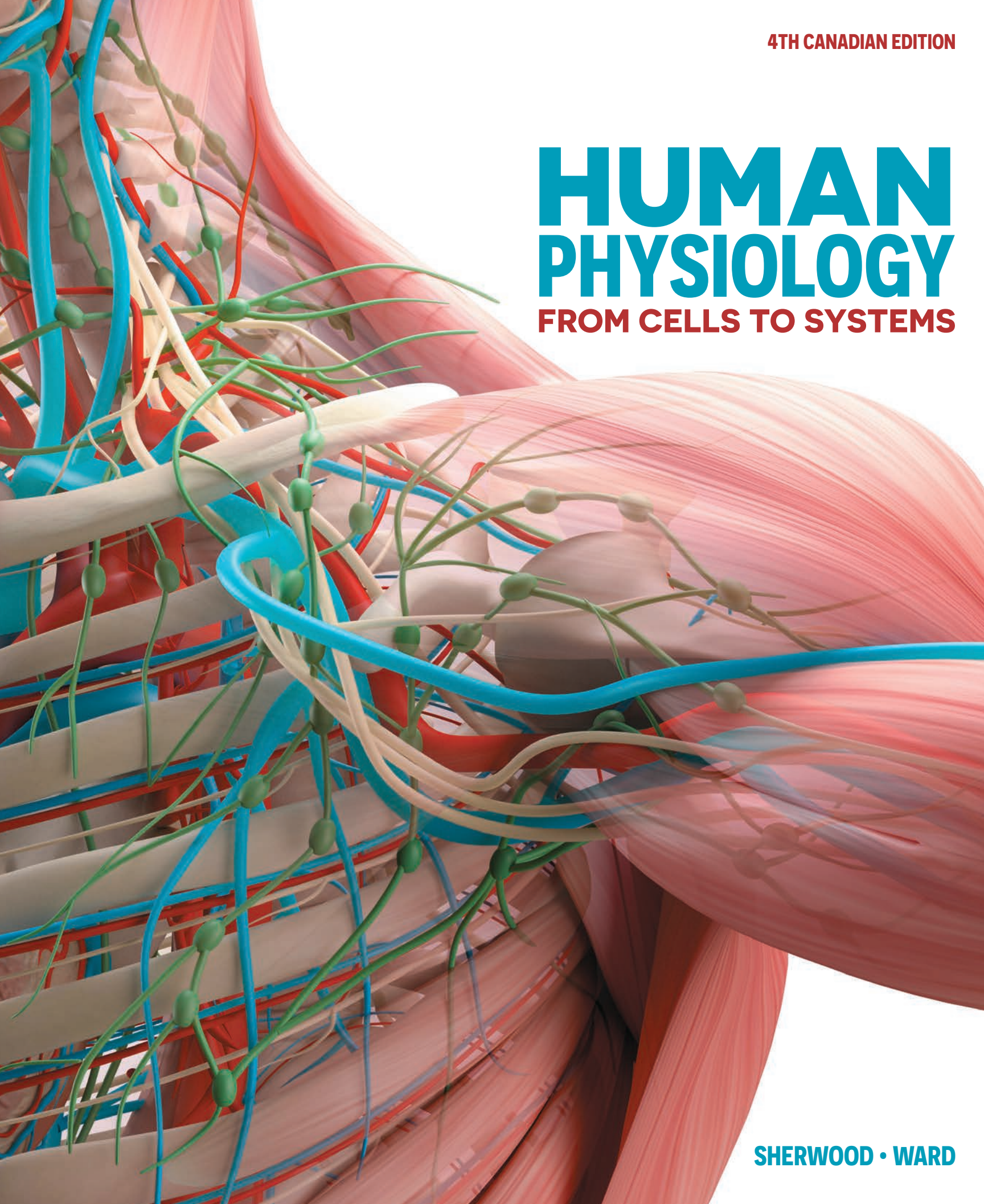


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