

# Human Physiology

---

**Third Edition**

**BRYAN DERRICKSON**

Valencia College

**WILEY**

**Vice President:** Lyssa Vanderbeek

**Editorial Director:** Michelle Renda

**Executive Editor:** Natalie Ruffatto

**Associate Marketing Director:** Michael Olsen

**Sr. Director, Advanced Content:** Angela Cohen

**Sr. Managing Editor:** Kimberly Monroe-Hill

**Sr. Creative Product Designer:** Thomas Nery

**Cover Photo:** Andrzej Wojcicki / Science Photo Library / Getty Images

This book was typeset in STIX TwoText 9.5/12 by Lumina Datamatics.

Wiley is a global leader in research and education, unlocking human potential by enabling discovery, powering education, and shaping workforces. For over 200 years, Wiley has fueled the world's knowledge ecosystem. Today, our high-impact content, platforms, and services help researchers, learners, institutions, and corporations achieve their goals in an ever-changing world. Visit us at [Wiley.com](http://Wiley.com).

Copyright © 2024 by John Wiley & Sons, Inc.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying recording, scanning or otherwise, except as permitted under Sections 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher or authorization through payment of the appropriate per copy fee to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 646-8600. Visit us at <http://www.wiley.com/permissions> to request permission for re-use or reproduction of Wiley content.

Readers should be aware that websites listed in this work may have changed or disappeared between when this work was written and when it is read. Neither the publisher nor authors shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

Evaluation copies are provided to qualified academics and professionals for review purposes only, for use in their courses during the next academic year. These copies are licensed and may not be sold or transferred to a third party. Upon completion of the review period, please return the evaluation copy to Wiley. Return instructions and a free of charge return shipping label are available at [www.wiley.com/go/returnlabel](http://www.wiley.com/go/returnlabel). If you have chosen to adopt this textbook for use in your course, please accept this book as your complimentary desk copy. Outside of the United States, please contact your local representative.

EPUB ISBN: 978-1-119-82233-2

The inside back cover will contain printing identification and country of origin if omitted from this page.

In addition, if the ISBN on the cover differs from the ISBN on this page, the one on the cover is correct.

#### **Library of Congress Cataloging-in-Publication Data**

Names: Derrickson, Bryan, author.

Title: Human physiology / Bryan Derrickson, Valencia College.

Description: Third edition. | Hoboken : Wiley, [2024] | Includes index.

Identifiers: LCCN 2024002420 (print) | LCCN 2024002421 (ebook) | ISBN

9781119821076 | ISBN 9781394202683 (adobe pdf) | ISBN 9781119822332

(epub)

Subjects: LCSH: Human physiology. | Human anatomy. | MESH: Physiological

Phenomena. | Anatomy

Classification: LCC QP36 .D47 2024 (print) | LCC QP36 (ebook) | DDC

612—dc23/eng/20240214

LC record available at <https://lcn.loc.gov/2024002420>

LC ebook record available at <https://lcn.loc.gov/2024002421>

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

# Brief Contents

<b>1</b>	An Introduction to Physiology	<b>1</b>
<b>2</b>	Chemical Composition of the Body	<b>19</b>
<b>3</b>	Cells	<b>57</b>
<b>4</b>	Metabolism	<b>93</b>
<b>5</b>	Transport Across the Plasma Membrane	<b>125</b>
<b>6</b>	Cell Signaling	<b>152</b>
<b>7</b>	The Nervous System and Neuronal Excitability	<b>183</b>
<b>8</b>	The Central Nervous System	<b>238</b>
<b>9</b>	Sensory Systems	<b>275</b>
<b>10</b>	Autonomic and Somatic Nervous Systems	<b>345</b>
<b>11</b>	Muscle	<b>367</b>
<b>12</b>	Control of Body Movement	<b>416</b>
<b>13</b>	The Endocrine System	<b>437</b>
<b>14</b>	The Cardiovascular System: The Heart	<b>487</b>
<b>15</b>	The Cardiovascular System: Blood Vessels and Hemodynamics	<b>527</b>
<b>16</b>	The Cardiovascular System: The Blood	<b>567</b>
<b>17</b>	The Immune System	<b>594</b>
<b>18</b>	The Respiratory System	<b>627</b>
<b>19</b>	The Urinary System	<b>667</b>
<b>20</b>	Fluid, Electrolyte, and Acid–Base Homeostasis	<b>709</b>
<b>21</b>	The Digestive System	<b>729</b>
<b>22</b>	Metabolic Adaptations, Energy Balance, and Temperature Regulation	<b>773</b>
<b>23</b>	The Reproductive Systems	<b>790</b>

APPENDIX A Measurements A-1

APPENDIX B Periodic Table B-3

APPENDIX C Normal Values for Selected Blood Tests C-4

APPENDIX D Normal Values for Selected Urine Tests D-6

GLOSSARY G-1

INDEX I-1

# Contents

## 1 An Introduction to Physiology 1

---

- Introduction 1
- 1.1 Physiology Defined 2**
- 1.2 Levels of Organization in the Body 2**
- 1.3 Life Processes 5**
- 1.4 Homeostasis 7**
  - Definition of Homeostasis 7
  - Homeostasis and Body Fluids 7
  - The Body's Internal and External Environments 7
  - Homeostasis and Mass Balance 9
  - Regulation of Homeostasis via Feedback Systems and Feedforward Control 9
  - Homeostatic Imbalances 13
- 1.5 Physiology as a Science 13**
  - The History of Physiology 13
  - The Scientific Method 14
  - Scientific Literature 15
  - Mechanistic Approach to Body Function 16
  - Concept Mapping 16
- 1.6 Key Themes of Physiology 16**
- Answers to Figure Questions 18

