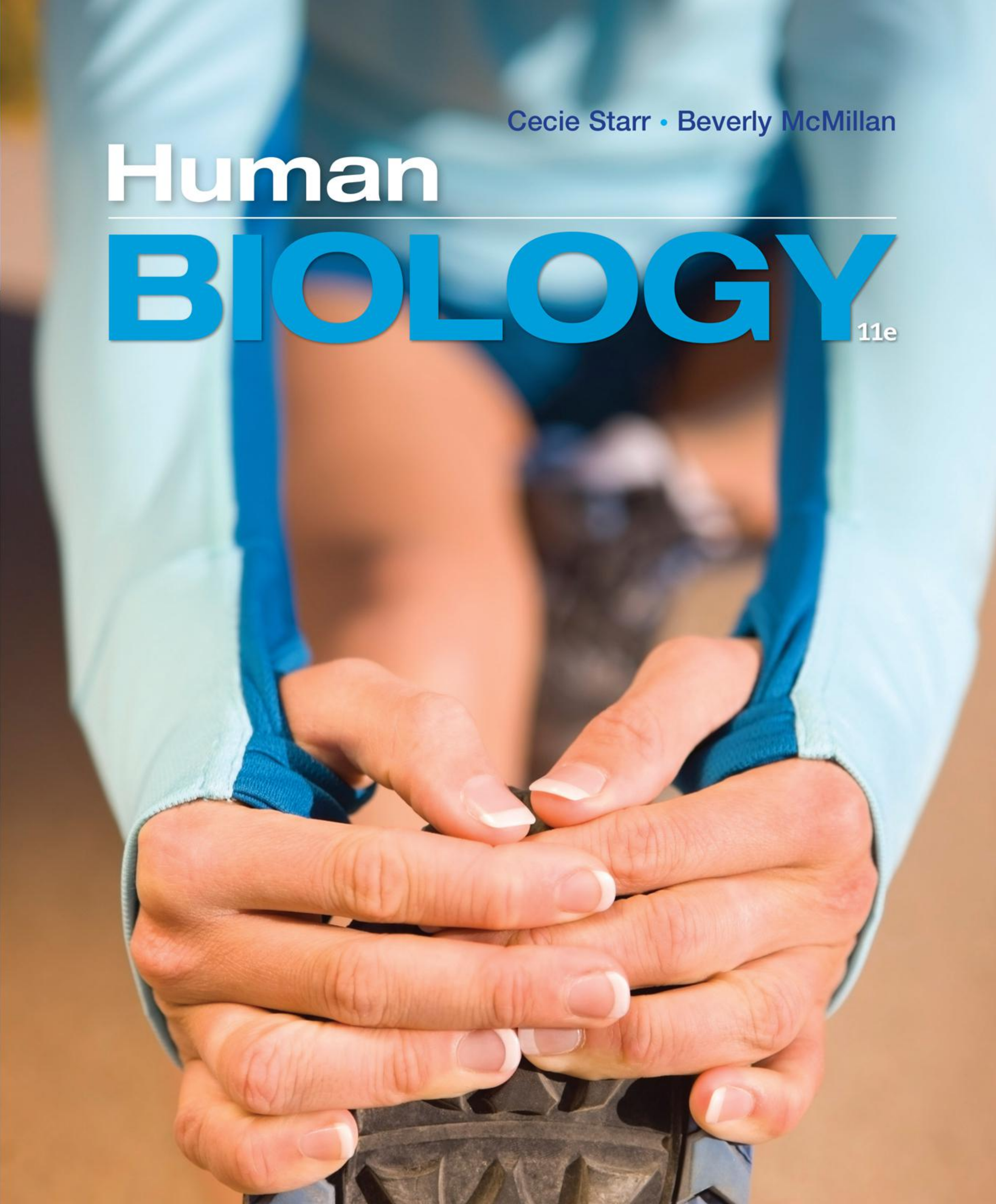
Cecie Starr • Beverly McMillan

Human BIOLOGY

11e



HUMAN BIOLOGY

Eleventh Edition

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Cecie Starr

Beverly McMillan

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***Human Biology*, Eleventh Edition**
Cecie Starr and Beverly McMillan

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Preface

This new edition of *Human Biology* continues our dedication to providing an accessible, relevant, and appealing introduction to the study of the human body. Although most students who use this book will not become scientists, all can benefit from a better understanding of body structures and their functions and from the real-world application of basic biological concepts and principles. Knowing how cells, tissues, organs, and organ systems work will help students make informed choices about lifestyle and nutrition, while having a deeper understanding of common diseases and disorders will help them navigate issues related to health care. In addition, some background in ecology will help them grasp why human activities such as adding greenhouse gases to the atmosphere put us and other species at risk. In this way, as they progress through this text, students will learn both the core concepts of human biology and how they apply to everyday situations, preparing them to make well-informed decision in their lives.

Features of This Edition

Each chapter opens with a concise real-life story and an engaging—and often dramatic—photograph. More than half of the streamlined opening stories are new to this edition. A brief *Links to Earlier Concepts* summary reminds students of relevant information that has been covered in previous chapters, and *Key Concepts* statements preview the current chapter's content. An eye-catching photograph or graphic that appears in icon form next to each key concept also occurs within a relevant section, as part of a visual message that threads through the chapter.

Sections The content of every chapter is organized as a series of Concepts, each explored in a numbered section that is two pages or less. A section's title reflects its concept, and sentence-style subsection headers guide students through the discussion. Bulleted sentences in the *Take-Home Message* summarize and reinforce the Concept and the section's supporting information.

Focus on Human Impact Our new *Focus on Human Impact* feature enriches the chapter's relevance to students' lives by exploring the impacts of our collective activities and individual choices on real-world concerns. For example, in Chapter 8, the *Focus on Human Impact* feature examines the challenges and benefits of blood donation efforts. In Chapter 16 it explores the growing commerce in human eggs used in assisted reproduction technologies.

On-Page Glossary As in the previous edition, an on-page glossary presents boldface key terms introduced in each section. This section-by-section glossary offers definitions in alternate wording and can also be used as a quick study and review aid. All terms are available in the end-matter glossary as well.

Self-Assessment Tools As with the previous edition, each text section closes with a focused *Take-Home Message* that allows students to check their grasp of the section contents before moving on. At the end of each chapter, Review, Self-Quiz, and Critical Thinking questions provide students with the opportunity to assess their understanding of the chapter's concepts. A graphic "thumbnail" from chapter sections serves as a visual reminder of each section's main content.

Enhancement Features As with the previous edition, *Think Outside the Book* features point students to opportunities to use library or online resources to learn more about a "real-world" subject related to a chapter's content. Concise *Explore on Your Own* exercises allow students to delve deeper into a selected chapter topic. At the close of each chapter a brief, timely, illustrated *Your Future* paragraph gives students a glimpse of promising developments on the frontiers of medical or genetic research.

Chapter-Specific Changes

Chapter 1 illustrates scientific methodology with a University of Missouri case study of how the protein content of breakfast influenced hunger and appetite in female college students. *Focus on Health*, which introduces coverage of infectious disease threats, adds a graphic on hand washing and other practices that can help prevent disease spread.

Chapter 2 introduces basic chemistry with a new opening vignette on phytochemicals in common foods. New graphics illustrate the shell model of atomic structure and ionic and covalent bonding. Updated photographs illustrate protein denaturation by heat and acids.

Chapter 3 illustrates different types of microscopy with new photographs and a new feature on microbiomes in the human body. A *Focus on Human Impact* feature focuses on the spread of cholera in Haiti in the aftermath of the 2010 earthquake.

Chapter 4 begins with an updated vignette on applications of stem cell technology. The chapter contains new photographs and improved graphics throughout.

Chapter 5 has updated illustrations and explores current ideas on vitamin D's physiological role in a new *Think Outside the Book*.

Chapter 6 introduces the muscular system with a new vignette on lab testing of oxygen use by working skeletal muscles. Several vivid new graphics and images enhance text discussions of the structure and functioning of whole skeletal muscles.

Chapter 7 uses new and reorganized graphics to show the heart's basic anatomy and location in the chest. An improved table and new illustration enhance Section 7.5 on blood pressure. Section 7.8 updates the chapter's coverage of cardiovascular disorders and treatment options for them.

Chapter 8 launches with a new vignette on blood typing, illustrated by a photograph of heart surgery underway. Revisions to Section 8.7, which covers hemostasis and blood clotting, include improved graphics to illustrate both topics. A *Focus on Human Impact* feature discusses the ongoing need for blood donors and procedures for becoming a donor.

Chapter 9 has new art to illustrate the workings of the complement system, antibody binding, and both cell-mediated and antibody-mediated immunity. Fresh art also appears in the reworked subsection on allergies.

Chapter 10's discussion of ventilation is illustrated by an improved graphic showing the related muscle movements. We also reworked the graphic illustrating the Heimlich maneuver. Updates include discussions of sleep apnea and the current controversy over electronic cigarettes in Section 10.7 on respiratory system disorders, with corresponding new photographs.

In **Chapter 11**, new micrographs help illustrate the structure of the small intestine's absorptive surface, and new artwork clearly shows the steps by which various types of nutrients are digested and absorbed. The updated section on human nutritional requirements presents the latest government guidelines for healthy eating. The discussion of vitamins and minerals includes up-to-date thinking on the nutritional importance of phytochemicals. Following the chapter's discussion of eating disorders, a *Focus on Human Impact* feature discusses efforts to reduce food waste in the United States and elsewhere.

Chapter 12 has a new diagram of kidney nephrons and the arterioles and capillaries associated with them.

In **Chapter 13**, reworked graphics provide an overview of information flow in the nervous system and show the structure of motor neurons. *Think Outside the Book* points interested students to the Human Connectome Project's efforts to map the brain's neural wiring. A new *Science Comes to Life* feature explores the use of technologies such as functional magnetic resonance imaging to study brain function and disorders. An updated *Focus on Health* includes the substances known as "bath salts," "Spice," and K2 in the discussion of psychotropic drugs.

Chapter 14 on sensory systems begins with a new opening vignette on the biology of itching. A simplified introduction to sensory receptors outlines the three main forms of receptors: free nerve endings, encapsulated receptors, and receptors that synapse directly with sensory neurons.

Chapter 15 has a fresh beginning with the story of Sultan Kosen, whose (now treated) pituitary tumor made him famous as possibly being the tallest man alive. The chapter also considers the suspected endocrine disrupting effects of phthalates in a new *Focus on Our Environment* feature.

For **Chapter 16**, a new opening vignette on the increasing use of assisted reproductive technologies (ART) introduces the chapter's discussion of reproductive systems. New graphics illustrate the ovarian cycle and the most common options for ART. Striking new images show pathogens responsible for a range of STDs. The section of reproductive cancers has an expanded discussion of prostate cancer. A *Focus on Human Impact* feature discusses the lucrative commerce in "donated" oocytes for use in assisted reproduction.

Chapter 17 has more explanatory and streamlined graphics to illustrate cleavage, early embryonic development, and development of extraembryonic membranes. It also provides an expanded discussion of lactation.

Chapter 18 revisions include new photographs to illustrate cytokinesis in animal cells and how events in meiosis produce the genetic and phenotypic diversity we observe in human populations.

Chapter 19 has a new opening vignette that uses the example of freckling to introduce concepts of heredity. Inheritance patterns of this and other familiar traits are used throughout the chapter in streamlined discussions of the role of probability in determining genetic outcomes, independent assortment, and other basic genetic concepts. In keeping with current research in human genetics, the chapter section on gene interactions (19.5) emphasizes the polygenic basis of traits such as eye color and skin color.

Chapter 20's discussions of chromosomes and human genetics includes general updating, a new example to illustrate the use of pedigree analysis, and numerous new photographs.

Chapter 21 uses a new opening vignette on the buccal (cheek) swab technique of obtaining cells for DNA analysis. A new example, spinal muscular dystrophy, illustrates the topic of expansion mutations as causes of human genetic disorders. Graphic improvements clarify the diagram of mRNA translation. Updates include outcomes of the Human Genome Project (HGP), the current status of gene therapy efforts, and recent uses of biotechnology in plant genetic engineering and animal cloning. *Your Future* alerts students to the discoveries of the 1,000 Genomes Project, which is rapidly adding to the knowledge gained from HGP analysis.

Chapter 22 has updated information on the sites and types of major cancers in males and females and updated text and graphics related to cancer diagnosis, treatment, and prevention.

Chapter 23 revisions include new graphics depicting *Homo habilis* and comparing the skeletal organization of modern primates (gorillas and humans). Updates on the emergence of early humans reflect recent interpretations of fossil evidence for the divergence of *Homo sapiens* and *H. erectus*, and interpretation of DNA evidence for interactions between modern non-African humans and Neanderthals.

Chapter 24 revisions include an updated opening vignette on wildfires in the western United States and striking new photographs to illustrate the food web concept.

Chapter 25 includes updates to the graphic on human population growth to reflect current estimates and streamlines the discussion of total fertility rate. Updating of sections on air pollution, climate change, solid waste management, and renewable energy sources includes numerous new photographs.

Student and Instructor Resources

MindTap for *Human Biology* 11e MindTap is a fully online, highly customizable learning experience built upon Cengage Learning content. MindTap combines student learning tools—readings, multimedia, activities, and assessments—into a singular Learning Path that guides students through their course. Instructors personalize the experience by customizing authoritative Cengage Learning content and learning tools, including the ability to add their own content in the Learning Path via apps that integrate into the MindTap framework seamlessly with Learning Management Systems. New to this edition are assignable problems and a digital Study Guide.

Cognero for *Human Biology* 11e Cengage Learning Testing Powered by Cognero is a flexible, online system that allows you to:

- author, edit, and manage test bank content from multiple Cengage Learning solutions
- create multiple test versions in an instant
- deliver tests from your LMS, your classroom, or wherever you want

Instructor's Companion Site for *Human Biology* 11e Everything you need for your course in one place! This collection of book-specific lecture and class tools is available online via www.cengage.com/login. Access and download PowerPoint® presentations, images, an instructor's manual, videos, and more.

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LEARNING ABOUT HUMAN BIOLOGY

1

LINKS TO EARLIER CONCEPTS

In this textbook, be on the lookout for a basic theme in biology: Complex structures and functions often emerge from the interactions of simpler ones.

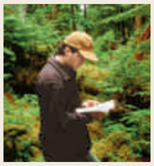
KEY CONCEPTS

Shared Features of Life

Living things have features that are not found in nonliving objects. These shared features include DNA, the genetic material, and the need to maintain a state of internal stability called homeostasis.

Life's Organization and Diversity

Nature is organized from simple to complex. The broadest level of life's organization is the biosphere—the whole living world. Sections 1.2–1.3



Studying Life

Critical thinking is the foundation for science. It also is valuable in many life decisions. Sections 1.4–1.7

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Even if you have never "officially" studied biology, you already know a lot about one living thing: yourself. You also have learned a lot about the natural world simply by experiencing it—from nonliving things like water and rocks to living ones like plants, bugs, and a trusty pet. We can study nature, including ourselves, in ways that may help us better understand the natural world and our place in it. That's what this book is for—to give you a fuller understanding of how your body works and where we humans fit in the larger world.

This first chapter of our survey of human biology starts with basic features shared by all forms of life. It sets the stage for a deeper journey into human biology, including a brief introduction to the chemical foundations of life, how our body cells are built and operate, and how the body's tissues, organs, and organ systems function.

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1.1 Shared Features of Life

■ **Several basic characteristics allow us to distinguish between living things and nonliving objects.**

cell An organized unit that can survive and reproduce by itself, using energy, necessary raw materials, and DNA instructions.

homeostasis A state of overall internal chemical and physical stability that is required for survival of cells and the body as a whole.

Living and nonliving things are all alike in some ways. For instance, both are made up of nature's fundamental substances, the elements (examples are carbon and hydrogen), which we will discuss in Chapter 2. On the other hand, all living things share some features that nonliving ones don't have. There are five basic characteristics of life.

1. **Living things consist of one or more cells.** A **cell** is an organized unit that can live and reproduce by itself, using energy, the required raw materials, and instructions in the genetic material DNA. Figure 1.1 shows a living bone cell. Cells are the smallest units that can be alive.
2. **Living things take in and use energy and materials.** Like other animals, and many other kinds of organisms, we humans take in energy and materials by consuming food (Figure 1.2). Our cells use the energy and raw materials in food to build and operate in ways that keep us alive. The energy for all cell activities comes from another special chemical found only in living things, ATP.
3. **Living things sense and respond to changes in the environment.** For example, a plant wilts when the soil around its roots dries out, and you might put on a sweater on a chilly afternoon.

