





ESSENTIALS OF ANATOMY & PHYSIOLOGY, EIGHTH EDITION

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Beth currently lives in Venice, Florida, with her husband John and daughter Melanie. As former Northerners, they greatly enjoy the ability to swim almost year round both in their pool and in the Gulf of Mexico.



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PREFACE

ESSENTIALS OF ANATOMY & PHYSIOLOGY Eighth Edition is designed for students who are enrolled in a one-semester course in human anatomy and physiology. The scope, organization, writing style, depth of presentation, and pedagogical aspects of the text have been tailored to meet the needs of students preparing for a career in one of the allied health professions, or taking the course as a general education requirement.

Acknowledgments

The development and production of this eighth edition has been a team effort. Our dedicated and creative teammates at McGraw-Hill Education have contributed greatly to the finished product. We gratefully acknowledge and applaud their efforts, and it has been a pleasure to work with these gifted professionals at each step of the process: Erin DeHeck (Product Developer), Matt Garcia (Senior Portfolio Manager), Vicki Krug (Senior Content Project Manager), and Valerie Kramer (Senior Marketing Manager).

Student-centric Revision

Students taking a one-semester course in anatomy and physiology have diverse backgrounds, including limited exposure to biology and chemistry, and this presents a formidable challenge to the instructor. To help meet this challenge, this text is written in a clear and concise manner, free from excess jargon, and simplifies the complexities of anatomy and physiology in ways that enhance understanding without diluting the essentials of the subject matter.

In preparation for this eighth edition, we surveyed 50 students (in a variety of majors, including allied health professions) and obtained detailed insight into how they would ideally engage with course materials. Stemming from those results, we adjusted the print and digital delivery of the content to align with student preferences.

Also, we are very pleased to incorporate real student data points and input, derived from thousands of our SmartBookTM users, to help guide our revision. SmartBookTM Heat Maps provided a quick visual snapshot of usage of portions of the text and the relative difficulty students experienced in mastering the content. With these data, we honed not only our text content revision but also the SmartBookTM probes.

Textbook Themes and Organization

There are two unifying themes in the content presentation: (1) the relationship between structure and function of body parts and (2) the mechanisms of homeostasis. In addition, the interrelationship of organ systems is noted where appropriate and useful.

The sequence of chapters and content within each chapter progresses from simple to complex. Chapters covering an organ system begin with anatomy to ensure that students are well prepared to understand the physiology that follows. Each organ system chapter concludes with a brief consideration of common disorders that the student may encounter in the clinical setting.

"Careers in" Opener and Learning Objectives

Each chapter begins with a list of major topics discussed in the chapter, along with an opening "Careers" vignette and image that relates the content theme of the chapter to real-world careers. Under each section header within every chapter, the learning objectives are noted. This informs students of the major topics to be covered and their minimum learning responsibilities.

Key Terms

Several features have been incorporated to assist students in learning the necessary technical terms that often are troublesome for beginning students.

- 1. Throughout the text, key terms are in bold or italic type for easy recognition, and they are defined at the time of first usage. A phonetic pronunciation follows for students who need help in pronouncing the term. Experience has shown that students learn only terms that they can pronounce.
- 2. Keys to Medical Terminology in Appendix A explains how technical terms are structured and provides a list of prefixes, suffixes, and root words to further aid an understanding of medical terminology.

Figures and Tables

Over 350 high-quality, full-color illustrations are coordinated with the text to help students visualize anatomical features and physiological concepts. Tables are used throughout to summarize information in a way that is more easily learned by students.

Clinical Insight

Numerous boxes containing related clinical information are strategically placed throughout the text. They serve to provide interesting and useful information related to the topic at hand. The Clinical Insight boxes are identified by a medical cross for easy recognition.

Check My Understanding

Review questions at the end of major sections challenge students to assess their understanding before proceeding.

Chapter Summary

The chapter summary is conveniently linked by section and briefly states the important facts and concepts covered in each chapter.

Changes in the Eighth Edition

The eighth edition has been substantially enhanced and improved.

Global Changes

- Added a "Careers in" section at the start of every chapter to show students how the chapter content relates to careers in the real world.
- Approximately 20 figures and tables were revised or are completely new.
- Revised descriptive language to improve the overall readability of the text. Terminology and phrasing more commonly used by students outside the classroom have been added where appropriate. By making the text easier to read, students will have an easier time grasping more complex anatomical and physiological content.
- Added the course guide of the seventh edition back into the lecture text to facilitate easier student use and completion.
- Updated terminology to align with the *Terminologia Anatomica*, *Terminologia Histologica*, and *Terminologia Embryologica*.

Chapter 1

- Added common alternative names to some regional terminology.
- Updated figure 1.6 to show the cross-section of the thoracic cavity in the correct standard orientation.

Chapter 2

- Updated organic molecule terminology for accuracy.
- Corrected the structure of fructose in multiple figures.
- Corrected the structure of the unsaturated fatty acid in figure 2.14.

Chapter 3

- Added free ribosomes to figure 3.1.
- Updated discussion of cell cycle to include phase names in both text and figures.

Chapter 4

- Reorganized entire chapter into table format for easier reading and to minimize redundant information.
- Updated terminology to align with the TH.

Chapter 5

- Updated tissue descriptions for dermis.
- Relabeled figure 5.6.

Chapter 6

- Rewrote the bone structure section to describe all bones, not just a long bone.
- Reordered figures 6.1 to 6.3 to follow the flow of the new bone structure section.
- Moved table 6.1 closer to figure 6.5 as they both discuss ossification.
- Added coloring legend to figure 6.6 to highlight the axial and appendicular skeletons.
- Relabeled minor updates in several figures.
- Updated mandibular terminology with NEW figure 6.13 added.
- Revised pectoral girdle section.
- Rewrote joint descriptions using matching terminology for clarity.
- Added NEW figure 6.29 to show osteoporosis.
- Revised figure 6.28 on fractures to combine art and text describing fractures.

Chapter 7

- Updated muscle terminology throughout the text to match TH. Updated terminology is more descriptive to promote student learning.
- Revised figure 7.2 to improve accuracy.
- Replaced old terminology on origins and insertions with updated attachment terminology.
- Updated all tables to match the attachment terminology update.

• Updated actions for some muscles so that all muscle actions describe the body part moved.

Chapter 8

- Updated terminology throughout chapter to align with the TA and TH.
- Added satellite cells to neuroglia section.
- Revised membrane potentials for clarity.
- Added a NEW figure 8.13 that shows superior, lateral, and median sections of the brain. Previous edition was only a median section.
- Added a NEW figure 8.14 depicting a frontal section of the cerebrum showing white matter and grey matter and highlighting the basal nuclei.
- Included the function of the basal nuclei in the cerebrum section.
- Included the superior colliculi, inferior colliculi, and substantia nigra in the section on the brainstem.
- Added a NEW Clinical Insight on aphasias.
- Added a NEW figure 8.20 that shows the four branches of spinal nerves and how they exit the vertebral canal.
- Updated figure 8.25 to match figure 8.24 color scheme.

Chapter 9

- Revised the sections on eyes and ears to clearly state that there are two of each and they function the same.
- Revised the flow of an action potential through the retina for accuracy and clarity.

Chapter 10

- Updated figure 10.2 to include calcitonin.
- Updated multiple figures to match style with figure 10.6. This includes color coding processes for clarity.
- Redesigned figures 10.10 and 10.13 completely to reflect negative-feedback loops.

Chapter II

- Revised description of hemoglobin breakdown for accuracy and clarity.
- Updated figure 11.6 to show positive-feedback within coagulation pathway.
- Revised section on hemostasis for clarity regarding negative- vs. positive-feedback mechanisms.
- Added the use of RhoGAM in the prevention of hemolytic disease of the newborn.

Chapter 12

- Updated figure 12.11 to match color scheme established in chapter 8 for autonomic pathways.
- Added a NEW figure 12.18 that illustrates the factors affecting blood pressure.
- Updated the values and terminology for hypertension to match new American Heart Association recommendations.

Chapter 13

- Added a description of regulatory T cells.
- Revised figure 13.9 to include regulatory T cells.

Chapter 14

- Revised chemoreceptor discussion to separate central and peripheral chemoreceptors.
- Added a NEW figure 14.10 that shows the effects of chemoreceptors on ventilation.

Chapter 15

- Revised the description of dentin so as to not be confused with bone tissue.
- Revised figure 15.7 to updated style.
- Revised figure 15.19 to updated style.

Chapter 16

- Revised the discussion of collecting ducts and papillary ducts to better clarify their inclusion as parts of the renal tubule according to the TH.
- Retitled table 16.2 to be more accurate.

Chapter 17

- Clarified the function of the cytoplasmic bridges in spermatogenesis.
- Added cytoplasmic bridges to figure 17.3.
- Updated terminology throughout to align with the TA and TH.
- Redesigned figure 17.8 to better represent ovarian follicular development.

Chapter 18

- Updated meiosis terminology.
- Added pronucleus as a term.
- Reordered artwork to better flow with text.
- Updated figure 18.7 to new style.
- Revised postnatal cardiovascular changes for clarity.





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Introduction to the Human **Body**



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Careers In

Students take a course in anatomy and physiology for a variety of reasons. Some are simply fulfilling a core requirement. Some are taking the course just because they find the human body interesting. Others are taking the course because they seek a career in health care.

The health care field offers many opportunities for individuals with an interest and a passion for helping others. However, many students are not aware of the diversity of options available. The "Careers In . . ." section at the start of each chapter describes health-related careers related to the chapter's content. Reading about the "Careers In . . ." will not just expose students to a broader range of health-related careers but will also show students how chapter content supports professionals within those fields.

CHAPTER OUTLINE

- 1.1 Anatomy and **Physiology**
- 1.2 Levels of Organization
 - · Chemical Level
 - Cellular Level
 - Tissue Level
 - Organ Level
 - Organ System Level
 - Organismal Level
- 1.3 Directional Terms
- 1.4 Body Regions
- 1.5 Body Planes and Sections
- 1.6 Body Cavities
 - Membranes of Body Cavities
- 1.7 Abdominopelvic **Subdivisions**
- 1.8 Maintenance of Life
 - Survival Needs
 - Homeostasis

Chapter Summary





Module 1

Body Orientation

YOU ARE BEGINNING a fascinating and challenging study—the study of the human body. As you progress through this text, you will begin to understand the complex structures and functions of the human organism.

This first chapter provides an overview of the human body to build a foundation of knowledge that is necessary for your continued study. Like the chapters that follow, this chapter introduces a number of new terms for you to learn. It is important that you start to build a vocabulary of technical terms and continue to develop it throughout your study. This vocabulary will help you reach your goal of understanding human anatomy and physiology.

1.1 Anatomy and Physiology

Learning Objective

1. Define anatomy and physiology.

Knowledge of the human body is obtained primarily from two scientific disciplines—anatomy and physiology—and each consists of a number of subdisciplines.

Human **anatomy** (ah-nat'-ō-mē) is the study of the structure and organization of the body and the study of the relationships of body parts to one another. There are two major subdivisions of anatomy. *Gross anatomy* involves the dissection and examination of various parts of the body without magnifying lenses. *Microanatomy*, also known as *histology*, consists of the examination of tissues and cells with various magnification techniques.

Human **physiology** (fiz-ē-ol'-ō-jē) is the study of the function of the body and its parts. Physiology involves observation and experimentation, and usually requires the use of specialized equipment and materials.

In your study of the human body, you will see that there is always a definite relationship between the anatomy and physiology of the body and body parts. Just as the structure of a knife is well suited for cutting, the structure (anatomy) of a body part enables it to perform specific functions (physiology). For example, the arrangement of bones, muscles, and nerves in your hands enables the grasping of large objects with considerable force and also the delicate manipulation of small objects. Correlating the relationship between structure and function will make your study of the human body much easier.

1.2 Levels of Organization

Learning Objectives

- 2. Describe the levels of organization in the human body.
- 3. List the major organs and functions for each organ system.

The human body is complex, so it is not surprising that there are several levels of structural organization, as shown in figure 1.1. The levels of organization from simplest to most complex are chemical, cellular, tissue, organ, organ system, and organismal (the body as a whole).

Chemical Level

The chemical level consists of *atoms, molecules*, and *macromolecules*. At the simplest level, the body is composed of chemical substances that are formed of atoms and molecules. Atoms are the fundamental building blocks of chemicals, and atoms combine in specific ways to form molecules. Some molecules are very small, such as water molecules, but others may be very large, such as the macromolecules of proteins. Various small and large molecules are grouped together to form organelles. An **organelle** (or"-ga-nel') is a complex of macromolecules acting like a "mini-organ" that carries out specific functions within a cell. Nuclei, mitochondria, and ribosomes are examples.

Cellular Level

Cells are the basic structural and functional units of the body because all of the processes of life occur within cells. A cell is the lowest level of organization that is alive. The human body is composed of trillions of cells and many different types of cells, such as muscle cells, blood cells, and nerve cells. Each type of cell has a unique structure that enables it to perform specific functions.

Tissue Level

Similar types of cells are usually grouped together in the body to form a tissue. Each body **tissue** consists of an aggregation of similar cells that perform similar functions. There are four major classes of tissues in the body: epithelial, connective, muscle, and nerve tissues.

Organ Level

Each **organ** of the body is composed of two or more tissues that work together, enabling the organ to perform its specific functions. The body contains numerous organs, and each has a definite structure and function. The stomach, heart, brain, and even bones are examples of organs. Later in this chapter, we will focus our attention on the body cavities. **Body cavities** are spaces within the body that contain organs, collectively referred to as **internal organs**.