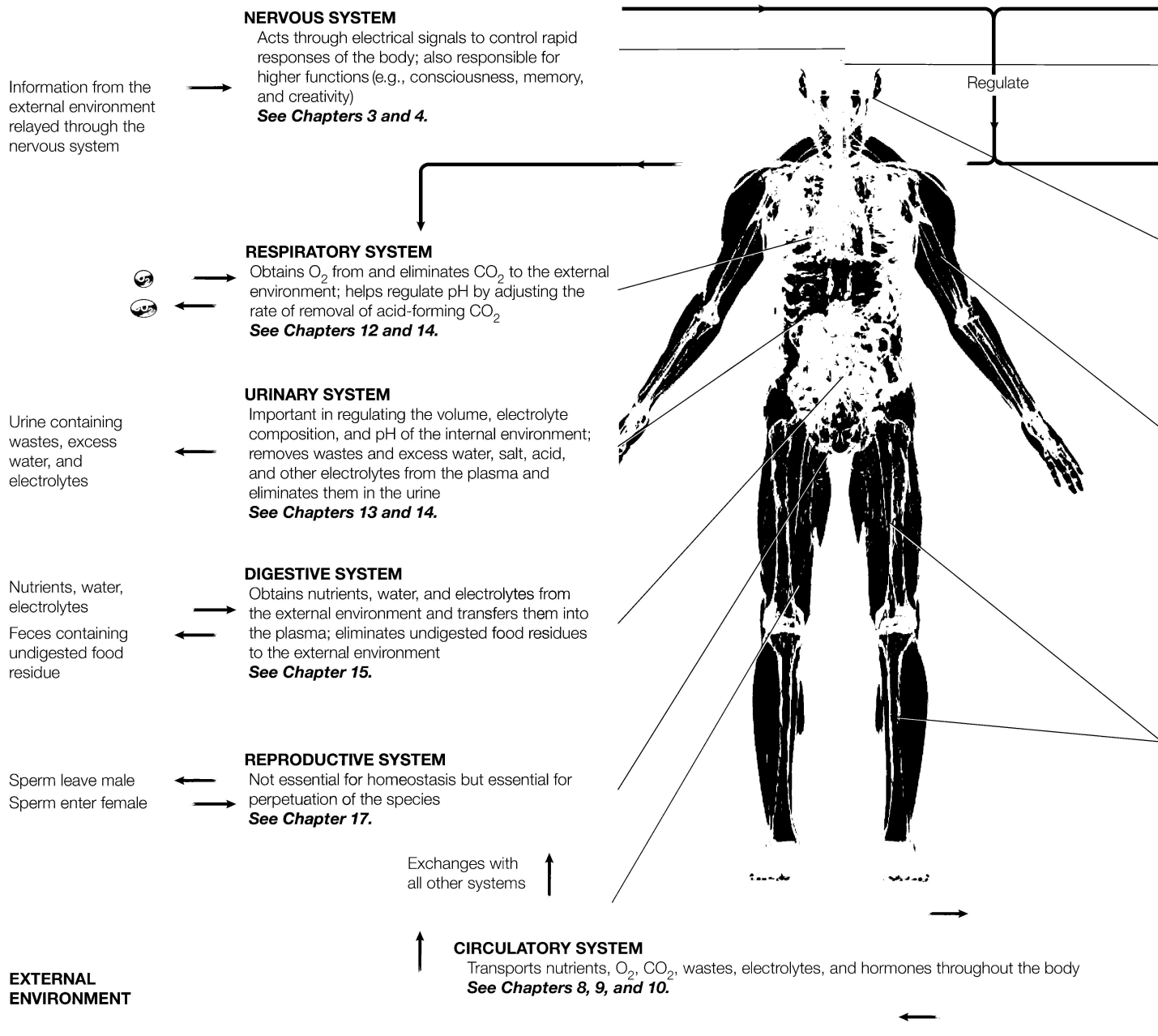
FROM CELLS TO SYSTEMS

