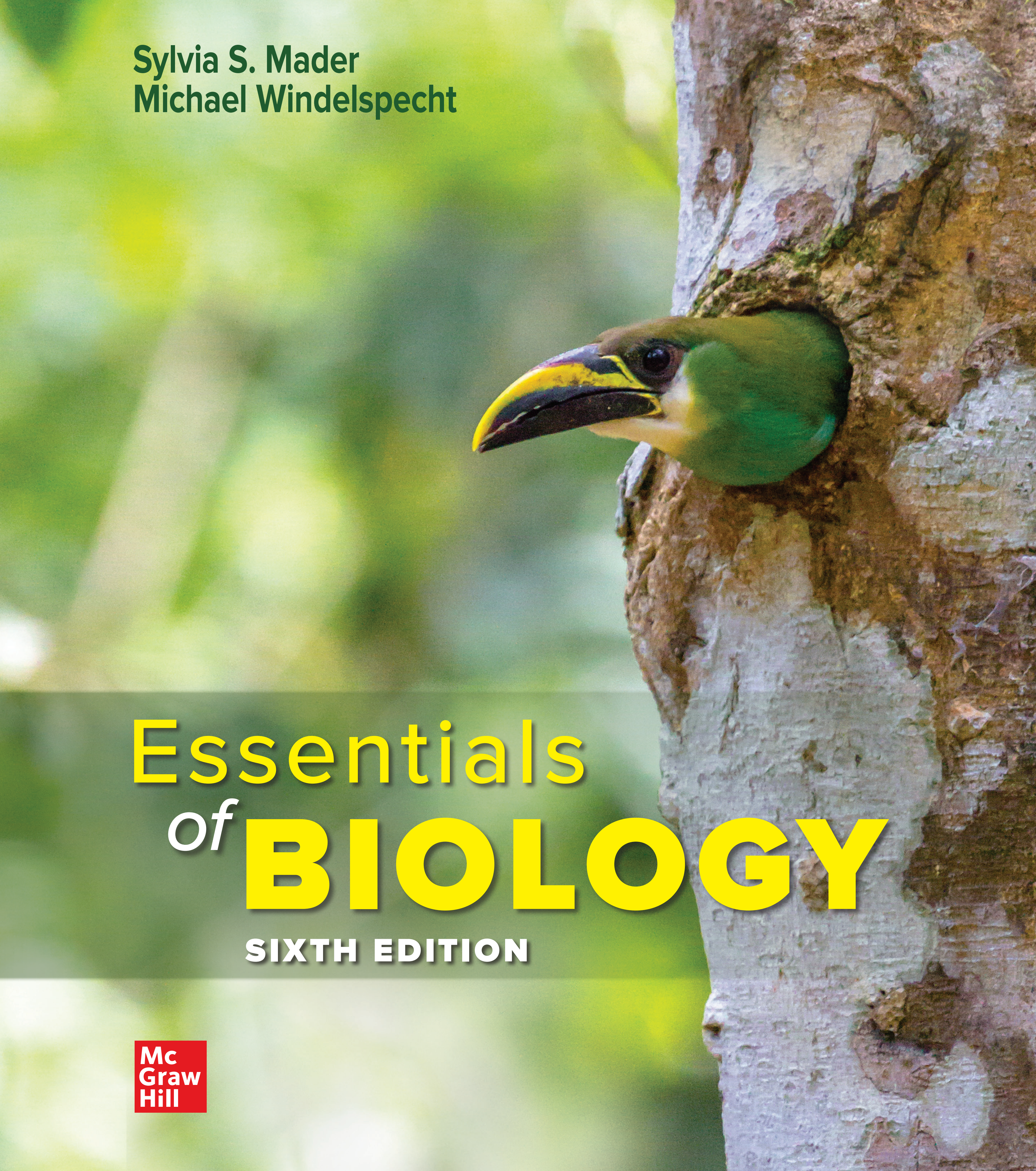
Sylvia S. Mader
Michael Windelspecht

Essentials of BIOLOGY

SIXTH EDITION



McGraw Hill

ESSENTIALS OF Biology

Sixth Edition

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Brief Contents

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About the Authors

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Dr. Sylvia S. Mader Sylvia Mader has authored several nationally recognized biology texts published by McGraw-Hill. Educated at Bryn Mawr College, Harvard University, Tufts University, and Nova Southeastern University, she holds degrees in both biology and education. Over the years, she has taught at University of Massachusetts, Lowell; Massachusetts Bay Community College; Suffolk University; and Nathan Mayhew Seminars. Her ability to reach out to science-shy students led to the writing of her first text, *Inquiry into Life,* which is now in its sixteenth edition. Highly acclaimed for her crisp and entertaining writing style, her books have become models for others who write in the field of biology.

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Dr. Michael Windelspecht As an educator, Dr. Windelspecht has taught introductory biology, genetics, and human genetics in the online, traditional, and hybrid environments at community colleges, comprehensive universities, and military institutions. For over a decade, he served as the Introductory Biology Coordinator at Appalachian State University, where he directed a program that enrolled over 4,500 students annually.

He received degrees from Michigan State University (BS, zoology–genetics) and the University of South Florida (PhD, evolutionary genetics) and has published papers in areas as diverse as science education, water quality, and the evolution of insecticide resistance. His current interests are in the analysis of data from digital learning platforms for the development of personalized microlearning assets and next-generation publication platforms. He is currently a member of the National Association of Science Writers and several science education associations. He has served as the keynote speaker on the development of multimedia resources for online and hybrid science classrooms. In 2015, he won the DevLearn HyperDrive competition for a strategy to integrate student data into the textbook revision process.

As an author and editor, Dr. Windelspecht has over 25 reference textbooks and multiple print and online lab manuals to his credit. He has founded several science communication companies, including Ricochet Creative Productions, which actively develops and assesses new technologies for the science classroom. You can learn more about Dr. Windelspecht by visiting his website at www.michaelwindelspecht.com.

Preface

Our modern society is based largely on the rapid advances in science and technology that have occurred over the past few decades. Students in today's world are being exposed, almost on a daily basis, to exciting new discoveries and insights that, in many cases, were beyond our predictions even a few short years ago. It is our task, as instructors, not only to make these findings available to our students, but to enlighten students as to why these discoveries are important to their lives and society. At the same time, we must provide students with a firm foundation in those core principles on which biology is founded, and in doing so, provide them with the background to keep up with the many discoveries still to come.

Essentials of Biology, s*ixth edition* is designed to provide students who are not majoring in science with a fundamental understanding of the science of biology. Even though these students are not scientists, an understanding of how science can help identify, analyze, and offer solutions to the many challenges facing human society is critical to our species' health and survival.

The following goals guided our preparation of this new edition:

- Update chapter openers and readings within the text to reflect more recent discoveries, or topics of interest, in the life sciences.
- Update statistics, maps, and tables to reflect changes in our scientific understanding of the topics in the chapters.
- Assess and redesign art to better fit the digital learning environment.
- Develop relevancy modules to supplement the text and enable instructors to show how biology is relevant to students' lives.

Relevancy

The use of real-world examples to demonstrate the importance of biology in the lives of students is widely recognized as an effective teaching strategy for the introductory biology classroom. Students want to learn about the topics they are interested in. The development of relevancy-based resources is a major focus for the authors of the Mader series of texts. Some examples of how we have increased the relevancy content of this edition include:

Relevancy Modules

We have authored a series of relevancy modules that supplement the content found within *Essentials of Biology*. These modules demonstrate the connections between biological content and topics of interest to society as a whole. Each module consists of an introduction to how biology relates to the topic, an overview of basic scientific concepts, and then a closer look at the application of these concepts to the topic. Discussion and assessment questions, specific to the modules, are also available.

These modules are available as a supplementary eBook to the existing text within Connect, and may be assigned by the instructor for use in a variety of ways in the classroom. Our current list of topics include:

- Scientific Thinking in Everyday Life
- Fermentation
- The Biology of Chocolate
- Cancer
- Evolution of a Weed
- Antibiotic Resistance
- Mega Crops
- Our Animal Ancestors
- The Biology of Weight Gain
- The Biology of Running a Marathon
- Climate Change
- Toxic Algae Blooms

New topics are planned for launch each year to keep these resources current.

BioNOW Videos

The BioNOW series of videos, narrated and produced by educator Jason Carlson, provide a relevant, applied approach that allows your students to feel they can actually do and learn biology themselves. While tying directly to the content of your course, the videos help students relate their daily lives to the biology you teach, and then connect what they learn back to their lives.

Each video provides an engaging and entertaining story about applying the science of biology to a real situation or problem. Attention is given to using tools and techniques that the average person would have access to, so your students see the science as something they could do and understand.

RicochetScience Website

The RicochetScience.com website, managed by Dr. Michael Windelspecht, provides content that is of interest to students who are not majoring in the sciences. For example, the PopScience articles on this site provide an excellent focus for classroom discussions on topics that are currently being debated in society, such as vaccines. The content is organized using the same topic areas that are the focus of the relevancy modules, making it simple for instructors to find and utilize these resources. The site also features videos and tutorial animations to assist students in recognizing the relevancy of what they are learning in the classroom.

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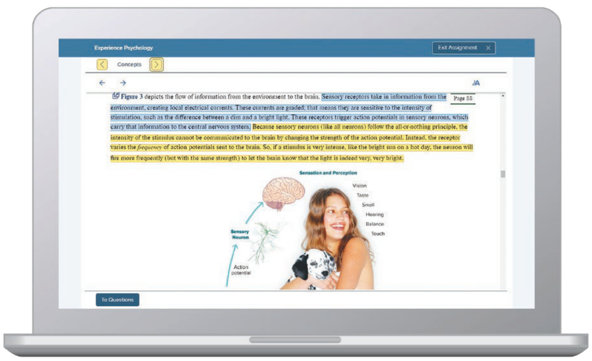

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Acknowledgments

Dr. Sylvia Mader is one of the icons of science education. Her dedication to her students, coupled to her clear, concise writing style, has benefited the education of thousands of students over the past four decades. As an educator, it is an honor to continue her legacy and to bring her message to the next generation of students.

As always, I had the privilege to work with a phenomenal group of people on this edition. I would especially like to thank you, the numerous instructors who have shared emails with me or have invited me into your classrooms, both physically and virtually, to discuss your needs as instructors and the needs of your students. You are all dedicated and talented teachers, and your energy and devotion to quality teaching is what drives a textbook revision.

