 Levels of organization in the body, showing an example for each level.

An extremely thin, oily, complex barrier, the *plasma membrane,* encloses the contents of each cell and controls movement of materials into and out of the cell. Thus, the cell's interior contains a combination of atoms and molecules that differs from the mixture of chemicals in the environment surrounding the cell. Given the importance of the plasma membrane and its associated functions for carrying out life processes, Chapter 3 is devoted entirely to this structure.

Organisms are independent living entities. The simplest forms of independent life are single-celled organisms such as bacteria and amoebas. Complex multicellular organisms, such as trees and humans, are structural and functional aggregates of trillions of cells (*multi* means "many"). In the simpler multicellular forms of life—for example, a sponge—the cells of the organism are all similar. However, more complex organisms, such as humans, have many kinds of cells, such as muscle cells, nerve cells, and gland cells.

Each human organism begins when an egg and sperm unite to form a single new cell, which multiplies and forms a growing mass through myriad cell divisions. If cell multiplication were the only process involved in development, all body cells would be essentially identical, as in the simplest multicellular lifeforms. However, during development of complex multicellular organisms such as humans, each cell also **differentiates**, or becomes specialized to carry out a particular function. As a result of cell differentiation, your body is made up of about 200 specialized types of cells.

Basic Cell Functions All cells, whether they exist as solitary cells or as part of a multicellular organism, perform certain basic functions essential for their own survival, including the following:

1. Obtaining food (nutrients) and O_2 from the environment surrounding the cell.

2. Performing chemical reactions that use nutrients and O_2 to provide energy for the cells, as follows:

$$\text{Food} + O_2 \rightarrow CO_2 + H_2O + \text{energy}$$

3. Eliminating to the cell's surrounding environment CO_2 and other by-products, or wastes, produced during these chemical reactions.

4. Synthesizing proteins and other components needed for cell structure, for growth, and for carrying out particular cell functions. For example, **enzymes** are specialized proteins that speed up particular chemical reactions in the body.

5. Largely controlling the exchange of materials between the cell and its surrounding environment.

6. Moving materials internally from one part of the cell to another, with some cells also being able to move themselves through their surrounding environment.

7. Being sensitive and responsive to changes in the surrounding environment.

8. In the case of most cells, reproducing. Exceptions are nerve cells and muscle cells, which lose the ability to reproduce soon after they are formed. This is the reason strokes, which result in lost nerve cells in the brain, and heart attacks, which cause death of heart muscle cells, can be so devastating.

Because all cells are remarkably similar in the ways they carry out these basic functions, they share many common characteristics despite their specialization.

Specialized Cell Functions In multicellular organisms, each cell also performs a specialized function, which is usually a modification or elaboration of a basic cell function. Here are a few examples:

- By taking special advantage of their protein-synthesizing ability, the gland cells of the digestive system secrete digestive enzymes that break down ingested food.
- Certain kidney cells can selectively retain the substances needed by the body while eliminating unwanted substances in the urine because of their highly specialized ability to control exchange of materials between the cell and its environment.
- Muscle contraction, which involves selective movement of internal structures to generate tension in the muscle cells, is an elaboration of the inherent ability of these cells to produce intracellular movement (*intra* means "within").
- Capitalizing on the basic ability of cells to respond to changes in their surrounding environment, nerve cells generate and transmit to other body regions electrical impulses that relay information about changes to which the nerve cells are responsive. For example, nerve cells in the ear can relay information to the brain about sounds in the body's surroundings.

Each cell performs these specialized activities in addition to carrying on the unceasing, fundamental activities required of all cells. The basic cell functions are essential for survival of individual cells, whereas the specialized contributions and interactions among the cells of a multicellular organism are essential for survival of the whole body.

Just as a machine does not function unless all its parts are properly assembled, the cells of the body must be specifically organized to carry out the life-sustaining processes of the body as a whole, such as digestion, respiration, and circulation. Cells are progressively organized into tissues, organs, body systems, and finally the whole body.

The tissue level: Tissues are groups of cells of similar specialization.