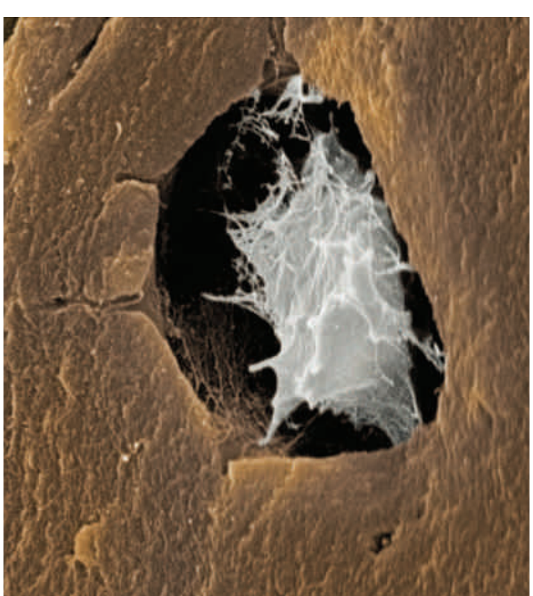

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Figure 1.1 Cells are the basic units of life. This is a picture of a bone cell.

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Figure 1.2 Humans take in energy by eating food. This girl's body will extract energy and raw materials from the raspberries perched on her fingers and use them for processes that are required to keep each of her cells, and her body as a whole, alive.

4. **Living things maintain homeostasis.** Changes inside and outside of organisms affect the ability of cells to carry out their activities. Mechanisms that maintain an overall internal state of chemical and physical stability compensate for these changes. This overall internal stability, called **homeostasis** (hoe-me-oh-STAY-sis, "staying the same"), is necessary for the survival of cells and, ultimately, for the survival of the body as a whole. How the human body's organ systems contribute to homeostasis is a major theme of this textbook.
5. **Living things reproduce and grow.** Organisms can make more of their own kind, based on instructions in DNA. Guided by DNA instructions, most organisms develop through a series of life stages. For us humans, the basic life stages are infancy, childhood, adolescence, and adulthood.

TAKE-HOME MESSAGE

WHAT CHARACTERISTICS SET LIVING ORGANISMS APART FROM NONLIVING OBJECTS?

- Living things are built of one or more cells, take in and use energy and materials, and sense and can respond to changes in their environment.
- Living things can reproduce and grow, based on instructions in DNA.
- The cell is the smallest unit that can be alive.
- Organisms maintain homeostasis by way of mechanisms that keep conditions inside the body within life-supporting limits.

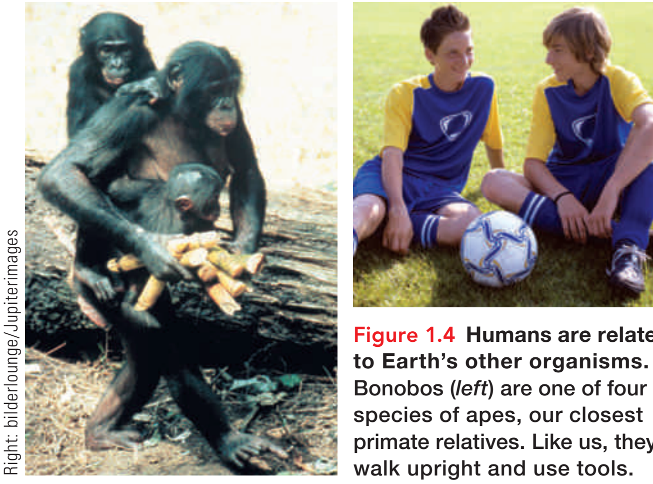
1.2 Our Place in the Natural World

- Human beings arose as a distinct group of animals during an evolutionary journey that began billions of years ago.

Humans have evolved over time

The term "evolution" means change over time. Chapter 23 explains how populations of organisms may evolve by way of changes in DNA. This biological evolution is a process that began billions of years ago on the Earth and continues today. In the course of evolution, major groups of life forms have come into being.

Figure 1.3 provides a snapshot of how we fit into the natural world. Humans, apes, and some other closely related animals are **primates** (PRY-mates). Primates are mammals, and mammals make up one group of **vertebrates** (VER-tuh-braytes), "animals with backbones." Of course, we share our planet with millions of other animal species, as well as with plants, fungi, countless bacteria, and other life forms. Biologists classify living things according to their characteristics, which in turn reflect their evolutionary heritage. Notice that Figure 1.3 shows three domains of life. Animals, plants, fungi, and microscopic organisms called protists are assigned to kingdoms in a domain called Eukarya (you-KARE-ee-uh). The other two domains are reserved for bacteria and some other single-celled life forms. Some biologists prefer different schemes. For example, for many years all living things were simply organized into five kingdoms—animals, plants, fungi, protists, and bacteria. The key point is that despite the basic features all life forms share, evolution has produced a living world of incredible diversity.



Left: Rich Buzzelli/Tom Stack & Associates
Right: bilderlounge/Jupiterimages

Figure 1.4 Humans are related to Earth's other organisms. Bonobos (*left*) are one of four species of apes, our closest primate relatives. Like us, they walk upright and use tools.

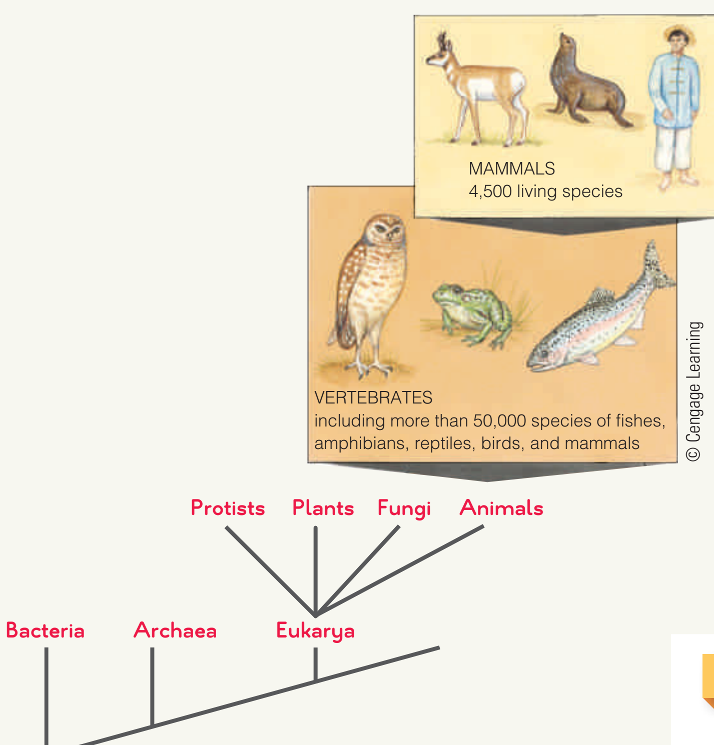


Figure 1.3 Animated! Organisms are classified into groups according to their characteristics. Humans are one of more than a million species in the animal kingdom, which is part of the domain Eukarya. Plants, fungi, and some other life forms make up other kingdoms in Eukarya. The domains Bacteria and Archaea contain vast numbers of single-celled organisms.

Humans are related to all other living things—but we have some distinctive characteristics

Due to evolution, humans are related to every other life form and share characteristics with many of them. For instance, we and other mammals are the only vertebrates that have body hair. We share the most features with apes, our closest primate relatives (Figure 1.4). We humans also have some distinctive features that appeared as evolution modified traits of our primate ancestor. For example, we have great manual dexterity due to the way muscles and bones in our hands are arranged and how our nervous system has become wired to operate them. Even more astonishing is the human brain. This extraordinarily complex organ gives us the capacity for sophisticated language and analysis, for developing advanced technology, and for a huge variety of social behaviors.

primates Distinct group of mammals that includes humans, apes, and their close relatives.

vertebrate Animal that has a backbone.

TAKE-HOME MESSAGE

WHY IS EVOLUTION A BASIC CONCEPT IN HUMAN BIOLOGY?

- Like all life forms, humans arose through evolution.
- Evolution has produced the features that set humans apart from other complex animals. These characteristics include sophisticated verbal skills, analytical abilities, and extremely complex social behavior.

1.3 Life's Organization

- **Nature is organized on many levels, from nonliving materials to the entire living world.**

Nature is organized on many levels

Nature is organized on eleven general levels, which you see summarized in Figure 1.5. At the most basic level are atoms, the smallest units of elements. Next come molecules, which are combinations of atoms. Atoms and molecules are the nonliving components from which cells are built. In humans and other multicellular organisms, cells are organized into tissues—muscle, bone tissue, and so forth. Different kinds of tissues make up organs, and systems of organs make up whole complex organisms.

We can study the living world on any of its levels. Many courses in human biology focus on organ systems, and a good deal of this textbook explores their structure and how they function.

Nature's organization doesn't end with individuals. Each organism is part of a population, such as the Earth's whole human population. In turn, populations of different organisms interact in communities of species occupying the same area. The example in Figure 1.5I is a community that includes trees, grasses, humans, and other organisms. Communities interact in ecosystems. The most inclusive level of organization is the **biosphere**. This term refers to all parts of the Earth's waters, crust, and atmosphere in which organisms live.

biosphere Parts of the Earth's waters, crust, and atmosphere where organisms live.

Organisms are connected through the flow of energy and cycling of materials

Organisms take in energy and materials to keep their life processes going. Where do these essentials come from? Energy flows into the biosphere from the sun (Figure 1.6). This solar energy is captured by "self-feeding" life forms such as plants, which use a sunlight-powered process called photosynthesis to make fuel for building tissues, such as a grain of wheat. Raw materials such as carbon that are needed to build the wheat plant come from air, soil, and water. Thus self-feeding organisms are the living world's basic food producers.

Animals, including humans, are the consumers: When we eat plant parts, or feed on animals that have done so, we take in materials and energy to fuel our body functions. You tap directly into stored energy when you eat bread made from grain, and you tap into it indirectly when you eat the meat of an animal that fed on grain. Organisms such as bacteria and fungi obtain energy and materials when they decompose tissues, breaking them down to substances that can be recycled back to producers. This one-way flow of energy through organisms, and the cycling of materials among them, means that all parts of the living world are connected.

Because of the interconnections among organisms, it makes sense to think of ecosystems as webs of life. With this perspective, we can see that the effects of events in one part of the web will eventually ripple through the whole and may even affect the entire biosphere. For example, we see evidence of large-scale impacts of human activities in the loss of biodiversity in many parts of the world, as well as in acid rain, climate change, and other concerns.

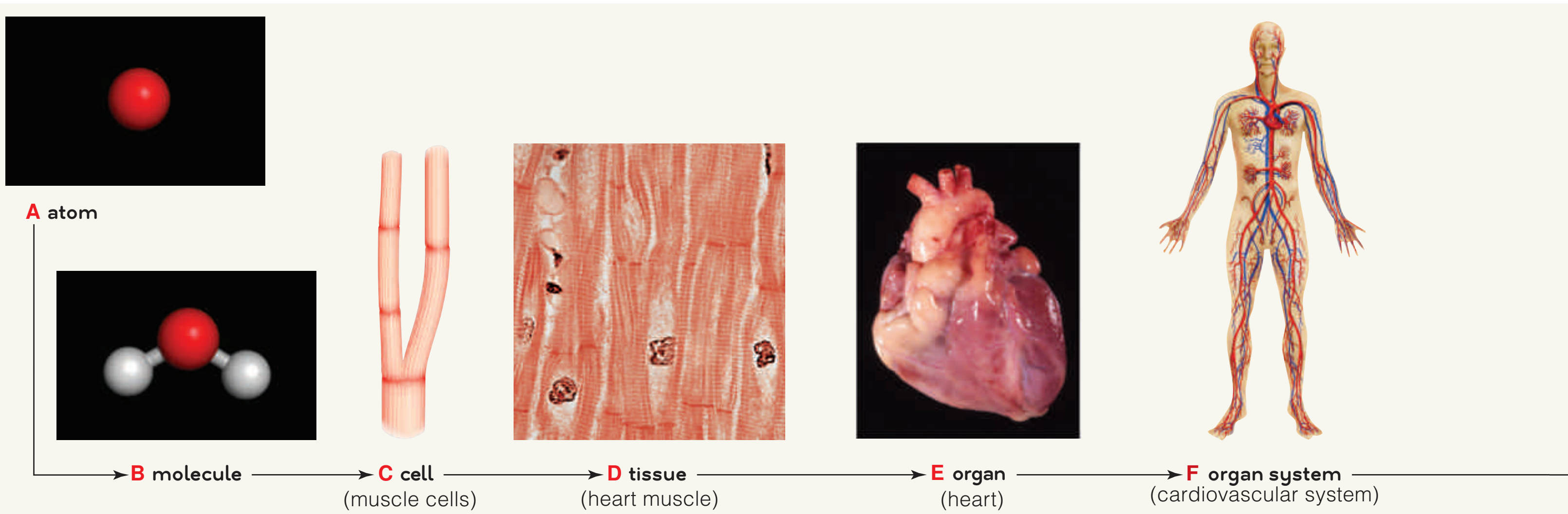
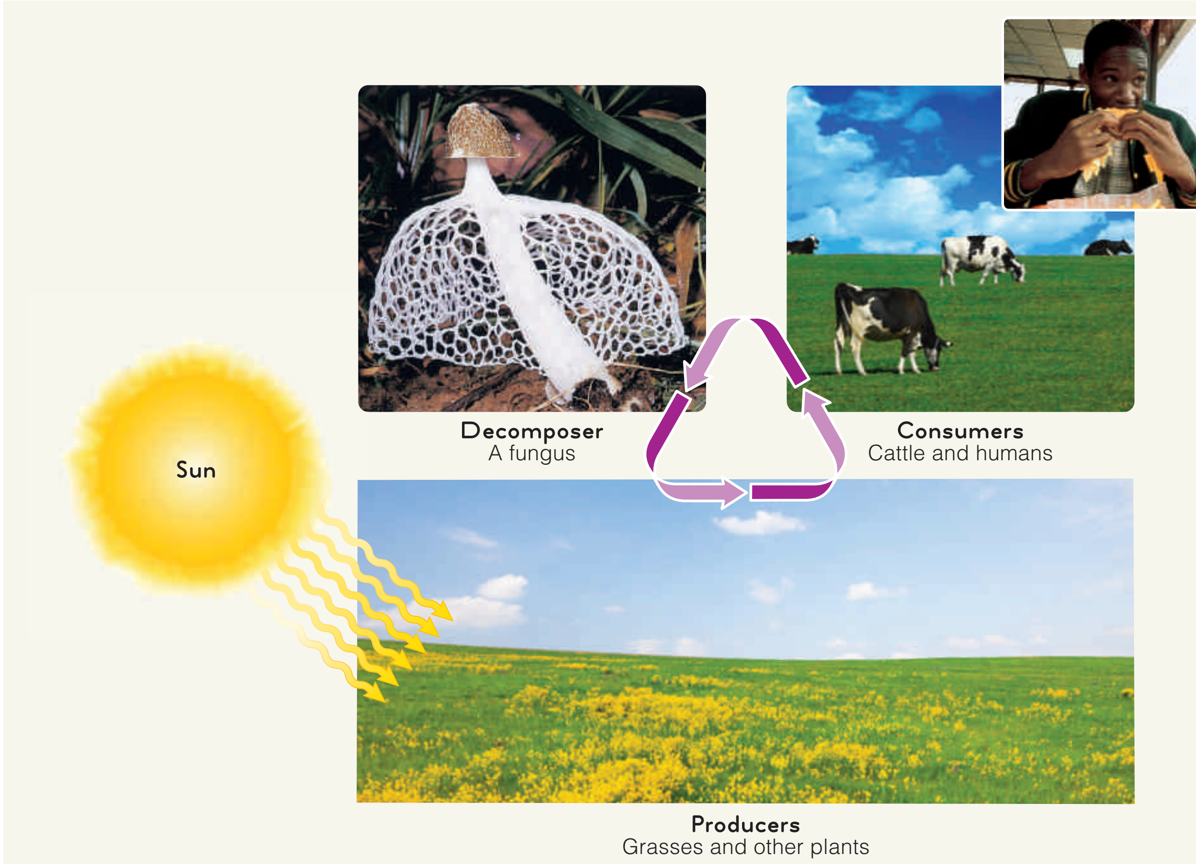


Figure 1.5 Animated! An overview of the levels of organization in nature. (A, B, C, F: © Cengage Learning; D: Ed Reschke/Peter Arnold; E: CMSP/Custom Medical Stock)



Clockwise from top left: Edward S. Ross; © iStockphoto.com/shaunl; Nancy J. Pierce/Science Source; © Ozerov Alexander/Shutterstock.com

Figure 1.6 Animated! The flow of energy and the cycling of materials maintain nature's organization. The bottom photograph shows producers—grasses and other plants. The plants obtained the energy to make their roots, seeds, and other parts from the sun. They obtained nutrients for their growth from soil and air. Consumers include animals, such as insects, birds, and humans, and decomposers include organisms such as fungi and bacteria. (© Cengage Learning)

TAKE-HOME MESSAGE

HOW IS NATURE ORGANIZED?