Many dedicated and talented individuals assisted in the development of this edition of *Essentials of Biology*. I am very grateful for the help of so many professionals at McGraw-Hill who were involved in bringing this book to fruition. Therefore, I would like to thank the following:

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- My digital expert, Eric Weber, for helping me envision the possibilities in our new digital world.
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- Lori Hancock and David Tietz for the photos within this text. Biology is a visual science, and their contributions are evident on every page.
- Michael McGee and Sharon O'Donnell who acted as my proofreaders and copyeditors for this edition.
- Jane Peden for her behind-the-scenes work that keeps us all functioning.

As both an educator and an author, communicating the importance of science represents one of my greatest passions. Our modern society is based largely on advances in science and technology over the past few decades. As I present in this text, there are many challenges facing humans, and an understanding of how science can help analyze, and offer solutions to, these problems is critical to our species' health and survival.

I also want to acknowledge my family and friends for all of their support. My wife, Sandy, who has never wavered in her support of my many projects. Over the course of my work with McGraw-Hill, I have watched the natural curiosity of my children, Devin and Kayla, develop them into the phenomenal individuals that they are today. Thank you both for your motivation in making our world a better place.

Michael Windelspecht, PhD

Blowing Rock, NC

Reviewers for This Edition

I would like to thank the individuals below for taking the time to review the content of the previous edition. Your comments and suggestions played an important part of this revision.

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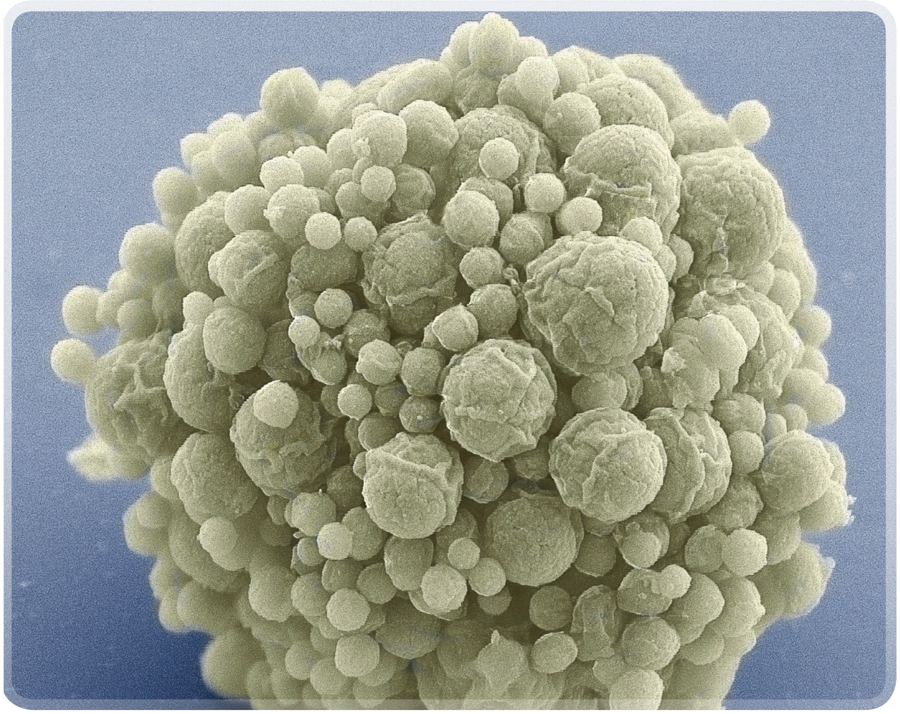

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CHAPTER 1

Biology: The Science of Life

Artificial Life

What are the minimal requirements for life? That question has occupied the minds of philosophers and scientists for thousands of years. However, in just the past decade, answers to this question have begun to emerge from a developing field of scientific study called artificial life.

One of the first of these studies occurred in 2010, when a research team led by Craig Venter (a pioneer in genetic research) was successful in removing the genetic information contained within the DNA of a bacterium and replacing it with a synthetic form of DNA.

In 2016, the same group of researchers took their research one step further. This time, they asked what minimal instructions were needed by a cell for it to be considered alive. They constructed a cell that functioned on just 473 genes (humans have around 19,000). In the process, they not only narrowed in on what the minimal requirements for life are, but also created the first example of an artificial species.

The development of artificial life opens up the opportunity for humans to construct cells that perform specific tasks, such as producing insulin, cleaning toxic waste, or producing fuel more efficiently. However, there are concerns about these new endeavors, and some scientists are urging constraint until the risks have been determined.

In this chapter, we will explore the concept of life by examining the general characteristics shared by all living organisms on our planet.

As you read through this chapter, think about the following questions:

1. What characteristics do you share with the diversity of life on the planet?
2. How does adaptation and the process of evolution relate to living organisms?
3. What are some of the challenges facing science and society today?

OUTLINE

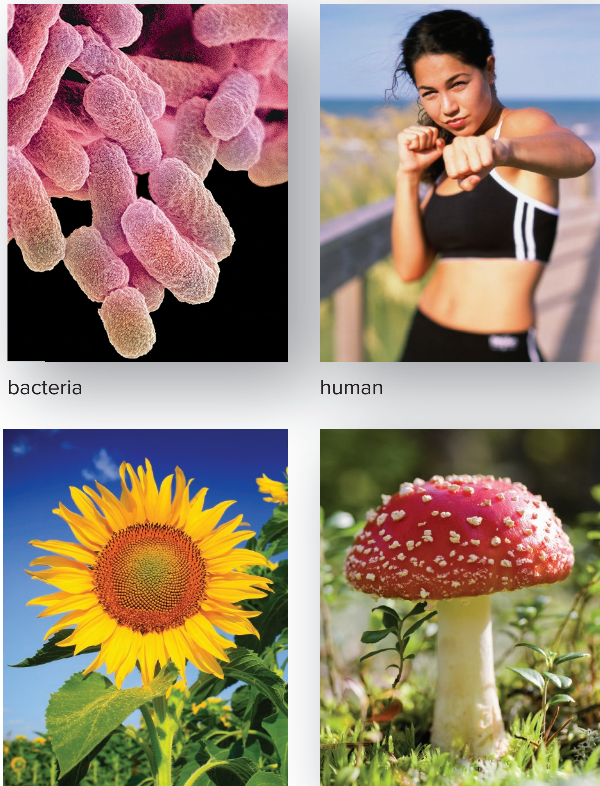


Figure 1.1 Diversity of life.
Biology is the study of life in all of its diverse forms.

(bacteria): ©Science Photo Library/Getty Images; (human): ©Purestock/Superstock; (plant): ©Zeljko Radojko/Shutterstock; (fungi): ©Jorgen Bausager/Getty Images

1.1 The Characteristics of Life

Learning Outcomes

Upon completion of this section, you should be able to

1. Explain the basic characteristics common to all living organisms.
2. Distinguish between the levels of biological organization.
3. Summarize how the terms *homeostasis, metabolism,* and *adaptation* relate to all living organisms.
4. Contrast chemical cycling and energy flow within an ecosystem.

As we observed in the chapter opener, life is diverse (Fig. 1.1). Life may be found everywhere on the planet, from thermal vents at the bottom of the ocean to the coldest reaches of Antarctica. **Biology** is the scientific study of life. Biologists study not only life's diversity but also the characteristics shared by all living organisms. These characteristics include levels of organization, the ability to acquire materials and energy, the ability to maintain an internal environment, the ability to respond to stimuli, the ability to reproduce and develop, and the ability to adapt and evolve to changing conditions. By studying these characteristics, we gain insight into the complex nature of life, which helps us distinguish between living organisms from nonliving things. In the next sections, we will explore these characteristics in more detail.

The complex organization of life begins with **atoms,** the basic units of matter. Atoms combine to form small **molecules,** which then join to form larger molecules within a **cell,** the smallest, most basic unit of life. Although a cell is alive, it is made from nonliving molecules (Fig. 1.2).

The majority of life on the planet, such as bacteria, are single-celled. Plants, fungi, and animals are multicellular organisms and are therefore composed of many types of cells, which often combine to form **tissues.** Tissues make up **organs,** as when various tissues combine to form the heart of an animal or the leaf of a plant. Organs work together in **organ systems;** for example, the heart and blood vessels form the cardiovascular system. Various organ systems often work together within complex **organisms.**

The organization of life extends beyond the individual organism. A **species** is a group of similar organisms that are capable of interbreeding. All of the members of a species within a particular area belong to a **population.** When populations interact, such as the humans, zebras, and trees in Figure 1.2, they form a **community.** At the **ecosystem** level, communities interact with the physical environment (soil, atmosphere, etc.). Collectively, the ecosystems on the planet are called the **biosphere,** the zone of air, land, and water at the surface of the Earth where living organisms are found.

Life Requires Materials and Energy

All life, from single cells to complex organisms, is not capable of maintaining organization or carrying on its necessary activities without an outside source of materials and energy. Food provides nutrient molecules, which are used as building blocks or energy sources. **Energy** is the capacity to do work, and it takes work to maintain the organization of the cell and the organism. When cells use nutrient molecules to make their parts and products, they carry out a sequence of chemical reactions. The term **metabolism** encompasses all the chemical reactions that occur in a cell.

Figure 1.2 **Levels of biological organization.**
All life is connected by levels of biological organization that extend from atoms to the biosphere.