SHERWOOD • WARD



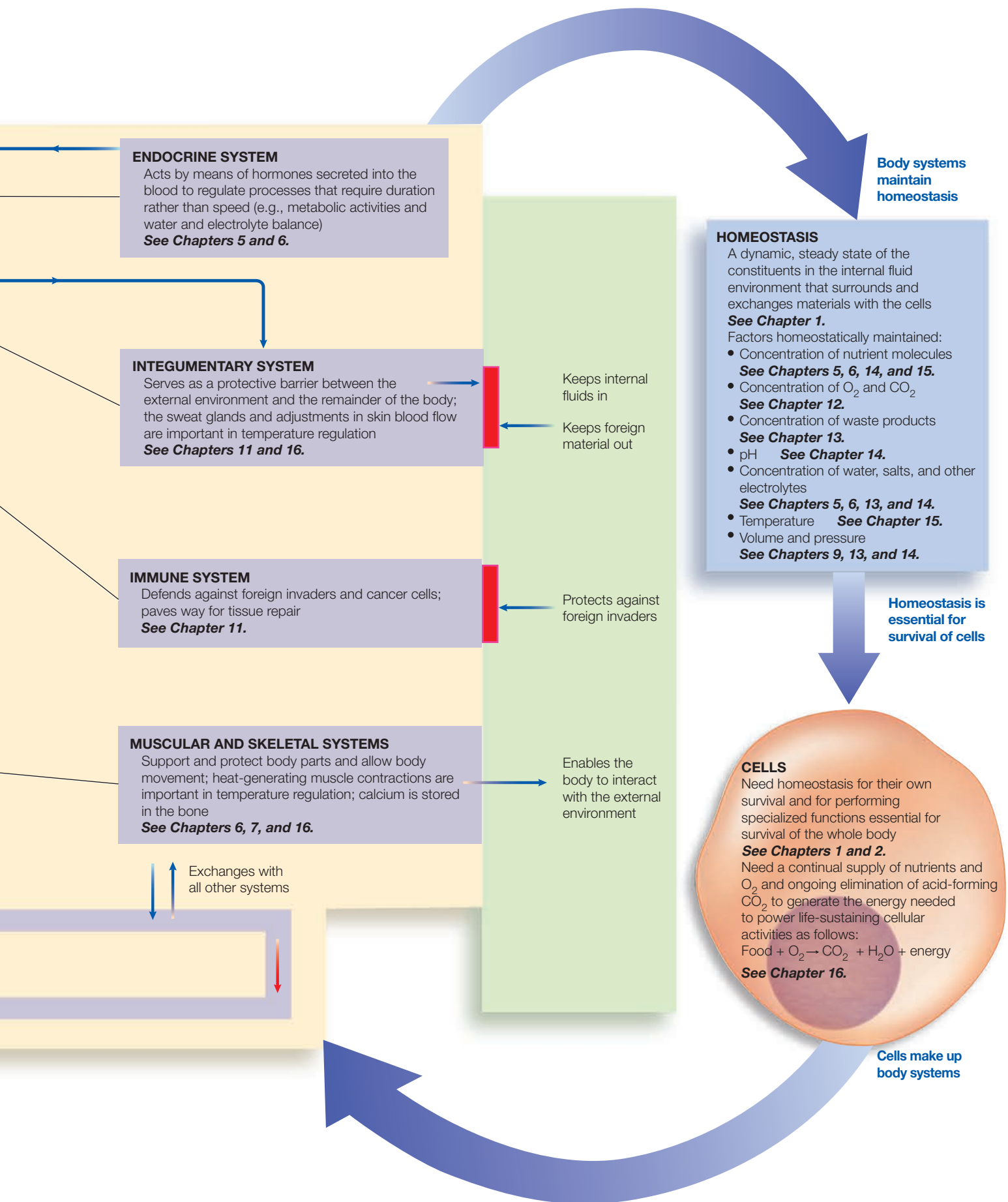
BODY SYSTEMS

Made up of cells organized according to specialization to maintain homeostasis
See Chapter 1.



Sebastian Kaulitzki/Shutterstock

Each chapter begins with a system-specific version of the pictorial homeostatic model that depicts how the body system discussed in the chapter functions within the body as a whole. The accompanying icon marks a special section at each chapter's end that focuses on how the system contributes to homeostasis. Together these features will give you a better perspective on homeostasis and the interdependency of body systems.



Human Physiology

From Cells to Systems

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To my family for all they have done for me in the
past, all they mean to me in the present,
and all I hope will yet be in the future:

My parents, Larry and Lee Sherwood
(both in memoriam)

My husband, Pater Marshall

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

My grandchildren, Lindsay Marple, Emily Marple,
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Lauralee Sherwood

To my family for their love and support
and to the students whose quest
for knowledge has inspired me

Christopher Ward

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Preface

Goals, Philosophy, and Theme

Our goal in writing physiology textbooks is to help students not only learn about how the body works but also to share our enthusiasm for the subject matter. We have been teaching physiology for over 40 years and remain awestruck at the intricacies and efficiency of body function. No machine can perform even a portion of natural body function as effectively. Most of us, even infants, have a natural curiosity about how our bodies work. When a baby first discovers it can control its own hands, it is fascinated and spends many hours manipulating them in front of its face. By capitalizing on students' natural curiosity about themselves, we 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, common-sense reasoning, and integration of ideas throughout.