- Nature is organized in levels that are sustained by a flow of energy and cycling of materials.
- Energy flows into the biosphere from the sun. Raw materials cycle within the biosphere as consumers obtain food from producers, and decomposers break down tissues to substances that help nourish producers.
- Because living things are interconnected, ecosystems are webs of life in which all the parts are linked.

G: © Lavaria Ferreri Liotti/Shutterstock.com; H: © Rafael Ramirez Lee/Shutterstock.com; I: © Robert J. Beyers II/Shutterstock.com; J: © Sebastien Burel/Shutterstock.com; K: NASA

1.4 Using Science to Explain Natural Events

- **Scientists try to explain natural phenomena by making and testing predictions. They search for evidence that may disprove or support the explanation they have proposed.**

Scientific studies are systematic

In your human biology course, you will be learning a great deal of science-based information about the human body. Sometimes scientists gather information about natural processes and events by doing experiments in a laboratory or in the field (Figure 1.7). An alternative is to record detailed observations of a phenomenon. Regardless, doing science requires a systematic approach that is sometimes called the **scientific method**. The following steps are common.

hypothesis Proposed explanation for an observation or how a natural process works.

scientific method Any systematic way of obtaining information about the natural world.

1. **Observe some natural phenomenon.** For example, nutritionists have documented a correlation between the amount of protein eaten at breakfast and the amount of calories consumed later in the day.
2. **Identify a question or problem to explore.** As you'll read later in this book, appetite—the desire to eat—is governed by hormones and certain parts of the brain. Does the amount of protein in your breakfast affect these control messages—and accordingly, how much you eat later on? Nutrition researchers at the University of Missouri decided to explore this question.
3. **Develop a scientifically testable hypothesis.** A **hypothesis** is a proposed explanation for an observation. The University of Missouri team hypothesized that for their subjects, eating breakfast, and particularly one rich in protein, would be more effective in tamping down appetite than eating a "normal protein" breakfast that had the same calorie content.
4. **Make a specific prediction.** The researchers predicted that young adult females who consumed a 350-calorie breakfast that contained 35 grams of protein (as in a plate of eggs) would want to eat less later in the day than subjects who received a 350-calorie meal that had 15 grams of protein (cereal and milk). As in this example, a prediction states what you should observe about the question or problem if the hypothesis is valid.
5. **Test the prediction.** The team recruited twenty volunteers—all females between the ages of 18 and 20, all clinically overweight but not currently dieting. The restrictions were important to avoid skewing results due to differences in bodily energy use related to dieting, gender, and age. The subjects also shared the habit of skipping breakfast—which they would be asked to do as an important part of the study.

The study was divided into three seven-day periods. During week one, subjects skipped breakfast as usual. During the second week, they received a 350-calorie breakfast of cereal and milk. For the third week the women ate a high-protein breakfast. The calorie content of lunches, dinners, and any snacks the subjects ate also were recorded. All the subjects filled out questionnaires rating their desire to eat on test days. They also underwent blood tests and brain scans to determine whether these subjective feelings correlated with any shifts in bodily controls. They did. Together, the findings clearly supported the hypothesis that eating breakfast, especially one high in protein, reduces the desire to eat during the remainder of the day.

The Missouri team reported its findings in the *American Journal of Clinical Nutrition* so others

Figure 1.7 **Scientists do research in the laboratory and in the field. A** Examining heart tissue from a deceased person to determine the cause of death. **B** Making field observations in an old-growth forest. **C** Weighing a polar bear in Alaska.

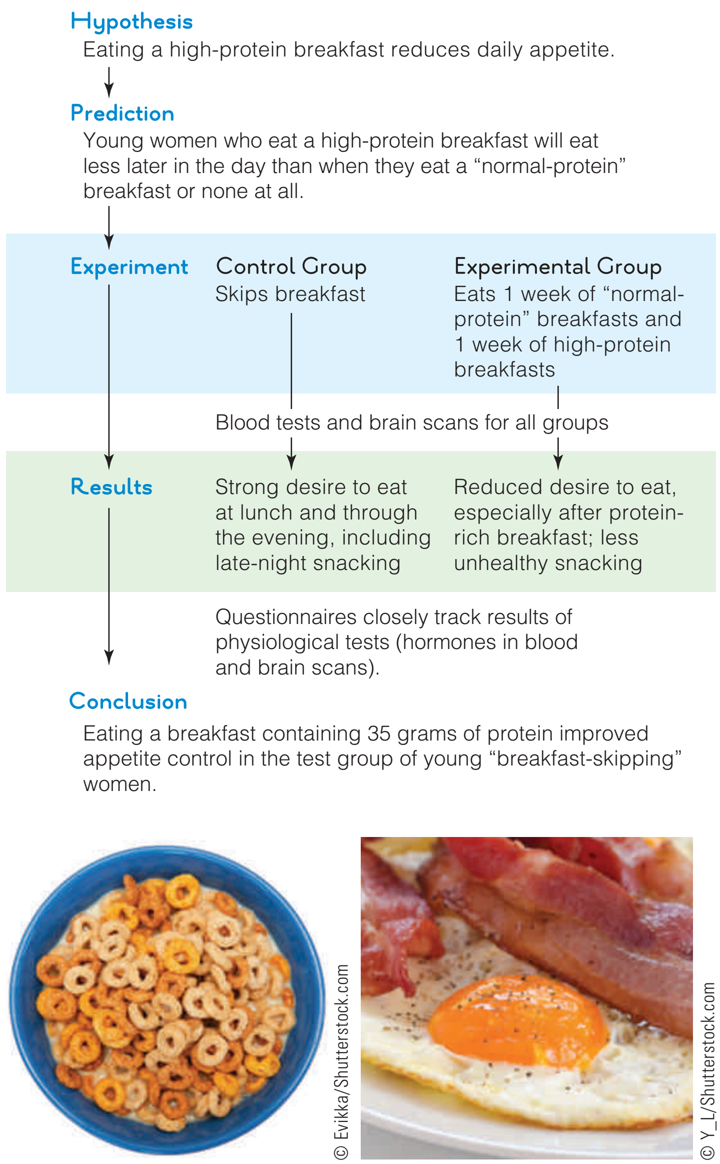


Figure 1.8 The Missouri protein breakfast study followed steps used in many scientific experiments. A key finding was that eating a protein-rich breakfast such as eggs staved off hunger longer that a relatively low-protein breakfast such as cereal and milk—even when the calorie count was the same.

interested in the same topic could accurately repeat the work. Hypotheses that are supported by the results of repeated testing are more likely to be correct.

Doing experiments is a common way to test a scientific prediction

An **experiment** is a test that is carried out under conditions that the researcher can control. Figure 1.8 shows the typical steps, using the Missouri study as an example. To get meaningful test results, as those researchers did, experimenters start by reviewing information and previous studies that may bear on their project. Then they design an experiment that will test any and all predictions of a hypothesis separately.

Most phenomena that we observe in the natural world are the result of interacting variables. A **variable** is a factor that can change with time or in different circumstances. Researchers design experiments to test one variable at a time. They also perform the test in a **control group** so that they can compare results between the control and experimental tests. In the protein breakfast study, the volunteers served as a control group during the week they skipped breakfast. It's important for a control group to be identical to the experimental one except for the variable being studied—in this case, how eating a high-protein breakfast affects appetite. Eliminating unwanted variables is crucial for obtaining reliable experimental results. For instance, if any of the participants in the breakfast food study were taking protein supplements on the side, the experimenters wouldn't have been able to determine if any reported changes in appetite were due to the nature of the food subjects ate.

Scientists usually can't study all the individuals in a group of interest. Results obtained from a subset of test subjects—especially a small one like twenty of the potentially millions of breakfast-skippers around the world—may differ from results obtained from the whole group. This sort of distortion is called **sampling error**. It's most likely to occur when a sample size is too small. To avoid such errors, researchers may try to assemble a test group that is large enough to be representative of the whole. If that's not feasible, only more experiments will clarify whether the original results are reliable. You can learn firsthand about sampling error in the *Explore on Your Own* exercise at the end of this chapter.

control group Group to which one or more experimental groups can be compared.

experiment Test carried out under controlled conditions that the researcher can manipulate.

sampling error Distortion of experimental results, often because the sample size is too small.

variable A factor that can change over time or under different circumstances.

In science, logic rules!

The conclusion a scientist draws from research can't be at odds with the findings used to support it. It has to be based on logic. In the Missouri breakfast study, the researchers couldn't conclude that eating a high-protein breakfast helps people lose weight. Their results did support the hypothesis that in young women, eating breakfast, especially ones high in protein, may help curb the desire to eat more later in the day.

TAKE-HOME MESSAGE

HOW DO SCIENTISTS STUDY THE NATURAL WORLD?

- Scientists begin by observing a natural event. They then pose a question about it.
- Next they propose a possible explanation, make a testable prediction about this hypothesis, and do one or more tests.
- In controlled experiments researchers study a single variable and compare the results to those obtained with a control group.

1.5 Critical Thinking in Science and Life

■ **To think critically, it is important to evaluate information before accepting it.**

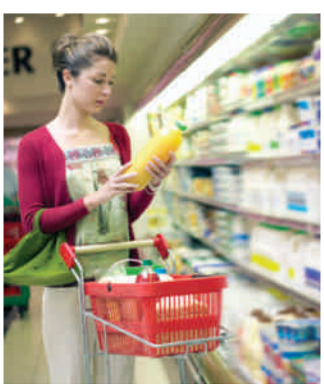
Have you ever tried a new or "improved" product and been disappointed when it didn't work as expected? Everyone learns, sometimes the hard way, how useful it can be to cast a skeptical eye on advertising claims or get an unbiased evaluation of, say, a used car you are considering buying. This objective evaluation of information is called *evidence-based* or **critical thinking**.

critical thinking Using systematic, objective strategies to judge the quality of information; evidence-based thinking.

fact Verifiable information, not opinion or speculation.

opinion A subjective judgment.

Scientists use critical thinking in their own work and to review findings reported by others. Anyone can make a mistake, and there is always a chance that pride or bias will creep in. Critical thinking is a smart practice in everyday life, too, because so many decisions we face involve scientific information. Will an herbal food supplement really boost your immune system? Is it safe to eat irradiated food? Table 1.1 gives guidelines for evidence-based critical thinking.



Cardinal/Corbis

Evaluate the source of information

An easy way to begin evaluating information is to notice where it is coming from and how it is presented. Here are two simple strategies for assessing sources.

TABLE 1.1 A Critical Thinking Guide and Checklist

To think critically about any subject:	
✔	***Do*** gather information or evidence from reliable sources.
✗	***Don't*** rely on hearsay.
✔	***Do*** look for facts that can be checked independently and for signs of obvious bias (such as paid testimonials).
✗	***Don't*** confuse *cause* with *correlation*.
✔	***Do*** separate *facts* from *opinions*.
Once you have formed your opinion:	
	Be able to state clearly your view on a subject.
	Be aware of the evidence that led you to hold this view.
	Ask yourself if there are alternative ways to interpret the evidence.
	Think about the kind of information that might make you reconsider your view.
	If you decide that nothing can ever persuade you to alter your view, recognize that you are not being objective about this subject.

Let credible scientific evidence, not opinions or hearsay, do the convincing For instance, if you are concerned about reports that heavy use of a cell phone might cause brain cancer, information on the website of the American Cancer Society is more likely to be reliable than something cousin Fred heard at work. Informal information may be correct, but you can't know for sure without investigating further.

Question credentials and motives For example, if an advertisement is designed to look like a news story, or a product is touted on TV or a blog by someone being paid for the job, your critical thinking antennae should go up. Is the promoter simply trying to sell a product with the help of "scientific" window dressing? Can any facts presented be checked out? Responsible scientists try to be cautious and accurate in discussing their findings and are willing to supply the evidence to back up their statements.

Evaluate the content of information

Even if information seems authoritative and unbiased, it is important to be aware of the difference between the cause of an event or phenomenon and factors that may only be correlated with it. For example, studies show that recirculation of air in an airplane's passenger cabin increases travelers' exposure to germs coughed or sneezed out by others. An "airplane cold," however, is caused directly by infection by a virus.

Also keep in mind the difference between facts and opinions or speculation. A **fact** is verifiable information, such as the price of a loaf of bread. An **opinion**—whether the bread tastes good—can't be verified because it involves a subjective judgment. Likewise, a marketer's prediction that many consumers will favor a new brand of bread is speculation, at least until there are statistics to back up the claim.

THINK OUTSIDE THE BOOK

Controversy swirls around claims that an extract from berries of the acai plant can produce rapid, easy weight loss. Using reputable sources such as the National Institutes of Health, do some Web research on this topic. What is the fuss all about?

TAKE-HOME MESSAGE

WHAT IS CRITICAL THINKING?

- Critical thinking is an objective, evidence-based evaluation of information.
- Critical thinking is required for doing science. It also is a smart strategy in many aspects of daily life.

1.6 Science in Perspective

- **A scientific theory explains a large number of observations.**

We know that the practice of science can yield powerful ideas, like the theory of evolution, that explain key aspects of life. At the same time, we also know that science is only one part of human experience.

It is important to understand what the word *theory* means in science

You've probably said, "I've got a theory about that!" This expression usually means that you have an untested idea about something. A **scientific theory** is the opposite: It is an explanation of a broad range of related natural events and observations that is based on repeated, careful testing of hypotheses. Table 1.2 lists some major scientific theories related to biology. Before scientific research established one of them, the germ theory of disease, some people tried to appease malevolent spirits they blamed for outbreaks of infectious disease (Figure 1.9).

A hypothesis usually becomes accepted as a theory only after years of testing by many scientists. Then, if the hypothesis has not been disproved, scientists may feel confident about using it to explain more data or observations. The theory of evolution—a topic we will look at in Chapter 23—is a prime example of a "theory" that is supported by tens of thousands of scientific observations.

Science demands critical thinking, so a theory can be modified, and even rejected, if results of new scientific tests call it into question. It's the same with other scientific ideas. Today, for instance, advances in technology are giving us a new perspective on subjects such as the links between emotions and health. Some "facts" in this textbook one day will likely be revised as we learn more about various processes. This willingness to reconsider ideas as new information comes to light is a major strength of science.

Science has limits

Because science requires an objective mindset, scientists can only do certain kinds of studies. No experiment can explain the "meaning of life," for example, or why each of us dies at a certain moment. Such questions have *subjective* answers that are shaped by our experiences and beliefs. Every culture and society has its own standards of morality and esthetics, and there are probably thousands of different sets of religious beliefs. All guide their members in deciding what is important and morally good and what is not. By contrast, the external world, rather than internal conviction, is the only testing ground for scientific views.

Because science does not involve value judgments, it sometimes has been or can be used in controversial ways. For example, some people worry about issues such as the use of animals in scientific research and possible negative consequences of genetic modification of food plants. There has been great debate over the causes of global climate change and the use of "industrial" fishing methods on the high seas. Meanwhile, whole ecosystems are being altered by technologies that each year allow millions of a forest's trees to be cut and hundreds of millions of fishes to be taken from the sea. The scientific community alone can't resolve these issues. That responsibility also belongs to us.

TABLE 1.2 Examples of Scientific Theories

Cell theory	All organisms consist of one or more cells, the cell is the basic unit of life, and all cells arise from existing cells.
Germ theory	Germs cause infectious diseases.
Theory of evolution	Change can occur in lines of descent.

Bettmann/Corbis

Figure 1.9 In the 1300s, people tried all sorts of strategies to ward off the bubonic plague epidemic—the Black Death—that may have killed half the people in Europe.

scientific theory Thoroughly tested explanation of a broad range of natural events and observations.

TAKE-HOME MESSAGE

WHAT ARE THE STRENGTHS AND LIMITS OF SCIENTIFIC STUDY?

- Science applies to questions and problems that can be tested objectively.
- A scientific theory remains open to tests, revision, and even rejection if new evidence comes to light.
- Responsibility for the wise use of scientific information must be shared by all.

1.7 Homeostasis CONNECTIONS

Section 1.1 introduced the concept of homeostasis—the state of chemical and physical stability inside the body that must exist if cells, and the whole body, are to stay alive. Homeostasis is one of the most important concepts in this textbook. Figure 1.10 is a visual summary of the main ideas, using the muscular system as an example. Each body system you will study during your human biology course performs functions that contribute to homeostasis in other systems. Those chapters conclude with a *Connections* section that summarizes each system's key contributions to homeostasis.