## 2 Chemical Composition of the Body 19

---

- Introduction 19
- 2.1 How Matter Is Organized 20**
  - The Atom 20
  - Chemical Elements 20
  - Structure of Atoms 20
  - Atomic Number and Mass Number 21
  - Atomic Mass 22
  - Ions, Molecules, Compounds, and Free Radicals 23
- 2.2 Chemical Bonds 24**
  - Ionic Bonds 24
  - Covalent Bonds 24
  - Hydrogen Bonds 26
  - Van der Waals Interactions 27
- 2.3 Chemical Reactions 29**
- 2.4 Inorganic Compounds and Solutions 30**
  - Water 30
  - Types of Liquid Mixtures 31
  - Ways to Express the Concentration of a Solution 32
  - Inorganic Acids, Bases, and Salts 32
  - The Concept of pH 33
  - Maintaining pH: Buffer Systems 34

- 2.5 Organic Compounds 35**
  - Carbon and Its Functional Groups 35
  - The Synthesis and Breakdown of Polymers 36
  - Carbohydrates 36
  - Lipids 38
  - Proteins 43
  - Nucleic Acids 51
  - Adenosine Triphosphate 52
- Answers to Figure Questions 55

## 3 Cells 57

---

- Introduction 57
- 3.1 Components of a Cell 58**
- 3.2 The Plasma Membrane 59**
  - Fluid Mosaic Model of the Plasma Membrane 59
  - Structure of the Plasma Membrane 59
  - Functions of Membrane Proteins 60
  - Membrane Fluidity 60
- 3.3 Cytoplasm 61**
  - The Cytosol 61
  - Organelles 62
- 3.4 Nucleus 69**
- 3.5 Gene Expression 71**
  - Transcription 72
  - Translation 73
- 3.6 Cell Division 75**
  - Somatic Cell Division 75
  - Control of Cell Destiny 77
- 3.7 Cellular Diversity 80**
- 3.8 Organization of Cells into Tissues 81**
  - Epithelial Tissue 81
  - Connective Tissue 83
  - Muscle Tissue 87
  - Nervous Tissue 87
  - Cell Junctions 88
- Answers to Figure Questions 91

## 4 Metabolism 93

---

- Introduction 93
- 4.1 An Overview of Metabolism 94**
- 4.2 Energy and Metabolism 95**
  - Forms of Energy 95
  - Exergonic and Endergonic Reactions 95
  - Activation Energy 95
  - Catalysts 96

<b>4.3</b>	<b>Enzymes</b>	<b>96</b>
	Definition of Enzymes	96
	Properties of Enzymes	97
	Enzyme Function	97
	Cofactors	98
	Factors That Influence the Rate of an Enzyme-Catalyzed Reaction	98
	Concept of a Metabolic Pathway	100
	Feedback Inhibition of a Metabolic Pathway	101
<b>4.4</b>	<b>ATP and Metabolism</b>	<b>101</b>
	Coupling of Catabolism and Anabolism by ATP	101
	Mechanisms of ATP Generation	102
	The Role of NAD <sup>+</sup> and FAD in Generating ATP	102
	Production of ATP via Cellular Respiration	102
<b>4.5</b>	<b>Carbohydrate Metabolism</b>	<b>108</b>
	Glucose Catabolism	108
	Glucose Anabolism	114
<b>4.6</b>	<b>Lipid Metabolism</b>	<b>116</b>
	Lipid Catabolism	116
	Lipid Anabolism	117
<b>4.7</b>	<b>Protein Metabolism</b>	<b>117</b>
	Protein Catabolism	117
	Protein Anabolism	117
<b>4.8</b>	<b>Nutrition and Metabolism</b>	<b>120</b>
	Minerals	120
	Vitamins	120
	Answers to Figure Questions	123

## 5 Transport Across the Plasma Membrane 125

	Introduction	125
<b>5.1</b>	<b>Selective Permeability of the Plasma Membrane</b>	<b>126</b>
<b>5.2</b>	<b>Gradients Across the Plasma Membrane</b>	<b>127</b>
<b>5.3</b>	<b>Classification of Membrane Transport Processes as Passive or Active</b>	<b>129</b>
<b>5.4</b>	<b>Passive Transport</b>	<b>129</b>
	The Principle of Diffusion	129
	Simple Diffusion	130
	Facilitated Diffusion	131
	Osmosis	135
<b>5.5</b>	<b>Active Transport</b>	<b>139</b>
	Primary Active Transport	140
	Secondary Active Transport	141
<b>5.6</b>	<b>Vesicular Transport</b>	<b>143</b>
	Endocytosis	143
	Exocytosis	145
<b>5.7</b>	<b>Transepithelial Transport</b>	<b>146</b>
	Overview of Transepithelial Transport	147
	Absorption and Secretion	147
	Transcytosis	148
	Answers to Figure Questions	150

## 6 Cell Signaling 152

	Introduction	152
<b>6.1</b>	<b>Methods of Cell-to-Cell Communication</b>	<b>153</b>
	Gap Junctions	153
	Cell-to-Cell Binding	153
	Extracellular Chemical Messengers	153
<b>6.2</b>	<b>Extracellular Chemical Messengers</b>	<b>154</b>
	Types of Extracellular Chemical Messengers	154
	Chemical Classes of Extracellular Messengers	157
	How Extracellular Messengers Reach Their Target Cells	158
<b>6.3</b>	<b>Receptors</b>	<b>158</b>
	Properties of Messenger–Receptor Binding	158
	Receptor Location	160
	Receptor Regulation	161
<b>6.4</b>	<b>Signal Transduction Pathways</b>	<b>163</b>
	The Process of Signal Transduction	163
	Signaling Pathways Activated by Lipid-Soluble Extracellular Messengers	165
	Signaling Pathways Activated by Water-Soluble Extracellular Messengers	167
	Signal Amplification	178
	Signal Termination	178
<b>6.5</b>	<b>Comparison of the Nervous and Endocrine Systems</b>	<b>180</b>
	Answers to Figure Questions	182

## 7 The Nervous System and Neuronal Excitability 183

	Introduction	183
<b>7.1</b>	<b>Overview of the Nervous System</b>	<b>184</b>
	Organization of the Nervous System	184
	Functions of the Nervous System	184
<b>7.2</b>	<b>Cells of the Nervous System</b>	<b>186</b>
	Neurons	186
	Neuroglia	189
	Myelination	191
	Regeneration and Repair of Neurons	192
<b>7.3</b>	<b>Electrical Signals in Neurons</b>	<b>195</b>
	Ion Channels	197
	Resting Membrane Potential	197
	Graded Potentials	206
	Action Potentials	208
	Effects of Extracellular Ion Concentrations on Neuronal Excitability	218
<b>7.4</b>	<b>Signal Transmission at Synapses</b>	<b>219</b>
	Electrical Synapses	220