Organ System Level

The organs of the body are arranged in functional groups so that their independent functions are coordinated to perform specific system functions. These coordinated, functional groups are called **organ systems**. The digestive and nervous systems are examples of organ systems. Most organs belong to a single organ system, but a few

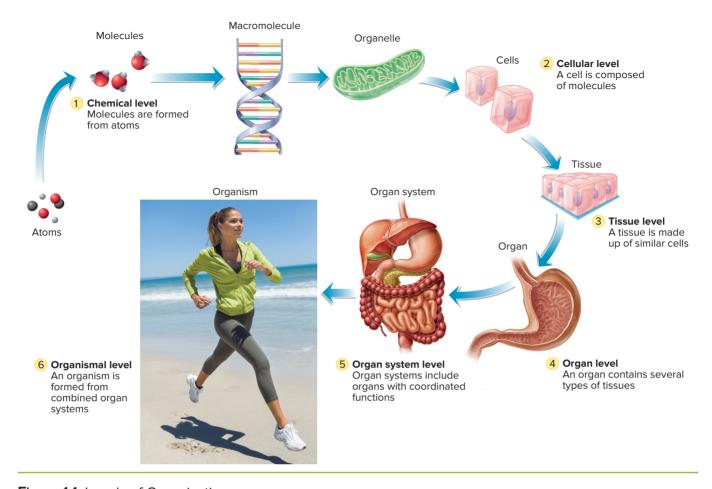


Figure 1.1 Levels of Organization.

Six levels of organization in the human body range from chemical (simplest) to organismal (most complex). ONOKY - Fabrice LEROUGE/Brand X Pictures/Getty Images

organs are assigned to more than one organ system. For example, the pancreas belongs to both the digestive and endocrine systems.

Figure 1.2 illustrates the 11 organ systems of the human body and lists the major organs and functions for each system. Although each organ system has its own unique functions, all organ systems support one another. For example, all organ systems rely on the cardiovascular system to transport materials to and from their cells. Organ systems work together to enable the functioning of the human body.

Organismal Level

The highest organizational level dealing with an individual is the *organismal level*, the human organism as a whole. It is composed of all of the interacting organ systems. All of the organizational levels from chemicals to organ systems contribute to the functioning of the entire body.



Check My Understanding

- 1. What are the organizational levels of the human body?
- 2. What are the major organs and general functions of each organ system?

1.3 Directional Terms

Learning Objective

4. Use directional terms to describe the locations of body parts.

Directional terms are used to describe the relative position of a body part in relationship to another body part. The use of these terms conveys a precise meaning enabling the listener or reader to locate the body part of interest. It is always assumed that the body is in a standard



Integumentary system

Organs: skin, hair, nails, and
associated glands
Functions: protects underlying tissues
and helps regulate body temperature



Organs: bones, ligaments, and associated cartilages Functions: supports the body, protects vital organs, stores minerals, and is the site of blood cell production



Muscular system

Organs: skeletal muscles and tendons
Functions: moves the body and
body parts and produces heat

Figure 1.2 The 11 Organ Systems of the Body.

position, the *anatomical position*, in which the body is standing upright with upper limbs at the sides and palms of the hands facing forward, as in figure 1.3. Directional terms occur in pairs, and the members of each pair have opposite meanings, as noted in table 1.1.

1.4 Body Regions

Learning Objective

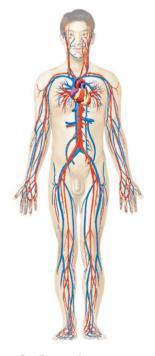
Locate the major body regions on a diagram or anatomical model.

The human body consists of an **axial** (ak'sē-al) **portion**, the head, neck, and trunk, and an **appendicular** (ap-pendik'-ū-lar) **portion**, the upper and lower limbs and their girdles. Each of these major portions of the body is divided into regions with special names to facilitate communication and to aid in locating body components.

The major **body regions** are listed in tables 1.2 and 1.3 to allow easy correlation with figure 1.4, which shows the locations of the major regions of the body. Take time to learn the names, pronunciations, and locations of the body regions.



Organs: nose, pharynx, larynx, trachea, bronchi, and lungs
Functions: exchanges O₂ and CO₂
between air and blood in the lungs, pH regulation, and sound production



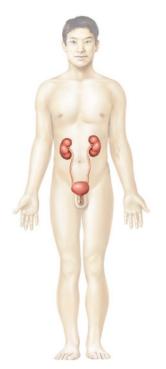
Cardiovascular system

Organs: blood, heart,
arteries, veins, and capillaries
Functions: transports heat and
materials to and from the body cells



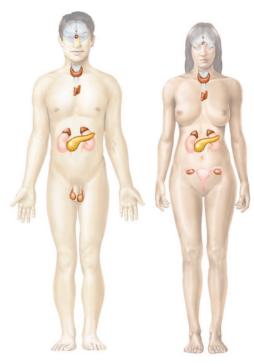
Lymphoid system

Organs: lymph, lymphatic vessels, and lymphoid organs and tissues Functions: collects and cleanses interstitial fluid, and returns it to the blood; provides immunity



Urinary system

Organs: kidneys, ureters, urinary bladder, and urethra Functions: regulates volume and composition of blood by forming and excreting urine



Endocrine system

Organs: hormone-producing glands, such as the pituitary and thyroid glands Functions: secretes hormones that regulate body functions



Nervous system

Organs: brain, spinal cord, nerves, and sensory receptors Functions: rapidly coordinates body functions and enables learning and memory



Digestive system

Organs: mouth, pharynx, esophagus, stomach, intestines, liver, pancreas, gallbladder, and associated structures Functions: digests food and absorbs nutrients



Male reproductive system

Organs: testes, epididymides, vasa deferentia, prostate, bulbo-urethral glands, seminal vesicles, and penis Functions: produces sperm and transmits them into the female vagina during sexual intercourse



Female reproductive system

Organs: ovaries, uterine tubes, uterus, vagina, and vulva Functions: produces oocytes, receives sperm, provides intrauterine development of offspring, and enables birth of an infant

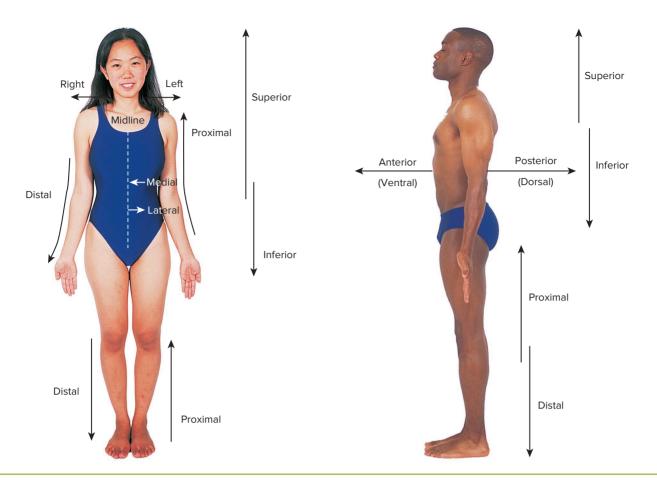


Figure 1.3 Anatomical Position and Directional Terms. (a) Eric Wise; (b) Eric Wise

Table 1.1 Directional Terms

Term	Meaning	Example
Anterior (ventral)	Toward the front or abdominal surface of the body	The abdomen is anterior to the back.
Posterior (dorsal)	Toward the back of the body	The spine is posterior to the face.
Superior (cephalic)	Toward the top/head	The nose is superior to the mouth.
Inferior (caudal)	Away from the top/head	The navel is inferior to the nipples.
Medial	Toward the midline of the body	The breastbone is medial to the nipples.
Lateral	Away from the midline of the body	The ears are lateral to the cheeks.
Parietal	Pertaining to the outer boundary of body cavities	The parietal pleura lines the pleural cavity.
Visceral	Pertaining to the internal organs	The visceral pleura covers the lung.
Superficial (external)	Toward or on the body surface	The skin is superficial to the muscles.
Deep (internal)	Away from the body surface	The intestines are deep to the abdominal muscles.
Proximal	Closer to the beginning	The elbow is proximal to the wrist.
Distal	Farther from the beginning	The hand is distal to the wrist.
Central	At or near the center of the body or organ	The central nervous system is in the middle of the body.
Peripheral	External to or away from the center of the body or organ	The peripheral nervous system extends away from the central nervous system.

Part 1 Organization of the Body

Region Head and Neck **Anterior Trunk** Posterior Trunk Lateral Trunk Auricular (aw-rik'-yuh-ler) Abdominal (ab-dom'-i-nal) Dorsum (dor'-sum) Axillary (ak'-sil-lary) Buccal (bu'-kal) Inquinal (ing'-gwi-nal) Gluteal (glu'-tē-al) Coxal (kok'-sal) Cephalic (se-fal'-ik) Pectoral (pek'-tor-al) Lumbar (lum'-bar) Inferior Trunk Cervical (ser'-vi-kal) Presternal (pre-ster'-nal) Sacral (sāk'-ral) Genital (jen'-i-tal) Cranial (krā'-nē-al) Pubic (pyoo'-bik) Perineal (per-i-nē'-al) Scapular (skap'-yuh-ler) Facial (fā'-shal) Sternal (ster'-nal) Vertebral (ver-tē'-bral) Nasal (nā'-zel) Umbilical (um-bil'-i-kal) Oral (or'-al) Orbital (or'-bit-al) Otic (o'-tic)

Table 1.2 Major Regions of the Axial Portion

Table 1.3 Major Regions of the Appendicular Portion

Region		
Upper Limb	Digital (di'-ji-tal)	Patellar (pa-tel'-lar)
Antebrachial (an-tē-brā'-kē-al)	Palmar (pal'-mar)	Pedal (pe'-dal)
Brachial (brā'-kē-al)	Lower Limb	Plantar (plan'-tar)
Carpal (kar'-pal)	Crural (krū'-ral)	Popliteal (pop-li-tē'-al)
Cubital (kū'-bi-tal)	Digital (di'-ji-tal)	Sural (sū'-ral)
Deltoid (del'-tòid)	Femoral (fem'-ōr-al)	Tarsal (tahr'-sul)

1.5 Body Planes and Sections

Learning Objective

Describe the three planes used in making sections of the body or body parts.

In studying the body or organs, you often will be observing the flat surface of a **section** that has been produced by a cut through the body or a body part. Such sections are made along specific **planes**. These well-defined planes—transverse, sagittal, and frontal planes—lie at right angles to each other, as shown in figure 1.5. It is important to understand the nature of the plane along which a section was made in order to understand the three-dimensional structure of an object being observed.

Transverse, or horizontal, **planes** divide the body into superior and inferior portions and are perpendicular to the longitudinal axis of the body.

Sagittal planes divide the body into right and left portions and are parallel to the longitudinal axis of the body. A **median plane** passes through the midline of the body and divides the body into equal left and right

halves. A **paramedian plane** does not pass through the midline of the body.

Frontal (coronal) planes divide the body into anterior and posterior portions. These planes are perpendicular to sagittal planes and parallel to the longitudinal axis of the body.

Cuts made through sagittal and frontal planes, which are parallel to the longitudinal axis of the body, produce longitudinal sections. However, the term *longitudinal section* also refers to a section made through the longitudinal axis of an individual organ, tissue, or other structure. Similarly, cuts made through the transverse plane produce *cross sections* of the body and can also be produced in organs and tissues when cutting at a 90° angle to the longitudinal axis. *Oblique sections* are created when cuts are made in between the longitudinal and cross-sectional axes.



Check My Understanding

3. How do sagittal, transverse, and frontal planes differ from one another?

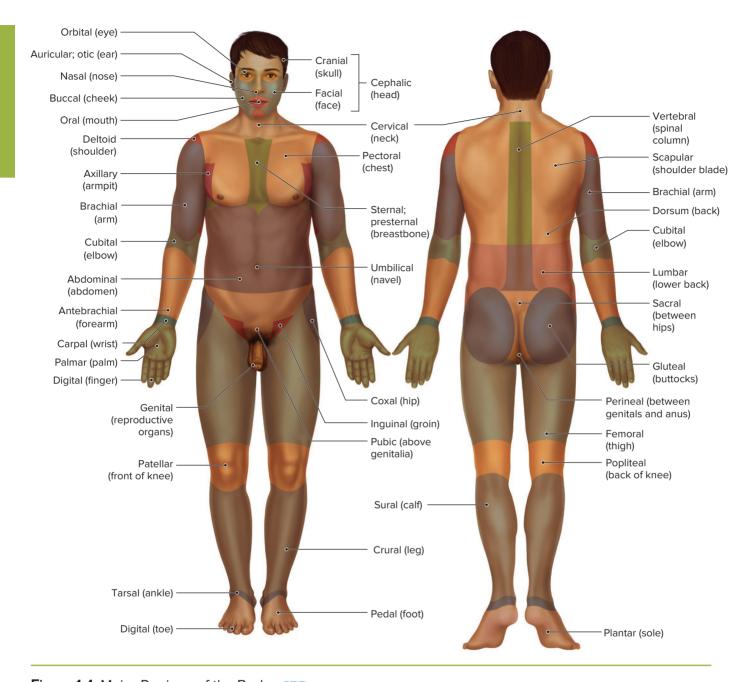


Figure 1.4 Major Regions of the Body.

1.6 Body Cavities

Learning Objectives

- 7. Locate the body cavities and their subdivisions and membranes on a diagram.
- 8. Name the organs located in each body cavity.

The body cavities protect and cushion the contained internal organs and permit changes in their size and shape without impacting surrounding tissues. Note the locations and subdivisions of these cavities in figure 1.6.

The **cranial cavity** is enclosed in the bones of the skull and contains the brain. Within the vertebral column is the **vertebral canal**, which contains the spinal cord. Note in figure 1.6 how the cranial bones and the vertebral column form the walls of these cavities and provide protection for these delicate organs.