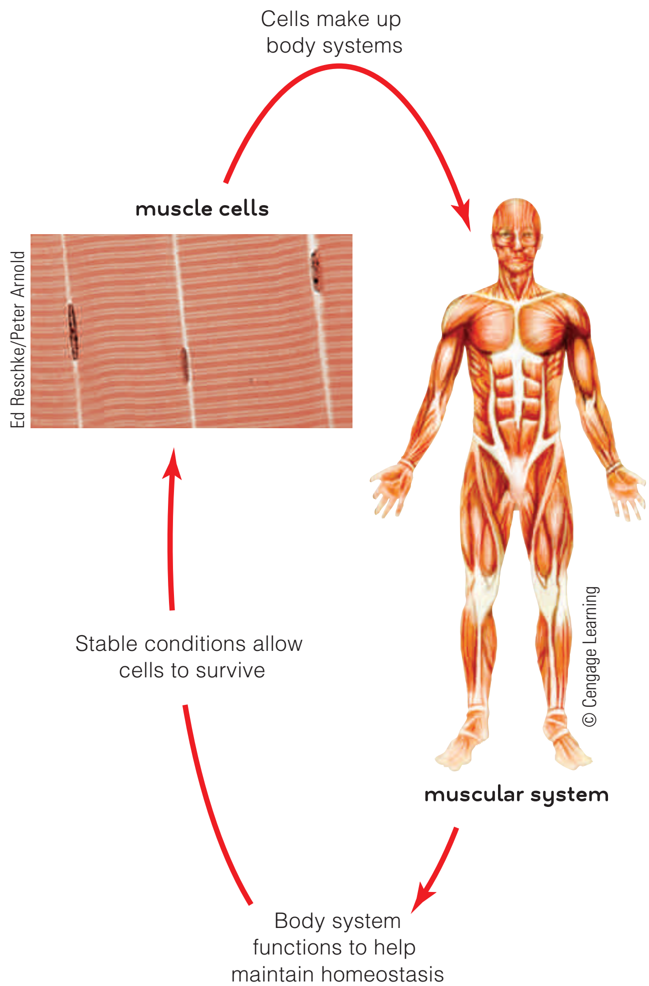


Figure 1.10 The body's survival depends on mechanisms that maintain internal homeostasis.

1.8 FOCUS ON HEALTH

Living in a World of Disease Threats

Each chapter of this book includes information about diseases and disorders. Regardless of whether it's a case of the sniffles, an injury, or a life-threatening cancer, illness is a sign of disturbed homeostasis. It means that affected cells aren't able to perform their normal functions.

From the beginning of human history, people have always lived with countless health threats. Today, however, some of the most pressing health problems, such as certain cancers, obesity, and type 2 diabetes, are related to lifestyle factors such as smoking, poor diet, and a sedentary lifestyle. We are also locked in an escalating global battle with infectious diseases caused by harmful bacteria, viruses, and parasites. Most of these foes are invisible to the naked eye. Figure 1.11 gives you an idea of what bacteria and viruses may look like under the microscope.

Today health officials worry especially about **emerging diseases**. These diseases are caused by pathogens that until recently did not infect humans or did so only in limited areas. Many are caused by viruses. This group includes several diseases you've probably heard about, such as the encephalitis caused by West Nile virus and the severe respiratory disease caused by the SARS virus (Figure 1.11B). You have probably also heard of—or even come down

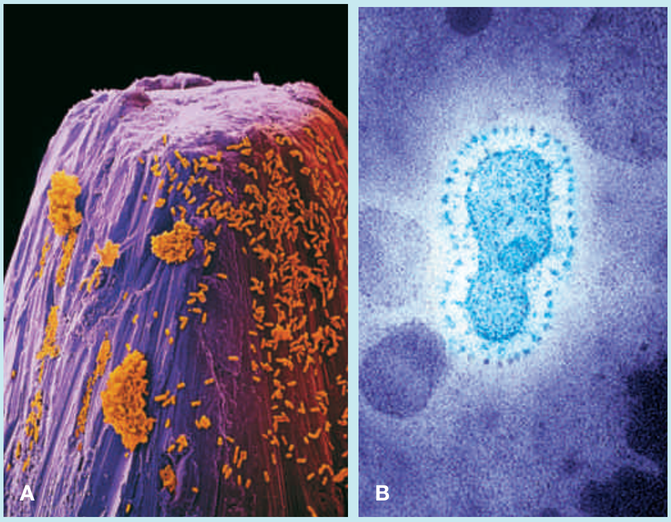


Figure 1.11 A wide variety of pathogens may live on or in the human body. A Bacteria on the tip of a pin. B The SARS virus, which causes an emerging respiratory disease. C Ad from a 1944 issue of *Life* magazine. Penicillin helped many soldiers survive what might otherwise have been deadly battlefield infections.
(A: Dr. Tony Brain & David Parker/Science Source; B: Sercomi/Science Source)

antibiotic Substance that can kill microorganisms.

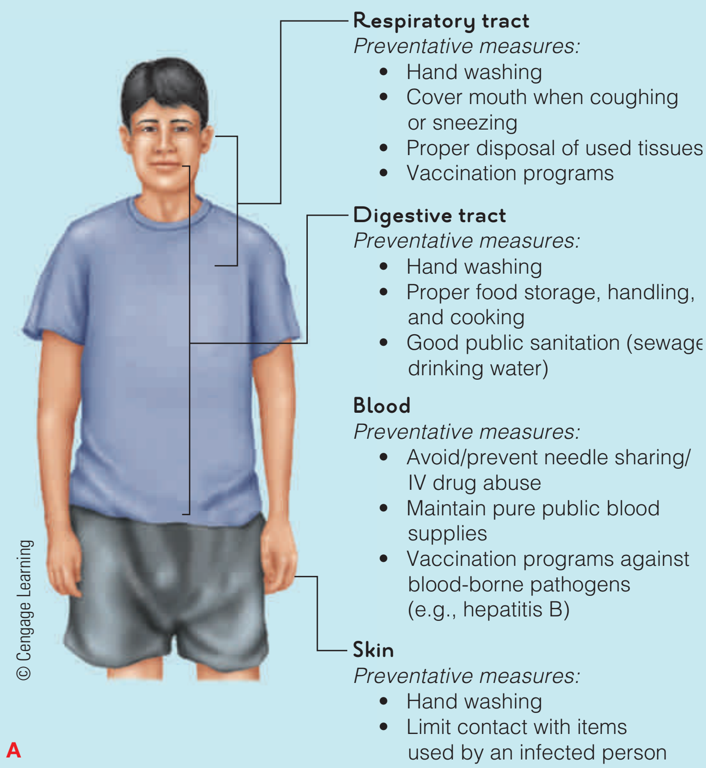
emerging disease Disease caused by a pathogen that until recently did not infect humans, or did so only rarely.

with—Lyme disease, which is a major emerging disease in the United States. It is caused by a species of bacteria, *Borrelia burgdorferi*, which ticks transmit when they suck blood. Luckily, most cases of Lyme disease can be cured easily with **antibiotics**.

So why have so many new diseases turned up in recent years? A few factors stand out. For one, there are simply many more of us on the planet, interacting with our surroundings and with each other. Each person is a potential target for pathogens. Also, more people are traveling, carrying diseases along with them. Another important factor is the misuse and overuse of antibiotics, which are not effective against viruses.

The first widely used antibiotic was penicillin, which was mass-produced in the 1940s (Figure 1.11C). Since then, hundreds of these powerful drugs have been developed. They have saved countless lives and prevented untold misery.

The best way to combat any disease is to prevent it in the first place. The common, and mostly simple, preventive measures listed in Figure 1.12 recognize that the human body, soil, water, and other animals all are reservoirs for a range of disease-causing organisms. You'll read more about this topic in Chapter 9, which considers immunity and other forms of body defenses against disease.



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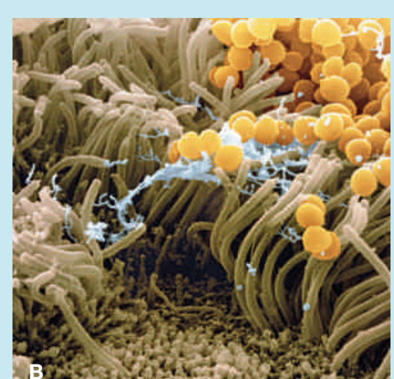
A



B

Juergen Berger/Science Source

Figure 1.12 Hand washing and other practices can help prevent the spread of many infectious diseases. A Preventative measures for avoiding infections caused by microbes that are transmitted in air, food, blood, or enter via the skin. **B** ***Staphylococcus aureus*** **bacteria (*yellow balls*) sticking to microscopic hairs on the tissue lining a person's nose. This strain is common in the nose, throat, and intestines. It is a leading cause of bacterial infections in humans.**

C

C: Image courtesy of the Advertising Archives

EXPLORE ON YOUR OWN

As you read in Section 1.4, having a sample of test subjects or observations that is too small can skew the results of experiments. This phenomenon is called *sampling error*. To demonstrate this for yourself, all you need is a partner, a blindfold, and a jar containing beans of different colors—jelly beans will do just fine (Figure 1.13). Have your partner stay outside the room while you combine 120 beans of one color with 280 beans of the other color in a bowl. This will give you a ratio of 30 to 70 percent. With the bowl hidden, blindfold your partner; then ask him or her to pick one bean from the mix. Hide the bowl again and instruct your friend to remove the blindfold and tell you what color beans are in the bowl, based on this limited sample. The logical answer is that all the beans are the color of the one selected.

Next repeat the trial, but this time ask your partner to select 50 beans from the bowl. Does this larger sample more closely approximate the actual ratio of beans in the bowl? You can do several more trials if you have time. Do your results support the idea that a larger sample size more closely reflects the actual color ratio of beans?

A **Natalie, blindfolded, randomly plucks a jelly bean from a jar of 120 green and 280 black jelly beans, a ratio of 30 to 70 percent.**

C **Still blindfolded, Natalie randomly picks 50 jelly beans from the jar and ends up with 10 green and 40 black ones.**

All Photos: © Cengage Learning/Gary Head

B **The jar is hidden before she removes her blindfold. She observes a single green jelly bean in her hand and assumes the jar holds only green jelly beans.**

D **The larger sample leads her to assume one-fifth of the jar's jelly beans are green and four-fifths are black (a ratio of 20 to 80 percent). Her larger sample more closely approximates the jar's green-to-black ratio. The more times Natalie repeats the sampling, the greater the chance she will come close to knowing the actual ratio.**

Figure 1.13 **Animated!** **Here's one way you can demonstrate sampling error.**

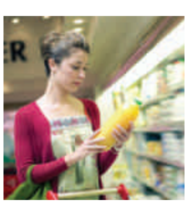
SUMMARY

Section 1.1 Humans have the characteristics found in all forms of life, as listed in Table 1.3.

Section 1.2 All life on Earth has come about through a process of evolution. The defining features of humans include a large and well-developed brain, great manual dexterity, sophisticated skills for language and mental analysis, and complex social behaviors.

Section 1.3 The living world is highly organized. Atoms, molecules, cells, tissues, organs, and organ systems make up whole, complex organisms. Each organism is a member of a population, populations live together in communities, and communities form ecosystems. The biosphere is the most inclusive level of biological organization. A continual flow of energy and cycling of raw materials sustains the organization of life.

Section 1.4 Science is an approach to gathering knowledge. There are numerous versions of the scientific method. Table 1.4 lists elements that are important in all of them. Reputable scientists must draw conclusions that are not at odds with the evidence used to support them.



Section 1.5 Critical thinking skills include scrutinizing information sources for bias, seeking reliable opinions, and separating the causes of events from factors that may only be associated with them.

Sections 1.6, 1.8 A scientific theory is a thoroughly tested explanation of a broad range of related phenomena. Science does not address subjective issues, such as religious beliefs and morality.

TABLE 1.3 Summary of Life's Characteristics

1. Living things consist of one or more cells.
2. Living things take in and use energy and materials.
3. Living things sense and respond to changes in their surroundings.
4. Living things maintain the internal steady state called homeostasis.
5. Living things reproduce and grow based on information in DNA.

TABLE 1.4 Scientific Method Review

Hypothesis	Possible explanation of a natural event or observation
Prediction	Proposal or claim of what testing will show if a hypothesis is correct
Experiment	Controlled procedure to gather observations that can be compared to prediction
Control group	Standard to compare test group against
Variable	Aspect of an object or event that may differ with time or between subjects
Conclusion	Statement that evaluates a hypothesis based on test results

REVIEW QUESTIONS

1. You are a living organism. Which characteristics of life do you exhibit?
2. Why is the concept of homeostasis meaningful in the study of human biology?
3. What is meant by biological evolution?
4. Study Figure 1.5. Then summarize what biological organization means.
5. Define and distinguish between:
   a. a hypothesis and a scientific theory
   b. an experimental group and a control group

SELF-QUIZ *Answers in Appendix VI*

1. Instructions in ______ govern how organisms are built and function.
2. A ______ is the smallest unit that can live and reproduce by itself using energy, raw materials, and DNA instructions.
3. ______ is a state in which an organism's internal environment is maintained within a tolerable range.
4. Humans are ______ (animals with backbones); like other primates, they also are ______.
5. Starting with cells, nature is organized on at least ______ levels.

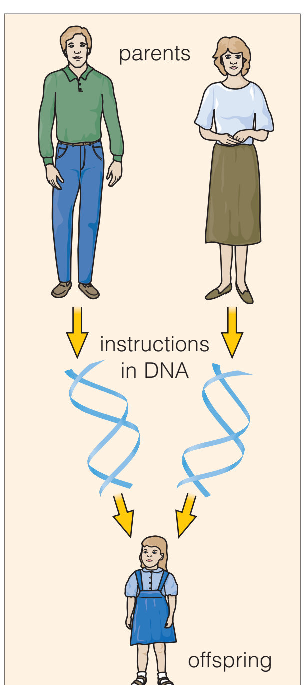
6. A scientific approach to explaining some aspect of the natural world includes all of the following except _______.
   a. a hypothesis c. faith-based views
   b. testing d. systematic observations

7. A controlled experiment should have all the following features except _______.
   a. a control group c. a variable
   b. a test subject d. many testable predictions

8. A related set of hypotheses that collectively explain some aspect of the natural world makes up a scientific _______.
   a. prediction d. authority
   b. test e. observation
   c. theory

9. Which of the following is not a feature of a scientific theory?
   a. It begins as a hypothesis.
   b. It eventually is accepted as absolute truth.
   c. It requires critical thinking.
   d. It is not accepted as a theory until it has been tested repeatedly.

10. The diagram below depicts the concept of _______.
   a. evolution
   b. reproduction
   c. levels of organization
   d. energy transfers in the living world



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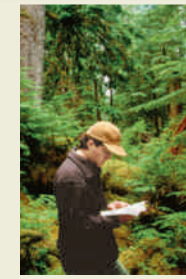
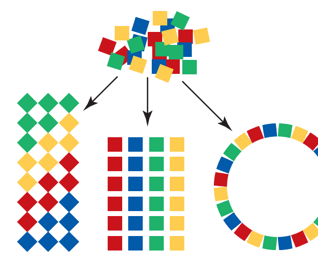
CRITICAL THINKING

1. The diagram to the right shows how tiles can be put together in different ways. How does this example relate to the role of DNA as the universal genetic material in organisms?

Your Future

Every day, scientists around the world are looking for answers to questions relating to human health, medicine, environmental issues, or other concerns that may affect your life. At the end of each chapter, *Your Future* gives you a quick preview of what the future is likely to bring with respect to an issue or concern related to the chapter's content.


Raymond Gehman/Documentary Value/Corbis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2. Court witnesses are asked "to tell the truth, the whole truth, and nothing but the truth." Research shows, however, that eyewitness accounts of crimes often are unreliable because even the most conscientious witnesses misremember details of what they observed. What other factors that might affect the "truth" a court witness presents?

3. Design a test (or series of tests) to support or refute this hypothesis: People who have no family history of high blood pressure (hypertension) but who eat a diet high in salt are more likely to develop high blood pressure than people with a similar family history but whose diet is much lower in salt.

4. In a popular magazine article the author reports health benefits attributed to a particular dietary supplement. What kinds of evidence should the article cite to help you decide whether the information is likely to be accurate?

5. Researchers studied 393 patients in a hospital's coronary care unit. In the experiment, volunteers were asked to pray daily for a patient's rapid recovery and for the prevention of complications and death.

   None of the patients knew if he or she was being prayed for. None of the volunteers or patients knew each other. The research team categorized how each patient fared as "good," "intermediate," or "bad." They concluded that "prayed for" patients fared a little better than other patients—the experiment having documented results that seemed to support the prediction that prayer might have beneficial effects for seriously ill patients.

   The results brought a storm of criticism, mostly from scientists who cited bias in the experimental design. For instance, the patients were categorized after the experiment was over, instead of as they were undergoing treatment, so the team already knew which ones had improved, stayed about the same, or gotten worse. Why do you suppose the experiment generated a heated response from many in the scientific community? Can you think of at least one other variable that might have affected the outcome of each patient's illness?