This text is designed for undergraduate students preparing for health-related careers, but its approach and depth are also 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 later more in-depth studies of selected aspects of physiology and related health sciences, as well as 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, pertinent information, we 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.

Organization

There is no ideal organization of physiologic processes into a logical sequence. With the sequence we chose for this book, most chapters build on material presented in immediately preceding chapters, yet each chapter is designed to stand alone, 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 to proceed, if desired, to a more in-depth coverage of a particular topic.

The general flow is from introductory information on cells and metabolism, to excitable tissue, to organ systems. We have tried to provide logical transitions from one chapter to the next. For example, Chapter 7, Muscle Physiology, ends with a discussion of cardiac muscle, which is carried forward in Chapter 8, Cardiac Physiology. Even topics that seem unrelated in sequence, such as Chapter 11, Body Defences, and Chapter 12, The Respiratory System, are linked together, in this case by discussion of the respiratory system's contribution to protection against inhaled viruses and particles.

Several organizational changes have been made, which we believe will enhance the students' understanding of human physiology and the readability of the text. For example, we have included three inserts called the Integration of Human Physiology. Each insert focuses on the integration of a number of body systems, to aid the instructor in teaching integrative physiology. Again, these inserts were designed to stand alone.

The first insert, for example, discusses the concept of locomotion, and contrasts locomotion in a healthy person with the problems associated with locomotion when disease disrupts normal neural communication. Each of the three integrative inserts is strategically placed, following the chapters upon which they build.

We have also placed the chapters discussing the nervous and endocrine systems near the beginning of the textbook. The decision to place these chapters in close proximity and near the start of the text was made based on the belief that it is important for the student to understand how communication takes place within the human body, as communication has a considerable influence on homeostasis.

More specific hormones are subsequently introduced in appropriate chapters, such as vasopressin and aldosterone in the chapters on the kidneys (Chapter 13) and fluid balance (Chapter 14). Intermediary metabolism (Chapter 2) of absorbed nutrient molecules is largely under endocrine control, providing a link from digestion (Chapter 15) and energy balance (Chapter 16) to the endocrine chapters. Chapter 6, The Endocrine Glands, pulls together the source, functions, and control of specific endocrine secretions discussed in Chapter 5, Principles of Endocrinology, and serves as a unifying capstone for homeostatic body function. Finally, building on the gonadotropic hormones introduced in Chapter 6, Chapter 17 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. Unlike other physiology texts, the skin is covered in the chapter on body defences (Chapter 11), in consideration of the skin's newly 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.

A concerted effort was made to bolster specific topics in each chapter. The following are some examples of this. The cell physiology chapter (Chapter 2) has been expanded and includes an introduction to excitable cells and neurons. The central nervous system (Chapter 3) has an expanded discussion on somatosensory mapping and plasticity of the motor cortex, and it introduces the Babinski reflex. In the following chapter, The Peripheral Nervous System, the topic of somatosensory mapping is carried forward from Chapter 3, and a more detailed discussion of mechanoreceptors has been included, as well as an introduction to the fight-or-flight response.

Also new to this edition is the inclusion of a feature called **Clinical Connections**. The beginning of most chapters has an introduction to a clinical case that is related to the content of the chapter. As you move through the chapter, this case is revisited to put the underlying physiology into context.

Departure from traditional groupings of material in several important instances has permitted more independent and more extensive coverage of topics that are frequently omitted or buried within chapters concerned with other subject matter. For example, a separate chapter (Chapter 14) is devoted to fluid balance and acid–base regulation, topics often included in the kidney chapter. Further, we have grouped energy balance and temperature regulation into an independent chapter (Chapter 16).

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 to present each topic. Each chapter is able to stand alone, especially with the cross-references provided, so that the sequence of presentation can be varied at the instructor's 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 defensive role of the leukocytes appears in the chapter on blood, so an instructor can choose to omit the more detailed explanations of immunity in Chapter 11, Body Defences.