Chemical Synapses	220
Excitatory and Inhibitory Postsynaptic Potentials	222
Types of Neurotransmitter Receptors	223
Removal of Neurotransmitter	225
Summation of Postsynaptic Potentials	226
Presynaptic Modulation	227
<b>7.5 Neurotransmitters</b>	<b>228</b>
Small-Molecule Neurotransmitters	229
Neuropeptides	233
<b>7.6 Neural Circuits</b>	<b>234</b>
Answers to Figure Questions	236

## **8 The Central Nervous System 238**

Introduction	238
<b>8.1 Spinal Cord</b>	<b>239</b>
Protective Coverings of the Spinal Cord	239
Spinal Nerves	239
Internal Organization of the Spinal Cord	239
Functions of the Spinal Cord	242
<b>8.2 Brain</b>	<b>244</b>
Protective Features of the Brain	244
Blood Supply of Oxygen and Glucose to the Brain	247
Cranial Nerves	248
The Parts of the Brain and Their Functions	250
<b>8.3 Integrative Functions of the Cerebrum</b>	<b>261</b>
Wakefulness and Sleep	261
Language	264
Emotions	264
Motivation	267
Learning and Memory	268
Answers to Figure Questions	274

## **9 Sensory Systems 275**

Introduction	275
<b>9.1 Overview of Sensation</b>	<b>276</b>
Definition of Sensation	276
The Major Events of Sensation	276
Sensory Receptors	276
Receptive Fields of Sensory Neurons	278
Sensory Coding	280
The Concept of a Sensory Pathway	286
<b>9.2 The Somatic Sensory System</b>	<b>287</b>
Tactile Sensations	287
Thermal Sensations	290

Pain Sensations	291
Proprioceptive Sensations	296
Somatic Sensory Pathways	299
The Primary Somatosensory Cortex	300
The Somatosensory Association Area	300
Visceral Sensations	300
<b>9.3 The Olfactory System</b>	<b>301</b>
The Olfactory Epithelium	301
Olfactory Transduction	301
The Olfactory Pathway	302
Odor Thresholds	303
Odor Adaptation	304
<b>9.4 The Gustatory System</b>	<b>304</b>
The Five Primary Tastes	304
Taste Buds	305
Taste Transduction	306
The Gustatory Pathway	307
Taste Thresholds	308
Taste Adaptation	308
<b>9.5 The Visual System</b>	<b>308</b>
Visible Light and the Electromagnetic Spectrum	308
Accessory Structures of the Eye	309
The Eye and Its Functional Components	309
Image Formation	313
Convergence of the Eyes	316
Photoreceptor Function	317
The Visual Fields of the Eyes	325
The Visual Pathway	327
The Primary Visual Cortex	327
The Visual Association Area	327
Light and Dark Adaptation	327
<b>9.6 The Auditory System</b>	<b>328</b>
The Ear and Its Functional Components	328
The Nature of Sound Waves	330
Transmission of Sound Waves Through the Ear	332
Sound Transduction	333
Electromotility	334
Pitch Discrimination	334
Loudness Discrimination	334
The Auditory Pathway	335
The Primary Auditory Cortex	335
The Auditory Association Area	335
Deafness	336
<b>9.7 The Vestibular System</b>	<b>338</b>
Utricle and Saccule	338
The Semicircular Ducts	338
The Equilibrium Pathway	339
Answers to Figure Questions	343

## 10 Autonomic and Somatic Nervous Systems 345

- Introduction 345
- 10.1 Autonomic Nervous System 346**
  - The Role of the ANS 346
  - Autonomic Motor Pathways 346
  - The Neuroeffector Junction 349
  - ANS Neurotransmitters and Receptors 350
  - The Physiology of the ANS 355
  - Autonomic Reflexes 357
  - Autonomic Control Centers 357
  - Biofeedback 359
- 10.2 Somatic Nervous System 360**
  - The Role of the Somatic Nervous System 360
  - Somatic Motor Pathways 360
  - The Neuromuscular Junction 360
  - Alteration of the Events at the NMJ by Chemical Agents 363
- Answers to Figure Questions 366

## 11 Muscle 367

- Introduction 367
- 11.1 Overview of Muscle 368**
  - Types of Muscle 368
  - Functions of Muscle 368
  - Properties of Muscle 368
- 11.2 Organization of Skeletal Muscle 370**
  - Components of a Skeletal Muscle Fiber 371
  - Muscle Proteins 375
- 11.3 Contraction and Relaxation of Skeletal Muscle Fibers 378**
  - The Sliding Filament Mechanism 378
  - The Contraction Cycle 379
  - Neuromuscular Junction 380
  - The Skeletal Muscle Action Potential 380
  - Excitation–Contraction Coupling in a Skeletal Muscle Fiber 381
  - Relaxation of a Skeletal Muscle Fiber 383
- 11.4 ATP Production in Skeletal Muscle 386**
  - Creatine Phosphate 386
  - Anaerobic Glycolysis 387
  - Aerobic Respiration 388
  - Muscle Fatigue 388
  - Oxygen Consumption After Exercise 388
- 11.5 Skeletal Muscle Mechanics 389**
  - The Motor Unit 389
  - The Muscle Twitch 389
  - Graded Contractions of Skeletal Muscle 390
  - Factors that Determine Muscle Tension 390
  - Muscle Tone 392