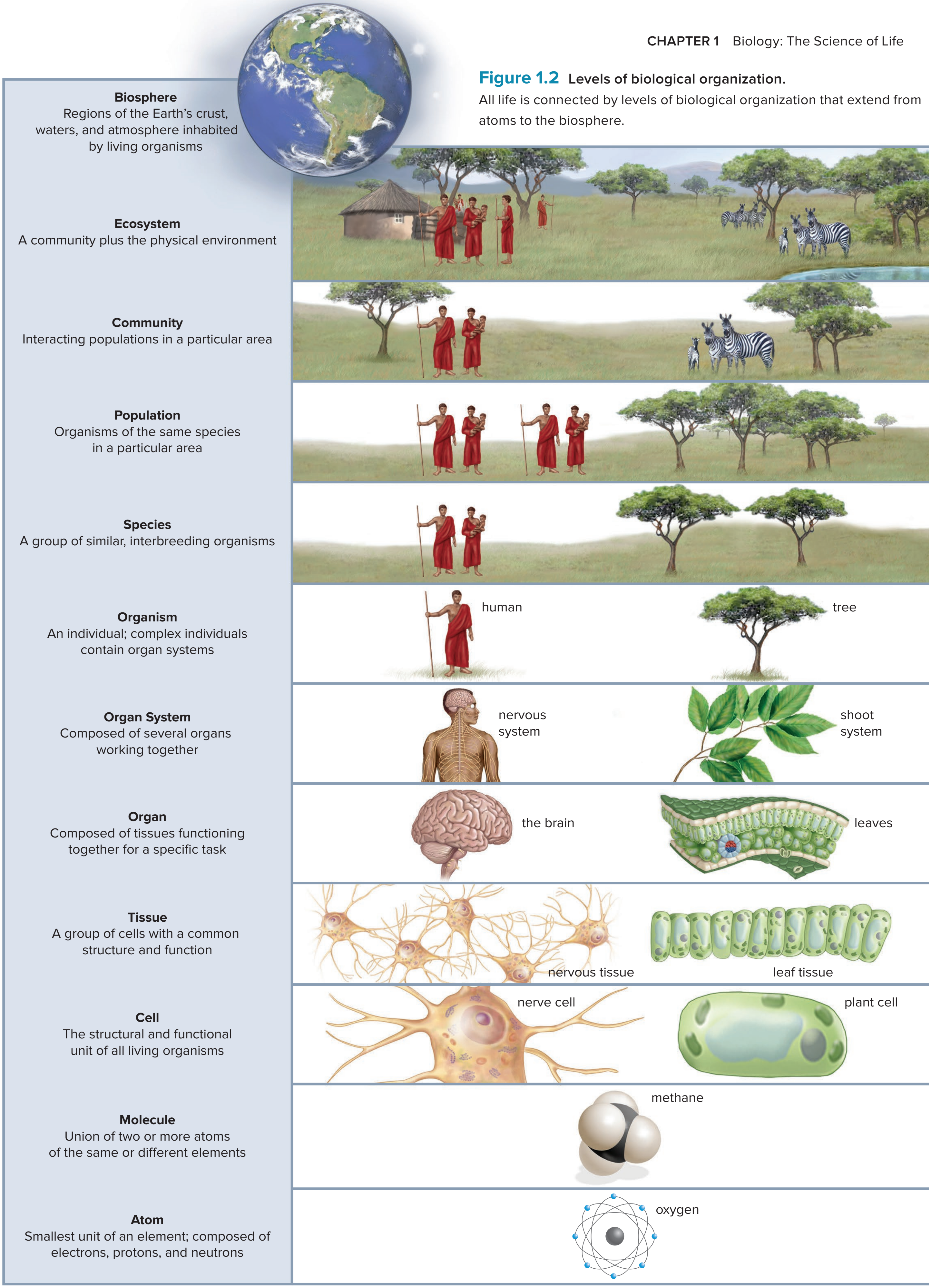


Figure 1.3 **Acquiring nutrient materials and energy.** All organisms, including this otter eating shellfish, require nutrients and energy.

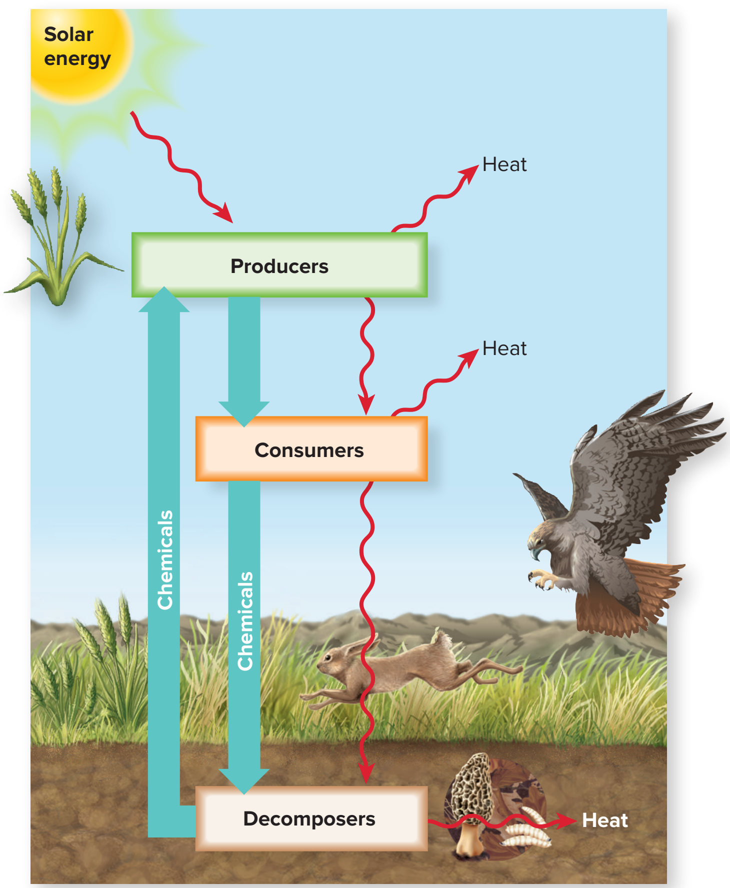


Figure 1.4 **Chemical cycling and energy flow in an ecosystem.** In an ecosystem, chemical cycling (aqua arrows) and energy flow (red arrows) begin when plants use solar energy and inorganic nutrients to produce their own food. Chemicals and energy are passed from one population to another in a food chain. Eventually, energy dissipates as heat. With the death and decomposition of organisms, chemicals are returned to living plants once more.

The ultimate source of energy for nearly all life on Earth is the sun. Plants and certain other organisms are able to capture solar energy and carry on photosynthesis, a process that transforms solar energy into the chemical energy of nutrient molecules (see Section 6.1). For this reason, these organisms are commonly called producers. Animals and plants get energy by metabolizing (Fig. 1.3), or breaking down, the nutrient molecules made by the producers (see Section 7.1).

The energy and chemical flow between organisms also defines how an ecosystem functions (Fig. 1.4). Within an ecosystem, chemical cycling and energy flow begin when producers, such as grasses, take in solar energy and inorganic nutrients to produce food (organic nutrients) by photosynthesis. Chemical cycling (aqua arrows) occurs as chemicals move from one population to another in a food chain, until death and decomposition allow inorganic nutrients to be returned to the producers once again. Energy (red arrows), on the other hand, flows from the sun through plants and the other members of the food chain as they feed on one another. The energy gradually dissipates and returns to the atmosphere as heat. Because energy does not cycle, ecosystems could not stay in existence without solar energy and the ability of photosynthetic organisms to absorb it.

Energy flow and nutrient cycling in an ecosystem largely determine where different ecosystems are found in the biosphere. The two most biologically diverse ecosystems—tropical rain forests and coral reefs—occur where solar energy is very abundant and nutrient cycling is continuous.

The availability of energy and nutrients also determines the type of biological communities that occur within an ecosystem. One example of an ecosystem in North America is the grasslands, which are inhabited by populations of rabbits, hawks, and various types of grasses, among many others. The energy input and nutrient cycling of a grassland are less than those of a rain forest, which means that the community structure and food chains of these ecosystems also differ.

Living Organisms Maintain an Internal Environment

For metabolic processes to continue, living organisms need to keep themselves stable with regard to temperature, moisture level, acidity, and other factors critical to maintaining life. Many of the metabolic activities of an organism are involved in maintaining **homeostasis,** or an internal environment that acts within a set of physiological boundaries.

Animals often vary their activity to regulate their internal environment. A chilly lizard may raise its internal temperature by basking in the sun on a hot rock. When it starts to overheat, it scurries for cool shade. Other organisms have control mechanisms that do not require any conscious activity. When you are studying and forget to eat lunch, your liver releases stored sugar to keep your blood sugar level within normal limits. Many of the organ systems of our bodies are involved in maintaining homeostasis.

Living Organisms Respond

Living organisms find energy and/or nutrients by interacting with their surroundings. Even single-celled organisms, such as bacteria, can respond to their environment. The beating of microscopic hairs or the snapping of whiplike tails moves them toward or away from light or chemicals. Multicellular organisms can manage more complex responses. A monarch butterfly can sense the approach of fall and begin its flight south, where resources are still abundant. A vulture can smell meat a mile away and soar toward dinner.

The ability to respond often results in movement: The leaves of a plant turn toward the sun, and animals dart toward safety. Appropriate responses help ensure survival of the organism and allow it to carry on its daily activities. Altogether, we call these activities the *behavior* of the organism.

Living Organisms Reproduce and Develop

Life comes only from life. Every living organism has the ability to **reproduce,** or make another organism like itself. Bacteria and other types of single-celled organisms simply split in two. In multicellular organisms, the reproductive process usually begins with the pairing of a sperm from one partner and an egg from the other partner. The union of sperm and egg, followed by many cell divisions, results in an immature individual, which grows and develops through various stages to become an adult.

An embryo develops into a whale or a yellow daffodil or a human because of the specific set of **genes,** or genetic instructions, inherited from its parents (Fig. 1.5). In all organisms, the genes are located on long molecules of **DNA (deoxyribonucleic acid),** the genetic blueprint of life. Variations in genes account for the differences between species and individuals. These differences are the result of **mutations,** or inheritable changes in the genetic information. Mutation provides an important source of variation in the genetic information. However, not all mutations are bad—the observable differences in eye and hair color are examples of mutations.

By studying DNA, scientists are able to understand not only the basis for specific traits, like susceptibility for certain types of cancer, but also the evolutionary history of the species. Reproduction involves the passing of genetic information from a parent to its offspring. Therefore, the information found within the DNA represents a record of our molecular heritage. This includes not only a record of the individual's lineage, but also how the species is related to other species.

DNA provides the blueprint or instructions for the organization and metabolism of the particular organism. All cells in a multicellular organism contain the same set of genes, but only certain ones are turned on in each type of specialized cell. Through the process of **development,** cells express specific genes to distinguish themselves from other cells, thus forming tissues and organs.