Lauralee Sherwood and Christopher Ward

For the Canadian Edition

The fourth Canadian edition of *Human Physiology: From Cells to Systems* has been substantially revised to meet the needs of Canadian students and instructors in core physiology programs, as well as related programs such as kinesiology, nursing, physical therapy, and zoology, where physiology represents an important component of the curriculum. The reorganization of the text has allowed for the inclusion of integrative physiology sections to assist the instructor in addressing this component of their course. A continued effort has been made by the authors to highlight topics of research important to Canadians, and to include statistics, organizations, and researchers from Canadian schools, institutes, and hospitals. The *Système international d'unités* (SI) and Canadian spelling have been used throughout. In addition to these changes, this fourth Canadian edition also provides students and instructors with updated physiological concepts, new figures and tables, new trends in physiological research, and current and relevant examples of the body's function in disease, exercise, and health. The end-of-chapter review questions have been retooled to the individual chapter's objectives. As well, the Nelson Education Testing Advantage (NETA) program was used to ensure high-quality test banks.

New to the Fourth Canadian Edition

Global changes to this edition

- Updated references to Canadian research
- Timely material incorporated throughout
- Over 280 figures, which include examples of extensively revised, and newly conceptualized ideas
- Every opportunity used to make the writing as clear, concise, well-organized, and relevant for readers as possible
- The inclusion of Clinical Connections feature to most chapters

Chapter 1—The Foundation of Physiology

- Updated references to Canadian research
- Updated information on stem cells

Chapter 2—Cell Physiology

- Updated discussion of neurons
- Expanded discussion on membrane potential and cellular communication

Chapter 3—The Central Nervous System

- Condensed and focused content on the CNS
- Reorganized the order of discussion of the CNS

Chapter 4—The Peripheral Nervous System: Sensory, Autonomic, Somatic

- Enhanced clarity for some content

Chapter 5—Principles of Endocrinology: The Central Endocrine Glands

- Streamlined content

Chapter 6—The Endocrine Glands

- This chapter repositioned to follow the chapter on the central endocrine glands
- Updated content

Chapter 7—Muscle Physiology

- Enhanced clarity of key concepts

Chapter 8—Cardiac Physiology

- Included discussion on how afterload affects stroke volume

Chapter 9—Vascular Physiology

- Updated discussion
- Clarified some key concepts

Chapter 10—The Blood

- Updated and clarified content

Chapter 11—Body Defences

- Updated content
- Streamlined content
- Enhanced clarity of discussion

Chapter 12—The Respiratory System

- Streamlined content
- Enhanced clarity of discussion

Chapter 13—The Urinary System

- Streamlined topic discussion

Chapter 14—Fluid and Acid–Base Balance

- Clinical case on diabetic ketoacidosis (DKA) to highlight the clinical relevance of fluid balance and acid–base regulation

- New brief discussion on the two types of diabetes insipidus (nephrogenic and central) as they relate to vasopressin
- Addition of new figures, including $\text{Na}^+ - \text{H}^+$ exchanger of the proximal nephron and a nomogram to help diagnose acid–base disorders

Chapter 15—The Digestive System

- Updated content

Chapter 16—Energy Balance and Temperature Regulation

- Updated to include current statistics

Chapter 17—The Reproductive System

- Updated content

In addition, pedagogical features unique to the fourth Canadian edition of *Human Physiology: From Cells to Systems* include a new addition: **Clinical Connections** have been added to most chapters. This feature serves to relate diseases and their symptoms to what is happening in the underlying physiology. The **Further Reading** list of relevant research articles from international journals within the **Concepts, Challenges, and Controversies** boxes is intended to facilitate further study, and the **Chapter Terminology** list of relevant key terms at the end of each chapter is available for students to review. **Why It Matters** boxes have been added to some chapters to draw attention to the importance of material that at first glance may appear trivial. The **Table of Contents** has been simplified to allow for easier navigation of the text, as have the **section headings** within each chapter. **Appendixes**, which include Reference Values for Commonly Measured Variables in Blood and Commonly Measured Cardiorespiratory Variables, and the **Glossary** have been expanded to accommodate new physiology concepts.

Text Features and Learning Aids

Implementing the homeostasis theme



A unique, easy-to-follow schematic of the relations between cells and systems to illustrate homeostasis is developed in the introductory chapter and presented on the inside front cover as a quick reference. Each chapter begins with its own quick reference, accompanied by a brief, written introduction emphasizing how the body system considered in the chapter functionally fits in with the body as a whole. This opening feature is designed to orient students to the homeostatic aspects of the material that follows. Then, at the close of each chapter, the **Chapter in Perspective: Focus on Homeostasis** is intended to put into perspective how the part of the body just discussed contributes to homeostasis. This capstone feature, the opening homeostatic model, and the introductory comments are designed to work together to facilitate comprehension of the interactions and interdependency of body systems, even though each system is discussed separately.