The two large body cavities in front of the vertebral column are divided by the *diaphragm*, a thin dome-shaped sheet of muscle. Above the diaphragm is the **thoracic cavity** and below it is the **abdominopelvic cavity**. The thoracic cavity is protected by the *thoracic cage* and contains the heart and lungs. The abdominopelvic

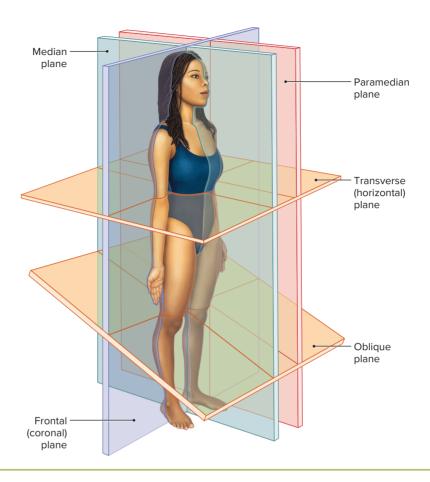


Figure 1.5 Anatomical Planes of Reference.

cavity is subdivided into a superior **abdominal cavity** and an inferior **pelvic cavity**, but there is no structural separation between them. To visualize the separation, imagine a transverse plane passing through the body just above the pelvis. The abdominal cavity contains the stomach, intestines, liver, gallbladder, pancreas, spleen, and kidneys. The pelvic cavity contains the urinary bladder, sigmoid colon, rectum, and internal reproductive organs.



Check My Understanding

- 4. What organs are located in the cranial cavity and vertebral canal?
- 5. What organs are located in the thoracic and abdominopelvic cavities?

Membranes of Body Cavities

The membranes lining body cavities support and protect the internal organs in the cavities.

Meninges

The cranial cavity and vertebral canal are lined by three layers of protective membranes that are collectively called the **meninges** (me-nin'-jez; singular, *meninx*). The outer membrane is attached to the wall of the cavity, and the inner membrane tightly envelops the brain and spinal cord. The meninges will be covered in chapter 8.

Serous Membranes

The thoracic and abdominopelvic cavity organs are supported and protected by **serous membranes**, or **serosae** (singular, *serosa*). The serous membranes are thin layers of tissue that line the body cavity and cover the internal organs. Serous membranes have an outer *parietal* (pahrī'-e-tal) *layer* that lines the cavity and an inner *visceral* (vis'-er-al) *layer* that covers the organ. The parietal and visceral layers secrete a watery lubricating fluid, generically called *serous fluid*, into the cavity formed between the layers. This arrangement is similar to that of a fist pushed into a balloon (figure 1.7). The serous membranes of the body are the pleura, serous pericardium, and peritoneum.

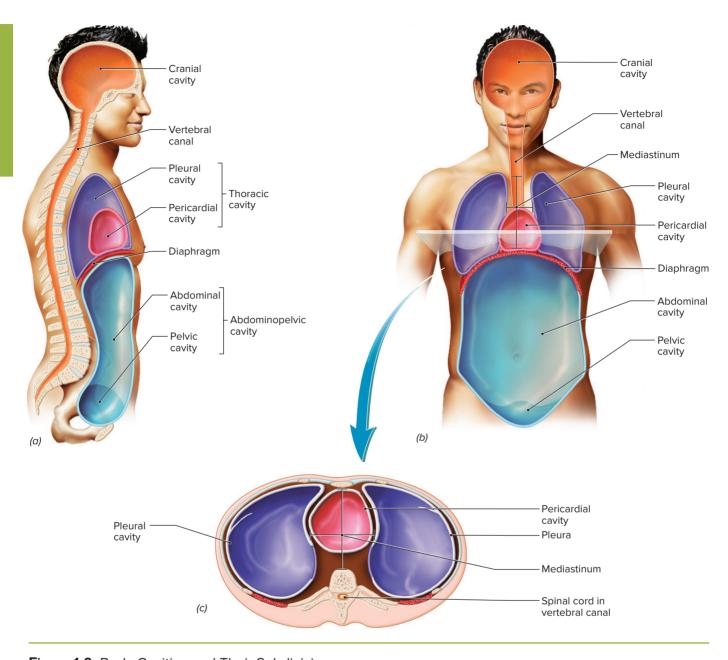


Figure 1.6 Body Cavities and Their Subdivisions. (a) Sagittal section. (b) Frontal section. (c) Transverse section through the thoracic cavity.

The serous membranes lining the thoracic cavity are called **pleurae** (singular, *pleura*). The walls of the left and right portions of the thoracic cavity are lined by the *parietal pleurae*. The surfaces of the lungs are covered by the *visceral pleurae*. The space between the parietal and visceral pleurae is called the **pleural cavity**. The pleural cavity contains a thin film of serous fluid called *pleural fluid*, which reduces friction as the pleurae rub against each other as the lungs expand and contract during breathing.

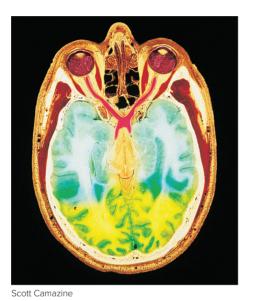
The left and right portions of the thoracic cavity are divided by a membranous partition, the *mediastinum* (mēdē-a-stī'-num). Organs located within the mediastinum include the heart, thymus, esophagus, and trachea.

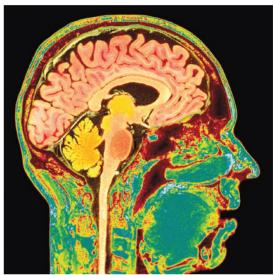
The heart is enveloped by the **serous pericar-dium** (per-i-kar'-dē-um), which is formed by membranes of the mediastinum. The thin *visceral layer of the serous pericardium* is tightly adhered to the surface of the heart. The *parietal layer of the serous pericardium* lines the inside surface of a loosely fitting sac around the heart. The space

Clinical Insight

Physicians use certain types of diagnostic imaging systems—for example, computerized tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET)—to produce images of sections of the body to help them diagnose disorders. In computerized tomography, an X-ray emitter and an X-ray detector rotate around the patient so that the X-ray beam passes through the body from hundreds of different angles. X-rays collected

by the detector are then processed by a computer to produce sectional images on a screen for viewing by a radiologist. A good understanding of sectional anatomy is required to interpret CT scans. Transverse sections, such as the image on the left, are always shown in the same way. Convention is to use supine (face up), inferior views as if looking up at the section from the foot of the patient's bed. What structures can you identify in the CT image shown on the right?





Du Cane Medical Imaging Ltd./Science Photo Library/Getty Images

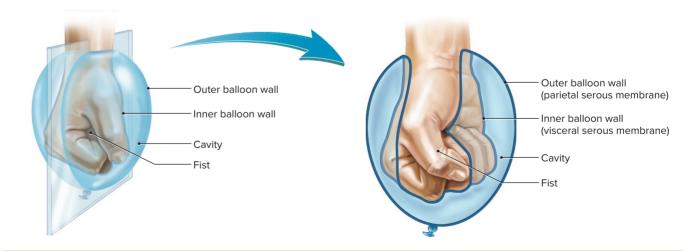


Figure 1.7 Model of a Serous Membrane.

Illustration of a fist pushed into a balloon as an analogy to a serous membrane.

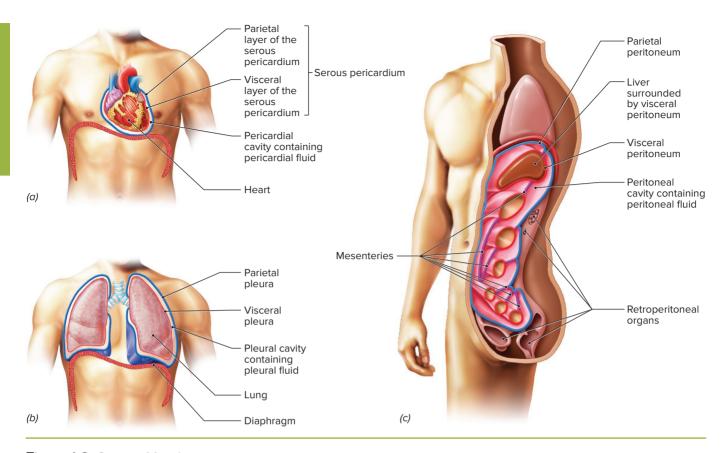


Figure 1.8 Serous Membranes.

(a) Anterior view of serous pericardium. (b) Anterior view of pleurae. (c) Sagittal view of peritoneum.

between the visceral and parietal layers of the serous pericardia is the **pericardial cavity**, and it contains serous fluid, called *pericardial fluid*, that reduces friction as the heart contracts and relaxes.

The walls of the abdominal cavity and the surfaces of abdominal organs are covered with the **peritoneum** (peri-tō-nē'-um). The *parietal peritoneum* lines the walls of the abdominal cavity but not the pelvic cavity. It descends only to cover the top of the urinary bladder. The kidneys, pancreas, and parts of the intestines are located behind the parietal peritoneum in a space known as the *retroperitoneal space*. The *visceral peritoneum*, an extension of the parietal peritoneum, covers the surface of the abdominal organs. Double-layered folds of the visceral peritoneum, the *mesenteries* (mes'-en-ter"-ēs), extend between the abdominal organs and provide support for them (see figure 1.8c). The space between the parietal and visceral peritoneum is called the **peritoneal cavity** and contains a small amount of serous fluid called *peritoneal fluid* (figure 1.8).



Check My Understanding

- 6. What membranes line the various body cavities?
- 7. What is the function of serous fluid?

1.7 Abdominopelvic Subdivisions

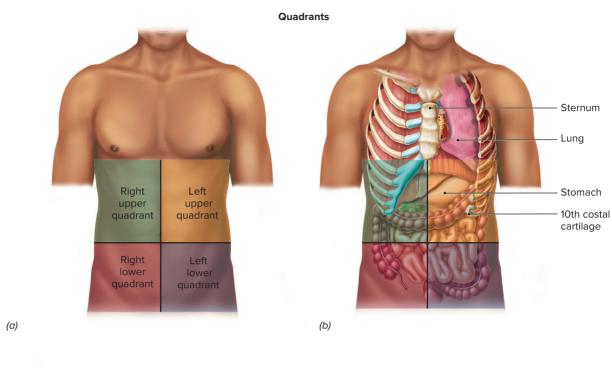
Learning Objectives

- 9. Name the abdominopelvic quadrants and regions.
- 10. Locate the abdominopelvic quadrants and regions on a diagram.

The abdominopelvic cavity is subdivided into either four quadrants or nine regions to aid health-care providers in locating underlying organs. Physicians may feel (palpate) or listen to (auscultate) the abdominopelvic region to examine it. Changes in firmness or sounds may indicate abnormalities in the structures of a quadrant or region.

The four quadrants are formed by two planes that intersect just above the umbilicus (navel), as shown in figure 1.9a. Note the organs within each quadrant.

The nine regions are formed by the intersection of two sagittal and two transverse planes, as shown in figure 1.9c. The sagittal planes extend inferiorly from the midpoints of the collarbones. The superior transverse plane lies just below the borders of the 10th costal cartilages, and the inferior transverse plane lies just below the top of the hip bones.



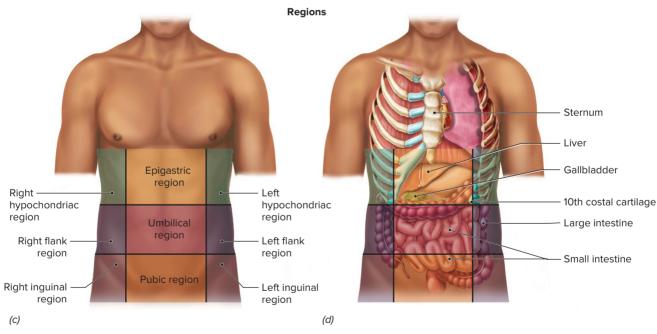


Figure 1.9 Abdominopelvic Subdivisions. The four quadrants and nine regions of the abdominopelvic cavity.

Study figures 1.8 and 1.9 to increase your understanding of the locations of the internal organs and associated membranes.

Now examine the colorplates that follow this chapter. They show an anterior view of the body in progressive

stages of dissection that reveals major muscles, blood vessels, and internal organs. Study these plates to learn the locations of the organs. Also, check your understanding of the organs within each abdominopelvic quadrant and region.



父 Check My Understanding

8. What are the four quadrants and nine regions of the abdominopelvic region?

1.8 Maintenance of Life

Learning Objectives

- 11. Define metabolism, anabolism, and catabolism.
- 12. List the five basic needs essential for human life.
- 13. Define homeostasis.
- 14. Explain how homeostasis relates to both healthy body functions and disorders.
- 15. Describe the general mechanisms of negativefeedback and positive-feedback.

Humans, like all living organisms, exhibit the fundamental processes of life. **Metabolism** (me-tab'-ō-lizm) is the term that collectively refers to the sum of all of the chemical reactions that occur in the body.

There are two phases of metabolism: anabolism and catabolism. Anabolism (ah-nab'-ō-lizm) refers to processes that use energy and nutrients to build the complex organic molecules that compose the body. Catabolism (kah-tab'-ō-lizm) refers to processes that release energy and break down complex molecules into simpler molecules.

Life is fragile. It depends upon the healthy functioning of trillions of body cells, which, in turn, depends upon factors needed for survival and the ability of the body to maintain relatively stable internal conditions.

Survival Needs

There are five basic needs that are essential to human life:

- 1. Food provides chemicals that serve as a source of energy and raw materials to grow and to maintain cells of the body.
- 2. Water provides the environment in which the chemical reactions of life occur.
- 3. **Oxygen** is required to release the energy in organic nutrients, which powers life processes.
- 4. **Body temperature** must be maintained close to 36.8°C (98.2°F) to allow the chemical reactions of human metabolism to occur.
- 5. **Atmospheric pressure** is required for breathing to occur.