Cells of similar structure and specialized function combine to form **tissues**, of which there are four *primary types:* muscle, nervous, epithelial, and connective (Figure 1-3). Each tissue consists of cells of a single specialized type, along with varying amounts of extracellular material (*extra* means "outside of").

- **Muscle tissue** consists of cells specialized for contracting, which generates tension and produces movement. The three types of muscle tissue include *skeletal muscle,* which moves the skeleton; *cardiac muscle,* which pumps blood out of the heart;

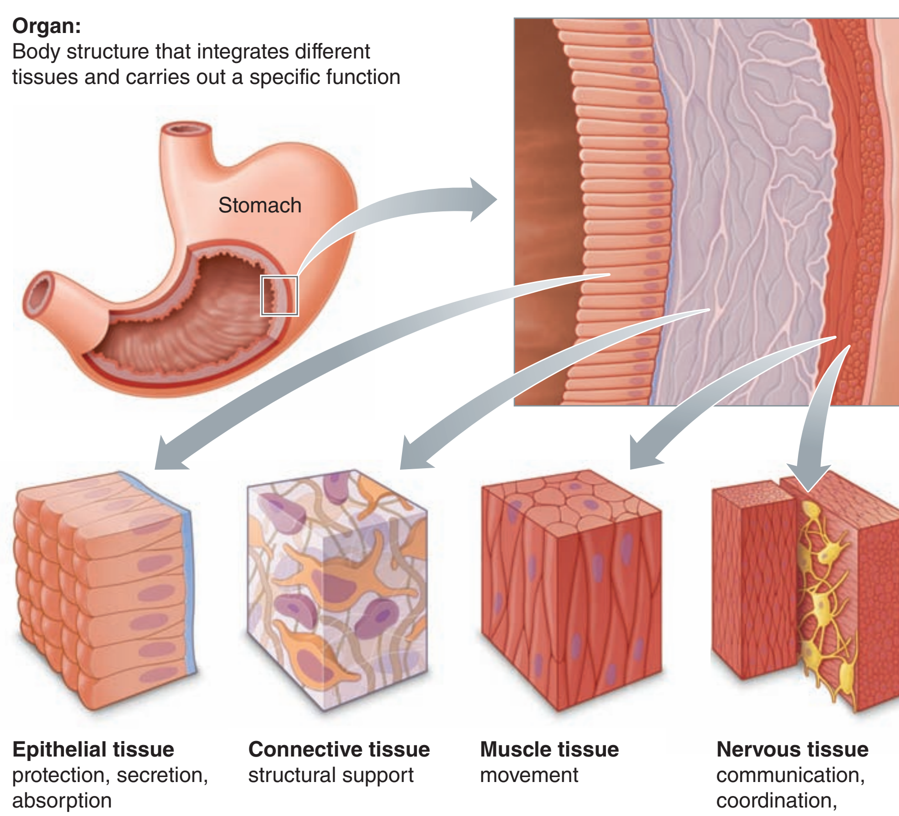


Figure 1-3 The stomach as an organ made up of all four primary tissue types.

and *smooth muscle,* which controls movement of contents through hollow tubes and organs, such as movement of food through the digestive tract.

- **Nervous tissue** consists of cells specialized for initiating and transmitting electrical impulses, sometimes over long distances. These electrical impulses act as signals that relay information from one part of the body to another. Such signals are important in communication, coordination, and control in the body. Nervous tissue is found in the brain, spinal cord, nerves, and special sense organs.
- **Epithelial tissue** consists of cells specialized for exchanging materials between the cell and its environment. Any substance that enters or leaves the body must cross an epithelial barrier. Epithelial tissue is organized into two general types of structures: *epithelial sheets* and *secretory glands*. Epithelial sheets are layers of tightly joined cells that cover and line various parts of the body. For example, the outer layer of the skin is epithelial tissue, as is the lining of the digestive tract. In general, epithelial sheets serve as boundaries that separate the body from its surroundings and from the contents of cavities that open to the outside, such as the digestive tract lumen. (A **lumen** is the cavity within a hollow organ or tube.) Only selective transfer of materials is possible between regions separated by an epithelial barrier. The type and extent of controlled exchange vary depending on the location and function of the epithelial tissue. For example, the skin can exchange little between the body and outside environment, making it a protective barrier. By contrast the epithelial cells lining the small intestine of the digestive tract are specialized for absorbing nutrients that have come from outside the body.