- How Skeletal Muscles Produce Body Movements 392
- Isotonic and Isometric Contractions 395
- 11.6 Types of Skeletal Muscle Fibers 397**
  - Slow Oxidative Fibers 398
  - Fast Oxidative–Glycolytic Fibers 398
  - Fast Glycolytic Fibers 398
  - Distribution and Recruitment of the Different Types of Skeletal Muscle Fibers 398
  - The Effect of Exercise on the Different Types of Skeletal Muscle Fibers 398
- 11.7 Myokines 400**
- 11.8 Cardiac Muscle 401**
- 11.9 Smooth Muscle 404**
  - Components of a Smooth Muscle Fiber 404
  - Contraction and Relaxation of a Smooth Muscle Fiber 405
  - Smooth Muscle Tone 406
  - Autonomic Innervation of Smooth Muscle 407
  - Types of Smooth Muscle 407
  - Autorhythmicity of Single-Unit Smooth Muscle 407
  - Action Potentials in Contractile Smooth Muscle Fibers 409
  - Excitation–Contraction Coupling in Smooth Muscle 409
  - Factors That Regulate Smooth Muscle Activity 411
  - The Stress–Relaxation Response of Smooth Muscle 411
  - ATP Production in Smooth Muscle 411
- 11.10 Regeneration of Muscle 412**
- Answers to Figure Questions 415

## 12 Control of Body Movement 416

- Introduction 416
- 12.1 Overview of Motor Control 417**
  - The Role of Lower Motor Neurons 417
  - Sources of Input to Lower Motor Neurons 417
- 12.2 Local Level of Motor Control 418**
  - Somatic Reflexes 418
  - Locomotion 424
- 12.3 Control of Movement by the Cerebral Cortex 425**
  - The Premotor Cortex 425
  - The Primary Motor Cortex 425
  - The Direct Motor Pathways 426
- 12.4 Control of Movement by the Brain Stem 428**
  - The Indirect Motor Pathways 428
  - Vestibular Nuclei 428
  - Reticular Formation 429
  - Superior Colliculus 429
  - Red Nucleus 430
- 12.5 The Basal Nuclei and Motor Control 430**
- 12.6 Modulation of Movement by the Cerebellum 432**
- Answers to Figure Questions 435

## 13 The Endocrine System 437

---

Introduction 437

### 13.1 Overview of the Endocrine System 438

Components of the Endocrine System 438

The Role of Hormone Receptors 438

Chemical Classes of Hormones 439

How Hormones Circulate Through the Blood 441

Mechanisms of Hormone Action 441

Hormone Interactions 444

Control of Hormone Secretion 445

### 13.2 Pituitary Gland 445

Anterior Pituitary 447

Posterior Pituitary 454

### 13.3 Thyroid Gland 456

Formation, Storage, and Release of Thyroid Hormones 457

Functions of Thyroid Hormones 458

Control of Thyroid Hormone Secretion 458

Calcitonin 459

### 13.4 Parathyroid Glands 461

### 13.5 Adrenal Glands 462

Adrenal Cortex 462

Adrenal Medulla 465

### 13.6 Pineal Gland 467

### 13.7 Pancreas 468

Cell Types of the Pancreatic Islets 469

Functions of Insulin 469

Functions of Glucagon 471

Control of Insulin and Glucagon Secretion 472

### 13.8 Ovaries and Testes 475

### 13.9 Other Endocrine Organs and Tissues 475

### 13.10 Endocrine Control of Growth 478

Bone Growth in Length and Thickness 478

Bone Remodeling 478

Hormones that Affect Bone Growth 479

Other Factors that Affect Bone Growth 480

### 13.11 The Stress Response 481

The Fight-or-Flight Response 481

The Resistance Reaction 481

Exhaustion 483

Stress and Disease 483

Answers to Figure Questions 485

## 14 The Cardiovascular System: The Heart 487

---

Introduction 487

### 14.1 Basic Design of the Cardiovascular System 488

The Pulmonary and Systemic Circulations 488

Parallel Flow Through the Systemic Circulation 490

### 14.2 Organization of the Heart 491

Pericardium and Heart Wall 492

Chambers of the Heart 493

Heart Valves 493

Fibrous Skeleton of the Heart 496

Coronary Circulation 496

### 14.3 Cardiac Muscle Fibers and the Cardiac Conduction System 499

Organization of Cardiac Muscle Fibers 499

Autorhythmic Cardiac Muscle Fibers: The Conduction System 501

Action Potentials in Contractile Cardiac Muscle Fibers 503

Excitation–Contraction Coupling in Contractile Cardiac Muscle Fibers 504

Refractory Period of Cardiac Muscle Fibers 505

ATP Production in Cardiac Muscle 506

Electrocardiogram 506

Correlation of ECG Waves with the Timing of Atrial and Ventricular Diastole and Systole 507

### 14.4 The Cardiac Cycle 510

Phases of the Cardiac Cycle 511

Duration of the Cardiac Cycle 511

Heart Sounds That Can Be Heard During the Cardiac Cycle 513

### 14.5 Cardiac Output 513

Definition of Cardiac Output 513

Factors that Regulate Stroke Volume 513

Factors that Regulate Heart Rate 517

### 14.6 Exercise and the Heart 522

Answers to Figure Questions 526

## 15 The Cardiovascular System: Blood Vessels and Hemodynamics 527

---

Introduction 527

### 15.1 Overview of the Vasculature 528

Blood Vessel Layers 529

Arteries 529

Arterioles 530

Capillaries 531

Venules 532

Veins 532

Blood Distribution 533

### 15.2 Capillary Exchange and Lymphatics 534

Capillary Exchange 534

The Lymphatic System 536

### 15.3 Hemodynamics 541

Relationship Between Blood Flow, the Pressure Gradient, and Resistance 541

Laminar and Turbulent Blood Flow 544

Blood Pressure 544

Vascular Compliance 548

Relationship Between Velocity of Blood Flow and  
Cross-Sectional Area **548**  
Venous Return **549**

#### **15.4 Control of Blood Flow 550**

Intrinsic Control of Blood Flow **552**  
Extrinsic Control of Blood Flow **555**

#### **15.5 Regulation of Mean Arterial Pressure 556**

Neural Regulation of Mean Arterial Pressure **556**  
Hormonal Regulation of Mean Arterial  
Pressure **559**

#### **15.6 Shock and Homeostasis 561**

Types of Shock **561**  
Homeostatic Responses to Shock **562**  
Signs and Symptoms of Shock **562**

Answers to Figure Questions **565**

## **16 The Cardiovascular System: The Blood 567**

Introduction **567**

#### **16.1 Overview of Blood 568**

Functions of Blood **568**  
Components of Blood **568**  
Origin and Development of Blood Cells **570**