Homeostasis

Homeostasis is the maintenance of a relatively stable internal environment by self-regulating physiological processes. Homeostasis keeps body temperature and the composition of blood and interstitial fluids within their healthy

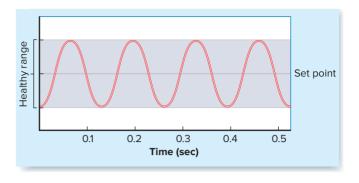


Figure 1.10 Healthy Range and Set Point.

range. This relatively stable internal environment is maintained in spite of the fact that internal and external factors tend to alter body temperature, and materials are continuously entering and exiting the blood and interstitial fluid.

All of the organ systems work in an interdependent manner to maintain homeostasis. For example, changes in one system tend to affect one or more other organ systems. Therefore, any disruption in one organ system tends to be corrected but may disrupt another organ system. The internal environment is maintained via a dynamic equilibrium where there is constant fluctuation taking place in order to maintain homeostasis. Malfunctioning or overcompensation in a homeostatic mechanism can lead to disorders and diseases.

The dynamic equilibrium of homeostasis is primarily maintained by physiologic processes called negativefeedback mechanisms. Body fluid composition and other physiological variables fluctuate near a healthy value, called a set point, and negative-feedback mechanisms are used to keep these variables within their healthy range (figure 1.10). For a negative-feedback mechanism to work, it needs to be able to monitor and respond to any changes in homeostasis. The structure of the negative-feedback mechanism allows it to function in exactly this manner and is a great example of how anatomical structure complements function. To monitor a physiological variable, a negative-feedback mechanism utilizes a receptor to detect deviation from the set point and send a signal notifying the integrating center about the deviation. The integrating center, which is the body region that knows the set point for the variable, processes the information from a receptor and determines the course of action that is needed. It then sends a signal that activates an effector. The effector will carry out the necessary response according to the directions of the integrating center and return the variable back toward the set point. In a negative-feedback mechanism, the response of the effector will always be the opposite of the change detected by the receptor (figure 1.11). Once the set point is reached, the negativefeedback mechanism will automatically turn off.

Our body's ability to maintain a relatively constant blood glucose level relies on negative-feedback mechanisms. When the blood glucose level begins to rise, as it does after a meal, there are receptors in the pancreas that can detect this stimulus (change). The beta cells of the pancreas act as an integrating center and release the hormone insulin in response to this change. Insulin travels through the blood to several effectors, one of which is the liver. Insulin causes the liver cells to take excess glucose out of the blood and thus decrease the blood glucose level back toward the set point. The pancreas possesses other receptors that can detect decreases in blood glucose, such as occurs between meals. The alpha cells of the pancreas, acting as the integrating center, release the hormone glucagon. Glucagon causes the liver to release glucose into the blood, which will increase blood glucose back toward the set point (figure 1.12).

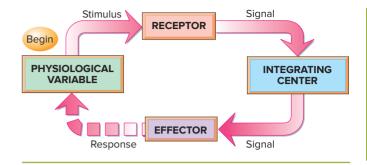


Figure 1.11 A Typical Negative-Feedback Mechanism.

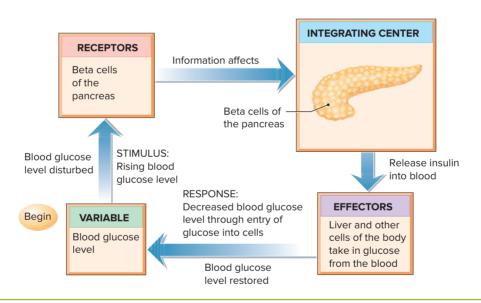


Figure 1.12 An Example of a Negative-Feedback Mechanism. The negative-feedback mechanism that regulates blood glucose level.

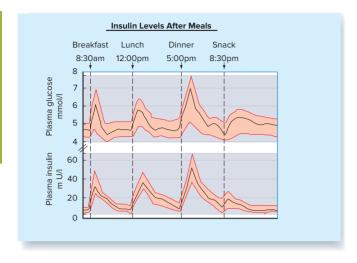


Figure 1.13 The Graded Response.

The graded response of insulin release is based on the amount of blood glucose elevation.

Source: The FASEB Journal C Kendall, vol. 28. no. 1 Supplement 1039.6.

It is important to note that the response of the integrating center will be stronger if the original stimulus is further from the set point. For example, if the blood glucose level rises sharply out of the healthy range, causing *hyperglycemia* (blood glucose level above the healthy range), the amount of insulin the beta cells release will be more than the amount released if the blood glucose level is elevated but is still within the healthy range. This type of response is called a *graded response* because it can respond on different levels (figure 1.13).

Positive-feedback mechanisms utilize the same basic components as negative-feedback mechanisms. However, the outcome of a positive-feedback mechanism is very different from that of a negative-feedback mechanism. A positive-feedback mechanism is used when the originating stimulus needs to be amplified and continued in order for the desired result to occur. A few examples of positivefeedback mechanisms include fever, activation of the immune response, formation of blood clots, certain aspects of digestion, and uterine contractions of labor. If you think about blood clot formation, blood clots do not form "normally"; when they begin to form, it occurs quickly and completely in order to stop blood loss. This is a necessary mechanism for overall homeostasis. Figure 1.14 illustrates the specific steps of the positive-feedback mechanism of saliva production.

Positive-feedback mechanisms can be harmful because they lack the ability to stop on their own. They will continue to amplify the effect of the original stimulus, which can push the body dangerously out of homeostasis, until the cycle is interrupted by an outside factor. For example, an uncontrolled fever can increase body temperature to a point that is fatal. For this reason,

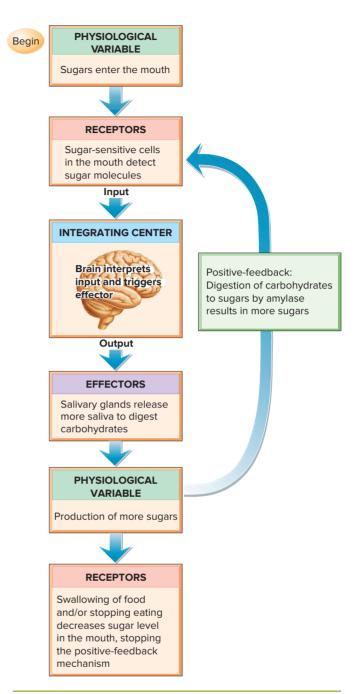


Figure 1.14 A Positive-Feedback Mechanism. Saliva is produced as needed, and production increases with continued stimulation.

positive-feedback mechanisms are used for rare events within the body, rather than for the daily maintenance of homeostasis.



9. What is homeostasis? How is homeostasis regulated?

Chapter Summary

1.1 Anatomy and Physiology

- Human anatomy is the study of body structure and organization.
- Human physiology is the study of body functions.

1.2 Levels of Organization

- The body consists of several levels of organization of increasing complexity.
- From simple to complex, the organizational levels are chemical, cellular, tissue, organ, organ system, and organismal.
- The organs of the body are arranged in coordinated groups called organ systems.
 - The 11 organ systems of the body are integumentary cardiovascular skeletal lymphoid muscular respiratory nervous urinary endocrine reproductive digestive

1.3 Directional Terms

- Directional terms are used to describe the relative positions of body parts.
- Directional terms occur in pairs, with the members of a pair having opposite meanings.

anterior–posterior proximal–distal superior–inferior external–internal medial–lateral parietal–visceral central–peripheral

1.4 Body Regions

- The body is divided into two major portions: the axial portion and the appendicular portion.
- The axial portion is subdivided into the head, neck, and trunk
- The head and neck contain cervical, cranial, and facial regions. The cranial and facial regions combine to form the cephalic region.
- The facial region consists of orbital, nasal, oral, and buccal regions.
- The trunk consists of anterior, posterior, lateral, and inferior regions.
- Anterior trunk regions include the abdominal, inguinal, pectoral, pubic, sternal, and umbilical regions.
- Posterior trunk regions include the dorsal, gluteal, lumbar, sacral, scapular, and vertebral regions.
- Lateral trunk regions are the axillary and coxal regions.
- Inferior trunk regions are the genital and perineal regions.

- The appendicular portion of the body consists of the upper and lower limbs.
- The upper limb is attached to the trunk at the shoulder.
 Regions of the upper limb are the antebrachial, brachial, carpal, cubital, deltoid, digital, and palmar regions.
- The lower limb is attached to the trunk at the hip. Regions of the lower limb are the crural, digital, femoral, patellar, pedal, plantar, popliteal, sural, and tarsal regions.

1.5 Body Planes and Sections

- Well-defined planes are used to guide sectioning of the body or organs.
- The common planes are transverse, sagittal, and frontal.
- The common planes produce longitudinal sections and cross sections of the body.

1.6 Body Cavities

- The cranial cavity is located within the skull, and the vertebral canal is located within the vertebral column.
- The thoracic cavity lies above the diaphragm. It consists of two lateral pleural cavities and the mediastinum, which contains the pericardial cavity.
- The abdominopelvic cavity lies below the diaphragm. It consists of a superior abdominal cavity and an inferior pelvic cavity.
- The body cavities are lined with protective and supportive membranes.
- The meninges consist of three membranes that line the cranial cavity and vertebral canal and that enclose the brain and spinal cord.
- The parietal pleurae line the walls of the thoracic cage, while the visceral pleurae cover the surfaces of the lungs.
- The pleural cavity is the space between the parietal and visceral pleurae.
- The parietal layer of the serous pericardium is a saclike membrane in the mediastinum that surrounds the heart.
 The visceral layer of the serous pericardium is attached to the surface of the heart.
- The pericardial cavity is the space between the parietal and visceral layers of the serous pericardium.
- The parietal peritoneum lines the walls of the abdominal cavity but does not extend into the pelvic cavity. The visceral peritoneum covers the surface of abdominal organs.
- The peritoneal cavity is the space between the parietal and visceral peritoneum.
- The mesenteries are double-layered folds of the visceral peritoneum that support internal organs.
- Kidneys, pancreas, and parts of the intestines are located behind the parietal peritoneum in the retroperitoneal space.

1.7 Abdominopelvic Subdivisions

- The abdominopelvic cavity is subdivided into either four quadrants or nine regions as an aid in locating organs.
- The four quadrants are

right upper right lower left upper

The nine regions are

epigastric right flank left hypochondriac pubic right hypochondriac left inguinal umbilical right inguinal

left flank

1.8 Maintenance of Life

- Metabolism is the sum of all of the body's chemical reactions.
 It consists of anabolism, the synthesis of body chemicals,
 and catabolism, the breakdown of body chemicals.
- The basic needs of the body are food, water, oxygen, body temperature, and atmospheric pressure.
- Homeostasis is the maintenance of a relatively stable internal environment.
- Homeostasis is regulated by negative-feedback mechanisms.
- Negative-feedback mechanisms consist of three components: receptors, integrating center, and effectors.
- Positive-feedback mechanisms promote an ever-increasing change from the norm.

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COLORPLATES OF THE HUMAN BODY

The five colorplates that follow show the basic structure of the human body. The first plate shows the anterior body surface and the superficial anterior muscles of a female. Succeeding plates show the internal structure as revealed by progressively deeper dissections.

Refer to these plates often as you study this text in order to become familiar with the relative locations of the body organs.

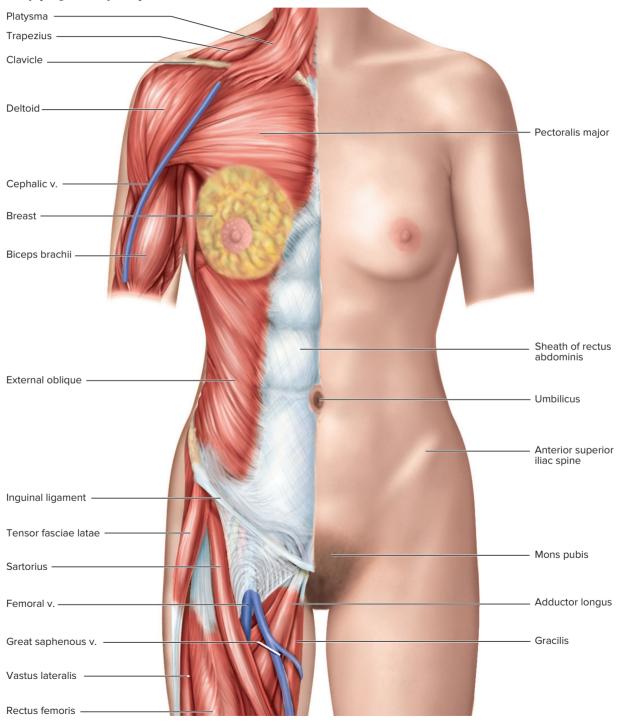


Plate 1 Superficial Anatomy of the Trunk (Female).

Surface anatomy is shown on the anatomical left, and structures immediately deep to the skin on the right (v. = vein). Source: Kenneth Saladin, Human Anatomy & Physiology: The Unity of Form and Function. Copyright © 2015 McGraw-Hill Education.