Glands are epithelial tissue derivatives specialized for secreting. **Secretion** is the release from a cell, in response to appropriate stimulation, of specific products that have been produced by the cell. Glands are formed during embryonic development by pockets of epithelial tissue that dip inward from the surface and develop secretory capabilities. The two categories of glands are *exocrine* and *endocrine* (Figure 1-4). During development, if the connecting cells between the epithelial surface cells and the secretory gland cells within the depths of the pocket remain intact as a duct between the gland and the surface, an exocrine gland is formed. **Exocrine glands** secrete through ducts to the outside of the body (or into a cavity that opens to the outside) (*exo* means "external"; *crine* means "secretion"). Examples are sweat glands and glands that secrete digestive juices. If, in contrast, the connecting cells disappear during development and the secretory gland cells are isolated from the surface, an endocrine gland is formed. **Endocrine glands** lack ducts and release their secretory products, known as *hormones,* internally into the blood (*endo* means "internal"). For example, the pancreas secretes insulin into the blood, which transports this hormone to its sites of action throughout the body. Most cell types depend on insulin for taking up glucose (sugar).

- **Connective tissue** is distinguished by having relatively few cells dispersed within an abundance of extracellular material. As its name implies, connective tissue connects, supports, and anchors various body parts. It includes such diverse structures as the loose connective tissue that attaches epithelial tissue to underlying structures; tendons, which attach skeletal muscles to bones; bone, which gives the body shape, support, and protection; and blood, which transports materials from one part of the body to another. Except for blood, the cells within connective tissue produce specific structural molecules that they release into the extracellular spaces between the cells. One such molecule is the rubber band–like protein fiber *elastin*; its presence facilitates the stretching and recoiling of structures

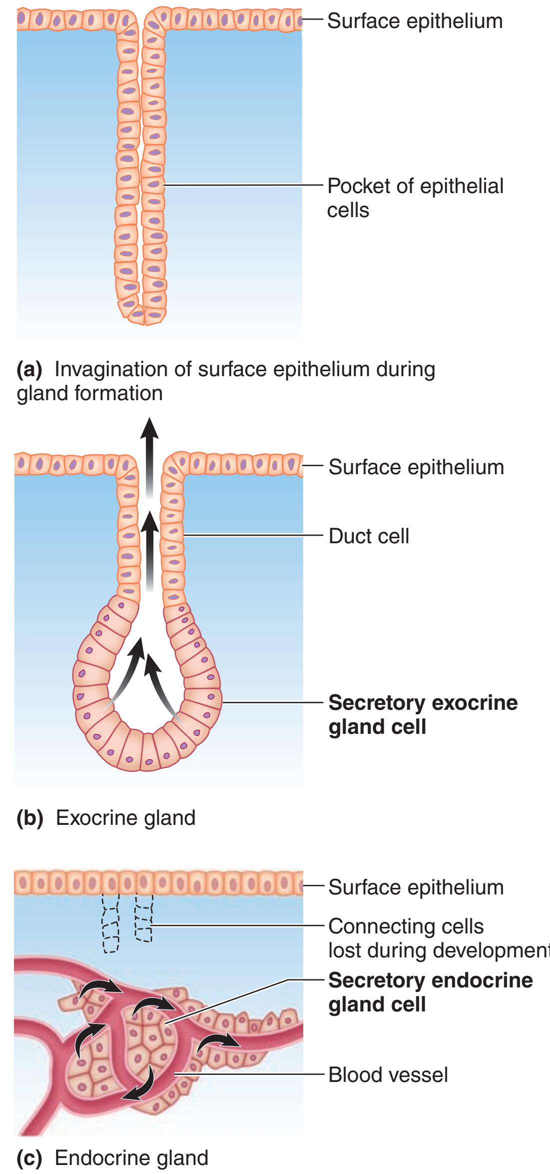


Figure 1-4 Exocrine and endocrine glands. (a) Glands form during development from pocketlike invaginations of surface epithelial cells. (b) Exocrine gland cells release their secretory product through a duct to the outside of the body (or to a cavity in communication with the outside). (c) Endocrine gland cells release their secretory product (a hormone) into the blood.