#### **16.2 Erythrocytes 572**

Functions of Erythrocytes **572**  
Formation of Erythrocytes **573**  
Erythrocyte Life Cycle **574**

#### **16.3 Leukocytes 578**

Types of Leukocytes **578**  
Functions of Leukocytes **579**  
Formation of Leukocytes **579**

#### **16.4 Platelets 579**

#### **16.5 Hemostasis 581**

Definition of Hemostasis **581**  
Vascular Spasm **581**  
Platelet Plug Formation **581**  
Blood Clotting **583**

#### **16.6 Blood Groups and Blood Types 586**

ABO Blood Group **586**  
Transfusions **587**  
Rh Blood Group **589**

Answers to Figure Questions **593**

## **17 The Immune System 594**

Introduction **594**

#### **17.1 Components of the Immune System 595**

Cells of the Immune System **595**  
Lymphoid Organs and Tissues **596**

#### **17.2 Innate Immunity 597**

First Line of Defense: External Physical and Chemical  
Barriers **597**  
Second Line of Defense: Internal Defenses **598**

#### **17.3 Adaptive Immunity 603**

Maturation of B Cells and T Cells **604**  
Types of Adaptive Immunity **604**  
Clonal Selection: The Principle **604**  
Antigens and Antigen Receptors **606**  
Major Histocompatibility Complex Proteins **607**  
Pathways of Antigen Processing **607**  
Cytokines **608**  
Cell-Mediated Immunity **610**  
Antibody-Mediated Immunity **613**  
Immunological Memory **616**  
Ways to Acquire Adaptive Immunity **617**  
Self-Recognition and Self-Tolerance **621**  
Allergic Reactions **621**  
Stress and Immunity **622**

Answers to Figure Questions **625**

## **18 The Respiratory System 627**

Introduction **627**

#### **18.1 Overview of the Respiratory System 628**

The Steps Involved in Respiration **628**  
Components of the Respiratory System **628**  
Functional Zones of the Respiratory System **634**  
Blood Flow, Resistance, and Pressure of the  
Pulmonary Circulation **634**

#### **18.2 Ventilation 636**

The Breathing Cycle **637**  
Factors that Affect Ventilation **640**  
Ventilation–Perfusion Matching **643**  
Patterns of Respiratory Movements **644**

#### **18.3 Lung Volumes and Capacities 645**

#### **18.4 Exchange of Oxygen and Carbon Dioxide 648**

Gas Laws: Dalton's Law and Henry's Law **648**  
Pulmonary and Systemic Gas Exchange **649**

#### **18.5 Transport of Oxygen and Carbon Dioxide 651**

Oxygen Transport **651**  
Carbon Dioxide Transport **656**  
Summary of Gas Exchange and Transport in Lungs  
and Tissues **657**

#### **18.6 Control of Ventilation 659**

Respiratory Center **659**  
Regulation of the Respiratory Center **660**

#### **18.7 Exercise and the Respiratory System 663**

Answers to Figure Questions **665**

## **19 The Urinary System 667**

Introduction **667**

#### **19.1 Overview of Kidney Functions 668**

#### **19.2 Organization of the Kidneys 668**

Nephrons **670**  
Blood Supply of the Kidneys **671**  
Juxtaglomerular Apparatus **671**

<b>19.3</b>	<b>Overview of Renal Physiology</b>	<b>671</b>
<b>19.4</b>	<b>Glomerular Filtration</b>	<b>672</b>
	Filtration Membrane	674
	Pressures that Affect Glomerular Filtration	675
	Glomerular Filtration Rate	675
	Regulation of the Glomerular Filtration Rate	676
<b>19.5</b>	<b>Tubular Reabsorption and Tubular Secretion</b>	<b>678</b>
	Principles of Tubular Reabsorption and Secretion	678
	Reabsorption and Secretion in Different Parts of the Renal Tubule and Collecting Duct	680
	Hormonal Regulation of Tubular Reabsorption and Secretion	686
<b>19.6</b>	<b>Production of Dilute and Concentrated Urine</b>	<b>690</b>
	Production of Dilute Urine	690
	Production of Concentrated Urine	692
<b>19.7</b>	<b>Evaluation of Kidney Function</b>	<b>695</b>
	Urinalysis	695
	Blood Tests for Kidney Function	695
	Renal Plasma Clearance	698
	Renal Failure	702
<b>19.8</b>	<b>Urine Transportation, Storage, and Elimination</b>	<b>702</b>
	Ureters	702
	Urinary Bladder	702
	Urethra	705
<b>19.9</b>	<b>Waste Management in Other Body Systems</b>	<b>705</b>
	Answers to Figure Questions	707

## 20 Fluid, Electrolyte, and Acid–Base Homeostasis 709

	Introduction	709
<b>20.1</b>	<b>Fluid Compartments and Fluid Balance</b>	<b>710</b>
	Body Fluid Compartments	710
	Sources of Body Water Gain and Loss	711
	Regulation of Body Water Gain	711
	Regulation of Water and Solute Loss	713
	Movement of Water Between Body Fluid Compartments	713
<b>20.2</b>	<b>Electrolytes in Body Fluids</b>	<b>717</b>
	Concentrations of Electrolytes in Body Fluids	717
	Functions of Specific Electrolytes	717
<b>20.3</b>	<b>Acid–Base Balance</b>	<b>720</b>
	Buffer Systems	720
	Exhalation of Carbon Dioxide	722
	Kidney Excretion of $H^+$	722
	Acid–Base Imbalances	724
	Answers to Figure Questions	728