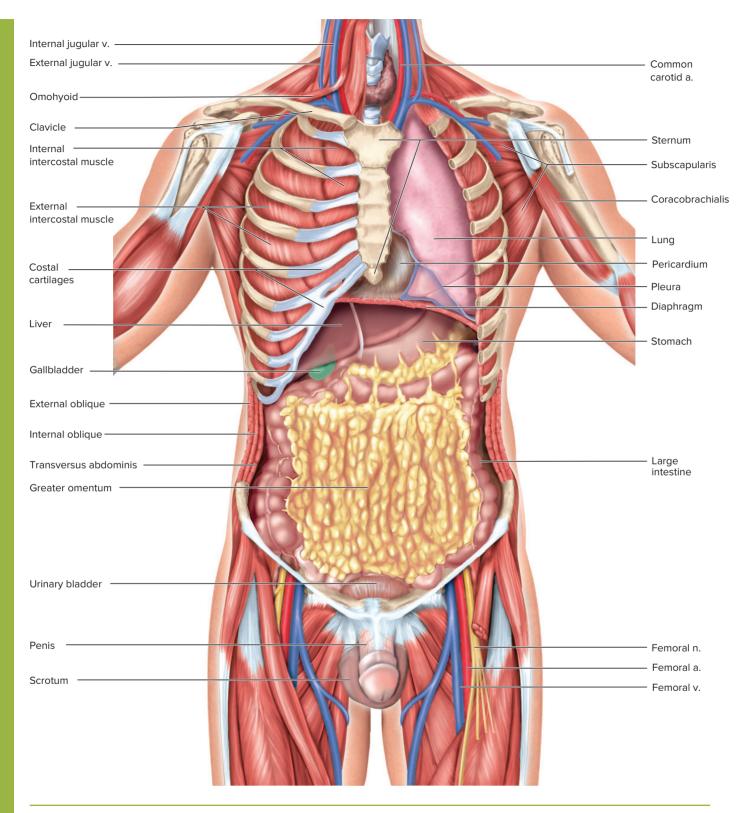


Plate 2 Anatomy at the Level of the Thoracic Cage and Greater Omentum (Male). The anterior body wall is removed, and the ribs, intercostal muscles, and pleurae are removed from the anatomical left (a. = artery; v. = vein; n. = nerve).

Source: Kenneth Saladin, Human Anatomy & Physiology: The Unity of Form and Function. Copyright © 2015 McGraw-Hill Education.

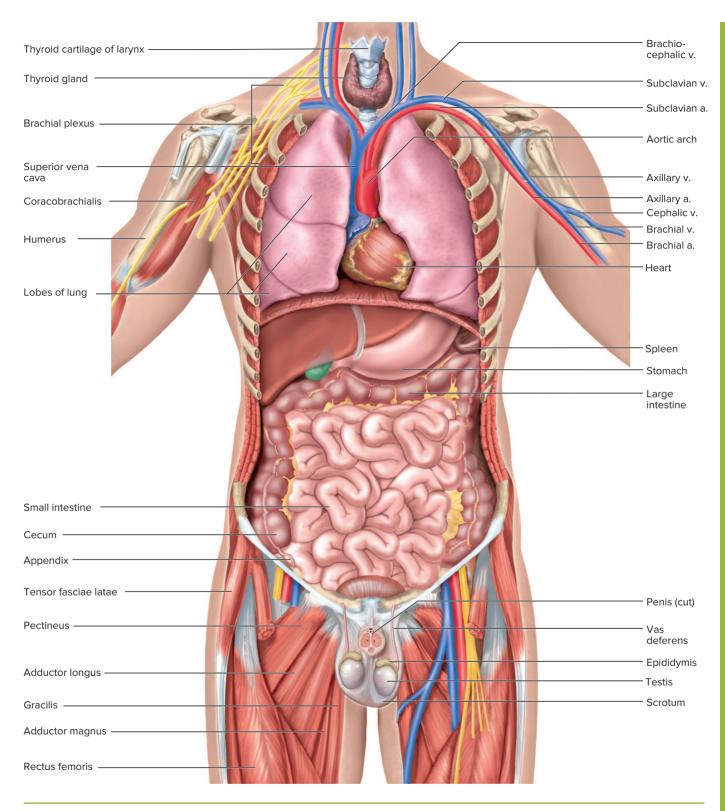


Plate 3 Anatomy at the Level of the Lungs and Intestines (Male).

The sternum, ribs, and greater omentum are removed (a. = artery; v. = vein).

Source: Kenneth Saladin, Human Anatomy & Physiology: The Unity of Form and Function. Copyright © 2015 McGraw-Hill Education.

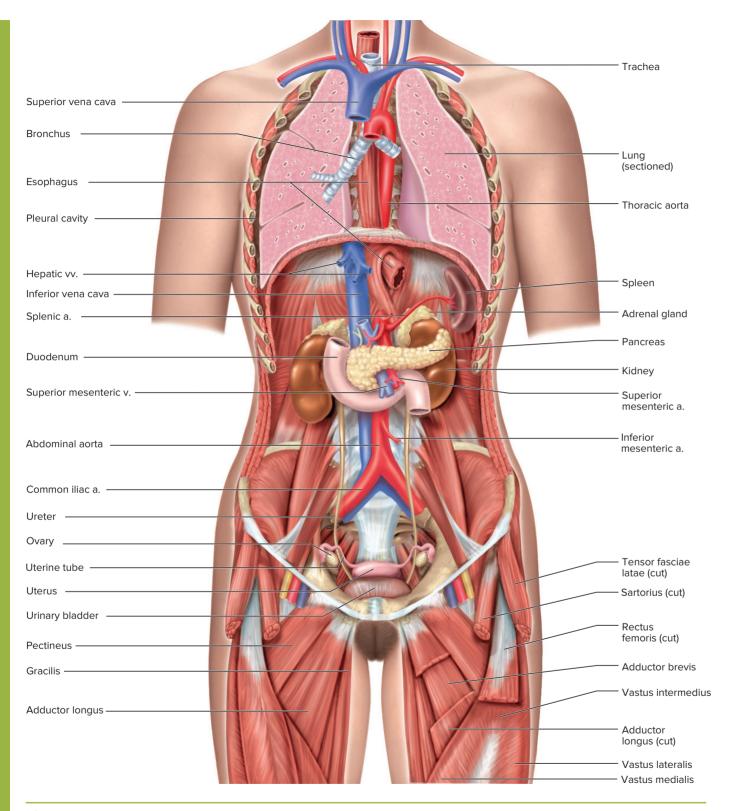


Plate 4 Anatomy at the Level of the Retroperitoneal Viscera (Female).

The heart is removed, the lungs are frontally sectioned, and the viscera of the peritoneal cavity and the peritoneum itself are removed (a. = artery; v. = vein; vv. = veins).

Source: Kenneth Saladin, Human Anatomy & Physiology: The Unity of Form and Function. Copyright © 2015 McGraw-Hill Education.

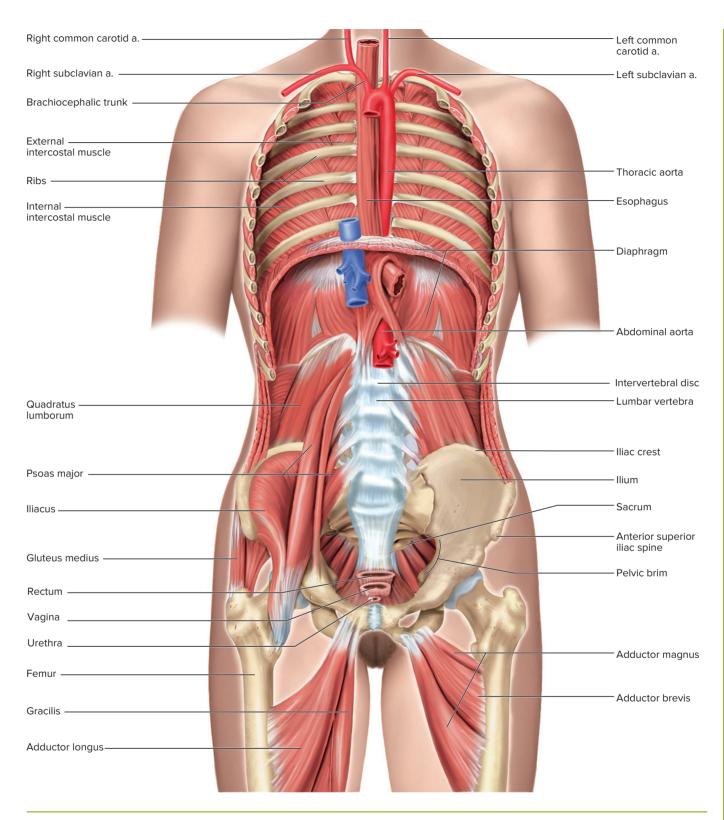


Plate 5 Anatomy at the Level of the Posterior Body Wall (Female).

The lungs and retroperitoneal viscera are removed (a. = artery).

Source: Kenneth Saladin, Human Anatomy & Physiology: The Unity of Form and Function. Copyright © 2015 McGraw-Hill Education.

Chemicals of Life



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Careers in

Have you ever wondered why the USDA (United States Department of Agriculture) recommends a certain number of protein, grain, fat, fruit, vegetable, dairy, and water servings every day? The answer is simple. You are what you eat. If examining food nutrition is something that interests you, you might consider becoming a *nutritionist*. Nutritionists have a vast knowledge of how chemicals affect the body. For example, a nutritionist understands that protein-rich foods such as meats and nuts provide necessary building units for the production of new proteins within your body. They also know how your body uses glucose, a carbohydrate, as its main energy source. Nutritionists work in a variety of settings, including hospitals, schools, private practices, wellness centers, and nursing homes. If you have ever wanted to be a chef but simply cannot cook, being a nutritionist may be the answer.

CHAPTER OUTLINE

- 2.1 Atoms and Elements
 - Atomic Structure
 - Isotopes
- 2.2 Molecules and Compounds
 - Chemical Formulae
 - Chemical Bonds
 - Chemical Reactions
- 2.3 Substances Composing the **Human Body**
 - Major Inorganic Substances
 - Major Organic Molecules

Chapter Summary





Module 2

Cells & Chemistry

A BASIC UNDERSTANDING OF CHEMISTRY is necessary for health-care professionals because the human body is composed of chemicals and the processes of life are chemical interactions.

2.1 Atoms and Elements

Learning Objectives

- 1. Describe the basic structure of an atom.
- 2. Distinguish between atoms, isotopes, and radioisotopes.

Anything that occupies space is **matter**. Chemistry is the scientific study of matter and the interactions of matter. The entire physical universe, both living and nonliving, is composed of matter. All matter is composed of **elements**, substances that cannot be broken down into simpler substances by ordinary chemical means. Carbon, hydrogen, and nitrogen are examples of chemical elements.

New elements are being discovered relatively frequently as technology continues to advance. As of the writing of this textbook, there were 118 elements in the periodic table. Most scientists consider 92 of these elements to be "naturally occurring," which generally means they can be found in samples of soil, air, and water. The remaining elements in the periodic table are man-made. The average person has detectable traces of approximately 60 elements in his or her body, but by most current definitions only 24 are recognized as being involved in maintaining life.

Figure 2.1 highlights the 12 elements of the human body that occur in significant amounts (totaling 99.9%). The four elements isolated in figure 2.1 (oxygen, carbon, hydrogen, and nitrogen) make up approximately 96% of the human body and are found making up the body's major organic molecules, discussed later in the chapter. Other remaining elements occur in very small amounts and are referred to as *trace elements*.

Atomic Structure APR

An **atom** (a'-tom) is the smallest single unit of an element. Atoms of a given element are similar to each other, and they are different from atoms of all other elements. Atoms of different elements differ in size, mass, and how they interact with other atoms.

Atoms are composed of three types of subatomic particles: protons, neutrons, and electrons. Each **proton** has a positive electrical charge. Each **neutron** is neutral, meaning it has no electrical charge. Protons and neutrons are located in the **nucleus** at the center of an atom. Each **electron** has a negative electrical charge.

Electrons orbit, or revolve around, the nucleus at high speeds in *electron shells* that are located at various distances from the nucleus. The first shell of electrons, the shell closest to the nucleus, can hold a maximum of two electrons, as is the case for hydrogen. Atoms react to fill their **valence** (outermost) **shell**. Therefore, hydrogen reacts to gain one electron to fill its valence shell with two electrons. All other atoms typically found in the human body react to fill the valence shell with eight electrons. Atoms always fill the lowest electron shells first. See the diagram of the atomic structures of hydrogen and carbon in figure 2.2.

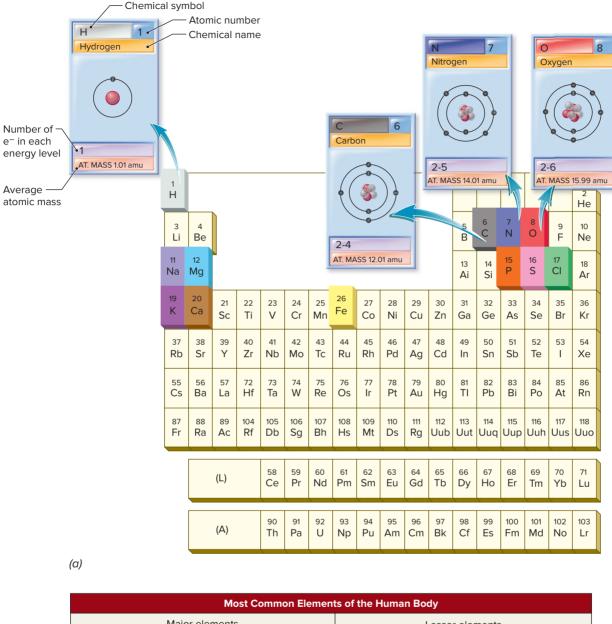
An atom is electrically neutral because it has the same number of protons as electrons, although the number of neutrons may vary. Most atoms are not stable in this state and have characteristic ways of losing, gaining, or sharing electrons to achieve stability, which is key to forming chemical bonds.

The atoms of each element are characterized by a specific atomic number, chemical symbol, and atomic mass. These characteristics are used to identify the element. The atomic number indicates the number of protons, and because they match, also the number of electrons in each atom. The **chemical symbol** is a shorthand way of referring to an element or to an atom of the element. The mass of either a proton or a neutron is defined as one atomic mass unit (amu). Because an electron's mass is only 0.005 amu, the **atomic mass** of an atom is simply the sum of the number of protons plus the number of neutrons in each atom. For example, an atom of carbon has an atomic number of 6, a chemical symbol of C, and an atomic mass of 12. From this information, you know that an atom of carbon has six protons, six electrons, and six neutrons.