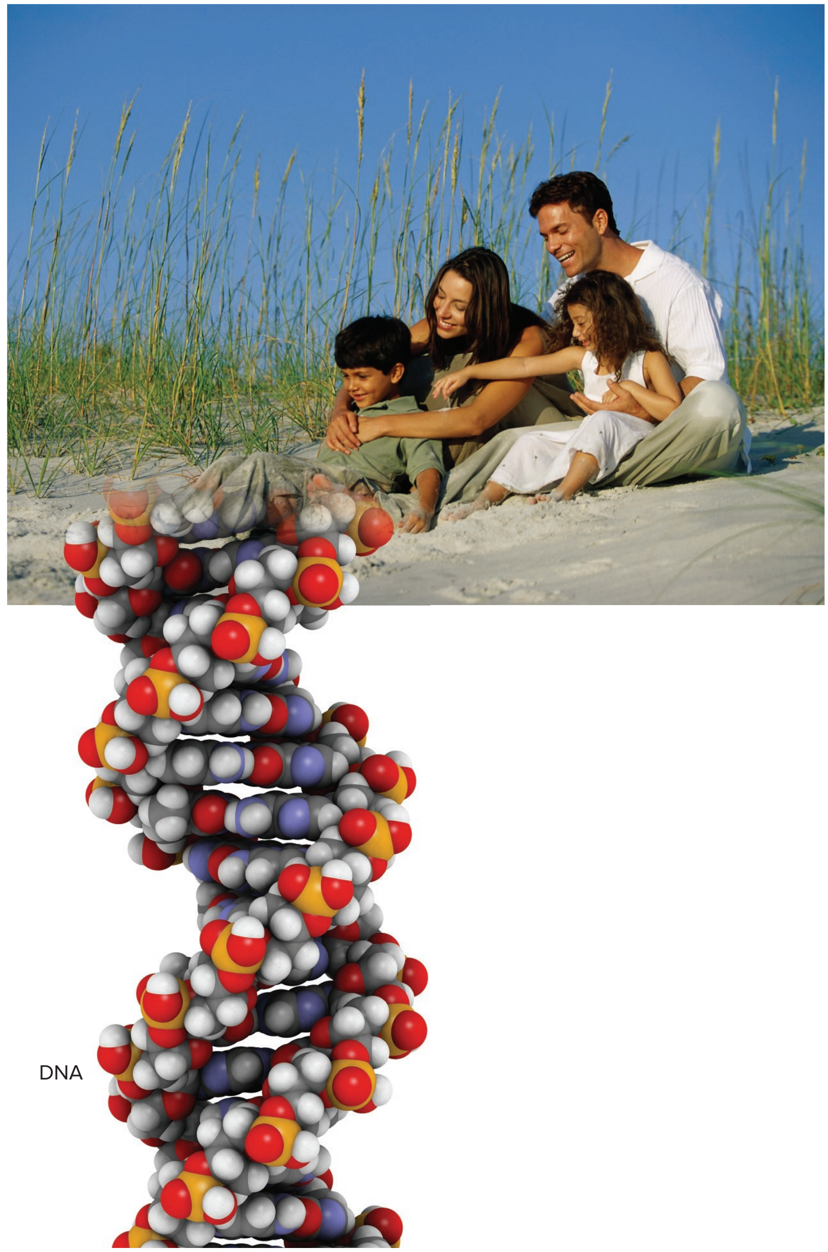


Figure 1.5 Reproduction is a characteristic of life. Whether they are single-celled or multicellular, all organisms reproduce. Offspring receive a copy of their parents' DNA and therefore a copy of the parents' genes.

(photo): ©Purestock/Superstock; (DNA): ©Molekuul/SPL/AGE Fotostock

Living Organisms Have Adaptations

Adaptations are modifications that make a species suited to their way of life. Some hawks have the ability to catch fish; others are best at catching rabbits. Hawks can fly, in part, because they have hollow bones to reduce their weight and flight muscles to depress and elevate their wings. When a hawk dives, its strong feet take the first shock of the landing, and its long, sharp claws reach out and hold onto the prey. Hawks have exceptionally keen vision, which enables them not only to spot prey from great heights but also to estimate distance and speed.

Humans also have adaptations that allow them to live in specific environments. Humans who live at extreme elevations in the Himalayas (over 13,000 feet, or 4,000 meters) have an adaptation that reduces the amount of hemoglobin produced in the blood (see Section 19.6). Hemoglobin is important for the transport of oxygen. Normally, as elevation increases, the amount of hemoglobin increases, but too much hemoglobin makes the blood thick, which can cause health problems. In some high-elevation populations, a mutation in a single gene reduces this risk.

Evolution, or the manner in which species become adapted to their environment, is discussed in the next section of this chapter.

1.1 CONNECTING THE CONCEPTS

All living organisms, from bacteria to humans, share the same basic characteristics of life.

Check Your Progress 1.1

1. List the basic characteristics common to all life.
2. List in order, starting with the least organized, the levels of biological organization.
3. Explain how chemical cycling and energy flow occur at both the organism and the ecosystem levels of organization.

1.2 Evolution: The Core Concept of Biology

Learning Outcomes

Upon completion of this section, you should be able to

1. Define the term *evolution*.
2. Explain the process of natural selection and its relationship to evolutionary processes.
3. Summarize the general characteristics of the domains and major kingdoms of life.

Despite diversity in form, function, and lifestyle, organisms share the same basic characteristics. As mentioned, they are all composed of cells organized in a similar manner. Their genes are composed of DNA, and they carry out the same metabolic reactions to acquire energy and maintain their organization. The unity of living organisms suggests that they are descended from a common ancestor—the first cell or cells.

An evolutionary tree is like a family tree (Fig. 1.6). Just as a family tree shows how a group of people have descended from one couple, an evolutionary tree traces the ancestry of life on Earth to a common ancestor. One couple can have diverse children, and likewise a population can be a common ancestor to several other groups, each adapted to a particular set of

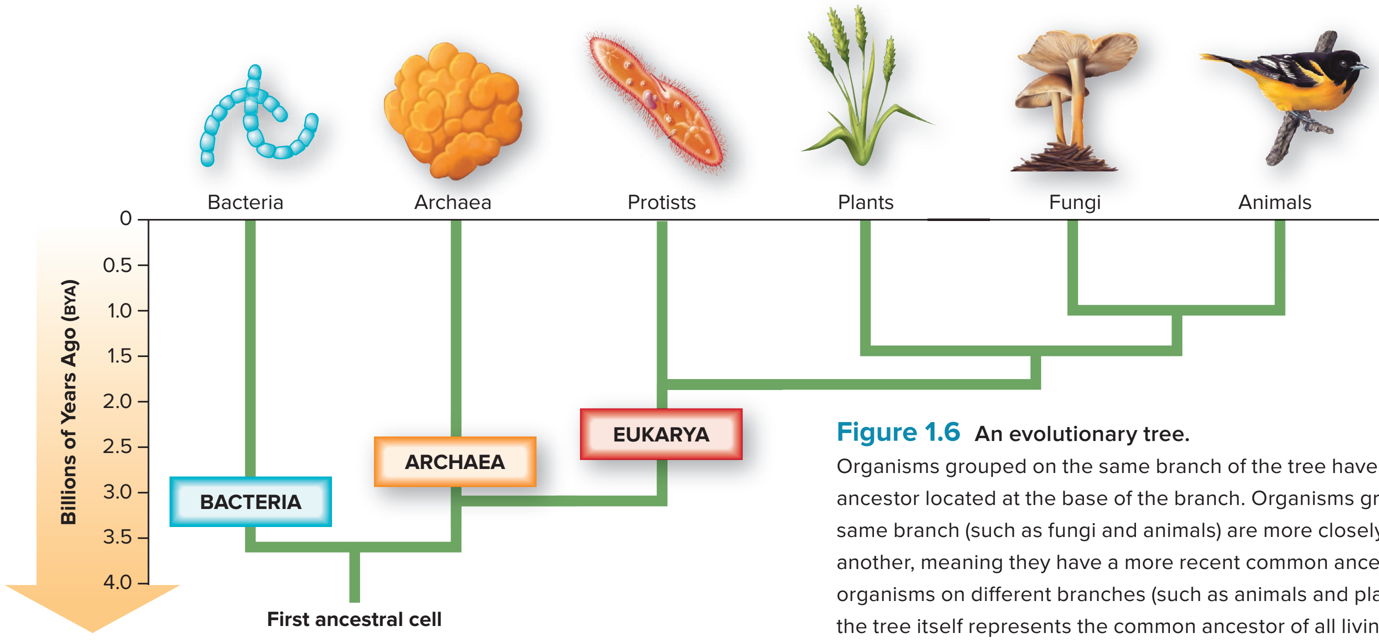


Figure 1.6 An evolutionary tree.
Organisms grouped on the same branch of the tree have a common ancestor located at the base of the branch. Organisms grouped on the same branch (such as fungi and animals) are more closely related to one another, meaning they have a more recent common ancestor than organisms on different branches (such as animals and plants). The base of the tree itself represents the common ancestor of all living organisms.

environmental conditions. **Evolution** is the process in which populations change over time to adapt to their environment, and pass on these changes to the next generation. Evolution is considered the unifying concept of biology because it explains so many aspects of biology, including the tremendous diversity of life on the planet and how living organisms arose from a single ancestor.

Natural Selection and Evolutionary Processes

In the nineteenth century, two naturalists—Charles Darwin and Alfred Russel Wallace—came independently to the conclusion that evolution occurs by means of a process called natural selection (see Section 14.1). Charles Darwin is the more famous of the two because he wrote a book called *On the Origin of Species,* which presented his observations on how the process of evolution worked using natural selection. Since that time, evolution has become the core concept of biology, not only because the theory explains so many different scientific observations, but because the wealth of data collected since Darwin's era supports the theory's importance in every aspect of the biological sciences.

The process of **natural selection** is the mechanism by which evolutionary change occurs. It is based on how a population changes in response to its environment. Environments may change due to the influence of living factors (such as a new predator) or nonliving factors (such as temperature). As the environment changes over time, some individuals of a species may possess certain adaptations that make them better suited to the new environment. Individuals of a species that are better adapted to their environment tend to live longer and produce more offspring than other individuals. This differential reproductive success, called *natural selection,* results in changes in the characteristics of a population over time. That is, adaptations that result in higher reproductive success tend to increase in frequency in a population from one generation to the next. This change in the frequency of traits in populations is called *evolution.*

The phrase "common descent with modification" sums up the process of evolution because it means that, as descent occurs from common ancestors, modifications occur that cause the organisms to be adapted (suited) to the environment. As a result, one species can be a common ancestor to several species, each adapted to a particular set of environmental conditions. Specific adaptations allow species to play particular roles in their environment.