## 21 The Digestive System 729

	Introduction	729
<b>21.1</b>	<b>Overview of the Digestive System</b>	<b>730</b>
	Components of the Digestive System	730
	Digestive Processes	730
	Layers of the GI Tract	731
	Neural Innervation of the GI Tract	732
	Authorhythmicity of GI Smooth Muscle	733
	Patterns of GI Motility	734
<b>21.2</b>	<b>Mouth</b>	<b>735</b>
	Components of the Mouth	735
	Mechanical Digestion in the Mouth	737
	Chemical Digestion in the Mouth	737
<b>21.3</b>	<b>Pharynx and Esophagus</b>	<b>737</b>
	Pharynx	738
	Esophagus	738
	Deglutition	738
<b>21.4</b>	<b>Stomach</b>	<b>740</b>
	Functions of the Stomach	740
	Organization of the Stomach	740
	Mechanical Digestion in the Stomach	742
	Chemical Digestion in the Stomach	742
	Vomiting	744
<b>21.5</b>	<b>Pancreas, Liver, and Gallbladder</b>	<b>744</b>
	Pancreas	745
	Liver	746
	Gallbladder	749
<b>21.6</b>	<b>Small Intestine</b>	<b>749</b>
	Functions of the Small Intestine	750
	Organization of the Small Intestine	750
	Intestinal Juice	750
	Brush-Border Enzymes of the Small Intestine	750
	Mechanical Digestion in the Small Intestine	752
	Chemical Digestion in the Small Intestine	752
	Absorption in the Small Intestine	754
<b>21.7</b>	<b>Large Intestine</b>	<b>759</b>
	Functions of the Large Intestine	760
	Organization of the Large Intestine	760
	Mechanical Digestion in the Large Intestine	761
	Chemical Digestion in the Large Intestine	761
	Water Absorption and Feces Formation in the Large Intestine	762
	The Defecation Reflex	762
<b>21.8</b>	<b>Phases of Digestion</b>	<b>764</b>
	Cephalic Phase	764
	Gastric Phase	764
	Intestinal Phase	765
	Hormones of the Digestive System	766
<b>21.9</b>	<b>Transport of Lipids by Lipoproteins</b>	<b>767</b>
	Answers to Figure Questions	771

## 22 Metabolic Adaptations, Energy Balance, and Temperature Regulation 773

Introduction 774

### 22.1 Metabolic Adaptations 774

Metabolism During the Absorptive State 774

Metabolism During the Postabsorptive State 775

Metabolism During Fasting and Starvation 777

### 22.2 Energy Balance 778

Definition of Energy Balance 778

Food Calories 778

Metabolic Rate 780

Adipose Tissue 781

Regulation of Food Intake 782

Obesity 782

### 22.3 Regulation of Body Temperature 783

Mechanisms of Heat Transfer 783

Hypothalamic Thermostat 784

Thermoregulation 784

Answers to Figure Questions 789

## 23 The Reproductive Systems 790

Introduction 790

### 23.1 Reproductive Cell Division 791

The Numbers of Chromosomes in Somatic Cells and Gametes 791

Meiosis 791

### 23.2 Male Reproductive System 793

Scrotum 793

Testes 793

Male Duct System 796

Accessory Sex Glands 797

Penis 798

Male Reproductive Hormones 802

### 23.3 Female Reproductive System 803

Ovaries 804

Fallopian Tubes 808

Uterus 808

Vagina 810

Vulva 810

Mammary Glands 811

Female Reproductive Hormones 811

Female Reproductive Cycle 813

### 23.4 The Human Sexual Response 817

### 23.5 Sex Determination and Sex Differentiation 818

Sex Determination 818

Sex Differentiation 818

### 23.6 Aging and the Reproductive Systems 821

### 23.7 Pregnancy and Labor 822

Embryonic Period 822

Fetal Period 826

Extraembryonic Membranes 827

The Decidua 828

The Placenta 828

Teratogens 829

Labor 829

Lactation 831

### 23.8 Contraception and Abortion 833

Contraception 833

Abortion 836

### 23.9 Infertility 836

Answers to Figure Questions 839

APPENDIX A Measurements A-1

APPENDIX B Periodic Table B-3

APPENDIX C Normal Values for Selected Blood Tests C-4

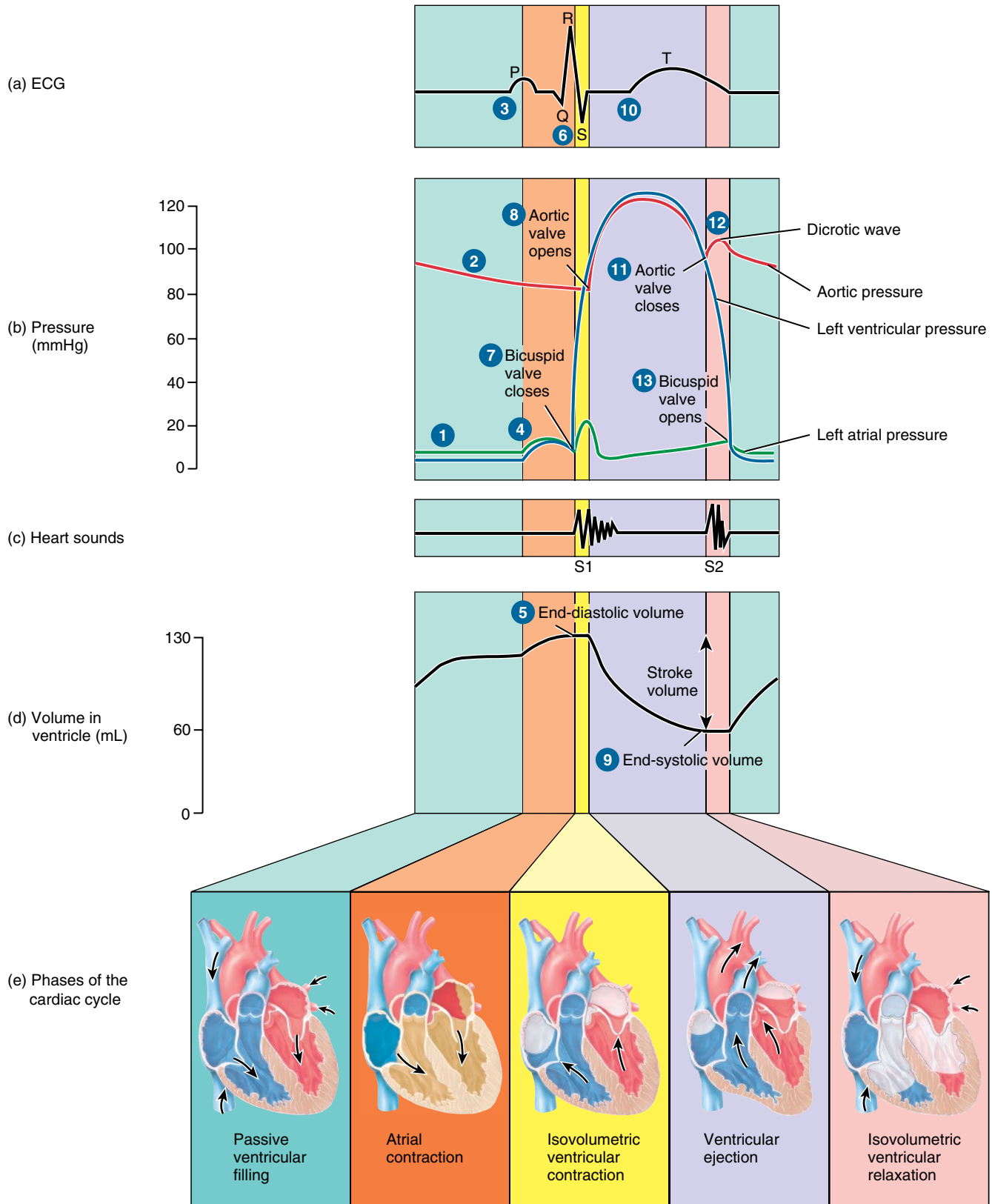
APPENDIX D Normal Values for Selected Urine Tests D-6