FIGURE FOCUS*: Milk-secreting glands are surrounded by musclelike cells that squeeze out the milk in response to oxytocin secreted into the blood when a baby breast-feeds. Are milk-secreting glands exocrine or endocrine? Is oxytocin secreted by an exocrine or endocrine gland? (Answers are in Appendix C.)*

such as the lungs, which alternately inflate and deflate during breathing.

Muscle, nervous, epithelial, and connective tissue are the primary tissues in a classical sense—that is, each is an integrated collection of cells with the same specialized structure and function. The term *tissue* is also often used, as in clinical medicine, to mean the aggregate of various cellular and extracellular components that make up a particular organ (for example, lung tissue or liver tissue).

The organ level: An organ is a unit made up of several tissue types.

Organs consist of two or more types of primary tissue organized to perform particular functions. The stomach, an example of an organ, is made up of all four primary tissue types (see Figure 1-3). The tissues of the stomach function collectively to store ingested food, move it forward into the rest of the digestive tract, and begin the digestion of protein. The stomach is lined with epithelial tissue that restricts the transfer of harsh digestive chemicals and undigested food from the stomach lumen into the blood. Epithelial gland cells in the stomach include exocrine cells, which secrete protein-digesting juices into the lumen, and endocrine cells, which secrete a hormone that helps regulate the stomach's exocrine secretion and muscle contraction. The stomach wall contains smooth muscle tissue, whose contractions mix ingested food with the digestive juices and push the mixture out of the stomach and into the intestine. The stomach wall also contains nervous tissue, which, along with hormones, controls muscle contraction and gland secretion. Connective tissue binds together all these various tissues.

The body system level: A body system is a collection of related organs.

Groups of organs are further organized into **body systems**. Each system is a collection of organs that perform related functions and interact to accomplish a common activity essential for survival of the whole body. For example, the digestive system consists of the mouth, pharynx (throat), esophagus, stomach, small intestine, large intestine, salivary glands, exocrine pancreas, liver, and gallbladder. These digestive organs cooperate to break food down into small nutrient molecules that can be absorbed into the blood for distribution to all cells.

The human body has 11 systems: circulatory, digestive, respiratory, urinary, skeletal, muscular, integumentary, immune, nervous, endocrine, and reproductive (Figure 1-5). Chapters 4 through 20 cover the details of these systems.

The organism level: The body systems are packaged into a functional whole body.

Each body system depends on the proper functioning of other systems to carry out its specific responsibilities. The whole body of a multicellular organism—a single, independently living individual—consists of the various body systems structurally and functionally linked as an entity that is separate from its surrounding environment. Thus, the body is made up of living cells organized into life-sustaining systems.

The different body systems do not act in isolation from one another. Many complex body processes depend on the interplay among multiple systems. For example, regulation of blood pressure depends on coordinated responses among the circulatory, urinary, nervous, and endocrine systems. Even though physiologists may examine body functions at any level from cells to systems (as indicated in the title of this book), their ultimate goal is to integrate these mechanisms into the big picture of how the entire organism works as a cohesive whole.

Currently, researchers are hotly pursuing several approaches for repairing or replacing tissues or organs that can no longer adequately perform vital functions because of disease, trauma, or age-related changes. (See the boxed feature on pp. 10 and 11, Concepts, Challenges, and Controversies. Each chapter has similar boxed features that explore in greater depth high-interest information on such diverse topics as environmental impact on the body, aging, ethical issues, discoveries regarding common diseases, and historical perspectives.)