The Hawaiian honeycreepers are a remarkable example of this process (Fig. 1.7). The more than 50 known species of honeycreepers (of which only 17 species remain today) all evolved from one species of finch, which likely originated in North America and arrived in the Hawaiian islands between 3 and 5 million years ago. Modern honeycreepers have an assortment of bill shapes adapted to different types of food. Some honeycreeper species have curved, elongated bills used for drinking flower nectar. Others have strong, hooked bills suited to digging in tree bark and seizing wood-boring insects or short, straight, finchlike bills for feeding on small seeds and fruits. Even with such dramatic differences in feeding habits and bill shapes, honeycreepers still share certain characteristics, which stem from their common finch ancestor. The various honeycreeper species are similar in body shape and size, as well as mating and nesting behavior.

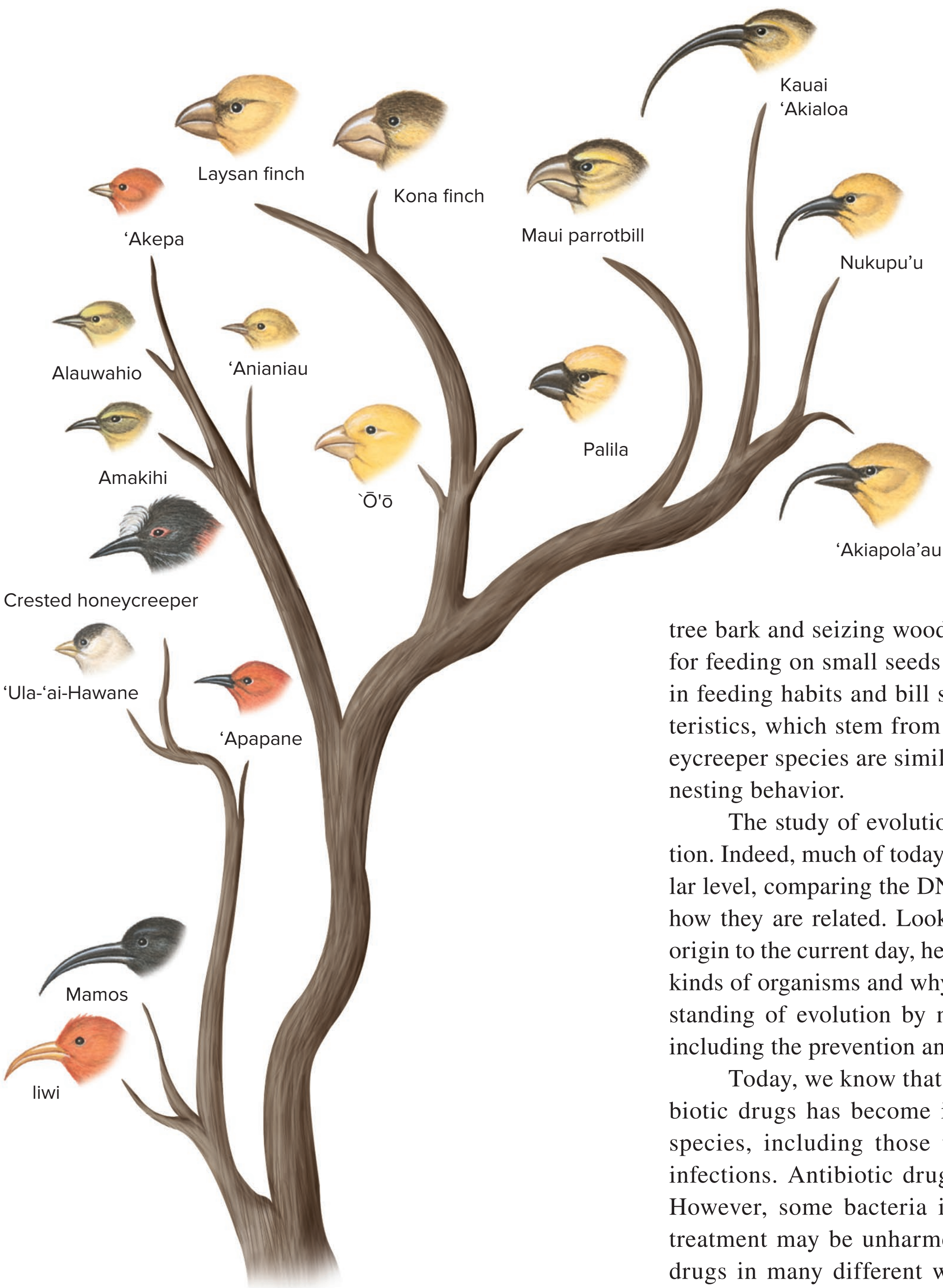


Figure 1.7 Evolution of Hawaiian honeycreepers. Hawaiian honeycreepers, descendants of a single ancestral species, display an amazing diversity of bill shapes and sizes.

The study of evolution encompasses all levels of biological organization. Indeed, much of today's evolution research is carried out at the molecular level, comparing the DNA of different groups of organisms to determine how they are related. Looking at how life has changed over time, from its origin to the current day, helps us understand why there are so many different kinds of organisms and why they have the characteristics they do. An understanding of evolution by natural selection also has practical applications, including the prevention and treatment of disease.

Today, we know that, because of natural selection, resistance to antibiotic drugs has become increasingly common in a number of bacterial species, including those that cause tuberculosis, gonorrhea, and staph infections. Antibiotic drugs, such as penicillin, kill susceptible bacteria. However, some bacteria in the body of a patient undergoing antibiotic treatment may be unharmed by the drug. Bacteria can survive antibiotic drugs in many different ways. For example, certain bacteria can endure treatment with penicillin because they break down the drug, rendering it harmless. If even one bacterial cell lives because it is antibiotic-resistant, then its descendants will inherit this drug-defeating ability. The widespread use of antibiotics has favored the evolution of resistant bacterial strains, which in turn is limiting the effectiveness of many classes of antibiotics.

Connections

How does evolution affect me personally?

Each year, starting around September, health agencies and pharmacies begin alerting us to get our annual flu vaccine. Often, people question the need to get an annual vaccine, and in the process, place themselves at risk of infection.

What we call the flu is actually a response by our bodies to an infection by influenza virus. Influenza viruses are relatively simple (see Section 17.1), but they have the ability to mutate each year, creating new strains that have not been seen before by our immune systems. Some of these changes have been responsible for strains that have created significant outbreaks in the human population.

The Centers for Disease Control and Prevention (CDC) and other agencies are responsible for monitoring the evolution of the influenza virus, and for developing annual vaccines. However, at times, the virus may evolve during the influenza season (as happened in 2018), thus reducing the effectiveness of that year's vaccine.

Organizing the Diversity of Life

Think of an enormous department store, offering thousands of different items for sale. The various items are grouped in departments—electronics, apparel, furniture, and so on—to make them easy for customers to find. Because life is so diverse, it is helpful to have a system that groups organisms into categories. Two areas of biology help us group organisms into categories: **Taxonomy** is the discipline of identifying and naming organisms according to certain rules, and **systematics** makes sense out of the bewildering variety of life on Earth by classifying organisms according to their presumed evolutionary relationships. As systematists learn more about evolutionary relationships between species, the taxonomy of a given organism may change. Systematists are even now making observations and performing experiments that will one day bring about changes in the classification system adopted by this text.

Categories of Classification

The classification categories, from least inclusive to most inclusive, are species, **genus, family, order, class, phylum, kingdom,** and **domain** (Table 1.1). Each successive category above species contains more types of organisms than the preceding one. Species placed within one genus share many specific characteristics and are the most closely related, while species placed in the same domain share only general characteristics. For example, all species in the genus *Pisum* look pretty much the same—that is, like pea plants—but species in the plant kingdom can be quite varied, as is evident when we compare grasses with trees. By the same token, only modern humans are in the genus *Homo,* but many types of species, from tiny hydras to huge whales, are members of the animal kingdom. Species placed in different domains are the most distantly related. For now, we will focus on the general characteristics of the domains and kingdoms of life.

Table 1.1 Levels of Biological Organization

Category	Human	Corn
Domain	Eukarya	Eukarya
Kingdom	Animalia	Plantae
Phylum	Chordata	Anthophyta
Class	Mammalia	Liliopsida
Order	Primates	Commelinales
Family	Hominidae	Poaceae
Genus	*Homo*	*Zea*
Species*	*H. sapiens*	*Z. mays*

*To specify an organism, you must use the full binomial name, such as *Homo sapiens*.

Table 1.2 Domains and Kingdoms of Life

Domain	Kingdom		Example
Archaea		 8,330×	Capable of living in extreme environments. *Methanosarcina mazei*, a methane-generating prokaryote.
Bacteria		 6,600×	Structurally simple but metabolically diverse. *Escherichia coli*, a prokaryote found in our intestinal tracts.
Eukarya	Protists	 250×	Diverse group of eukaryotes, many single-celled. *Euglena*, an organism with both plant and animal-like characteristics.
Eukarya	Plants		Multicellular photosynthesizers. The bristlecone pine, *Pinus longaeva,* one of the oldest organisms on the planet.
Eukarya	Animals		Multicellular organisms that ingest food. *Homo sapiens*—humans.
Eukarya	Fungi		Multicellular decomposers. *Amanita*—a mushroom.

Domains

The most inclusive and general levels of classification are the domains (Table 1.2). Biochemical evidence (obtained from the study of DNA and proteins) suggests that there are only three domains of life: **domain Bacteria, domain Archaea,** and **domain Eukarya.** Both domain Archaea and domain Bacteria contain prokaryotes. Prokaryotes are single-celled, and they lack the membrane-bound nucleus found in the eukaryotes of domain Eukarya.