Isotopes

As mentioned in the preceding section, all atoms of an element have the same number of protons and electrons. However, some atoms may have different numbers of neutrons. An atom of an element with a different number of neutrons is called an **isotope** (i'-so-tōp). For example, hydrogen has three isotopes: ¹H, ²H, and ³H (figure 2.3). All isotopes of an element have the same chemical properties because they have the same number of protons and electrons.

Certain isotopes of some elements have an unstable nucleus that emits high-energy radiation as it breaks down to form a more stable nucleus. Such isotopes are called *radioisotopes*. Certain radioisotopes are used in the diagnosis of disorders and in the treatment of cancer. See the clinical insight box later in this chapter.



Most Common Elements of the Human Body							
(collectively comp	Major elements ose more than 9	8% of body weight)	Lesser elements (collectively compose less than 1% of body weight)				
Chemical symbol		Body weight	Chemical symbol		% Body weight		
	Oxygen	65.0	S	Sulfur	0.25		
C	Carbon	18.0	K	Potassium	0.25		
Н	Hydrogen	10.0	Na	Sodium	0.15		
N	Nitrogen	3.0	CI	Chlorine	0.15		
Ca	Calcium	1.5	Mg	Magnesium	0.05		
Р	Phosphorus	1.0	Fe	Iron	0.006		
(b)							

Figure 2.1 The Periodic Table of Elements. (a) Detailed description of how to read the table. (b) The 12 most abundant elements in the human body.

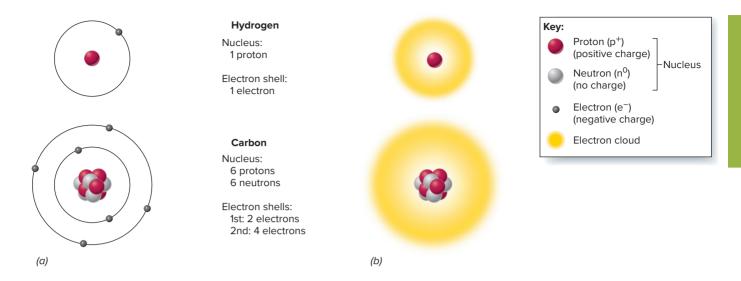


Figure 2.2 Atomic Structures of Hydrogen and Carbon. (a) Electron shell models. (b) Electron cloud models. These models show the most likely locations of the electrons.

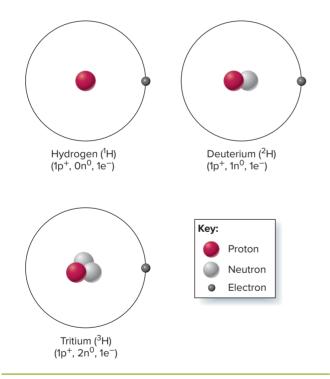


Figure 2.3 The Three Isotopes of Hydrogen. Notice that only the number of neutrons changes.

Check My Understanding

- 1. What is the relationship among matter, elements, and atoms?
- 2. What is the basic structure of an atom?

2.2 Molecules and Compounds

Learning Objectives

- 3. Explain the meaning of a chemical formula.
- 4. Compare and contrast molecular formula and structural formula.
- 5. Compare and contrast ionic, nonpolar covalent, polar covalent, and hydrogen bonds.
- 6. Compare synthesis, decomposition, exchange, and reversible reactions.

A few elements exist separately in the body, but most are chemically bound to others to form molecules. Some molecules are composed of like elements-an oxygen molecule (O_2) , for example. Others, such as water (H_2O) , are composed of different kinds of elements. **Compounds** are substances composed of atoms from two or more different elements. Thus, the chemical structure of water may be referred to as both a molecule and a compound. Whether a substance is called a molecule or a compound also depends upon the type of chemical bond used to build the substance. Molecules are built by covalent bonds only, while compounds are built by either ionic or covalent bonds. All organic substances are built with covalent bonds, and thus are called **organic molecules**. Chemical bonds are discussed in more detail shortly.

Chemical Formulae

A chemical formula expresses the chemical composition of a substance. Two major types of chemical formulae exist, the molecular formula and the structural formula. A molecular formula expresses the composition of a single molecule. In a molecular formula, chemical

symbols indicate the elements involved, while subscripts identify the number of atoms of each element in the molecule. For example, the molecular formula for water is H₂O, which indicates that two atoms of hydrogen combine with one atom of oxygen to form a water molecule. The molecular formula does not describe how the two hydrogen atoms and one oxygen atom in a water molecule are attached to each other. There are many possibilities: H-H-O, H-O-H, or O-H-H, for example. Even if the order in which the atoms are attached is known, the atoms may not be arranged in a straight line as indicated above. A structural formula is a diagram that both indicates the composition and number of atoms and illustrates how the atoms are linked to one another. Many figures in the text will use structural formulae. Figures 2.5 and 2.7 are good examples.

Up to this point it has been mentioned that molecules are composed of atoms that are "chemically combined." However, no mention has been made as to how this occurs. We will explore this next.

Chemical Bonds APR

Chemicals are combined when electrons interact to form **chemical bonds,** which join atoms together to form a molecule. A chemical bond is a force of attraction between

two atoms. An atom combines with another atom in order to fill its valence shell. A full valence shell makes an atom more stable. To do this, atoms either (1) receive or lose electrons, which results in the formation of an ionic bond. or (2) share electrons, which leads to the formation of a covalent bond.

Ionic Bonds

Consider the interaction of sodium and chlorine in the formation of sodium chloride (table salt), as shown in figure 2.4. Sodium has a single electron in its valence shell, while chlorine has seven electrons in its valence shell. Note in step 2 of figure 2.4 that, after transferring an electron from sodium to chlorine, sodium now has 11 protons (+) and 10 electrons (-), while chlorine has 17 protons (+) and 18 electrons (-). Thus, the transfer of an electron from sodium to chlorine causes the sodium atom to have a net electrical charge of +1 and the chlorine atom to have a net electrical charge of -1.

Atoms or groups of atoms with a net electrical charge, either positive or negative, are called ions. Thus, the transfer of an electron from sodium to chlorine has (1) resulted in the valence shell of each atom being filled with electrons and (2) produced a sodium ion (Na^+) and a chloride ion (Cl^-) . Positively charged ions, such as Na⁺, are called cations.



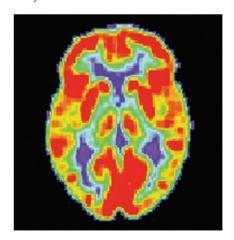
🔂 Clinical Insight -

Nuclear medicine is the medical specialty that uses radioisotopes in the diagnosis and treatment of disease. Very small amounts of weak radioisotopes may be used to tag biological molecules in order to trace the movement or metabolism of these molecules in the body. Special instruments can detect the radiation emitted by the radioisotopes and identify the location of the tagged molecules.

In nuclear imaging, the emitted radiation creates an image on a special photographic plate or computer screen. In this way, it is possible to obtain an image of various organs or parts of organs where the radioisotopes accumulate. Positron emission tomography (PET) uses certain radioisotopes that emit positrons (positively charged electrons), and it enables precise imaging similar to computerized tomography (CT) scans. PET can be used to measure processes, such as blood flow, rate of metabolism of selected substances, and effects of drugs on body functions. It is a promising technique for both the diagnosis of disease and the study of healthy physiological processes.

Another form of nuclear medicine involves the use of radioisotopes to kill cancerous cells. Certain radioisotopes may be attached to specific biological

molecules and injected into the blood. When these molecules accumulate in cancerous tissue, the emitted radiation kills the cancerous cells. A similar effect is obtained by implanting pellets of radioactive isotopes directly in cancerous tissue.



Positron Emission Tomography (PET). Transverse section through the head. The highest level of brain activity is indicated in red, with successively lower levels represented by yellow, green, and blue.

Photo Researchers/Science History Images/Alamy Stock Photo

A simple example of covalent bonding is found in a

molecule of hydrogen gas. A hydrogen atom with a single

electron requires one more electron to fill its valence shell. Two hydrogen atoms can form a molecule of hydrogen gas

(H₂) by sharing their electrons. In this way, the valence

shell of both atoms is complete and a single covalent bond

is formed. The single covalent bond is shown in a struc-

tural formula as a single straight line between chemical symbols for hydrogen (H–H), as is illustrated in figure 2.5a.

Double and triple covalent bonds can also form. A molecule of gaseous oxygen (O_2) is formed when two oxygen atoms share two pairs of electrons. Each oxygen atom

Negatively charged ions, such as Cl⁻, are called *anions*. The force of attraction that holds cations and anions together as an *ionic compound* is an **ionic bond**.

Covalent Bonds

Atoms that form molecules by sharing electrons are joined by **covalent bonds.** The shared electrons orbit around each atom for part of the time so that they may be counted in the valence shell of each atom. Thus, the valence shell of each atom is filled.

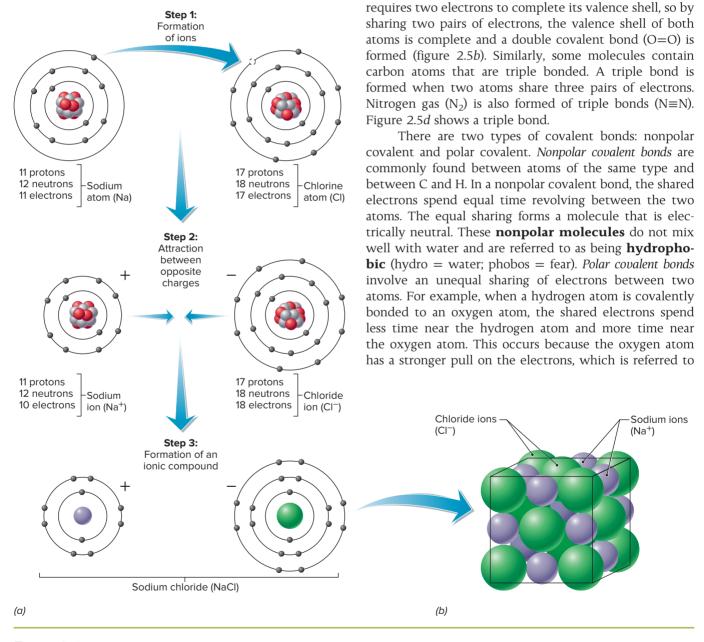


Figure 2.4 The Synthesis of Sodium Chloride by the Formation of an Ionic Bond. (a) The transfer of an electron from sodium to chlorine converts sodium to a cation and chlorine to an anion. (b) The attraction between these oppositely charged ions is an ionic bond.

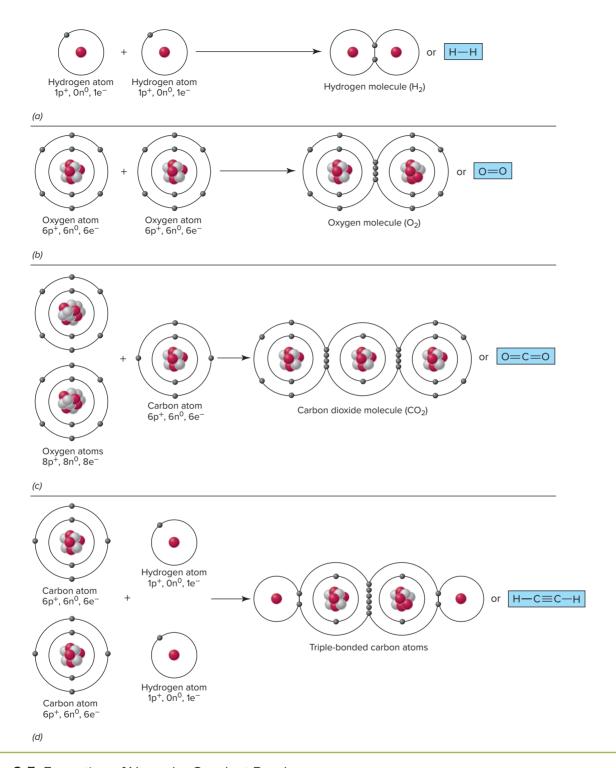


Figure 2.5 Formation of Nonpolar Covalent Bonds.

as *electronegativity*. In this situation the hydrogen atom becomes slightly positively charged, notated as δ^+ , and the oxygen becomes slightly negatively charged, notated as δ^- (figure 2.6). Most molecules formed by polar covalent bonds are called **polar molecules** because different areas of the molecule have a different electrical charge. Polar molecules and ions tend to mix well with water and

are thus referred to as **hydrophilic** (philos = loving). A good rule of thumb in determining whether a substance is hydrophobic or hydrophilic is "like mixes with like." For a substance to mix with water, it must be like water, meaning it must also be electrically charged.

It is important to note that a molecule may contain polar covalent bonds and still be a nonpolar molecule. The

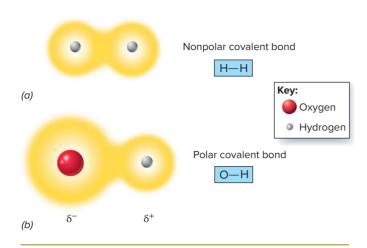


Figure 2.6 Types of Covalent Bonds. Comparison of electron locations in *(a)* nonpolar versus *(b)* polar covalent bonds.

carbon dioxide molecule in figure 2.5c is a great example; while the C=O bonds are polar covalent bonds, the molecule is linear and symmetrical so that the opposing bonds cancel one another, making the entire structure similar (nonpolar) throughout.