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 Lauralee Sherwood's four decades of teaching experience. Knowing which areas are likely to give students the most difficulty, she has tried to develop links that help them relate the new material to something with which they are already familiar.

Pathophysiology and clinical coverage



Another effective way to keep students' interest is to help them realize they are learning worthwhile and applicable material. Because most 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 featured throughout the text.

Check Your Understanding

Check Your Understanding questions serve as study breaks for students to test their knowledge before continuing with more material. These questions are different than the **Written Questions** that cover the same content at the end of the chapter. Many of the new section questions involve doing something other than copying an answer from a text description, such as drawing and labelling, preparing a chart, predicting based on information provided, and so on.

Boxed features

Two types of boxed features are integrated within the chapters, and in most cases they conclude with a list of journal articles and references pertinent to the topic. As much as possible, the journal articles and references are Canadian.



Concepts, Challenges, and Controversies boxes expose students to high-interest, tangentially relevant information on such diverse topics as stem cell research, acupuncture, new discoveries regarding common diseases such as strokes, historical perspectives, and body responses to new environments such as those encountered in space flight and deep-sea diving.

The **Why It Matters** boxes can be used by students and instructors to help glean the importance of, for example, a seeming simple reaction, shedding light on how something small and apparently insignificant can in actuality have an impact on large-scale system-wide function.

The **Integration of Human Physiology** pages are intended to enrich the understanding of the issues covered within the chapters. These pages are distinct and easy to find due to their purple background and dark purple edges. They build on the concepts introduced within the chapters and complement the physiological processes presented. These pages are included to highlight both the normal physiological responses and the abnormal physiological responses to stimuli, such as movement, altitude, and exercise.

Pedagogical illustrations

The anatomic illustrations, schematic representations, photographs, tables, and graphs are designed to complement and reinforce the written material. Unique to this book are the numerous

process-oriented figures with step-by-step descriptions, which provide a concise visual aid for understanding the processes.

Flow diagrams are used extensively to help students integrate the written information. In the flow diagrams, light and dark shades of the same colour denote a decrease or an increase in a controlled variable, such as blood pressure or the concentration of blood glucose.

Integrated, colour-coded figure/table combinations help students better visualize what part of the body is responsible for what activities. For example, the 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 colour in the figure and the table.

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

Key terms and word derivations

In most cases, key terms are defined as they appear in the text. These terms are key to understanding the concepts outlined within each chapter. A chapter terminology section also appears at the end of each chapter. Many key terms are also found in the glossary.

End-of-chapter learning and review

A **Chapter Terminology** list of relevant key terms appears at the end of each chapter for students to review. The **Review Exercises** at the end of each chapter include a variety of question formats for students to self-test their knowledge and application of the facts and concepts presented. Also available are **Quantitative Exercises** that provide the students with an opportunity to practise calculations that will enhance their understanding of complex relationships. A **Points to Ponder** section features thought-provoking problems that encourage students to analyze what they have learned, and the **Clinical Consideration**, a mini case history, challenges them to apply their knowledge to a patient's specific symptoms. Answers and explanations for all of these questions are found in Appendix E.

Appendixes, Glossary, and Study Cards

The appendixes are designed for the most part to help students brush up on some foundation material they are assumed to have studied in prerequisite courses.

- **Appendix A, Système international d'unités (SI)**, is a conversion table between metric measures and their Imperial equivalents.
- 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, to reserve valuable text space for discussion of physiology concepts, we have provided **Appendix B, A Review of Chemical Principles** as a handy reference for the review of basic chemistry concepts that apply to physiology.

- Likewise, **Appendix C, Storage, Replication, and Expression of Genetic Information**, can serve as a reference for students and, when appropriate, be used by the instructor as assigned material. It includes a discussion of DNA and chromosomes, protein synthesis, cell division, and mutations.
- **Appendix D, Principles of Quantitative Reasoning**, is designed to help students become more comfortable working with equations and translating back and forth between words, concepts, and equations. This appendix supports the Quantitative Exercises in the end-of-chapter material.
- **Appendix E, Answers to End-of-Chapter Objective Questions, Quantitative Exercises, Points to Ponder, and Clinical Considerations**, provides answers to all objective learning activities, solutions to the Quantitative Exercises, and explanations for the Points to Ponder and Clinical Considerations.
- **Appendix F, Reference Values for Commonly Measured Variables in Blood and Commonly Measured Cardiorespiratory Variables**, provides normal male and female values.
- **Appendix G, A Deeper Look into Chapter 11: The Respiratory System**, provides greater detail on the terminology and gas laws covered in Chapter 11.
- The **Glossary**, which offers a way to review the meaning of key terminology, includes phonetic pronunciations of the entries.
- The **Study Cards** present the major points of each chapter in concise, section-by-section bulleted lists, including cross-references for page numbers, figures, and tables. With this summary design, students can review more efficiently by using both written and visual information to focus on the main concepts.