Prokaryotes are structurally simple but metabolically complex. Archaea live in aquatic environments that lack oxygen or are too salty, too hot, or too acidic for most other organisms. Perhaps these environments are similar to those of the primitive Earth, and maybe archaea are representative of the first cells that evolved. Bacteria are found almost everywhere—in the water, soil, and atmosphere, as well as on our skin and in our mouths and large intestines. Although some bacteria cause diseases, others perform useful services, both environmental and commercial. For example, they are used to conduct genetic research in our laboratories (the *E. coli* in Table 1.2 is one example), to produce innumerable products in our factories, and to purify water in our sewage treatment plants.

Kingdoms

Historically, the classification of domain Eukarya divided organisms into one of four kingdoms (see Fig. 1.6). **Protists** (kingdom Protista) are a very diverse group of eukaryotic organisms, some of which are single-celled and others multicellular. Some protists are photosynthetic, some are decomposers, and some ingest their food. The other three kingdoms all have protists as their ancestors. Among the **fungi** (kingdom Fungi) are the familiar molds and mushrooms that, along with many types of bacteria, help decompose dead organisms. **Plants** (kingdom Plantae) are well known as multicellular photosynthesizers. **Animals** (kingdom Animalia) are multicellular organisms that ingest their food.

However, the development of improved techniques in analyzing the DNA of organisms suggests that not all protists share the same evolutionary lineage, meaning that the evolution of eukaryotes has occurred along several paths (and is not as linear as shown in Fig. 1.6). A new taxonomic group, called a **supergroup,** is being developed to explain these evolutionary relationships. There are currently five supergroups for domain Eukarya. However, as studies continue, the relationship and structure of these groups are being revised. We will take a closer look at supergroups in Section 17.4.

Scientific Naming

Biologists give each living organism a two-part scientific name called a **binomial name.** For example, the scientific name for the garden pea is *Pisum sativum;* our own species is *Homo sapiens*. The first word is the genus, and the second word is the specific epithet of a species within a genus. The genus may be abbreviated, such as *P. sativum* or *H. sapiens*. Scientific names are universally used by biologists to avoid confusion. Common names tend to overlap, and often they are from the languages of the people who use the names. But scientific names are based on Latin, a universal language that not too long ago was well known by most scholars. Table 1.2 provides some examples of binomial names.

In the next section, we will explore the process by which scientists study life.

CONNECTING THE CONCEPTS

1.2 The process of evolution explains the diversity of living organisms on Earth today.

Check Your Progress 1.2

1. List the eight classification categories, from least to most inclusive.
2. Describe the process of natural selection, and explain its relationship to evolutionary change.
3. Explain why the concept of descent with modification is important in understanding the evolutionary process.

1.3 Science: A Way of Knowing

Learning Outcomes

Upon completion of this section, you should be able to

1. Identify the steps of the scientific method.
2. Describe the basic requirements for a controlled experiment.
3. Distinguish between a theory and a hypothesis.

Biology is the scientific study of life. Religion, aesthetics, ethics, and science are all ways that humans have of finding order in the natural world. Science differs from the other disciplines by its process, which often involves the use of the scientific method (Fig. 1.8). The scientific method acts as a guideline for scientific studies. Scientists often modify or adapt the process to suit their particular area of study.

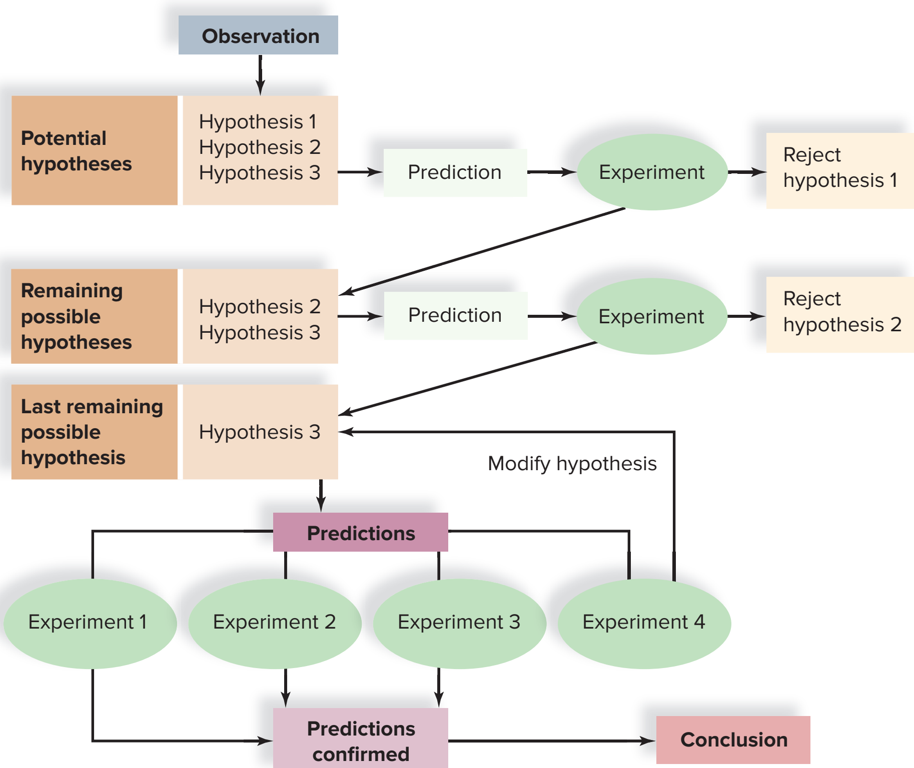


Figure 1.8 **Flow diagram for the scientific method.** The scientific method is an orderly series of stages that scientists use as a guideline for investigating that natural and physical world.

Start with an Observation

Scientists believe that nature is orderly and measurable—that natural laws, such as the law of gravity, do not change with time—and that a natural event, or *phenomenon,* can be understood more fully through **observation**—a formal way of watching the natural world. Scientists rely on their senses (sight, hearing, touch) to make observations, but also extend the ability of their senses by using instruments; for example, a microscope enables them to see objects that could never be seen by the naked eye. Finally, scientists may expand their understanding even further by taking advantage of the knowledge and experiences of other scientists. For instance, they may look up past studies on the internet or at the library, or they may write or speak to others who are researching similar topics.

Develop a Hypothesis

After making observations and gathering knowledge about a phenomenon, a scientist uses inductive reasoning. **Inductive reasoning** occurs whenever a person uses creative thinking to combine isolated facts into a cohesive whole. Chance alone can help a scientist arrive at an idea. The most famous case pertains to the antibiotic penicillin, which was discovered in 1928. While examining a petri dish of bacteria that had accidentally become contaminated with the mold *Penicillium,* Alexander Fleming observed an area around the mold that was free of bacteria. Fleming had long been interested in finding cures for human diseases caused by bacteria, and he was very knowledgeable about antibacterial substances. So when Fleming saw the dramatic effect of *Penicillium* mold on bacteria, he reasoned that the mold might be producing an antibacterial substance.

We call such a possible explanation for a natural event a **hypothesis.** A hypothesis is based on existing knowledge, so it is much more informed than a mere guess. Fleming's hypothesis was supported by further study. In most cases, a hypothesis is not supported and must be either modified and subjected to additional study or rejected.

All of a scientist's past experiences, no matter what they might be, may influence the formation of a hypothesis. But a scientist considers only hypotheses that can be tested by experiments or further observations. Moral and religious beliefs, while very important to our lives, differ among cultures and through time and are not always testable.

Make a Prediction and Perform Experiments

Scientists often perform an **experiment,** which is a series of procedures designed to test a specific hypothesis. The manner in which a scientist intends to conduct an experiment is called the **experimental design.** A good experimental design ensures that scientists are testing what they want to test and that their results will be meaningful. If the hypothesis is well prepared, then the scientist should be able to make a **prediction** of what the results of the experiment will be. If the results of the experiment do not match the prediction, then the scientist must revisit the initial hypothesis and design a new set of experiments.

Experiments can take many forms, depending on the area of biology that the scientist is examining. For example, experiments in the laboratory may be confined to tubes and beakers, whereas ecological studies may require large tracts of land. However, in all experimental designs, the researcher attempts to keep all of the conditions constant except for an **experimental variable** (or independent variable), which is the factor in the experiment that is being deliberately changed. The result is called the **responding variable** (or dependent variable) because its value is based on the experimental variable.

To ensure that the results will be meaningful, an experiment contains both test groups and a **control group.** A test group is exposed to the experimental variable, but the control group is not. If the control group and test groups show the same results, the experimenter knows that the hypothesis predicting a difference between them is not supported.

Scientists often use **model systems** and model organisms to test a hypothesis. Some common model organisms are shown in Figure 1.9. Model organisms are chosen because they allow the researcher to control aspects of the experiment, such as age and genetic background. Cell biologists may use mice for modeling the effects of a new drug. Like model organisms, model systems allow the scientist to control specific variables and environmental conditions in a way that may not be possible in the natural environment. For example, ecologists may use computer programs to model how human activities will affect the climate of a specific ecosystem. While models provide useful information, they do not always answer the original question completely. For example, medicine that is effective in mice should ideally be tested in humans, and ecological experiments that are conducted using computer simulations need to be verified by actual field experiments. Biologists, and all other scientists, continuously revise their experiments to better understand how different factors may influence their original observation.

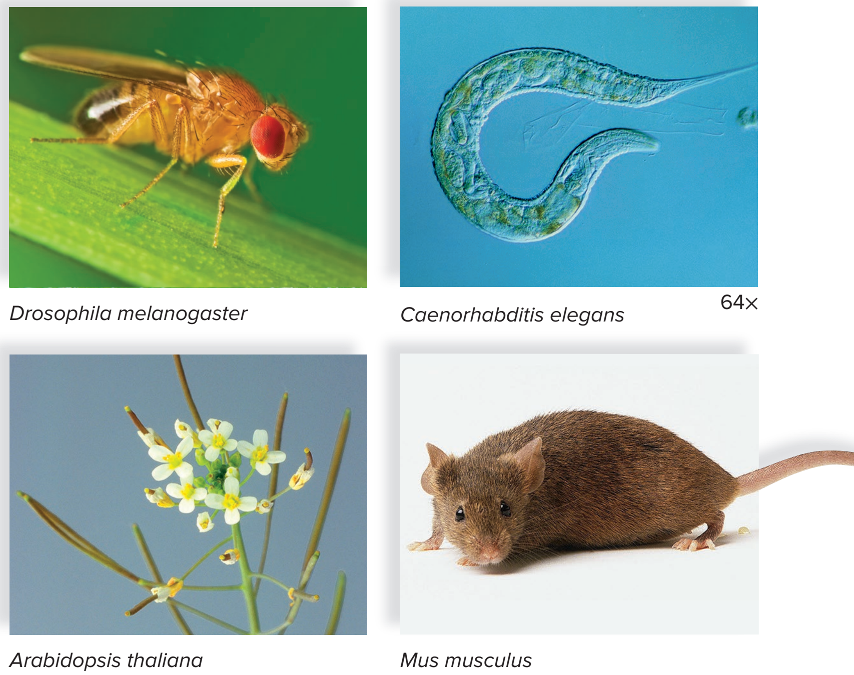


Figure 1.9 Model organisms used in scientific studies. *Drosophila melanogaster* is used as a model organism in the study of genetics. *Mus musculus* is used in the study of medicine. *Caenorhabditis elegans* is used by developmental biologists, and *Arabidopsis thaliana* is used by botanists to understand plant genetics.