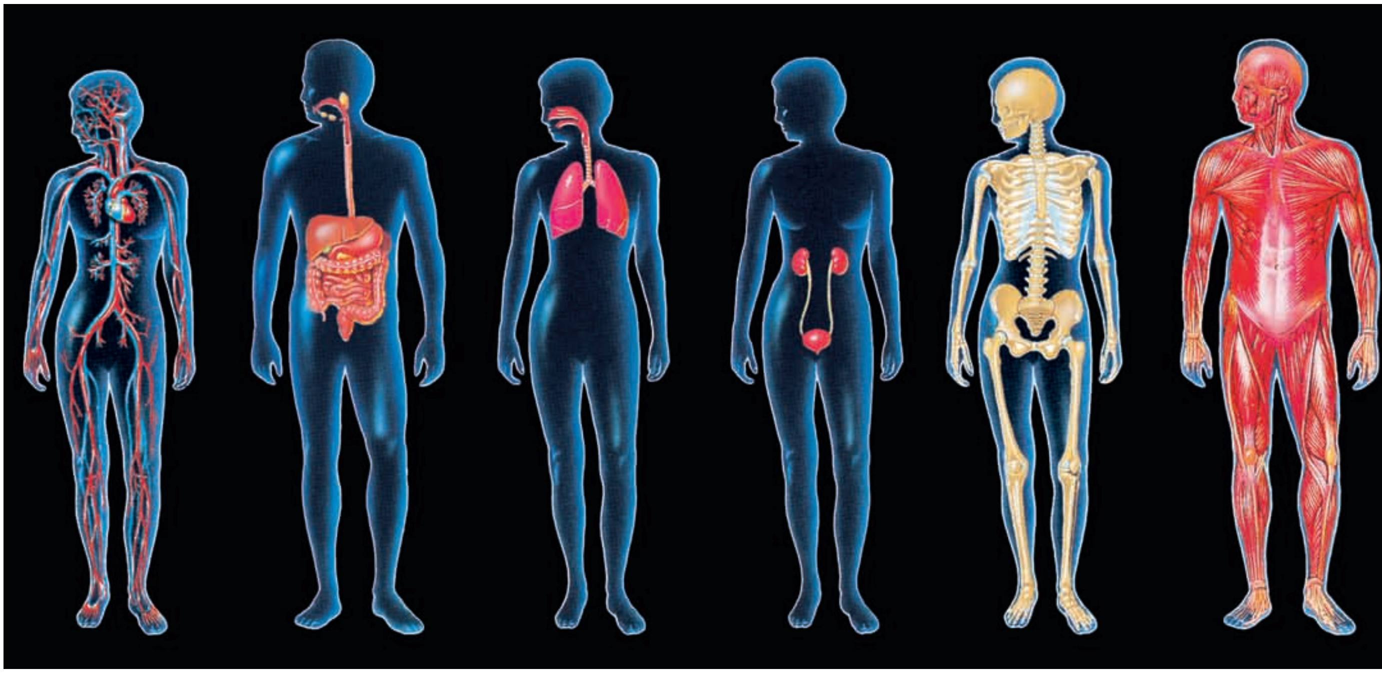
We next focus on how the different body systems normally work together to maintain the internal conditions necessary for life.

Check Your Understanding 1.2

1. List and describe the levels of organization in the body.
2. State the basic cell functions.
3. Name the four primary types of tissue and give an example of each.

1.3 Concept of Homeostasis

If each cell has basic survival skills, why can't the body cells live without performing specialized tasks and being organized according to specialization into systems that accomplish functions essential for the whole organism's survival? The cells in a multicellular organism cannot live and function without contributions from the other body cells because most cells are not in direct contact with the external environment. The **external environment** is the surrounding environment in which an organism lives. A single-celled organism such as an amoeba obtains nutrients and O_2 directly from its immediate external surroundings and eliminates wastes back into those surroundings. A muscle cell or any other cell in a multicellular organism has the same need for life-supporting nutrient and O_2 uptake and waste elimination; yet, the muscle cell is isolated from the external environment surrounding the body. How can it make vital exchanges with the external environment with which it has no contact? The key is the presence of a watery internal environment. The **internal environment** is the fluid that surrounds the cells and through which they make life-sustaining exchanges.