About the Nelson Education Teaching Advantage (NETA)



The Nelson Education Teaching Advantage (NETA) program delivers research-based instructor resources that promote student engagement and higher-order thinking to enable the success of Canadian students and educators. Be sure to visit Nelson Education's **Inspired Instruction** website at <http://www.nelson.com/inspired/> to find out more about NETA. Don't miss the testimonials of instructors who have used NETA supplements and seen student engagement increase!

Instructor Resources

Downloadable instructor supplements

All NETA and other key instructor ancillaries can be accessed through www.nelson.com/instructor, giving instructors the ultimate tools for customizing lectures and presentations.



NETA Test Bank: This resource was written by Dr. Alice Khin, University of Alberta. It includes over 5000 questions; 1750 questions are multiple-choice questions written according to NETA guidelines for effective construction and development of higher-order questions. The Test Bank was copy-edited by a NETA-trained editor. Also included are fill in the blank, matching, and true-or-false test items as well as essay questions. The NETA Test Bank is available in a new, cloud-based platform. **Nelson Testing Powered by Cognero®** is a secure online testing system that allows you to author, edit, and manage test bank content from any place you have Internet access. No special installations or downloads are needed, and the desktop-inspired interface, with its drop-down menus and familiar, intuitive tools, allows you to create and manage tests with ease. You can create multiple test versions in an instant, and import or export content into other systems. Tests can be delivered from your learning management system, your classroom, or wherever you want. Nelson Testing Powered by Cognero® for *Human Physiology: From Cells to Systems*, Fourth Canadian Edition, also be accessed through www.nelson.com/instructor. Printable versions of the Test Bank in Microsoft® Word® and PDF formats are available by contacting your sales and editorial representative.

NETA PowerPoint: Microsoft® PowerPoint® lecture slides for every chapter have been created by Dr. Stephen Donald Turnbull, University of New Brunswick. There is an average of 100 slides per chapter, many featuring key figures, tables, and photographs from *Human Physiology: From Cells to Systems*, Fourth Canadian Edition. Incorporating animations and “build slides,” these illustrations with labels from the book have been formatted to allow optimal display in PowerPoint®. NETA principles of clear design and engaging content have been incorporated throughout, making it simple for instructors to customize the deck for their courses.

Image Library: This resource consists of over 600 digital copies of figures, short tables, and photographs used in the book. Instructors may use these JPEG to customize the NETA PowerPoint or create their own PowerPoint presentations.

NETA Instructor's Manual: This resource was written by Dr. Coral Murrant, University of Guelph. It is organized according to the textbook chapters and addresses key educational concerns, such as typical stumbling blocks student face and how to address them. It also includes elements of a traditional Instructor's Manual, including lecture outlines, discussion topics, student activities, Internet connections, media resources, and testing suggestions that will help time-pressed instructors more effectively communicate with their students and also strengthen the coverage of course material.

DayOne: DayOne—Prof InClass is a PowerPoint presentation that instructors can customize to orient students to the class and their text at the beginning of the course.

MindTap



MindTap for Human Physiology: From Cells to Systems, Fourth Canadian Edition, is a personalized teaching experience with relevant assignments that guide students to analyze, apply, and elevate thinking, allowing instructors to measure skills and promote better outcomes with ease. A fully online learning solution, MindTap combines all student learning tools—readings, multimedia, activities, and assessments—into a single Learning Path that guides the student through the curriculum. Instructors personalize the experience by customizing the presentation of these learning tools to their students, even seamlessly introducing their own content into the Learning Path.