(*Drosophila melanogaster*): ©janeff/Getty Images; (*Caenorhabditis elegans*): ©Sinclair Stammers/Science Source; (*Arabidopsis thaliana*): ©Wildlife GmbH/Alamy Stock Photo; (*Mus musculus*): ©Steve Gorton/Getty Images

Collect and Analyze the Data

The results of an experiment are referred to as the **data.** Mathematical data are often displayed in the form of a graph or table. Sometimes studies rely on statistical data. Statistical analysis allows a scientist to detect relationships in the data that may not be obvious on the surface. Let's say an investigator wants to know if eating onions can prevent women from getting osteoporosis (weak bones). The scientist conducts a survey asking women about their onion-eating habits and then correlates these data with the condition of their bones. Other scientists critiquing this study would want to know the following: How many women were surveyed? How old were the women? What were their exercise habits? What criteria were used to determine the condition of their bones? And what is the probability that the data are in error? The greater the variance in the data, the greater the probability of error. In any case, even if the data do suggest a correlation, scientists would want to know if there is a specific ingredient in onions that has a direct biochemical or physiological effect on bones. After all, correlation does not necessarily mean causation. It could be that women who eat onions eat lots of vegetables and have healthier diets overall than women who do not eat onions. In this way, scientists are skeptics who always pressure one another to keep investigating.

Develop a Conclusion

Scientists must analyze the data in order to reach a **conclusion** about whether a hypothesis is supported or not. Because science progresses, the conclusion of one experiment can lead to the hypothesis for another experiment (see Fig. 1.8). In other words, results that do not support one hypothesis can often help a scientist formulate another hypothesis to be tested. Scientists report their findings in scientific journals, so that their methodology and data are available to other scientists. Experiments and observations must be *repeatable*—that is, the reporting scientist and any scientist who repeats the experiment must get the same results, or else the data are suspect.

Scientific Theory

The ultimate goal of science is to understand the natural world in terms of **scientific theories,** which are accepted explanations for how the world works. Some of the basic theories of biology are the cell theory, which says that all organisms are composed of cells; the gene theory, which says that inherited information dictates the form, function, and behavior of organisms; and the theory of evolution, which says that all organisms have a common ancestor and that each organism is adapted to a particular way of life.

The theory of evolution is considered the unifying concept of biology because it pertains to many different aspects of organisms. For example, the theory of evolution enables scientists to understand the history of life, the variety of organisms, and the anatomy, physiology, and development of organisms. The theory of evolution has been a very fruitful scientific theory, meaning that it has helped scientists generate new testable hypotheses. Because the theory of evolution has been supported by so many observations and experiments for over 150 years, some biologists refer to this theory as a **principle,** a term sometimes used for a theory that is generally accepted by an overwhelming number of scientists. Other scientists prefer the term **law** instead of principle.

An Example of a Controlled Study

We now know that most stomach and intestinal ulcers (open sores) are caused by the bacterium *Helicobacter pylori*. Let's say investigators want to determine which of two antibiotics is best for the treatment of an ulcer. When clinicians do an experiment, they try to vary just the experimental variables—in this case, the medications being tested. Each antibiotic is administered to an independent test group, but the control group is not given an antibiotic. If by chance the control group shows the same results as one of the test groups, the investigators may conclude that the antibiotic in that test group is ineffective, because it does not show a significant difference in treatment to the control group. The study depicted in Figure 1.10 shows how investigators may study this hypothesis.

Hypothesis: Newly discovered antibiotic B is a better treatment for ulcers than antibiotic A, which is in current use.

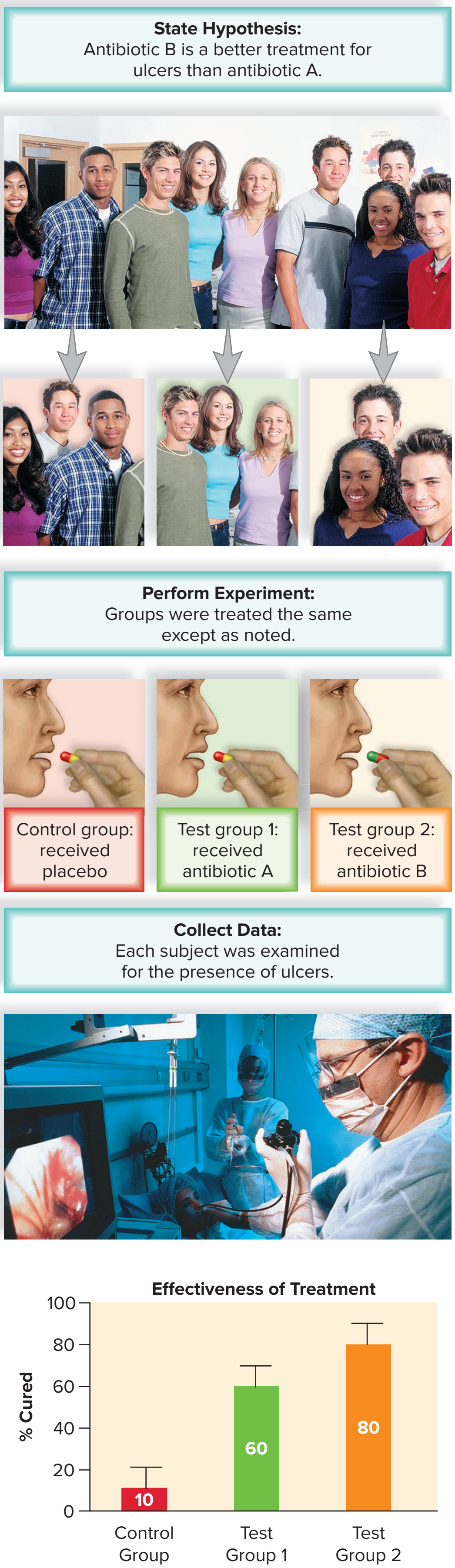


Figure 1.10 A controlled laboratory experiment to test the effectiveness of two medications in humans.

In this study, a large number of people were divided into three groups. The control group received a placebo and no medication. One of the test groups received medication A, and the other test group received medication B. The results are depicted in a graph, and it shows that medication B was a more effective treatment than medication A for the treatment of ulcers.

In any experiment, it is important to reduce the number of possible variables (differences). In this experiment, those variables may include factors such as differences in sex, weight, or previous illnesses among the individuals. Therefore, the investigators *randomly* divide a large group of volunteers equally into experimental groups. The hope is that any differences will be distributed evenly among the three groups. The larger the number of volunteers (the sample size), the greater the chance of reducing the influence of external variables. This is why many medical studies often involve thousands of individuals.

The three groups are to be treated like this:

Control group: Subjects with ulcers are not treated with either antibiotic.
Test group 1: Subjects with ulcers are treated with antibiotic A.
Test group 2: Subjects with ulcers are treated with antibiotic B.

After the investigators have determined that all volunteers do have ulcers, they will want the subjects to think they are all receiving the *same* treatment. This is an additional way to protect the results from any influence other than the medication. To achieve this end, the subjects in the control group can receive a **placebo,** a treatment that appears to be the same as that administered to the other two groups but actually contains no medication. Overall, the goal of a placebo is to analyze whether other undetermined factors may be influencing the study.

The Results

After 2 weeks of administering the same amount of medication (or placebo) in the same way, the stomach and intestinal linings of each subject are examined to determine if ulcers are still present. Endoscopy, a procedure depicted in the lower photograph in Figure 1.10, is one way to examine a patient for the presence of ulcers. This procedure, which is performed under sedation, involves inserting an endoscope—a small, flexible tube with a tiny camera on the end—down the throat and into the stomach and the upper part of the intestine. Then, the doctor can see the lining of these organs and can check for ulcers. Tests performed during an endoscopy can also determine if *H. pylori* is present.

Because endoscopy is somewhat subjective, it is probably best if the examiner is not aware of which group the subject is in; otherwise, the examiner's prejudice may influence the examination. When neither the patient nor the technician is aware of the specific treatment, it is called a *double-blind* study.

In this study, the investigators may decide to determine the effectiveness of the medication by the percentage of people who no longer have ulcers. So, if 20 people out of 100 still have ulcers, the medication is 80% effective. The difference in effectiveness is easily read in the graph portion of Figure 1.10.

Conclusion: On the basis of their data, the investigators conclude that their hypothesis has been supported.

Publishing the Results

Scientific studies are customarily published in a scientific journal (Fig. 1.11), so that all aspects of a study are available to the scientific community. Before information is published in scientific journals, it is typically reviewed by experts, who ensure that the research is credible, accurate, unbiased, and well executed. Another scientist should be able to read about an experiment in a scientific journal, repeat the experiment in a different location, and get the same (or very similar) results. Some articles are rejected for publication by

Figure 1.11 **Scientific publications.** Scientific journals, such as *Science,* are scholarly journals in which researchers share their findings with other scientists. Scientific magazines, such as *Discover* and *New Scientist,* contain articles that are usually written by reporters for a broader audience.

reviewers when they believe there is something questionable about the design of an experiment or the manner in which it was conducted. This process of rejection is important in science, because it causes researchers to critically review their hypotheses, predictions, and experimental designs, so that their next attempt will more adequately address their hypotheses. Often, it takes several rounds of revision before research is accepted for publication in a scientific journal.