Circulatory system heart, blood vessels, blood

Digestive system mouth, pharynx, esophagus, stomach, small intestine, large intestine, salivary glands, exocrine pancreas, liver, gallbladder

Respiratory system nose, pharynx, larynx, trachea, bronchi, lungs

Urinary system kidneys, ureters, urinary bladder, urethra

Skeletal system bones, cartilage, joints

Muscular system skeletal muscles

Figure 1-5 Components of the body systems.

Body cells are in contact with a privately maintained internal environment.

The fluid collectively contained within all body cells is called **intracellular fluid (ICF)**. The fluid outside the cells is called **extracellular fluid (ECF)**. Note that the ECF is outside the cells but inside the body. Thus, the ECF is the internal environment of the body. You live in the external environment; your cells live in the body's internal environment.

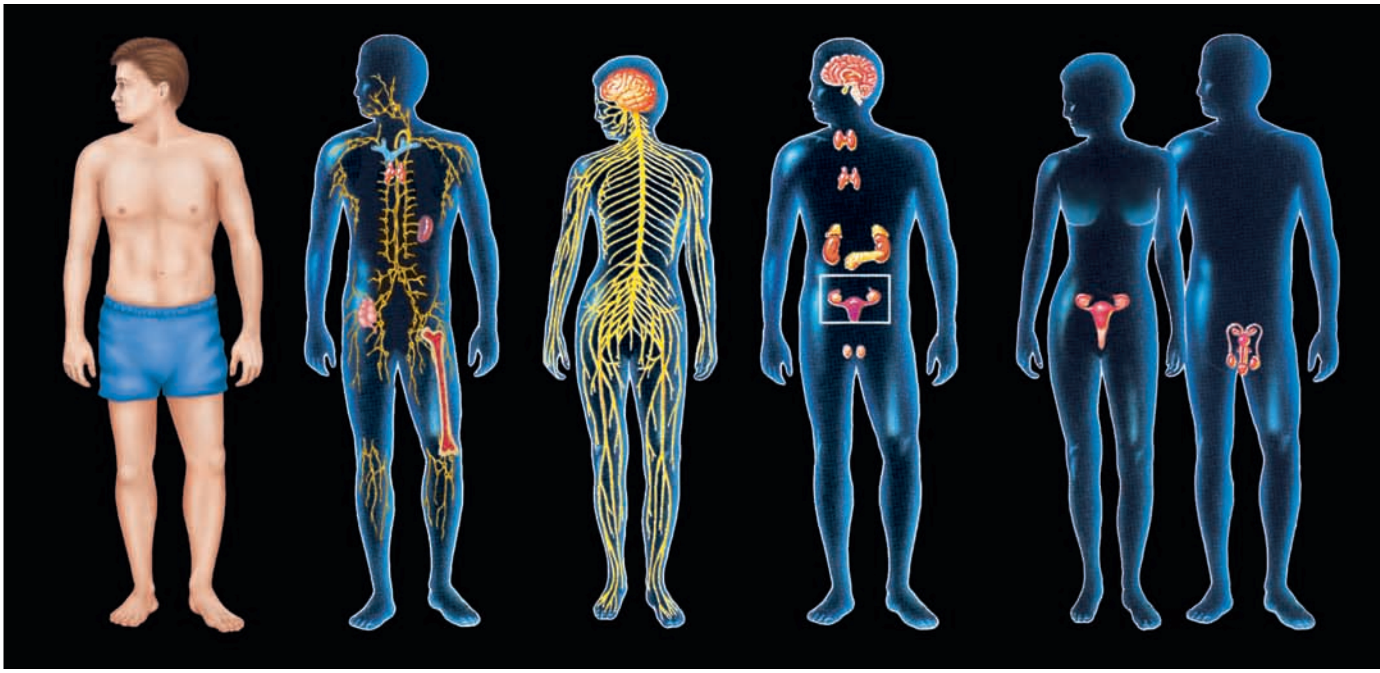
ECF is made up of two components: the **plasma**, the fluid portion of the blood, and the **interstitial fluid**, which surrounds and bathes the cells (*inter* means "between"; *stitial* means "that which stands") (Figure 1-6).