2 CHEMISTRY OF LIFE

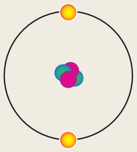
LINKS TO EARLIER CONCEPTS

DNA guides the processes that assemble atoms into the parts of cells, and eventually into whole organisms (1.1–1.3).

Atoms are the nonliving raw materials for building living things (1.3).

Properties of water are important in mechanisms that help maintain homeostasis (1.1, 1.7).

KEY CONCEPTS



Atoms and Elements

Atoms are the basic units of matter. Each chemical element consists of a single type of atom. Bonds between atoms form molecules. Sections 2.1–2.4

Water and Body Fluids

Life depends on properties of water. Substances dissolved in the water of body fluids have major effects on all body functions. Sections 2.5–2.7

Biological Molecules

Biological molecules include carbohydrates, lipids, proteins, and nucleic acids. All contain atoms of the element carbon. Sections 2.8–2.13

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A single carrot contains about one hundred different kinds of phytochemicals—substances that plants manufacture as part of their life processes. You may have heard of beta-carotene, which gives carrots, pumpkins, and some other fruits and vegetables their orange-yellow color. Dark green leafy vegetables like spinach contain it too. Your body uses beta-carotene to make vitamin A, which is required for pigments important in vision and for healthy bones and teeth. Eating foods rich in beta-carotene and some other phytochemicals also may help ward off heart disease and certain cancers. On the other hand, taking in too much beta-carotene—from supplements, say—can cause digestive problems and even increase the cancer risk in people who smoke. In this chapter we survey some simple chemical basics that relate to the study of human biology—including how certain substances serve as vital nutrients, present health hazards, or both.

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Homeostasis Preview

In this chapter we discuss two topics that bear directly on the body's ability to maintain the internal stability of homeostasis. These are the properties of water and changes in the chemical makeup of body fluids.

2.1 Atoms and Elements

- Pure substances called elements are the basic raw material of living things.
- Each element consists of one type of atom.
- The parts of atoms determine how the molecules of life are put together.
- Link to Life's organization 1.3

Elements are pure substances

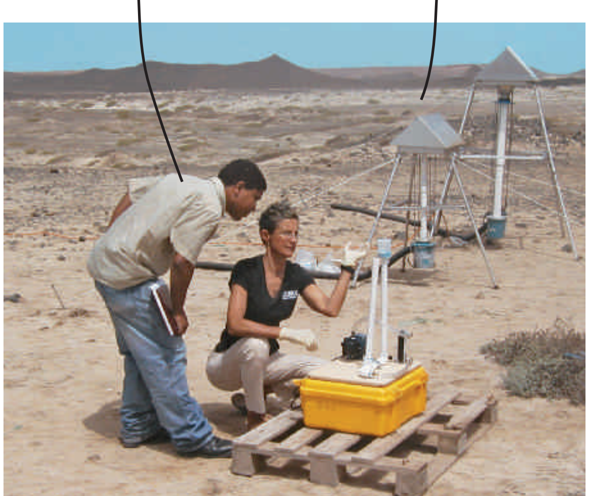
Like all else on Earth, your body consists of chemicals. Some of them are solids, others liquid, still others gases. Each of these chemicals consists of one or more elements. An **element** is a pure substance: that is, it cannot be broken down to another substance by ordinary physical or chemical techniques. There are more than ninety natural elements on Earth, and scientists have created many other artificial ones.

atom Smallest unit having the properties of a given element.

element Pure substance that cannot be broken down to another substance by ordinary chemical or physical techniques.

Human	
Oxygen	65
Carbon	18
Hydrogen	10
Nitrogen	3
Calcium	2
Phosphorus	1.1
Potassium	0.35
Sulfur	0.25
Sodium	0.15
Chlorine	0.15
Magnesium	0.05
Iron	0.004
Iodine	0.0004

Earth's crust	
Oxygen	46.6
Silicon	27.7
Aluminum	8.1
Iron	5.0
Calcium	3.6
Sodium	2.8
Potassium	2.6
Magnesium	2.1
Other elements	1.5



Cape Verde National Institute of Meteorology and Geophysics and the U.S. Geological Survey

Figure 2.1 **Everything in the biosphere, from humans to the Earth's crust, is made of elements.**

Overall, organisms consist mostly of four elements: oxygen, carbon, hydrogen, and nitrogen. The human body also contains some calcium, phosphorus, potassium, sulfur, sodium, and chlorine, plus many different trace elements (Figure 2.1). A trace element is one that makes up less than 0.01 percent of body weight. Trace elements are extremely important, however. For example, without the trace element iron, your red blood cells can't carry oxygen. The body's chemical makeup is finely tuned. Many trace elements found in our tissues—such as arsenic, selenium, and fluorine—are toxic in amounts larger than normal.

Atoms of the same or different elements can combine into molecules—the first step in biological organization. Molecules in turn can combine to form larger structures, as described shortly.

Atoms are composed of smaller particles

An **atom** is the smallest unit that has the properties of a given element. A million could fit on the period at the end of this sentence. In spite of their tiny size, however, all atoms are composed of more than one hundred kinds of subatomic particles. The ones we are concerned with in this book are protons, electrons, and neutrons, illustrated in Figure 2.2.

All atoms have one or more protons. These particles carry a positive charge, marked by a plus sign (p^+). Atoms also have one or more neutrons, which have no charge. Neutrons and protons make up the atom's core, the atomic nucleus. Electrons move around the nucleus, in the space that occupies 99.99 percent of the atom's volume. Electrons have a negative charge, which we write as e^-. An atom usually has equal numbers of electrons and protons.

Each element is assigned an "atomic number," which is the number of protons in its atoms. Elements also have a "mass number"—the sum of the protons and neutrons in the nucleus of their atoms. Appendix II of this textbook has charts of the elements and of the atomic numbers of the common elements in living things.

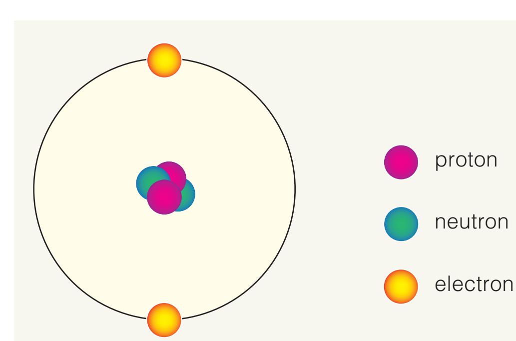


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Figure 2.2 **Animated!** **Atoms consist of subatomic particles.** This model does not show what an atom really looks like. Electrons travel in spaces located around a nucleus of protons and neutrons. These spaces are about 10,000 times larger than the nucleus.

Isotopes are varying forms of atoms

Atoms of a given element have exactly the same number of protons, but they may have different numbers of neutrons. When an atom of an element has more or fewer neutrons than the most common number, it is called an **isotope** (EYE-so-tope). For instance, while a "standard" carbon atom has six protons and six neutrons, the isotope called carbon 14 has six protons and *eight* neutrons. These two forms of carbon atoms also can be written as ^{12}C and ^{14}C. The prefix *iso-* means "same," and all isotopes of an element interact with other atoms in the same way. Most elements have at least two isotopes. Cells can use any isotope of an element for their metabolic activities, because the isotopes behave the same as the standard form of the atom in chemical reactions.

isotope An atom of an element that has a different number of neutrons than the most common, standard number.

radioisotope An isotope with an unstable nucleus that becomes stable by emitting energy and particles, a process known as radioactive decay.

tracer Molecule with a detectable substance such as a radioisotope attached to it.

Have you heard of radioactive isotopes? They are isotopes of elements such as uranium, which emit energy. This unexpected chemical behavior is what we call radioactivity.

The nucleus of a **radioisotope** is unstable, but it stabilizes itself by emitting energy and certain types of particles. This process, called radioactive decay, occurs spontaneously, and it transforms a radioisotope into an atom of a different element. The decay process happens at a known rate. For instance, over a predictable time span, potassium 40 becomes argon 40. Scientists can use radioactive decay rates to determine the age of very old substances, such as ancient rocks and fossils. Radioisotopes also have important uses in medicine, as you can see in Section 2.2.

TAKE-HOME MESSAGE

WHAT ARE ELEMENTS AND ATOMS?

- An element is a pure substance. Each kind consists of atoms having the same number of protons.
- Atoms are tiny particles and are the building blocks of all substances.
- Atoms consist of electrons moving around a nucleus of protons and (except for hydrogen) neutrons.

2.2 PET Scanning—Using Radioisotopes in Medicine

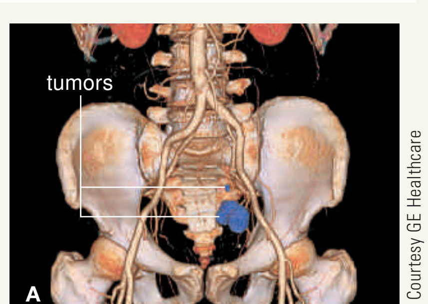
SCIENCE COMES TO LIFE

Emissions from radioisotopes can reveal the activity of body cells. As a result, they are useful tools in medicine because they permit physicians to diagnose disease, or track its course, without doing surgery.

The technology called PET (short for Positron Emission Tomography) is a prime example. Figure 2.3A shows a PET scan from a cancer patient. The patient was injected with a **tracer**—a molecule in which radioisotopes have been substituted for some atoms. The cells in a cancerous tumor are more active than normal body cells, so they take up the tracer faster. A scanner then detects radioactivity that becomes concentrated in the tumors.

Figure 2.3B shows a leukemia patient about to have a scan of her heart prior to a bone marrow transplant. A radioactive tracer injected into her bloodstream will allow the scanner to make video images of her heart pumping blood—helping her doctor decide if her heart is healthy enough for surgery.

Radioisotopes also are used to help treat some cancers. For example, implanted "seeds" of radioactive iodine or palladium may be used to kill cancerous prostate cells. For safety's sake, such treatments use only radioisotopes that decay quickly into a different, more stable element.



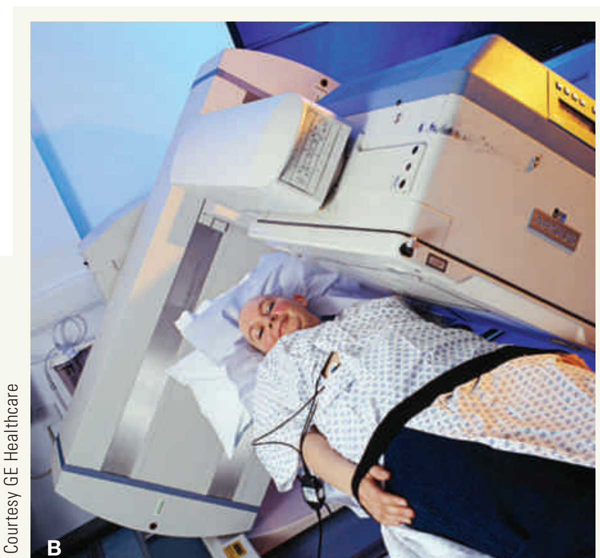


Figure 2.3 Animated! **Radioisotopes have important medical uses. A PET image showing tumors (*blue*) in and near the bowel of a cancer patient. B Patient about to have a MUGA (multi-gated) scan that uses a radioactive tracer to produce video images of heart function.**

2.3 Chemical Bonds: How Atoms Interact

- Atoms may share, give up, or gain electrons.
- Whether an atom will interact with other atoms depends on how many electrons it has.
- Chemical bonds between atoms form molecules.

Atoms interact through their electrons

By way of their electrons, atoms of many elements interact with other atoms. Electrons may be shared, one atom may donate one or more electrons to another atom, or an atom may receive electrons from other atoms. Which of these events takes place depends on how many electrons a given atom has and how the electrons are arranged.

You've probably heard that like charges (++ or −−) repel each other and unlike charges (+−) attract. Electrons carry a negative charge, so they are attracted to the positive charge of protons. On the other hand, electrons repel each other. In an atom, electrons respond to these pushes and pulls by moving around the atomic nucleus in "shells" (Figure 2.4). A shell has three dimensions, like the space inside a balloon, and the electron or electrons inside it travel in "orbitals." Each orbital is like a room that can hold no more than two occupants. This means that in an atom, a maximum of two electrons can occupy an orbital. Recall from Section 2.1 that atoms of different elements differ in how many electrons they have. They also differ in how many of their "rooms" are filled.

Hydrogen is the simplest atom. It has one electron in a single shell (Figure 2.4A). In atoms of other elements, the first shell holds two electrons. Any additional electrons are in shells farther from the nucleus.

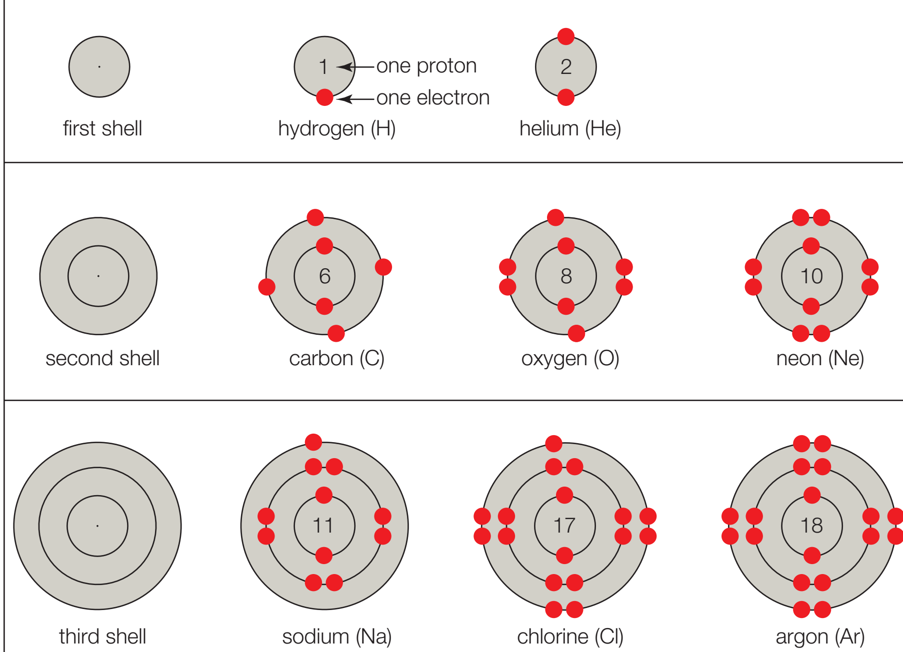
The shells around an atom's nucleus are equivalent to energy levels. The shell closest to the nucleus is at the lowest energy level. Each shell farther out from the nucleus is at a progressively higher energy level. Because the atoms of different elements have different numbers of electrons, they also have different numbers of shells that electrons can occupy (Figure 2.4B and 2.4C). A shell can have up to eight electrons, but not more. This means that larger atoms, which have more electrons than smaller ones do, also have more shells.

chemical bond Link that forms between atoms when their electrons interact.

molecule Structure that forms when chemical bonding joins atoms.

Chemical bonds join atoms into molecules

When the electrons of atoms interact, the link between the atoms is called a **chemical bond**. This chemical bonding joins atoms into a new type of structure, a **molecule** (Table 2.1).



A The first shell corresponds to the first energy level, and it can hold up to two electrons. Hydrogen has one proton, so it has one electron and one vacancy. A helium atom has two protons, two electrons, and no vacancies.

B The second shell corresponds to the second energy level, and it can hold up to eight electrons. Carbon has six electrons, so its first shell is full. Its second shell has four electrons and four vacancies. Oxygen has eight electrons and two vacancies. Neon has ten electrons and no vacancies.

C The third shell corresponds to the third energy level, and it can hold up to eight electrons. A sodium atom has eleven electrons, so its first two shells are full; the third shell has one electron. Thus, sodium has seven vacancies. Chlorine has seventeen electrons and one vacancy. Argon has eighteen electrons and no vacancies.

Figure 2.4 The shell model helps you visualize the vacancies in an atom's outer orbitals. Each circle represents all of the orbitals on one energy level. The larger the circle, the higher the energy level. (© Cengage Learning)

Bonds form because an atom is most stable when its outer shell is filled. For atoms that have too few electrons to fill their outer shell, chemical bonding with other atoms can provide stability. As shown in Figure 2.4A, hydrogen and helium atoms have a single shell. The shell is full when it contains two electrons. Some other kinds of atoms that have unfilled outer shells tend to form chemical bonds that fill vacant "slots" in their outer shell so that it has a full set of eight electrons. Atoms of oxygen, carbon, hydrogen, and nitrogen—the most abundant elements in the body—are in this category. Look for electron vacancies in an atom's outer shell and you will always have a clue as to whether the atom will bond with others.