Aplia

Aplia™ is a Cengage Learning online homework system dedicated to improving learning by increasing student effort and engagement. Aplia makes it easy for instructors to assign frequent online homework assignments. Aplia provides students with prompt and detailed feedback to help them learn as they work through the questions, and features interactive tutorials to fully engage them in learning course concepts. Automatic grading and powerful assessment tools give instructors real-time reports of student progress, participation, and performance, and while Aplia's easy-to-use course management features let instructors flexibly administer course announcements and materials online. With Aplia, students will show up to class fully engaged and prepared, and instructors will have more time to do what they do best... teach.

Jacqueline Carnegie of the University of Ottawa revised the MindTap and Aplia resources to ensure close alignment to the fourth Canadian edition.

Student Ancillaries

MindTap



Stay organized and efficient with **MindTap**—a single destination with all the course material and study aids you need to succeed. Built-in apps leverage social media and the latest learning technology. For example,

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Self-quizzing allows you to assess your understanding.

Visit www.nelson.com/student to start using **MindTap**. Enter the Online Access Code from the card included with your text. If a code card is *not* provided, you can purchase instant access at NELSONbrain.com.

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Reviewers

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Christopher Ward

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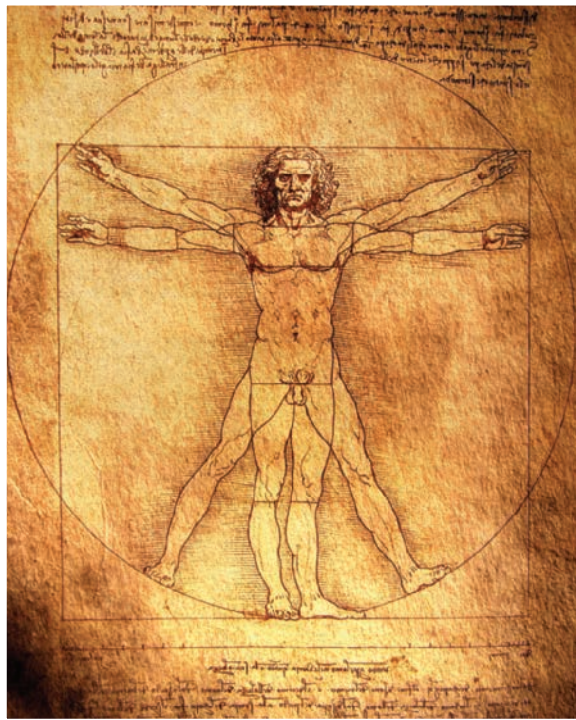
development of innovative teaching methodologies to enhance undergraduate, graduate, and medical student learning. He is credited with the launch of online courses and blended learning initiatives, and is part of a curricular redesign team responsible for pioneering facilitated small-group learning at Queen's Faculty of Medicine. A cardiac physiologist, Dr. Ward also maintains an active laboratory and graduate research team that focuses on studying the electrical activity of the heart and understanding how ion channel function can be modulated by disease states.

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Joseph Smuczek, M.D. Dr. Smuczek completed his medical training and postgraduate family medicine training at McMaster University. He is currently a practising physician with the division of Primary Care at Trillium Health Partners in Mississauga, Ontario. He has been actively involved in undergraduate education and medical education and has previously taught undergraduate-level human anatomy and human physiology at Brock University and University of Guelph-Humber.

Homeostasis Systems and Cells

Body systems maintain homeostasis



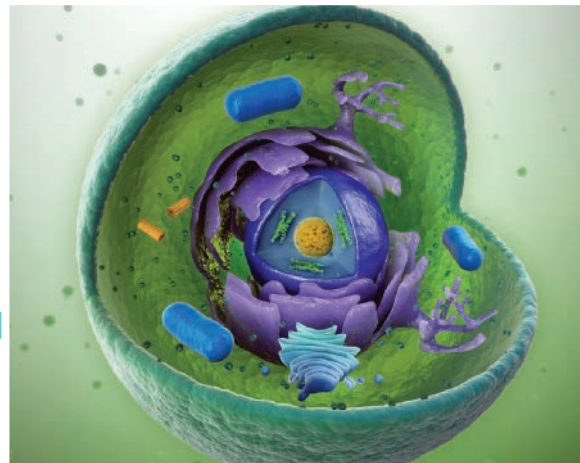
Da Vinci's Vitruvian Man

Homeostasis

Homeostasis is the maintenance by the highly coordinated, regulated actions of the body systems of relatively stable chemical and physical conditions in the internal fluid environment that bathes the body's cells.

Homeostasis is essential for survival of cells

Cells make up body systems



Animal cell cut-away

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