No matter how remote a cell is from the external environment, it can make life-sustaining exchanges with its surrounding fluid. Particular body systems accomplish the transfer of materials between the external environment and the internal environment so that the composition of the internal environment is appropriately maintained to support the life and functioning of the cells. The digestive system transfers the nutrients required by all body cells from the external environment into the plasma, and the respiratory system transfers O_2 from the external environment into the plasma. The circulatory system distributes these nutrients and O_2 throughout the body. Materials are thoroughly mixed and exchanged between the plasma and the interstitial fluid across the capillaries, the smallest and thinnest of blood vessels. As a result, the nutrients and O_2 originally obtained from the external environment are delivered to the interstitial fluid, from which the body cells pick up these needed supplies. Similarly, wastes produced by the cells are released into the interstitial fluid, picked up by the plasma, and transported to the organs that specialize in eliminating these wastes from the internal environment to the external environment. The lungs remove CO_2 from the plasma and blow out this waste, and the kidneys remove other wastes for elimination in the urine.

Thus, a body cell takes in essential nutrients from its watery surroundings and eliminates wastes into these same surroundings, just as an amoeba does. The main difference is that each body cell must help maintain the composition of the internal environment so that this fluid continuously remains suitable to support the existence of all body cells. In contrast, an amoeba does nothing to regulate its surroundings.

Body systems maintain homeostasis, a dynamic steady state in the internal environment.

Body cells can live and function only when the ECF is compatible with their survival; thus, the chemical composition and physical state of this internal environment must be maintained within narrow limits. As cells take up nutrients and O_2 from the internal environment, these essential materials must constantly be replenished. Likewise, wastes must constantly be removed from the internal environment so that they do not reach toxic



levels. Other aspects of the internal environment important for maintaining life, such as temperature, also must be kept relatively constant. Maintenance of a relatively stable internal environment is termed **homeostasis** (*homeo* means "similar"; *stasis* means "to stand or stay").

The functions performed by each body system contribute to homeostasis, thereby maintaining within the body the environment required for the survival and function of all cells. Cells, in turn, make up body systems. This is the central theme of physiology and of this book: *Homeostasis is essential for the survival of each cell, and each cell, through its specialized activities as part of a body system, helps maintain the internal environment shared by all cells* (Figure 1-7, p. 12).

The internal environment must be kept relatively stable, but this does not mean that its composition, temperature, and other characteristics are absolutely unchanging. Both external and internal factors continuously threaten to disrupt homeostasis. When any factor starts to move the internal environment away from optimal conditions, the body systems initiate appropriate counter-reactions to minimize the change. For example, when you're exposed to a cold environmental temperature (an external factor), your body temperature tends to fall. In response, the temperature control center in your brain initiates compensatory measures, such as shivering, to raise your body temperature to normal. By contrast, when you exercise, your working muscles produce extra heat (an internal factor) that tends to increase your body temperature. In response, the temperature control center brings about sweating and other compensatory measures to reduce your body temperature to normal.

Thus, homeostasis is not a rigid, fixed state but a dynamic steady state in which changes that occur are minimized by compensatory physiological responses. The term *dynamic* refers to each homeostatically regulated factor being marked by continuous change, whereas *steady state* implies that these changes do

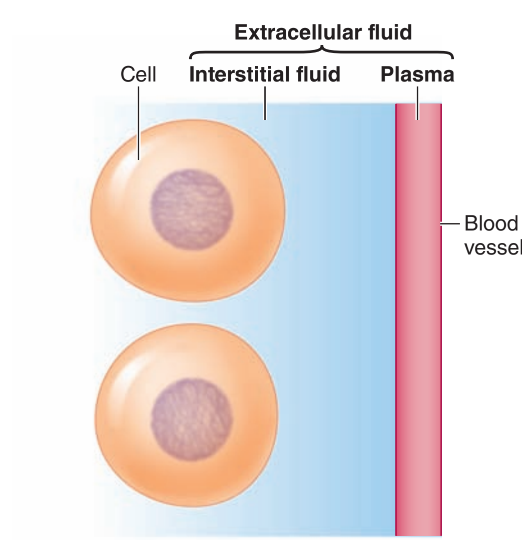


Figure 1-6 Components of the extracellular fluid (internal environment).