In Figure 2.4 you can count the electron vacancies in the outer shell of each of the atoms pictured. Atoms like helium, which have no vacancies, are said to be *inert*. They usually don't take part in chemical reactions.

Molecules may contain atoms of a single element or of different elements

Many molecules contain atoms of only one element. Molecular nitrogen (N_2), with its two nitrogen atoms, is an example. Many other molecules are **compounds**—they combine two or more elements in proportions that never vary. For example, water is a compound. No matter where water molecules are—in a lake or your bathtub—each one always has one oxygen atom bonded to two hydrogen atoms. Figure 2.5 explains how to read the notation used in representing chemical reactions that occur between atoms and molecules.

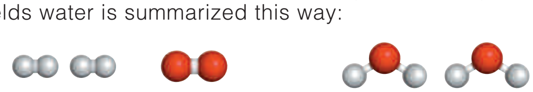
In a **mixture**, two or more kinds of molecules simply mingle. The proportions may or may not be the same. For example, the sugar sucrose is a compound of carbon, hydrogen, and oxygen. If you swirl together molecules of sucrose and water, you'll get a mixture—sugar-sweetened water. If you keep the same amount of water but add more sucrose, you will still have a mixture—just an extremely sweet one, such as syrup.

compound Molecule containing atoms of two or more elements in proportions that are always the same.

mixture Substance in which two or more kinds of molecules mingle in proportions that may vary.

We use symbols for elements when writing *formulas*, which identify the composition of compounds. For example, water has the formula H_2O. Symbols and formulas are used in *chemical equations*, which are representations of reactions among atoms and molecules.

In written chemical reactions, an arrow means "yields." Substances entering a reaction (reactants) are to the left of the arrow. Reaction products are to the right. For example, the reaction between hydrogen and oxygen that yields water is summarized this way:



$$2H_2 + O_2 \longrightarrow 2H_2O$$

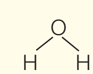
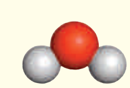
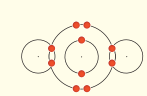
(hydrogen) (oxygen) (water)

Reactants	Products
4 hydrogen atoms + 2 oxygen atoms	4 hydrogen atoms + 2 oxygen atoms

Note that there are as many atoms of each element to the right of the arrow as there are to the left. Although atoms are combined in different forms, none is consumed or destroyed in the process. The total mass of all products of any chemical reaction equals the total mass of all its reactants. All equations used to represent chemical reactions, including reactions in cells, must be balanced this way.

Figure 2.5 Symbols are a shorthand way to describe chemical reactions. (© Cengage Learning)

TABLE 2.1 Different Ways to Represent the Same Molecule

Common name	Water	Familiar term.
Chemical name	Hydrogen oxide	Describes the elements making up the molecule.
Chemical formula	H_2O	Indicates proportions of elements. Subscripts show number of atoms of an element per molecule. There is no subscript when only one atom is present.
Structural formula	H—O—H 	Represents a bond as a single line between atoms. The bond angles also may be represented.
Structural model		Shows the positions and relative sizes of atoms.
Shell model		Shows how pairs of electrons are shared.

TAKE-HOME MESSAGE

WHAT IS A CHEMICAL BOND?

- A chemical bond is a link between the electron structures of atoms. Chemical bonds join atoms into molecules.
- Atoms with an unfilled outer shell tend to interact with other atoms in ways that fill the shell, such as forming chemical bonds.
- Atoms with a filled outer shell are inert—they do not form bonds.
- A compound is a molecule formed from atoms of different elements.
- A mixture is any blend of two or more kinds of molecules.

2.4 Important Bonds in Biological Molecules

- **The characteristics of atoms determine which types of bonds form in biological molecules.**

An ionic bond joins atoms that have opposite electrical charges

Overall, an atom carries no charge because it has as many electrons as protons. That balance can change if an atom has a vacancy—an unfilled orbital—in its outer shell. For example, a chlorine atom has one vacancy and therefore can gain one electron. A sodium atom, on the other hand, has a single electron in its outer shell, and that electron can be knocked out or pulled away. When an atom gains or loses an electron, the balance between its protons and its electrons shifts so that it has a positive or negative charge. An atom or other particle that has a charge is called an **ion**.

It's common for neighboring atoms to accept or donate electrons among one another. When one atom loses an electron and one gains, both become ionized. Depending on conditions inside the cell, the ions may separate, or they may stay together as a result of the mutual attraction of their opposite charges. An association of two ions that have opposite charges is called an **ionic bond**. Figure 2.6 shows how sodium ions (Na^+) and chloride ions (Cl^-) interact through ionic bonds, forming NaCl, or table salt.

The process in which an atom or molecule loses one or more electrons to another atom or molecule is known as *oxidation*. It's what causes a match to burn and an iron nail to rust, and it is part of all kinds of important metabolic events in body cells.

biological molecule Molecule that contains carbon and forms in a living organism.

covalent bond Bond in which the atoms share two electrons.

hydrogen bond Link between a covalently bonded hydrogen atom and another atom taking part in a separate covalent bond.

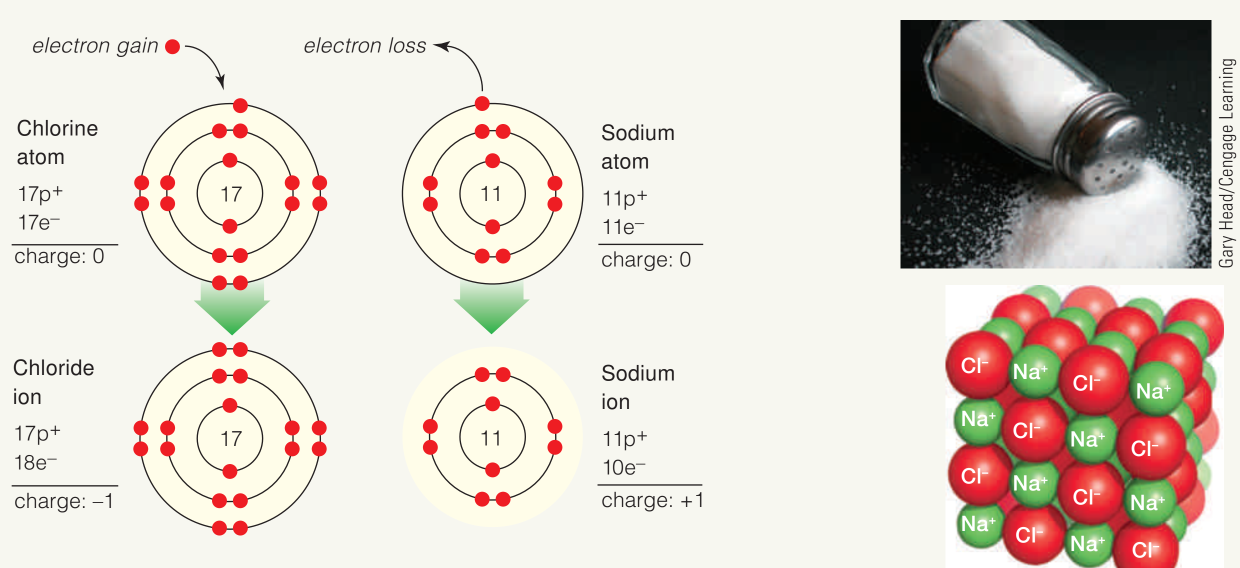
ion A charged atom.

ionic bond Bond between two ions having opposite charges.

In a covalent bond, atoms share electrons

In a **covalent bond**, atoms *share* two electrons (Figure 2.7). The bond forms when two atoms each have a lone electron in their outer shell and each atom's attractive force "pulls" on the other's unpaired electron. The tug is not strong enough to pull an electron away completely, so the two electrons share an orbital. Covalent bonds are extremely strong and stable.

As you saw in Table 2.1, in structural formulas a single line between two atoms means they share a single covalent bond. Molecular hydrogen, a molecule that consists of two hydrogen atoms, has this kind of bond and can be written as H—H. In a *double* covalent bond, two atoms share two electron pairs, as in an oxygen molecule (O=O). In a *triple* covalent bond, two atoms share three pairs of electrons. A nitrogen molecule (N≡N) is this way. All three examples are gases. When you breathe, you inhale H_2, O_2, and N_2 molecules.



A A chlorine atom (Cl) becomes a negatively charged chloride ion (Cl^-) when it gains an electron and fills the vacancy in its third, outermost shell.

B A sodium atom (Na) becomes a positively charged sodium ion (Na^+) when it loses the electron in its third shell. The atom's full second shell is now its outermost, so it has no vacancies.

C Salt crystals are cubical. Why? The mutual attraction of opposite charges holds the sodium and chloride ions together in a cube-shaped arrangement.

Figure 2.6 Animated! **An ionic bond may form between two oppositely charged atoms.** (© Cengage Learning)

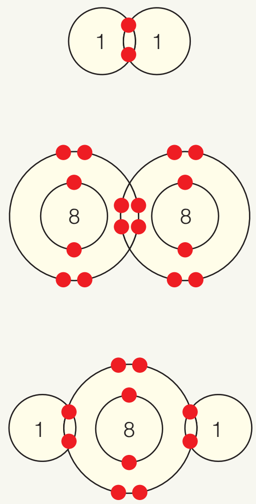


Figure 2.7 Animated! Shared electrons make up covalent bonds. Two atoms with unpaired electrons in their outer shell become more stable by sharing electrons. Two electrons are shared in each covalent bond. When the electrons are shared equally, the covalent bond is nonpolar. If one atom exerts more pull on the shared electrons, the covalent bond is polar.

In a *nonpolar* covalent bond, the two atoms pull equally on electrons and so share them equally. The term "nonpolar" means there is no difference in charge at the two ends ("poles") of the bond. Molecular hydrogen is a simple example. Its two hydrogen atoms, each with one proton, attract the shared electrons equally.

In a *polar* covalent bond, two atoms don't share electrons equally. The atoms are of different elements, and one has more protons than the other. The one with the most protons pulls more, so its end of the bond ends up with a slight negative charge. We say it is "electronegative." The atom at the other end of the bond ends up with a slight positive charge. For instance, a water molecule (H—O—H) has two polar covalent bonds. The oxygen atom carries a slight negative charge, and each of the two hydrogen atoms has a slight positive charge.

A hydrogen bond links polar molecules

A **hydrogen bond** is a weak link that has formed between a covalently bonded hydrogen atom and another atom taking part in a separate covalent bond. The dotted lines in the diagram in Figure 2.8 represent this link.

Individual hydrogen bonds are weak, so they form and break easily. Despite this property, hydrogen bonds are vital in **biological molecules**—molecules that contain carbon and that are formed in living things. For example, the genetic material DNA is built of two long strands of chemical units that hydrogen bonds hold together. In Section 2.5 you will learn how hydrogen bonds between water molecules contribute to properties of water that make it essential for life.

Table 2.2 summarizes the main chemical bonds that form in biological molecules.

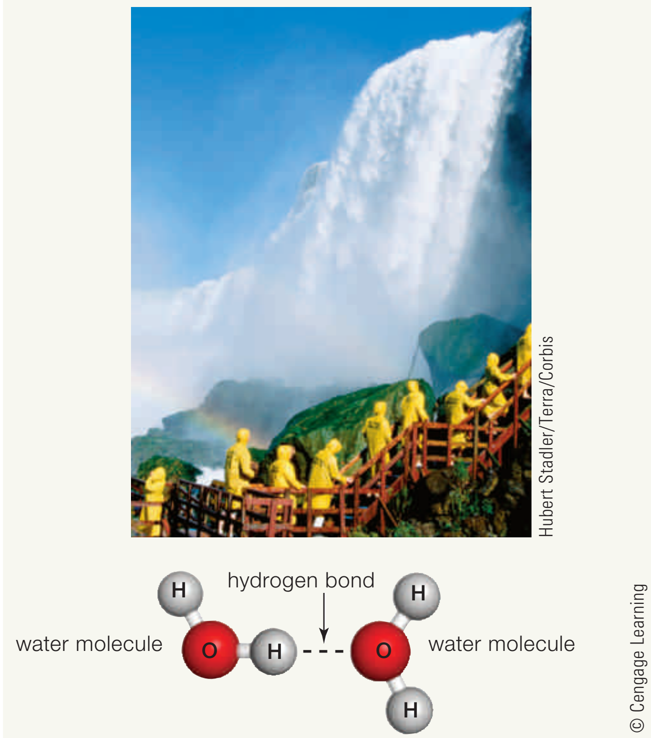


Figure 2.8 Animated! Hydrogen bonds can form when a hydrogen atom is already covalently bonded in a molecule. The hydrogen's slight positive charge attracts an atom with a slight negative charge that is already covalently bonded to something else. In the diagram, a hydrogen bond between a hydrogen atom and an oxygen atom links two water molecules. As a result, the molecules tend to stay together in droplets and streams.

TABLE 2.2 Major Chemical Bonds in Biological Molecules

Bond	Characteristics
Ionic	Joined atoms have opposite charges.
Covalent	Strong; joined atoms share electrons. In a *polar* covalent bond one end is slightly positive, the other slightly negative.
Hydrogen	Weak; joins a hydrogen (H^+) atom in one polar molecule with an electronegative atom in another polar molecule.

TAKE-HOME MESSAGE

WHAT ARE THE MAIN TYPES OF CHEMICAL BONDS THAT OCCUR IN BIOLOGICAL MOLECULES?

- Biological molecules are formed mainly by ionic bonds, covalent bonds, and hydrogen bonds.
- In an ionic bond, ions of opposite charge attract each other and stay together.
- In a covalent bond, atoms share electrons. If the electrons are shared equally, the bond is nonpolar. If the sharing is not equal, the bond is polar—slightly positive at one end, slightly negative at the other.
- In a hydrogen bond, a covalently bound hydrogen atom attracts a small, negatively charged atom in a different molecule or in another part of the same molecule.

2.5 Water: Necessary for Life

- **Many life processes require water.**
- **Other life processes occur only after substances have dissolved in water.**

Life on Earth probably began in water, and for all life forms it is indispensable. Human blood is more than 90 percent water, and water helps maintain the shape and internal structure of our cells. As described next, three properties of water suit it for its key roles in the body.

Hydrogen bonds make water liquid

Water is a liquid at body temperature. As a result, our watery blood flows and our cells have the fluid they need to function properly. What keeps water liquid? You may recall that while a water molecule has no net charge, it does carry charges that are distributed unevenly. The water molecule's oxygen end is slightly negative and its hydrogen end is a bit positive (Figure 2.9A). This uneven distribution of charges makes water molecules "polar." Because they are polar, the molecules can attract other water molecules and form hydrogen bonds with them. Collectively, the bonds are so strong that they hold the water molecules close together (Figure 2.9B and 2.9C). This effect of hydrogen bonds is why water is a liquid unless its temperature falls to freezing or rises to the boiling point.

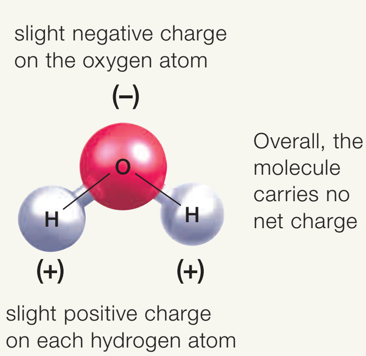
hydrophilic Chemically attracted to water.

hydrophobic Chemically repelled by water.

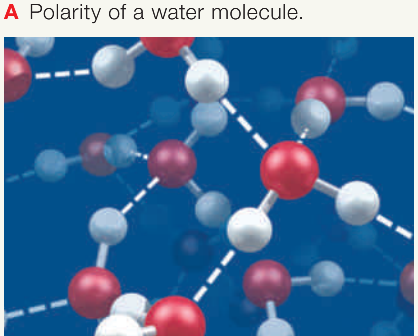
Water attracts and hydrogen-bonds with other polar substances. Because polar molecules are attracted to water, they are said to be **hydrophilic**, or "water loving." Water repels nonpolar substances, such as oils. Hence nonpolar molecules are **hydrophobic**, or "water fearing." We will return to these concepts when we look at the structure of cells in Chapter 3.