Hydrogen Bonds

A hydrogen bond is a weak attractive force between a slightly positive area and a slightly negative area of a polar molecule. These attractions may occur between different sites within the same molecule or between different molecules. They may also occur between polar molecules and ions. Figure 2.7c illustrates how the slightly negative oxygen atom of one water molecule attracts the slightly positive hydrogen atom of a different water molecule to form a hydrogen bond. It is important to note that the bonds between oxygen and hydrogen within one molecule are polar covalent bonds. The hydrogen bonds between water molecules are responsible for many of water's unique characteristics that help support life, which is why space exploration focuses so heavily on identifying other planets with water. For example, based on atomic mass, water should be a gas at room temperature. However, the hydrogen bonds keep water liquid at room temperature. Hydrogen bonds also play an important role in protein and nucleic acid structure, as you will

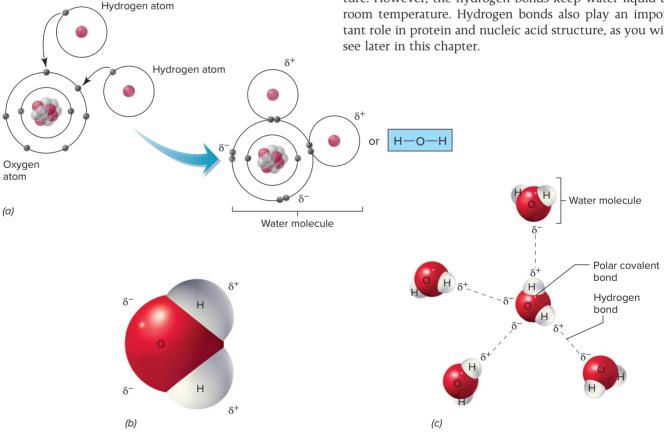


Figure 2.7 Hydrogen Bonds in Water.

(a) The synthesis of a water molecule by the formation of polar covalent bonds. (b) Space-filling model of water molecule. (c) Hydrogen bonds forming between adjacent water molecules.



💙 Check My Understanding

- 3. How do ionic and covalent bonds join atoms to form molecules or compounds?
- 4. How are nonpolar covalent bonds and polar covalent bonds different?
- 5. What are hydrogen bonds?

Chemical Reactions

In chemical reactions, bonds between atoms are formed or broken, and the result is a new combination of atoms. There are four basic types of chemical reactions: synthesis, decomposition, exchange, and reversible reactions. Such reactions occur continuously within the body. In general, a chemical reaction begins with one or more substance(s) referred to as the reactant(s). The reaction occurs and the new combination(s) of atoms is (are) called the product(s). Figure 2.8 shows a few examples of chemical reactions.

Synthesis (anabolic) reactions form new chemical bonds. Energy is required to form new bonds. Atoms or simple molecules combine to form a more complex product. The reaction of hydrogen and oxygen (reactants) to form water (product) is an example. Figure 2.8b shows how energy may be used to combine amino acids to form a protein. Synthesis reactions produce complex molecules used in the growth and repair of body parts. Synthesis reactions may be generalized as

$$A + B \rightarrow AB$$

A decomposition (catabolic) reaction is the opposite of a synthesis reaction. Chemical bonds of a complex molecule are broken to form two or more simpler molecules, releasing energy in the process. For example, water can decompose to form hydrogen and oxygen. Decomposition reactions are used to break down food molecules to form nutrients usable by body cells. Figure 2.8c shows how glycogen may be decomposed to form glucose, thus releasing energy. Decomposition reactions may be generalized as

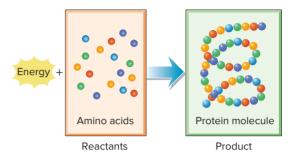
$$AB \rightarrow A + B$$

Exchange (rearrangement) reactions occur when different reactants exchange components, resulting in the breakdown of the reactants and the formation of new products. Thus, exchange reactions involve both decomposition of the reactants and synthesis of the new products. The dehydration synthesis and hydrolysis reactions discussed later in this chapter are examples of exchange reactions. Exchange reactions may be generalized as

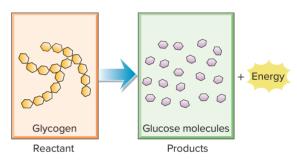
$$AB + CD \rightarrow AD + CB$$



(a) Chemical reaction



(b) Anabolic (or synthesis) reaction



(c) Catabolic (or decomposition) reaction

Figure 2.8 Types of Chemical Reactions.

(a) General example of a chemical reaction. (b) A synthesis reaction uses energy to form bonds, resulting in one or more larger products. (c) A decomposition reaction breaks bonds, releasing energy and resulting in numerous smaller products.

Reversible reactions exist in which the reactants and products may convert in both directions. Several factors determine the reversibility of a reaction, such as energy available and relative abundance of reactants and products. The reactions of chemical buffers are great examples of exchange reactions that are also reversible reactions. Chemical buffers are discussed later in this chapter. Reversible reactions are indicated by a double arrow:

$$A + B \rightleftharpoons AB$$



🔇 Check My Understanding

6. How do synthesis, decomposition, exchange, and reversible reactions differ?

2.3 Substances Composing the Human Body

Learning Objectives

- Distinguish between inorganic substances and organic molecules.
- 8. Explain the importance of water and its locations in the body.
- 9. Compare and contrast electrolytes and nonelectrolytes, and acids and bases.
- 10. Explain the use of the pH scale.
- 11. Explain the importance of buffers.
- 12. Distinguish between carbohydrates, lipids, proteins, and nucleic acids and their roles in the body.
- 13. Explain the role of enzymes.
- 14. Describe the mechanism of enzymatic action.
- 15. Describe the structure and function of adenosine triphosphate (ATP).

Substances composing the human body include both inorganic substances and organic molecules. **Inorganic substances** may contain either carbon or hydrogen in the same substance, *but not both*. Bicarbonates, such as sodium bicarbonate (NaHCO₃), are an exception to this rule. **Organic molecules** always contain *both* carbon and hydrogen, and they usually also contain oxygen. Recall from chapter 1 that large complex molecules are called *macromolecules*. The carbon atoms form the "backbone" of organic macromolecules.

Major Inorganic Substances

The major inorganic substances in the body are water, most acids and bases, and inorganic salts. Acids, bases, and mineral salts **ionize** to release ions when dissolved in water, as you will see shortly.

Water

Water is by far the most abundant molecule found within cells and in the extracellular fluid. Water composes about two-thirds of the body weight. Water generally occurs within the body as part of a mixture called an aqueous solution. A solution is a mixture composed of a solvent and one or more solutes. A solvent is a liquid used to dissolve or suspend substances. Solutes are the substances dissolved or suspended in the solvent. In this aqueous solution, water is acting as a solvent. Recall from earlier in the chapter that water is a solvent for electrically charged substances, such as polar molecules and ions. Chemical reactions that occur in the body take place in this aqueous solution. Water is used to transport many solutes throughout the body, through the plasma membrane of a cell, or from one part of the cell to another. Another function of water is that it is a great lubricant in the body.

Water is also important in maintaining a constant cellular temperature, and thus a constant body temperature, because it absorbs and releases heat slowly. Evaporative cooling (sweating) through the skin also involves water. Another function of water is as a reactant in the breakdown (hydrolysis) of organic molecules.

The specific locations where water is found in the body are called *water compartments*. They are

Intracellular fluid (ICF): fluid within cells; about 65% of the total body water.

Extracellular fluid (ECF): all fluid not in cells; about 35% of the total body water.

Interstitial fluid (tissue fluid): fluid in spaces between cells.

Plasma: fluid portion of blood. Lymph: fluid in lymphatic vessels.

Transcellular fluids: fluid in more limited locations, such as serous fluid, cerebrospinal fluid (CSF–located within and around the brain and spinal cord), and synovial fluid (in certain joints).

Electrolytes APR

When ionic compounds are dissolved in water, they tend to ionize (dissociate), releasing ions. The process of ionization involves the formation of *hydration spheres* by water using its polar nature to separate ions from each other (figure 2.9a). Such compounds are called **electrolytes** (ē-lek'-trō-lītz) because when dissolved they can conduct an electrical current. Acids, bases, and salts are types of electrolytes (figure 2.10). Substances that dissolve in water without ionizing and therefore do not conduct electrical current are termed **nonelectrolytes**, such as the glucose molecule in figure 2.9b. Nonelectrolytes are usually organic molecules, which are discussed later in the chapter. The composition and concentration of electrolytes and nonelectrolytes in the body must be kept within narrow limits to maintain homeostasis.

Acids and Bases

An **acid** is a chemical that releases **hydrogen ions (H⁺)** into solution.

The stronger the acid, the greater is the degree of ionization, which results in a greater concentration of H^+ . Hydrochloric acid (HCl) is a strong acid. It ionizes into hydrogen and chloride ions (H^+ and Cl^-).

$$HCI \rightarrow H^+ + CI^-$$

A **base** decreases the concentration of H^+ in a solution by combining with the H^+ . The stronger the base, the greater is its ability to combine with H^+ . Some bases combine directly with H^+ . Other bases, such as sodium

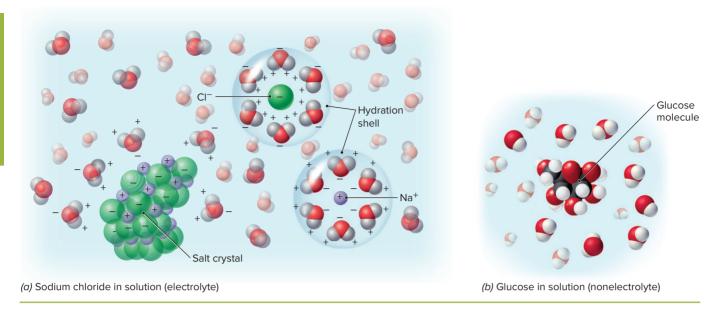


Figure 2.9 Comparison of an Electrolyte and a Nonelectrolyte in an Aqueous Solution.

hydroxide (NaOH), ionize to release hydroxide ions (OH⁻), which combine with H⁺ to form water.

$$NaOH \rightarrow Na^{+} + OH^{-}$$

 $H^{+} + OH^{-} \rightarrow HOH$

The symbol **pH** is a measure of the hydrogen ion concentration in a solution.

Measurement of pH Chemists have developed a pH scale that is used to indicate the measure of acidity or alkalinity (basicity) of a solution, meaning the relative concentrations of hydrogen ions (H⁺) and hydroxide ions (OH⁻) in a solution. The **pH scale** ranges from 0 to 14. These ions are equal in concentration at pH 7, so a solution with a pH of 7 is neither an acid nor a base and is referred to as neutral. For example, pure water has a pH of 7.

Acids contain more H⁺ than OH⁻ and have a pH less than 7. Bases contain more OH⁻ than H⁺ and have a pH greater than 7. There is a tenfold difference in the concentrations of H⁺ and OH⁻ when the pH changes by one unit. For example, an acid with a pH of 4 has a concentration of H⁺ that is 10 times greater than that of an acid with a pH of 5. Some examples of pH values for body fluids include blood (7.4), stomach acid (1-2), urine (6), and intestinal fluid (8).

Buffers Cells of the body are especially sensitive to pH changes. Even slight changes can be harmful. The hydrogen ion concentration (pH) of blood and other body fluids is maintained within narrow limits by the lungs, kidneys, and buffers in body fluids. A **buffer** is a chemical or a combination of chemicals that either picks up excess H⁺ or releases H⁺ to keep the pH of a solution rather

constant. The carbonic acid-bicarbonate buffer system illustrated in figure 2.11 is the most important buffer system in the body. Notice that carbonic acid and bicarbonate ions react in a reversible reaction whose direction is determined by pH.

Buffers are extremely important in maintaining the healthy pH of body fluids, but they can be overwhelmed by a disruption of homeostasis. The healthy pH of the arterial blood is 7.35 to 7.45. In *acidosis*, the pH is less than 7.35, and a patient could go into a coma. In *alkalosis*, the pH range is greater than 7.45, and a patient may have uncontrolled muscle contractions. Extreme variations, outside of 6.8–8.0, may be fatal.

Salts

Like acids and bases, salts are ionic compounds that ionize in an aqueous solution, but they do not produce

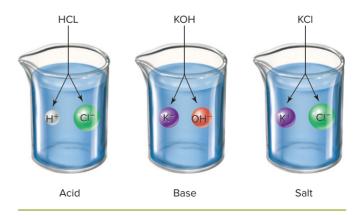


Figure 2.10 Ionization in Water. lonization of an acid, a base, and a salt in water.

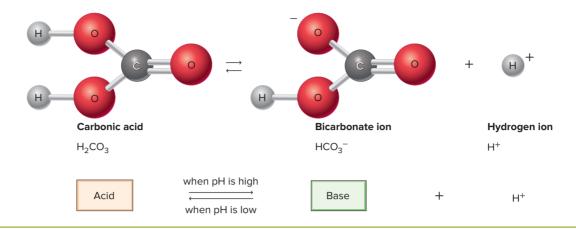


Figure 2.11 Carbonic Acid—Bicarbonate Buffer System.

Carbonic acid ionizes to release H⁺ when pH is high. Bicarbonate ion combines with H⁺ when pH is low.

hydrogen or hydroxide ions. The most important salts in the body are sodium, potassium, and calcium salts. Calcium phosphate is the most abundant salt because it is a main component of bones and teeth. Sodium chloride (NaCl), a common salt in body fluids, ionizes into sodium and chloride ions (Na⁺ and Cl⁻).

$$NaCI \rightarrow Na^{+} + CI^{-}$$

Salts provide ions that are essential for healthy body functioning. Physiological processes in which ions play an essential role include blood clotting, muscle and nervous functions, and pH and water balance (table 2.1).



Check My Understanding

- 7. Where is water located in the body and why is it so important?
- 8. What is the relationship between acids, bases, and pH?
- 9. What are salts and why are they important?

Major Organic Molecules

The major organic macromolecules of the body are carbohydrates, lipids, proteins, and nucleic acids (table 2.2). Another molecule, adenosine triphosphate (ATP), is also considered here because it plays such a vital role in the transfer of energy within cells.