GLOSSARY G-1

INDEX I-1

**FIGURE 14.19 Cardiac cycle.** (a) ECG. (b) Changes in left atrial pressure (green line), left ventricular pressure (blue line), and aortic pressure (red line) as they relate to the opening and closing of heart valves. (c) Heart sounds. (d) Changes in left ventricular volume. (e) Phases of the cardiac cycle.

A cardiac cycle includes all of the events associated with a single heartbeat.



**Question** How much blood remains in each ventricle at the end of ventricular diastole in a resting person? What is this volume called?

number of progressively smaller cells, called blastomeres.

**Clitoris (KLI-to-ris)** An erectile organ of the female, located at the front end of the vulva, that is homologous to the male penis.

**Clone (KLŌN)** A population of identical cells.

**Cochlea (KOK-lē-a)** A winding, cone-shaped tube forming a portion of the inner ear and containing the organ of Corti.

**Cochlear duct** The membranous cochlea consisting of a spirally arranged tube enclosed in the bony cochlea and lying along its outer wall. Also called the scala media (SCA-la MĒ-dē-a).

**Colon** The portion of the large intestine consisting of ascending, transverse, descending, and sigmoid portions.

**Colony-stimulating factor (CSF)** One of a group of molecules that stimulates development of leukocytes.

**Common bile duct** A tube formed by the union of the common hepatic duct and the cystic duct that empties bile into the duodenum at the ampulla of Vater (hepatopancreatic ampulla).

**Concentration gradient** A difference in the concentration of a chemical from one place to another.

**Cone** The type of photoreceptor in the retina that is specialized for highly acute color vision in bright light.

**Connective tissue** One of the most abundant of the four basic tissue types in the body, performing the functions of binding and supporting; consists of relatively few cells in a generous matrix (the ground substance and fibers between the cells).

**Consciousness (KON-shus-nes)**

A state of wakefulness in which an individual is fully alert, aware, and oriented, partly as a result of feedback between the cerebral cortex and reticular activating system.

**Contractility (kon'-trak-TIL-i-tē)** The ability of cells or parts of cells to generate force actively to undergo shortening for movements. Muscle fibers (cells) exhibit a high degree of contractility.

**Control center** Part of a feedback system that sets the range of values within which a controlled variable should be maintained, evaluates input from receptors, and generates output commands.

**Convergence (con-VER-jens)** A synaptic arrangement in which the synaptic end bulbs of several presynaptic neurons terminate on one postsynaptic neuron. The medial movement of the two eyeballs so that both are directed toward a near object being viewed in order to produce a single image.

**Cornea (KOR-nē-a)** The part of the outer layer of the eye that is transparent.

**Corona radiata (kō-RŌ-na rā-dē-A-ta)**

The innermost layer of granulosa cells that is firmly attached to the zona pellucida around a secondary oocyte.

**Coronary artery disease (CAD)** A condition such as atherosclerosis that causes narrowing of coronary arteries so that blood flow to the heart is reduced. The result is coronary heart disease, in which the heart muscle receives inadequate blood flow due to an interruption of its blood supply.

**Corpus albicans (KOR-pus AL-bi-kanz)**

A mass of white fibrous scar tissue in the ovary that forms after the corpus luteum regresses.

**Corpus luteum (LOO-tē-um)** A yellowish body in the ovary formed when a follicle has discharged its secondary oocyte; secretes estrogens, progesterone, relaxin, and inhibin.

**Corticobulbar pathway** Motor pathway that conveys information for voluntary control of skeletal muscles of the head.

**Corticobulbar tract** Motor (descending) tract that conveys information from the motor cortex to the brain stem for voluntary control of skeletal muscles of the head.

**Corticospinal pathway** Motor pathway that conveys information for voluntary control of skeletal muscles of the limbs and trunk.

**Cranial nerve** One of 12 pairs of nerves that connect the brain to sensory receptors and effectors in the head, neck, and many organs in the thoracic and abdominal cavities. Each is designated by a Roman numeral and a name.

**Cushing's syndrome** Condition caused by a hypersecretion of glucocorticoids characterized by spindly legs, "moon face," "buffalo hump," pendulous abdomen, flushed facial skin, poor wound healing, hyperglycemia, osteoporosis, hypertension, and increased susceptibility to disease.

**Cytokinesis (sī'-tō-ki-NĒ-sis)** Distribution of the cytoplasm into two separate cells during cell division; coordinated with nuclear division (mitosis).

**Cytolysis (sī-TOL-i-sis)** The rupture of living cells in which the contents leak out.

**Cytoplasm (SĪ-tō-plasm)** Cytosol plus all organelles except the nucleus.

**Cytoskeleton** Complex internal structure of cytoplasm consisting of microfilaments, microtubules, and intermediate filaments.