Water can absorb and hold heat

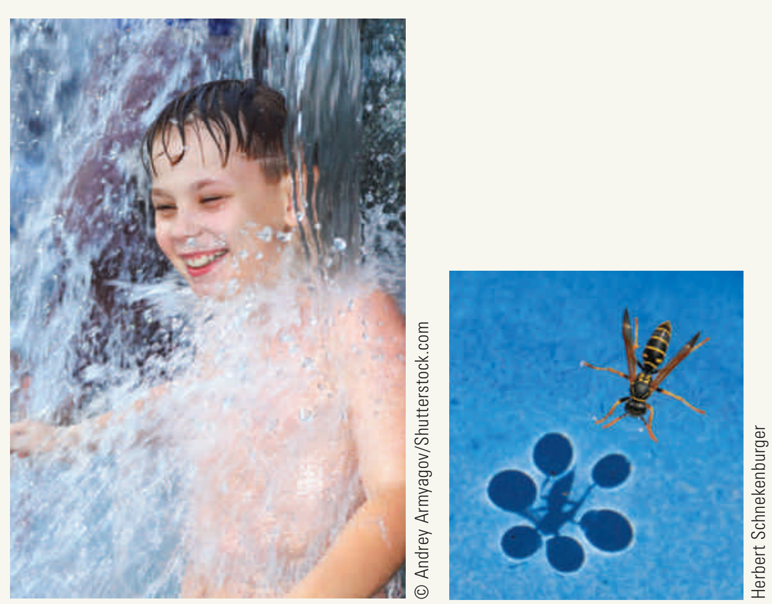
Water's hydrogen bonds give it a high *heat capacity*—the ability to absorb a great deal of heat energy before water warms significantly or evaporates. This is because it takes a large amount of heat to break the many hydrogen bonds in a quantity of water. Water's ability to absorb a lot of heat before becoming hot is the reason it was used to cool automobile engines in the days before alcohol-based coolants became available. In a similar way, water helps stabilize the temperature inside cells, which are mostly water. The chemical reactions in cells produce heat, yet cells must stay fairly cool in order for their proteins to function properly.



A Polarity of a water molecule.



B Hydrogen bonds between molecules in liquid water (*dashed lines*).



C Water's cohesion. When water flows from a fountain, gravity pulls molecules away from the surface. The individual water molecules don't scatter every which way, however, because hydrogen bonds pull inward on those at the surface. *Right*: Cohesion gives water a skinlike surface (*left*) that can support lightweight objects, such as a leaf or an insect.

Figure 2.9 Animated! Water is essential for life. (© Cengage Learning)

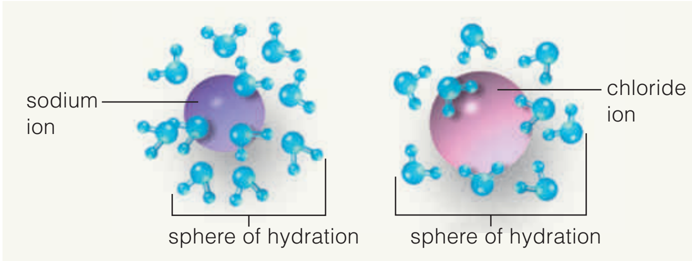


Figure 2.10 Animated! Charged substances dissolve easily in water. This diagram depicts water molecules clustered around a sodium ion and a chloride ion. The clusters are called "spheres of hydration." (© Cengage Learning)

When water absorbs enough heat energy, hydrogen bonds between water molecules break apart. Then liquid water evaporates: Molecules at its surface begin to escape into the air. Heat is lost when a large number of water molecules evaporate. This is why sweating helps cool you off on a hot, dry day. Your sweat is 99 percent water. When it evaporates from the millions of sweat glands in your skin, heat leaves with it.

Water is a solvent

Water also is a superb **solvent**, which means that ions and polar molecules easily dissolve in it. In chemical terms a dissolved substance is called a **solute** (SAHL-yoot). When a substance dissolves, water molecules cluster around its individual molecules or ions and form "spheres of hydration." This is what happens to solutes in blood and other body fluids. Most chemical reactions in the body occur in water-based solutions.

Figure 2.10 shows what happens to table salt (NaCl) when you pour some into a glass of water. After a while, the salt crystals separate into Na^+ and Cl^-. Each Na^+ attracts the negative end of some of the water molecules while each Cl^- attracts the positive end of others.

antioxidant Substance that gives up an electron to a free radical.

free radical An unstable molecule that includes an atom with an electron vacancy in its outer shell.

solute A dissolved substance.

solvent Water-based solution in which polar molecules and ions easily dissolve.

TAKE-HOME MESSAGE

WHAT ARE THE CHEMICAL PROPERTIES OF WATER THAT HELP SUPPORT LIFE?

- A water molecule is polar. Its oxygen atom is slightly positive and its hydrogen atoms are slightly negative.
- Polarity allows water molecules to form hydrogen bonds with one another and with other polar (hydrophilic) substances.
- Water molecules tend to repel nonpolar (hydrophobic) substances.
- The hydrogen bonds in water help it stabilize temperature in body fluids and allow it to dissolve many substances.

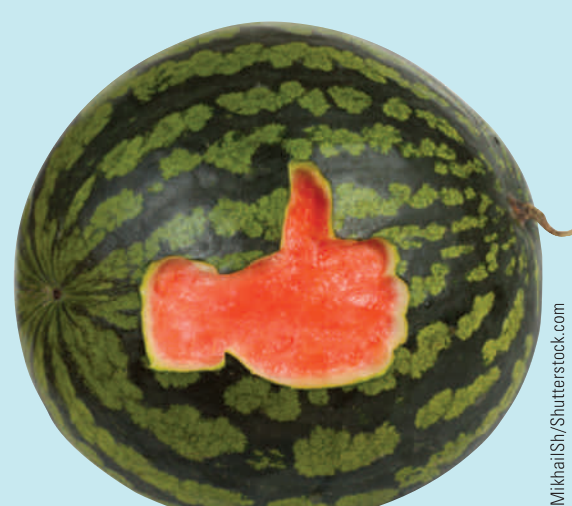
FOCUS ON HEALTH

2.6 Antioxidants Help Protect Cells

The oxidations that go on in our cells (Section 2.4) release unstable molecules called **free radicals**. A free radical is missing an electron in its outer shell. To fill the empty slot, the free radical can easily attract an electron from a stable molecule. This "theft" disrupts the once-stable molecule's structure and functioning.

Cell operations can release large numbers of free radicals, and outside factors like ultraviolet radiation in sunlight produce even more. When large numbers of free radicals are present in the body, they pose a serious threat to many cell molecules, including the genetic material DNA.

An **antioxidant** can give up an electron to a free radical before the rogue damages cells. The body makes some antioxidants, including the hormone melatonin (Chapter 15), but this homegrown chemical army isn't enough to counter the ongoing production of free radicals. You can, however, eat powerful antioxidants in the form of fruits and vegetables that contain certain phytochemicals. One example is the lycopene that makes tomatoes, strawberries, and watermelon red. Vitamin C and flavonoids in some citrus fruits, cantaloupes, and plums, and lutein zeaxanthin in leafy greens, are other examples. Nutritionists recommend adding phytochemicals to the diet by eating lots of the foods that contain them, using supplements only in moderation (Figure 2.11).



© MikhailSh/Shutterstock.com

Figure 2.11 The lycopene that makes watermelon red is an antioxidant that helps counter free radicals.

2.7 Acids, Bases, and Buffers: Body Fluids in Flux

acid Substance that donates protons (H^+) to other solutes or to water molecules when it dissolves in water.

base Substance that accepts H^+ when it dissolves in water.

hydrogen ion A proton, H^+.

hydroxide ion The negatively charged molecule OH^-.

pH scale Measure of the concentration of H^+ in a fluid.

- **Ions such as H^+ dissolved in the fluids inside and outside cells influence cell functions.**
- **Buffer systems help maintain proper ion balance.**

Every instant of every day, chemical reactions in or outside your cells add or remove substances from your body fluids. Homeostasis—and our health—depend on the body's ability to manage these changes.

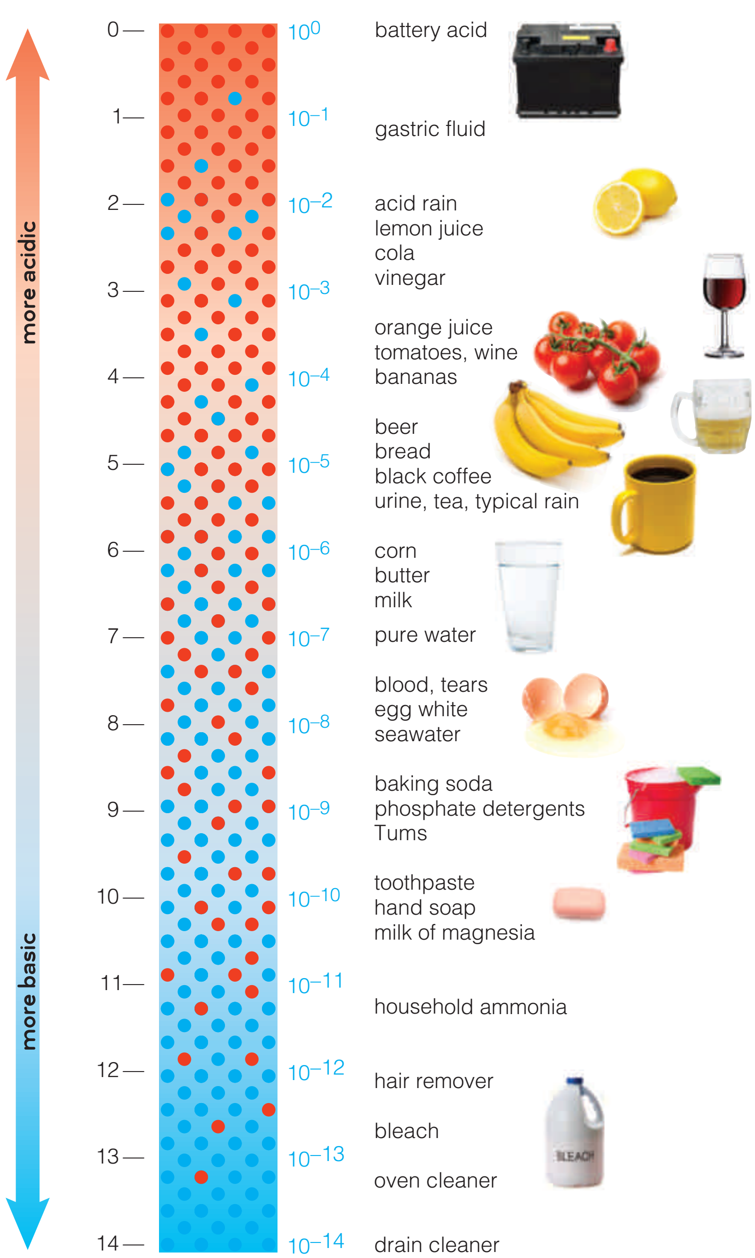


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Figure 2.12 The pH scale indicates the acidity of a solution.

The pH scale indicates the concentration of hydrogen ions in fluids

As you know, a water molecule, H_2O, consists of two hydrogen atoms and one oxygen atom. Depending on chemical conditions, a water molecule can naturally separate into two ions—a proton, also called a **hydrogen ion**, or H^+—and a **hydroxide ion** (OH^-). These ions are the basis for the **pH scale** (Figure 2.12). This numerical scale represents the concentration (relative amount) of H^+ in water, blood, and other fluids. There are huge numbers of hydrogen ions in the body and they can have major effects on body functions.

Pure water (not rainwater or tap water) always has equal numbers of H^+ and OH^- ions. This state is *neutrality*, or pH 7, on the pH scale. Each unit of change away from neutrality corresponds to a tenfold increase or decrease in the concentration of H^+.

The watery fluid inside most body cells is about 7 on the pH scale. Blood and the watery fluids outside cells usually have a slightly higher pH, ranging between 7.3 and 7.5. These facts are relevant because proteins and many other biological molecules can function properly only within a narrow pH range. Even small changes in pH can drastically affect life processes.

Acids give up H^+ and bases accept H^+

An **acid** donates protons (as H^+) to other solutes or to water molecules when it dissolves in water. A **base** accepts H^+ when it dissolves in water. When either an acid or a base dissolves, OH^- then forms in the solution as well. *Acidic* solutions, such as black coffee and lemon juice, release more H^+ than OH^-; their pH is below 7. *Basic* solutions, such as household bleach and dissolved baking soda, release more OH^- than H^+. Basic solutions are also called *alkaline* fluids; their pH is above 7.

Most acids are classed as either weak or strong. Weak acids, such as acetic acid, don't readily donate H^+. Depending on the pH, they just as easily accept H^+ as give it up, so they alternate between acting as an acid and acting as a base. On the other hand, strong acids totally give up H^+ when they dissociate in water. The hydrochloric acid (HCl) in your stomach and sulfuric acid (H_2SO_4) are examples.

High concentrations of strong acids or strong bases can be helpful in the stomach. For instance, when you eat, cells in your stomach secrete HCl, which separates into H^+ and Cl^- in water. The

H^+ ions make stomach fluid more acidic, and the increased acidity switches on enzymes that can chemically break down food. The acid also helps kill harmful bacteria. Eating too much of certain kinds of foods can lead to "acid stomach." Antacids are strong bases. For example, milk of magnesia releases magnesium ions and OH^-, which combines with excess H^+ in your stomach fluid. This chemical reaction raises the fluid's pH, and your acid stomach goes away.

Strong acids or bases can also be harmful. For example, many drain cleaners and other household products can cause severe chemical burns. So can sulfuric acid in car batteries. Smoke from fossil fuels and motor vehicle exhaust releases strong acids that alter the pH of rain (Figure 2.13). This "acid rain" is an environmental threat discussed in Chapter 25.

A salt releases other kinds of ions

Salts are compounds that release ions *other than* H^+ and OH^- in solutions. Salts and water often form when a strong acid and a strong base interact. Depending on a solution's pH value, salts can form and dissolve easily. Many salts dissolve into ions that have key functionsin cells. For example, nerve impulses depend on ions of sodium, potassium, and calcium.

Buffers protect against shifts in pH

Because shifts in pH can seriously disrupt body functions, there must be homeostatic mechanisms to counteract them. Fortunately, body fluids usually stay at a consistent pH because they are stabilized by **buffers**—substances that can compensate for pH changes by donating or accepting H^+. Pairs of buffers, often a weak acid or a base and its salt, operate as a balancing system that can keep the pH of a solution stable.

For example, when a base is added to a fluid, OH^- is released. However, if the fluid is buffered, the weak acid partner gives up H^+. The H^+ combines with the OH^-, forming a small amount of water that does not affect pH. So, a buffered fluid's pH stays constant even when a base is added to the fluid.

A key point to remember is that the action of a buffer can't make new hydrogen ions or eliminate those that already are present. It can only bind or release them.

Carbon dioxide forms in many reactions in the body and it takes part in an important buffer system in the blood. In this system it combines with water to form the compounds carbonic acid and bicarbonate. When the acidity of blood starts to drop (that is, its pH starts to rise) due to other factors, the carbonic acid neutralizes the excess OH^- by releasing H^+:

$$\underset{\text{carbonic acid}}{H_2CO_3} \longrightarrow \underset{\text{bicarbonate}}{HCO_3^-} + H^+$$

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© Mark Smith/Shutterstock.com; inset: © iStockphoto.com/Linda Steward

Figure 2.13 Acids produced by human activities affect the environment. In this photograph, emissions of sulfur dioxide spew from a coal-burning power plant. Sulfur dioxide is a major component of acid rain. The eroded statue pictured here is evidence of the damage it can do.

When the blood becomes more acidic, the bicarbonate absorbs excess H^+ and thus shifts the balance of the buffer system toward carbonic acid:

$$\underset{\text{bicarbonate}}{HCO_3^-} + H^+ \longrightarrow \underset{\text{carbonic acid}}{H_2CO_3}$$

Together these reactions usually keep the blood pH slightly basic, beween 7.3 and 7.5, but a buffer system can neutralize only so many ions. Even slightly more than that limit causes the pH to swing widely.

A buffer system failure in the body can be disastrous for homeostasis. If blood's pH (7.3–7.5) declines to even 7, a person will fall into the deep state of unconsciousness called a *coma*. In *acidosis*, carbon dioxide builds up in the blood, too much carbonic acid forms, and blood pH plummets. The condition called *alkalosis* is an abnormal increase in blood pH. Untreated, acidosis or alkalosis can cause death.

buffer Chemical that stabilizes the pH of a solution by donating or accepting hydrogen ions (H^+).

salt Compound that releases ions other than H^+ and OH^- in a solution.

TAKE-HOME MESSAGE

HOW DO ACIDS, BASES, SALTS, AND BUFFERS AFFECT THE MAKEUP OF BODY FLUIDS?

- Cell processes produce large numbers of hydrogen ions (H^+), which are chemically active and make body fluids more acidic.
- The pH scale represents the relative amount of hydrogen ions in body fluids.
- Acids release H^+ ions, and bases accept them.
- Salts release ions other than H^+ and OH^-.
- Buffer systems counteract potentially harmful shifts in the pH of body fluids.

2.8 Molecules of Life

- **Biological molecules are compounds built on atoms of the element carbon.**

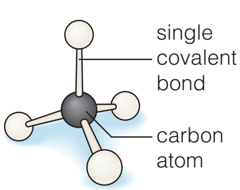
Biological molecules contain carbon

You may remember from Section 2.4 that substances containing the element carbon and formed in living things are called biological molecules. The four main kinds of biological molecules are carbohydrates, lipids, proteins, and nucleic acids. All biological molecules are **organic compounds**—that is, they contain carbon and at least one hydrogen atom. An **inorganic compound** is one that doesn't have both carbon and hydrogen. Water (H_2O) is an example.