Before beginning a study of the various organic molecules, it is important to understand one reversible reaction that will help to clarify a great deal about how biochemistry (chemistry in living things) in general works. The reaction involves two processes, dehydration synthesis and hydrolysis. **Dehydration synthesis** literally means "remove water to bond together," while **hydrolysis** means "break with water." Figure 2.12*a* shows that in dehydration synthesis one molecule gives up a hydrogen atom, which then combines with a *hydroxyl group* (–OH) given up by a second molecule to form water. The two molecules involved will need to re-form bonds where the H and –OH were removed in order to refill their valence shells. They satisfy this need by combining with each other,

 Table 2.1
 Important Inorganic Ions

lon	Symbol	Functions
Bicarbonate	HCO ₃ -	Helps maintain acid–base balance
Calcium	Ca ²⁺	Major component of bones and teeth; required for muscle contraction and blood clotting
Carbonate	CO ₃ ²⁻	Major component of bones and teeth; helps maintain acid—base balance
Chloride	CI-	Helps maintain water balance
Hydrogen	H ⁺	Helps maintain acid-base balance
Hydroxide	OH-	Helps maintain acid-base balance
Phosphate	PO ₄ ³⁻	Major component of bones and teeth; required for energy transfer; helps maintain acid-base balance
Potassium	K ⁺	Required for muscle and nervous function
Sodium	Na ⁺	Required for muscle and nervous function; helps maintain water balance

 Table 2.2
 Important Organic Molecules

Macromolecule	Building Units	Examples	Functions
Carbohydrates	Monosaccharides	Glucose	Primary energy source for cells
	(simple sugars)	Starch	Storage form in plants; common in plant foods
		Glycogen	Storage form in animals; stored in liver and muscles
Lipids	Glycerol, fatty acids	Triglycerides (fats)	Energy source and storage
	Diglyceride, phosphate group	Phospholipids	Cell structure
	Cholesterol (4C rings)	Steroids	A variety of functions (e.g., sex hormones promote sexual development)
Proteins	Amino acids	Structural proteins	Cell structure
		Functional proteins	Nonstructural functions (e.g., catalyze chemical reactions and chemical transport)
Nucleic acids	Nucleotides	DNA	Storage of genetic information
		RNA	Processing of genetic information leading to protein synthesis
		ATP	Energy carrier for cellular processes

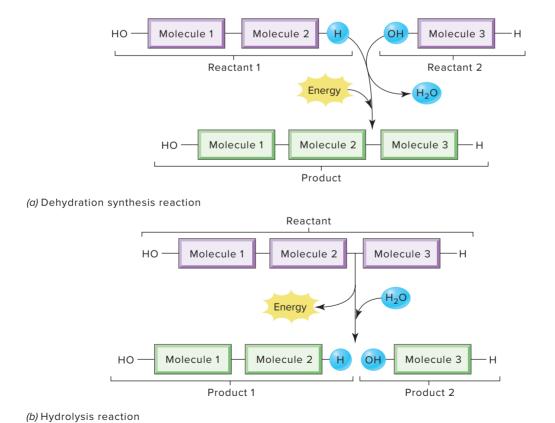


Figure 2.12 Common Reactions Involving Organic Molecules. Basic model for *(a)* dehydration synthesis and *(b)* hydrolysis reactions.

forming a new bond. In a hydrolysis reaction (figure 2.12b), the opposite occurs. Water "attacks" a chemical bond between two molecules, causing it to break. The resulting molecules have extra electrons that bind to the water molecule and split it, with H bonding to one molecule and –OH bonding to the other. Understanding this mechanism will assist your understanding of how organic macromolecules are synthesized and decomposed.

Carbohydrates

Carbohydrates (kar"-bo-hi 'drātz) are formed of carbon, hydrogen, and oxygen. In each carbohydrate molecule, there are two hydrogen atoms for every carbon and oxygen atom. Therefore, C, H, and O are said to have a 1:2:1 ratio. Carbohydrates are the primary source of nutrient energy for cells of the body. Carbohydrates are classified according to molecular size as monosaccharides, disaccharides, or polysaccharides (figure 2.13).

The simplest carbohydrates are **monosaccharides** (mon- \bar{o} -sak'-ah- $r\bar{i}$ ds). For example, **glucose** ($C_6H_{12}O_6$) is a six-carbon monosaccharide (hexose) that is the major carbohydrate fuel for cells. It is often called blood sugar because it is the form in which carbohydrates are transported to body cells. Fructose and galactose are other hexoses found in foods. Glucose, fructose, and galactose have the same molecular formula ($C_6H_{12}O_6$) but are chemically bonded differently. Molecules with the same molecular formula but different structures are called *isomers*. Monosaccharides are the *building units* that chemically combine to produce larger carbohydrates.

The chemical combination of two monosaccharides forms a **disaccharide** ($d\bar{i}$ -sak'-ah- $r\bar{i}$ d), a double sugar. The common disaccharides in foods are *maltose*, or malt sugar (glucose + glucose); *sucrose*, or table sugar (glucose + fructose); and *lactose*, or dairy sugar (glucose + galactose). Collectively, monosaccharides and disaccharides are called *simple sugars* and are used only as a source of energy.

A **polysaccharide** (pol-ē-sak'-ah-rīd) is a macromolecule formed by the chemical combination of many monosaccharide units. Two polysaccharides are important to our study: glycogen and starch. Both are formed of many glucose units. Glycogen and starch are sometimes referred to as *complex carbohydrates*. Complex carbohydrates are a source of energy and also make up the fiber in our diets.

Glycogen is the storage form of carbohydrates in animals, including humans. Some of the excess glucose in blood is converted into glycogen and stored primarily in the liver, but small amounts are stored in muscle cells. Glycogen serves as a reserve energy supply that can be quickly converted into glucose. For example, whenever the level of blood glucose declines, the liver converts glycogen into glucose via catabolic (hydrolysis) reactions to increase the blood glucose level.

Starch is the storage form of carbohydrates in plants, so it is present in many foods derived from plants.

Lipids

Lipids are a large, diverse group of organic macromolecules that consist of carbon, hydrogen, and oxygen atoms. Carbon atoms form the backbone of the molecules, and there are many times more hydrogen atoms than oxygen atoms. The most abundant lipids in the body are triglycerides (fats), phospholipids, and steroids.

Molecules of **triglycerides** (tri-glys'-er-ids), or **fats**, consist of one **glycerol** (glys'-er-ol) molecule and three **fatty acid** molecules joined together (figure 2.14). Triglycerides are the most concentrated energy source found in the body and are the most abundant lipids in our diet. Excess nutrients (energy reserves) are stored as triglycerides in the adipocytes (fat cells) of the body, primarily around internal organs and beneath the skin. Fats are nonpolar molecules that do not mix well with water, meaning they are *hydrophobic*.

Phospholipids (fos'-fo-lip'-idz) are molecules similar to triglycerides. The basic difference is that one of the fatty acids is replaced with a phosphate group. Table 2.1 shows a phosphate group, which is a very important component of many organic molecules. Unlike fats, phospholipids are partially soluble in water, or amphiphilic. The end of the molecule with the phosphate group is polar and therefore soluble in water but not in lipids, while the end with the two fatty acids is nonpolar and therefore lipid-soluble but insoluble in water. Thus, phospholipids can join-or serve as an interface between a water environment on one side and a lipid environment on the other. They are major components of plasma membranes that surround cells and certain organelles within the cell (see chapter 3). Figure 2.15 shows the basic structure of a phospholipid molecule.

Steroids constitute another group of lipids, and their molecules characteristically contain four carbon rings. Cholesterol (kō-les'-ter-ol), vitamin D, certain adrenal hormones, and sex hormones are examples of steroids. Figure 2.16 shows several examples of steroids. Cholesterol is an essential component of body cells and serves as the raw material for the synthesis of other steroid molecules.

Proteins

Proteins (pro'-tēns) are large, complex macromolecules composed of smaller molecules (building units) called **amino acids**. There are 20 different kinds of amino acids used in building proteins, and each is composed of carbon, hydrogen, oxygen, and nitrogen. Each amino acid consists of a central C atom that is attached to four separate components. Three components are the same in all amino acids. The first is simply a hydrogen atom, and the other two

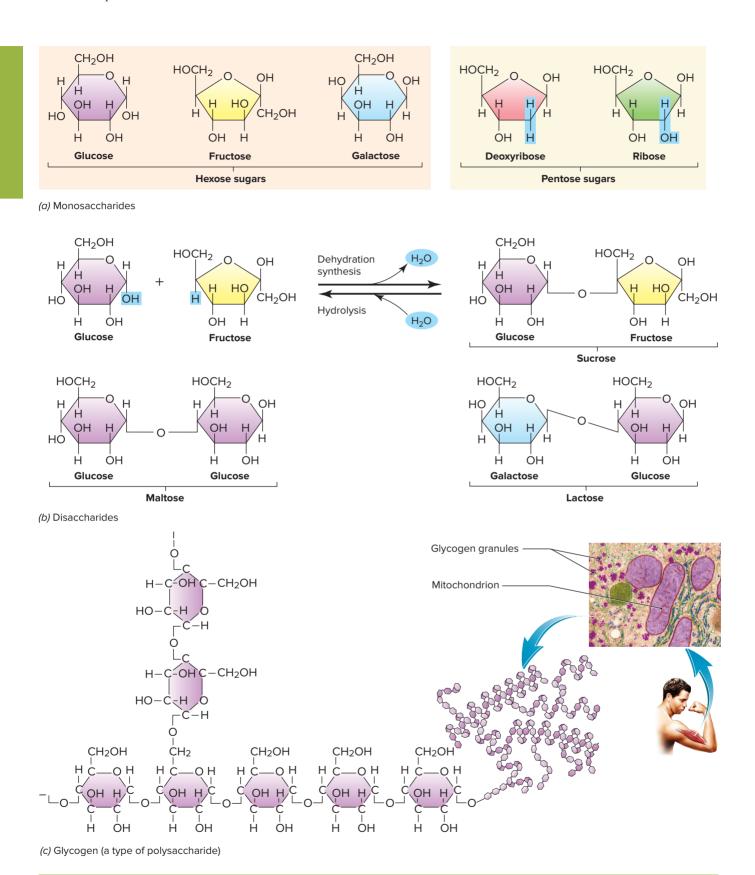


Figure 2.13 Carbohydrates.

(a) The building units of carbohydrates are monosaccharides. (b) Two monosaccharides combine to form a disaccharide. (c) The combination of many monosaccharide units forms a polysaccharide.

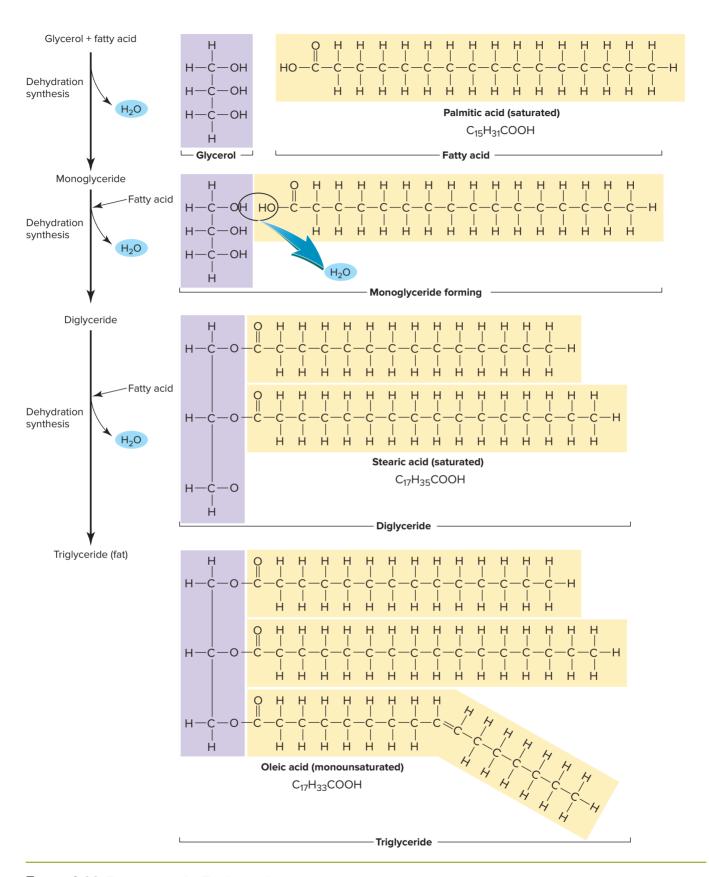


Figure 2.14 Formation of a Triglyceride.

A triglyceride molecule consists of three fatty acids joined to a glycerol molecule by three successive dehydration synthesis reactions.

Clinical Insight

Triglycerides may be classified as either saturated or unsaturated fats. In saturated fats (e.g., animal fats), the bonds of the carbon atoms in the fatty acids are saturated (filled) by hydrogen atoms so that the carboncarbon bonds are all single bonds. Saturated fats, such as butter and lard, are solid at room temperature. Excessive saturated fats in the diet are associated with an increased risk of heart disease (coronary artery disease).

In unsaturated fats (plant oils), not all carbon bonds in the fatty acids are filled with hydrogen atoms, and one or more double carbon-carbon bonds are present. Fatty acids of monounsaturated fats (e.g., olive, peanut, and canola oils) have one carbon-carbon double bond; those of polyunsaturated fats (e.g., corn,

safflower, and soy oils) have two or more carbon-carbon double bonds. Unsaturated fats occur as oils at room temperature.

Hydrogenation, the process of adding hydrogen atoms to unsaturated fats, converts most carboncarbon double bonds to carbon-carbon single bonds and changes vegetable oil to a solid (e.g., margarine) at room temperature. This process also changes the bonding pattern of some fatty acids to form trans fats, which increase the risk of coronary artery disease even more than do saturated fats. It is better to cook with oils than with lard or margarine because saturated and trans fats are more easily converted into the "bad" cholesterol associated with heart disease.