**Cytosol (SĪ-tō-sol)** Fluid portion of cytoplasm in which solutes are dissolved and organelles are suspended. Also called intracellular fluid.

## D

**Defecation (def-e-KĀ-shun)** The discharge of feces from the rectum.

**Deglutition (dē-gloo-TISH-un)** The act of swallowing.

**Dehydration (dē-hī-DRĀ-shun)** Excessive loss of water from the body or its parts.

**Dendrite (DEN-drīt)** A neuronal process that carries electrical signals, usually graded potentials, toward the cell body.

**Diabetes mellitus (dī-a-BĒ-tēz MEL-i-tus)**

An endocrine disorder caused by an inability to produce or use insulin. It is characterized by the three "polys": polyuria (excessive urine production), polydipsia (excessive thirst), and polyphagia (excessive eating).

**Diagnosis** Distinguishing one disease from another or determining the nature of a disease from signs and symptoms by inspection, palpation, laboratory tests, and other means.

**Dialysis** The removal of waste products from blood by diffusion through a selectively permeable membrane.

**Diaphragm (DĪ-a-fram)** Any partition that separates one area from another, especially the dome-shaped skeletal muscle between the thoracic and abdominal cavities; a dome-shaped device that is placed over the cervix, usually with a spermicide, to prevent conception.

**Diarrhea (dī-a-RĒ-a)** Frequent defecation of liquid caused by increased motility of the intestines.

**Diastole (dī-AS-tō-lē)** In the cardiac cycle, the phase of relaxation or dilation of the heart muscle, especially of the ventricles.

**Diastolic (dī-as-TOL-ik) pressure (DP)**

The force exerted by blood on arterial walls during ventricular relaxation; the lowest blood pressure measured in the large arteries, normally about 70 mmHg in a young adult.

**Diencephalon (dī-en-SEF-a-lon)** A part of the brain consisting of the thalamus, hypothalamus, and pineal gland.

**Diffusion (dī-FŪ-zhun)** The random mixing of particles from one location to another because of the particles' kinetic energy.

**Digestion (dī-JES-chun)** The mechanical and chemical breakdown of food to simple molecules that can be absorbed and used by body cells.

**Digestive system** Body system that ingests food, breaks it down, processes it, and eliminates wastes from the body.

**Direct motor pathways** Motor tracts that convey information from the motor cortex to cause voluntary movements of skeletal muscles. Also called the pyramidal pathways.

**Disease** An illness characterized by a recognizable set of signs and symptoms.

**Disorder** Any abnormality of structure or function.

**Dorsal column** Sensory (ascending) tract that conveys information up the spinal cord to the brain for sensations of touch, pressure, vibration, and proprioception.

**Dorsal column pathway** Sensory pathway that conveys information for touch, pressure, vibration, and proprioception.

Visual acuity, 312  
 Visual association area, 256, 327  
 Visual cortex, 327  
 Visual fields, 325  
 Visual pathway, 327  
 Visual system. *See also* Eyes  
   accessory structures, 309, 309*f*  
   accommodation, 315*f*, 316  
   binocular vision, 316  
   defined, 308  
   image formation, 312–315  
   light and dark adaptation, 330  
   phototransduction and, 320–324, 322*f*  
   refraction of light rays, 313–314, 314*f*  
   visible light and, 308–309  
   visual acuity, 312  
   visual association area, 327  
   visual cortex, 327  
   visual pathway, 326*f*, 327  
   visual processing, 321–330  
 Vital capacity, 647  
 Vitamin C, 665  
 Vitamin D, 123, 167  
 Vitamin K, 584–585  
 Vitamins  
   absorption of, 757  
   bone growth and, 480–481  
   defined, 120  
   function of, 120–122  
   list of, 122*t*  
 Vitamin supplements, 121  
 Vitreous humor, 313  
 Vocal cords, 631, 633  
 Volatile acids, 722  
 Voltage, 197

Voltage-gated  $\text{Ca}^{2+}$  channels  
   defined, 362  
 Voltage-gated channels, 197, 199*t*, 350*f*, 410  
 Voltmeter, 201  
 Volts, 197  
 Voluntary stage, swallowing, 738  
 Vomiting, 744  
 Vomiting center, 744  
 von Willebrand factor (VWF), 581  
 Vulva, 810

## W

Wandering macrophages, 595  
 Warfarin (Coumadin), 586  
 Warm receptors, 290, 291*f*  
 Water  
   absorption of, 757  
   ADH in balance of, 713, 714*f*  
   defined, 711  
   dehydration and, 712  
   drinking too much, 716  
   gain regulation, 711–712  
   as inorganic compound, 29*f*  
   intoxication, 716  
   loss regulation, 713  
   as lubricant, 31  
   molecule formation, 29*f*  
   movement between fluid compartments,  
     713, 716  
   polar molecules, 31*f*  
   as solvent, 30–31  
   sources of gain and loss, 711, 711*f*  
   thermal properties of, 31  
   thirst center and, 712, 712*f*  
 Water reabsorption, 680, 687–688, 687*f*

Water-soluble extracellular messengers  
   circulation of, 158*f*  
   defined, 157  
   signaling pathway activation, 167–178  
 Water-soluble hormones  
   circulation of, 441*f*  
   defined, 440  
   mechanisms of action, 440–444,  
     442*f*–443*f*  
 Water-soluble vitamins, 121, 122*t*  
 Wave summation, 390  
 Weight discrimination, 296  
 Wernicke's area, 256  
 White adipocytes, 789  
 White blood cells. *See* Leukocytes  
 White matter, 191–092, 194*f*  
 Wolffian ducts, 818  
 Word blindness, 264  
 Word deafness, 264  
 Wound healing, 625

## X

X chromosomes, 817

## Y

Yawning, 644*t*  
 Y chromosomes, 817  
 Yolk sac, 828

## Z

Z discs, 373  
 Zinc, 121*t*  
 Zona pellucida, 807, 822  
 Zonular fibers, 310  
 Zygotes, 808, 823