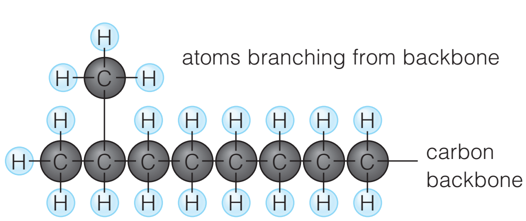
Carbon's key feature is versatile bonding

If you look back to Figure 2.1, you can see that the human body consists mostly of oxygen, hydrogen, and carbon. The oxygen and hydrogen are mainly in the form of water inside and outside our cells. Carbon makes up more than half of what is left.

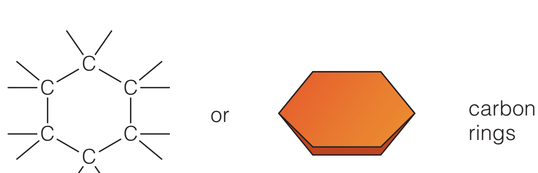
Carbon's importance to life starts with its versatile bonding behavior. As you can see in the sketch at left, each carbon atom can share pairs of electrons with as many as four other atoms. The covalent bonds are fairly stable, because the carbon atoms share pairs of electrons equally. This type of bond links carbon atoms together in chains. The chains form a backbone to which atoms of hydrogen, oxygen, and other elements can attach.



The angles of the covalent bonds help produce the shapes of organic compounds. A chain of carbon atoms, bonded covalently one after another, forms a backbone from which other atoms can project:



A carbon backbone with only hydrogen atoms attached to it is a **hydrocarbon**. The backbone also may form a ring, like this:



Functional groups affect the chemical behavior of organic compounds

Biological molecules also have parts called functional groups. A **functional group** is an atom or cluster of atoms that are covalently bonded to carbon. The kind, number, and arrangement of these groups determine the specific properties of molecules, such as polarity or acidity.

Figure 2.14 shows some functional groups. For example, sugars and other organic compounds classified as alcohols have one or more hydroxyl groups (—OH). Reactions between amine groups and carboxyl groups produce the chemical backbone of proteins.

Small differences in a biological molecule's functional groups can result in major differences in the body (Figure 2.15). Human sex hormones are an example. In females, estrogen guides the development of outward sexual traits such as the "filling out" of breasts. In males, testosterone produces outward traits such as beard growth. Chemically the hormones are almost identical, except that estrogen has a hydroxl group in the location where testosterone has an oxygen atom, and testosterone has a methyl group that estrogen lacks.

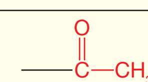
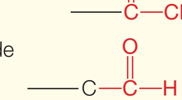
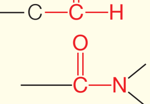
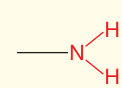
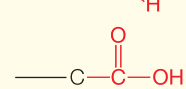
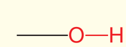
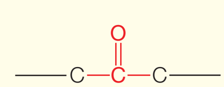
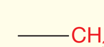
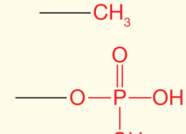
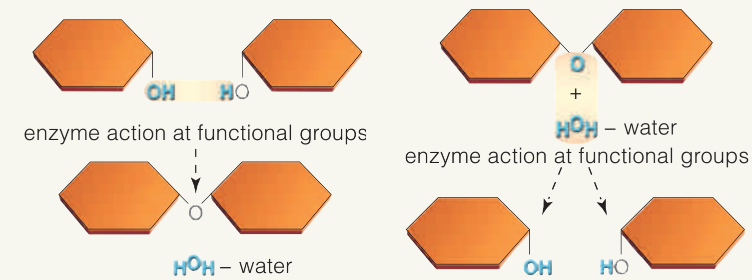
Group	Structure	Character	Formula	Found in:
acetyl		polar, acidic	$—COCH_3$	some proteins, coenzymes
aldehyde		polar, reactive	—CHO	simple sugars
amide		weakly basic, stable, rigid	—C(O)N—	proteins nucleotide bases
amine		very basic	$—NH_2$	nucleotide bases amino acids
carboxyl		very acidic	—COOH	fatty acids amino acids
hydroxyl		polar	—OH	alcohols sugars
ketone		polar, acidic	—CO—	simple sugars nucleotide bases
methyl		nonpolar	$—CH_3$	fatty acids some amino acids
phosphate		polar, reactive	$—PO_4$	nucleotides DNA, RNA phospholipids proteins
sulfhydryl		forms rigid disulfide bonds	—SH	cysteine many cofactors

Figure 2.14 Animated! Functional groups help determine the properties of biological molecules. (© Cengage Learning)

Both: © Jupiterimages

Figure 2.15 Small differences in functional groups are the basis for bodily differences produced by estrogens, the female sex hormones, and the male sex hormone testosterone. We discuss these hormones more fully in Chapter 16.



A Condensation. An —OH group from one molecule combines with an H atom from another. Water forms as the two molecules bond covalently.

B Hydrolysis. A molecule splits, then an —OH group and an H atom from a water molecule become attached to sites exposed by the reaction.

Figure 2.16 Animated! Metabolic reactions build, rearrange, and break apart most biological molecules. (© Cengage Learning)

condensation reaction Chemical reaction that covalently bonds two molecules into a larger one. Water often forms as a by-product.

enzyme Type of protein that speeds up chemical reactions.

functional group Atom or atoms bonded to carbon in a molecule and that helps determine the molecule's chemical properties.

hydrocarbon Molecule having only hydrogen atoms bonded to a carbon backbone.

hydrolysis reaction Chemical reaction that splits a large molecule into smaller parts, often using a water molecule in the process.

inorganic compound Compound that does not contain both carbon and hydrogen.

monomer Small subunit of a larger molecule.

organic compound Compound that contains carbon and one or more hydrogen atoms.

polymer Large molecule built of monomer subunits.

Cells have chemical tools to assemble, break apart, and rearrange biological molecules

How do cells make the organic compounds they need for their structure and functioning? To begin with, whatever happens in a cell requires energy, which is provided by a compound called ATP that you will learn more about shortly. Chemical reactions in cells also require a class of proteins called **enzymes**, which make reactions take place faster than they would on their own. Table 2.3 lists some of the ways cells alter organic compounds. Two important types of reactions are called condensation and hydrolysis.

Condensation reactions As a cell builds or changes organic compounds, a common step is the **condensation reaction**. Often in this kind of reaction, enzymes remove a hydroxyl group from one molecule and an H atom from another, then speed the formation of a covalent bond between the two molecules (Figure 2.16A). The discarded hydrogen and oxygen atoms may combine to form a molecule of water (H_2O). Because this kind of reaction often forms water as a by-product, condensation is sometimes called *dehydration* ("un-watering") *synthesis*. Cells can use condensation reactions to assemble polymers. *Poly-* means "many," and a **polymer** is a large molecule built of three to millions of subunits. The subunits, called **monomers**, may be the same or different.

Hydrolysis reactions **Hydrolysis** is the reverse of condensation (Figure 2.16B). In a first step, enzymes that act on particular functional groups split molecules into two or more parts. Then they attach an —OH group and a hydrogen atom from a molecule of water to the exposed sites. With hydrolysis, cells can break apart large polymers into smaller units when these are required for building blocks or energy.

In addition to condensation and hydrolysis, cells may obtain needed organic compounds by relocating functional groups. One molecule gives up a functional group that immediately is attached to another molecule. The transfer changes the structure and function of both molecules involved. Electrons may also move from one molecule to another. Chapter 3 will describe the key role electron transfers have in producing a cell's supply of energy.

TABLE 2.3 Some Ways Cells Alter Organic Compounds

Type of Reaction	What Happens
Condensation	Two molecules covalently bond into a larger one.
Hydrolysis	A molecule splits into two smaller ones, releasing water.
Transfer of functional groups	One molecule gives up a functional group, and a different molecule immediately accepts it.
Electron transfer	One molecule donates electrons to another molecule.
Rearrangement	Moving internal bonds converts one type of organic compound to another.

TAKE-HOME MESSAGE

WHAT ARE THE MAIN TYPES OF BIOLOGICAL MOLECULES?

- The main types of biological molecules are carbohydrates, lipids, proteins, and nucleic acids.
- Biological molecules are organic compounds: They contain carbon and one or more hydrogen atoms.
- Organic compounds vary in their structure and function, due partly to their functional groups.
- Proteins called enzymes speed chemical reactions in cells.
- Chemical reactions in cells combine, break apart, or rearrange biological molecules, as in condensation and hydrolysis.

2.9 Carbohydrates: Plentiful and Varied

- **Carbohydrates are the most abundant biological molecules.**
- **Cells use carbohydrates to help build cell parts or package them for energy.**

carbohydrate A biological molecule built of carbon, hydrogen, and oxygen atoms, usually in a 1:2:1 ratio.

monosaccharide The simplest class of carbohydrate, consisting of a single sugar monomer. A glucose molecule is an example.

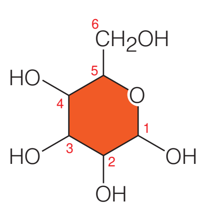
oligosaccharide A carbohydrate that consists of a short chain of sugar units. Sucrose is an example.

polysaccharide A complex carbohydrate that consists of straight or branched chains of sugar monomers. Cellulose is an example.

Most **carbohydrates** consist of carbon, hydrogen, and oxygen atoms in a 1:2:1 ratio. Due to differences in structure, chemists separate carbohydrates into three major classes: monosaccharides, oligosaccharides, and polysaccharides.

Simple sugars are the simplest carbohydrates

Saccharide comes from a Greek word for sugar. A **monosaccharide**, meaning "one monomer of sugar," is the simplest carbohydrate. It has at least two —OH groups joined to the carbon backbone plus an aldehyde or a ketone group. Monosaccharides usually taste sweet and dissolve easily in water. The most common ones have a backbone of five or six carbons; for example, there are five carbon atoms in deoxyribose, the sugar in DNA. The simple sugar glucose is the main energy source for body cells. Each glucose molecule (below) has six carbons, twelve hydrogens, and six oxygens. (Notice how it meets the 1:2:1 ratio noted above.) Glucose is a building block for larger carbohydrates. It also is the parent molecule (precursor) for many compounds, such as vitamin C, which are derived from sugar monomers.



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Grapes, a natural source of sucrose in the diet.

Oligosaccharides are short chains of sugar units

Unlike the simple sugars, an **oligosaccharide** is a short chain of two or more sugar monomers that are joined by dehydration synthesis. (*Oligo-* means "a few.") The type known as *di*saccharides consists of just two sugar units. Lactose, sucrose, and maltose are examples. Lactose (a glucose and a galactose unit) is a milk sugar. Sucrose, the most plentiful sugar in nature, consists of one glucose and one fructose unit (Figure 2.17). You consume sucrose when you eat fruit, among other plant foods. Table sugar is sucrose crystallized from sugar cane and sugar beets.

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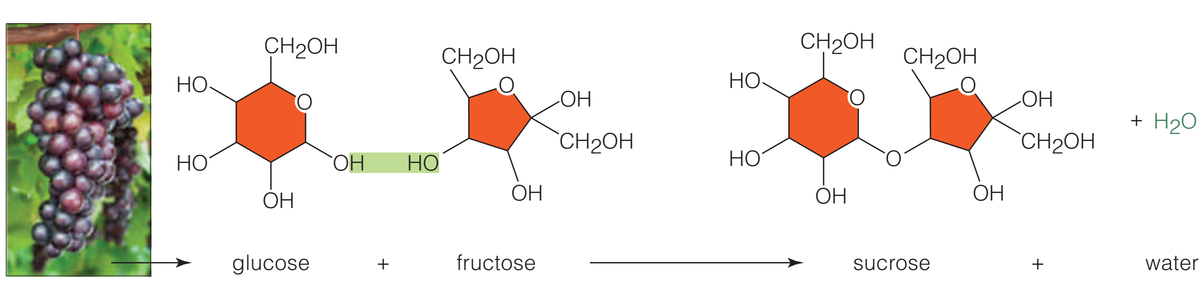
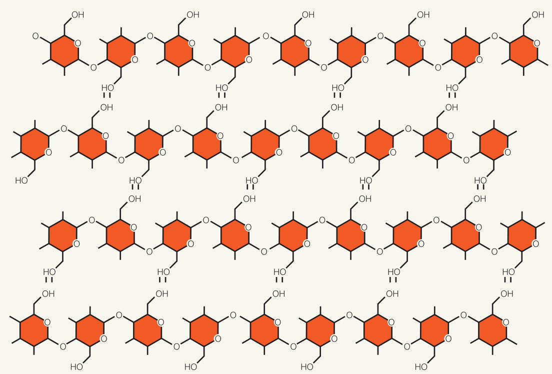
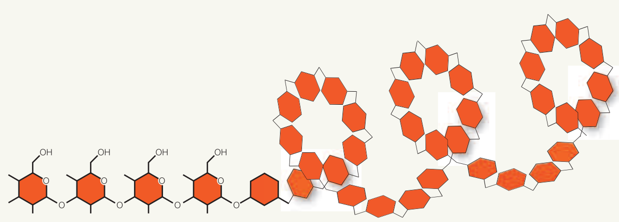


Figure 2.17 **Sucrose, or table sugar, is a disaccharide formed from glucose and fructose. As you can see in this diagram, the synthesis of a sucrose molecule is a condensation reaction, which forms water as a by-product.** (© Cengage Learning)



A Cellulose occurs only in plants. Chains of glucose units stretch side by side and hydrogen-bond at many —OH groups. The hydrogen bonds stabilize the chains in tight bundles that form long fibers, such as cotton fibers humans use for clothing.



B In amylose, one type of starch, glucose units are monomers that form a coiling polymer chain. Plants store starch in their roots, stems, leaves, seeds, and fruits, such as apples.

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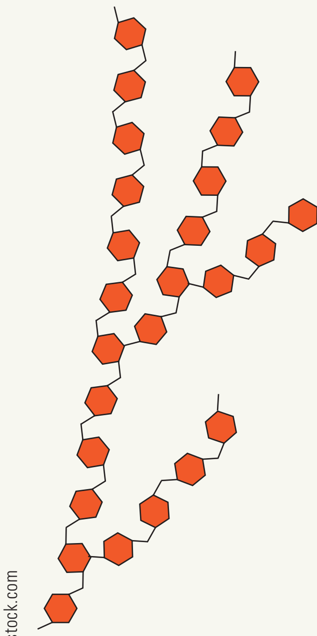

C Glycogen. This polysaccharide is an energy reservoir. The liver and muscles of active animals, including people, store large amounts of it.

Figure 2.18 **Animated!** **Complex carbohydrates are chains of many sugar monomers. This diagram shows the structure of A cellulose, B starch, and C glycogen. Glucose is the basic building block of all three of these carbohydrates.** (© Cengage Learning)

Proteins and other large molecules often have oligosaccharides attached as side chains to their carbon backbone. Some chains have key roles in activities of cell membranes, as you will read in Chapter 3. Others are important in the body's defenses against disease.

Polysaccharides are sugar chains that store energy

The "complex" carbohydrates, or **polysaccharides**, are straight or branched chains of sugar monomers. Often thousands are joined by dehydration synthesis. The many chemical bonds in polysaccharides store a great deal of energy. That energy is released to cells when the digestive system breaks these sugars down. Polysaccharides make up most of the carbohydrates humans eat. The most common ones—glycogen, starch, and cellulose—consist only of glucose.

Plants store a large amount of glucose in the form of cellulose (Figure 2.18A). Humans don't have digestive enzymes that can break down the cellulose in whole grains, vegetables, fruits, and other plant tissues. We do benefit from it, however, as undigested "fiber" that adds bulk and so helps move wastes through the lower part of the digestive tract.

Many plant-derived foods are rich in starch, which is one form in which plants store glucose. In starch the glucose subunits form a string, as with the starch amylose illustrated in Figure 2.18B.

The polysaccharide glycogen is one form in which animals store sugar, most notably in muscles and the liver (Figure 2.18C). When a person's blood sugar level falls, liver cells break down glycogen and release glucose to the blood. When you exercise, your muscle cells tap into their glycogen stores as a quick source of energy.

TAKE-HOME MESSAGE

WHAT ARE CARBOHYDRATES?

- Carbohydrates range from simple sugars such as glucose to molecules composed of many sugar units.
- From simple to complex, the three major types of carbohydrates are monosaccharides, oligosaccharides, and polysaccharides.
- Cells use carbohydrates for energy or as raw materials for building cell parts.