Scientific magazines (Fig. 1.11), such as *New Scientist* or *Discover,* differ from scientific journals in that they report scientific findings to the general public. The information in these articles is usually obtained from articles first published in scientific journals.

As mentioned previously, the conclusion of one experiment often leads to another experiment. The need for scientists to expand on findings explains why science changes and the findings of yesterday may be improved upon tomorrow.

1.3 CONNECTING THE CONCEPTS

The scientific method is the process by which scientists study the natural world and develop explanations for their observations.

Check Your Progress 1.3

1. Summarize the purpose of each step in the scientific method.
2. Explain why a controlled study is important in research.
3. Explain why publishing scientific studies is important.

1.4 Challenges Facing Science

Learning Outcomes

Upon completion of this section, you should be able to

1. Distinguish between science and technology.
2. Summarize some of the major challenges currently facing science.

As we have learned in this chapter, science is a systematic way of acquiring knowledge about the natural world. Science is a slightly different endeavor than technology. **Technology** is the application of scientific knowledge to the interests of humans. Scientific investigations are the basis for the majority of our technological advances. It is often the case that a new technology, such as your cell phone or a new drug, is based on years of scientific investigations. In this section, we are going to explore some of the challenges facing science, technology, and society.

Climate Change

The term **climate change** refers to changes in the normal cycles of the Earth's climate that may be attributed to human activity. Climate change is primarily due to an imbalance in the chemical cycling of the element carbon. Normally, carbon is cycled within an ecosystem. However, due to human activities, more carbon dioxide is being released into the atmosphere than is being removed. In 1850, atmospheric CO_2 was at about 280 parts per million (ppm); today, it is over 400 ppm (Fig. 1.12) and increasing annually. This increase is largely due to the burning of fossil fuels and the destruction of forests to make way for farmland and pasture. Today, the amount of carbon dioxide released into the atmosphere is about twice the amount that remains in the atmosphere. It's believed that most of this dissolves in the oceans, which is increasing their acidity. The increased amount of carbon dioxide (and other gases) in the atmosphere is causing a rise in temperature called **global warming.** These gases allow the sun's rays to pass through, but they absorb and radiate heat back to Earth, a phenomenon called the *greenhouse effect.*

There is consensus among scientists from around the globe that climate change and global warming are causing significant changes in many of the Earth's ecosystems and represent one of the greatest challenges of our time. Throughout this text, we will return to how climate change is affecting ecosystems, reducing biodiversity, and contributing to human disease. We will examine climate change in more detail in Section 31.2.

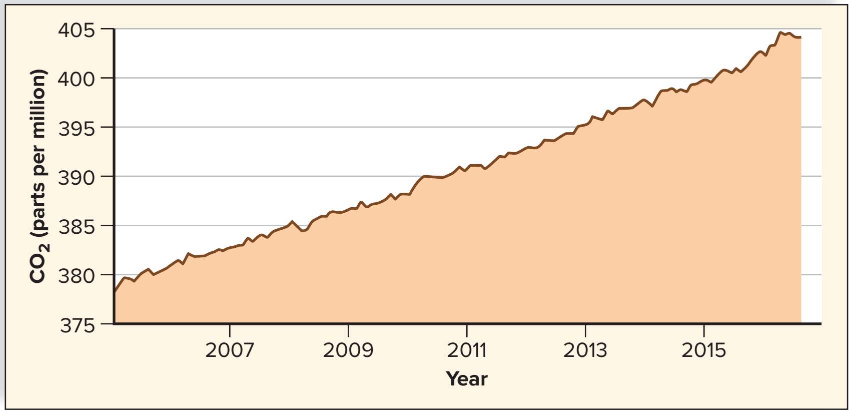


Figure 1.12 **Increases in atmospheric carbon dioxide concentrations.**
The global average carbon dioxide concentration now exceeds 400 ppm and is the major contributing factor to climate change and global warming.
Source: "Global Climate Change: Facts," National Oceanic and Atmospheric Administration, 2018, www.climate.nasa.gov.

Biodiversity and Habitat Loss

Biodiversity is the total number and relative abundance of species, the variability of their genes, and the different ecosystems in which they live. The biodiversity of our planet has been estimated to be around 8.7 million species (not counting bacteria), and so far, approximately 2.3 million have been identified and named. **Extinction** is the death of a species or larger classification category. It is estimated that presently we are losing hundreds of species every year due to human activities and that as much as 38% of all species, including most primates, birds, and amphibians, may be in danger of extinction before the end of the century. In many cases, these extinctions are associated with climate change (Fig. 1.13). Many biologists are alarmed about the present rate of extinction and hypothesize it may eventually rival the rates of the five mass extinctions that occurred during our planet's history. The last mass extinction, about 65 million years ago, caused many plant and animal species, including the dinosaurs, to become extinct.

The two most biologically diverse ecosystems—tropical rain forests and coral reefs—are home to many organisms. These ecosystems are also threatened by human activities. The canopy of the tropical rain forest alone supports a variety of organisms, including orchids, insects, and monkeys. Coral reefs, which are found just offshore of the continents and islands near the equator, are built up from calcium carbonate skeletons of sea animals called corals. Reefs provide a habitat for many animals, including jellyfish, sponges, snails, crabs, lobsters, sea turtles, moray eels, and some of the world's most colorful fishes. Like tropical rain forests, coral reefs are severely threatened as the human population increases in size. Some reefs are 50 million years old, yet in just a few decades, human activities have destroyed an estimated 25% of all coral reefs and seriously degraded another 30%. At this rate, nearly three-quarters could be destroyed within 40 years. Similar statistics are available for tropical rain forests.

The destruction of healthy ecosystems has many unintended effects. For example, we depend on them for food, medicines, and various raw materials. Draining of the natural wetlands of the Mississippi and Ohio Rivers and the construction of levees have worsened flooding problems, making once fertile farmland undesirable. The destruction of South American rain forests has killed many species that may have yielded the next miracle drug and has decreased the availability of many types of lumber. We are only now beginning to realize that we depend on ecosystems even more for the services they provide. Just as chemical cycling occurs within a single ecosystem, so all ecosystems keep chemicals

Figure 1.13 **Climate change and extinction.**
The Bramble Cay melomys (*Melomys rubicola*) was native to Australian great barrier reef islands. However, it has not been observed since 2009 and is believed to be the first mammalian species to go extinct as a result of climate change.
©Polaris/Newscom

cycling throughout the biosphere. The workings of ecosystems ensure that the environmental conditions of the biosphere are suitable for the continued existence of humans. In fact, several studies show that ecosystems cannot function properly unless they remain biologically diverse. We will explore the concept of biodiversity in greater detail in Chapters 30 through 32 of the text.

Emerging and Reemerging Diseases

Over the past decade, avian influenza (H5N1 and H7N9), swine flu (H1N1), severe acute respiratory syndrome (SARS), and Middle East respiratory syndrome (MERS) have been in the news. These are called **emerging diseases** because they are relatively new to humans. Where do emerging diseases come from? Some may result from new and/or increased exposure to animals or insect populations that act as vectors for disease. Changes in human behavior and use of technology can also result in new diseases. SARS is thought to have arisen in the Guangdong province of China due to the consumption of civets, a type of exotic cat considered a delicacy. The civets were possibly infected by exposure to horseshoe bats sold in open markets. Legionnaires' disease emerged in 1976 due to bacterial contamination of a large air-conditioning system in a hotel. The bacteria thrived in the cooling tower used as the water source for the air-conditioning system.

In addition, globalization results in the transport all over the world of diseases that were previously restricted to isolated communities. The first SARS cases were reported in southern China in November 2002. By the end of February 2003, SARS had reached nine countries/provinces, mostly through airline travel.

Some pathogens mutate and change hosts, jumping from birds to humans, for example. Before 1997, avian flu was thought to affect only birds. A mutated strain jumped to humans in the 1997 outbreak. To control that epidemic, officials killed 1.5 million chickens to remove the source of the virus. New forms of avian influenza (bird flu) are being discovered every few years.

Reemerging diseases are also a concern. Unlike an emerging disease, a reemerging disease has been known to cause disease in humans for some time, but generally has not been considered a health risk due to a relatively low level of incidence in human populations. Even so, reemerging diseases can cause problems. An excellent example is the Ebola outbreak in West Africa of 2014–2015. Ebola outbreaks have been known since 1976, but generally have affected only small groups of humans. The 2014–2015 outbreak was a much larger event. Although the exact numbers may never be known, it is estimated that over 28,000 people were infected, with over 11,000 fatalities. The outbreak has disrupted the societies of several West African nations.

CONNECTING THE CONCEPTS

1.4 There are many challenges facing society that are being investigated by the scientific community.

Both emerging and reemerging diseases have the potential to cause health problems for humans across the globe. Scientists investigate not only the causes of these diseases (for example, the viruses), but also their effects on our bodies and the mechanisms by which they are transmitted. We will take a closer look at viruses in Section 17.1 of the text.

Check Your Progress 1.4

1. Explain the relationship between science and technology.
2. Summarize why climate change, biodiversity loss, and emerging diseases are some of the more important challenges currently facing the scientific community.

SUMMARIZE

An understanding of the diversity of life on Earth is essential for the well-being of humans. The process of science helps us increase our knowledge of the natural world.

All living organisms, from bacteria to humans, share the same basic characteristics of life.

The process of evolution explains the diversity of living organisms on Earth today.

The scientific method is the process by which scientists study the natural world and develop explanations for their observations.

There are many challenges facing society that are being investigated by the scientific community.

1.1 The Characteristics of Life

All organisms share the following characteristics of life:

- Organization: The levels of biological organization are as follows (from smallest to largest): **atoms → molecules → cells → tissues → organs → organ systems → organisms → species → populations → communities → ecosystems → biosphere.** In an ecosystem, populations interact with one another and with the physical environment.
- Acquire materials and energy from the environment: Organisms need an outside source of nutrients and energy for **metabolism.** While chemicals cycle within an ecosystem, producers are needed to capture energy for use within the ecosystem.
- Maintain an internal environment: A stable internal environment, called **homeostasis,** allows organisms to perform their metabolic activities more effectively.
- Respond to stimuli: Organisms react to internal and external events.
- **Reproduce** and develop: The genetic information of life is carried in the molecules of **deoxyribonucleic acid** (**DNA**) found in every cell. Reproduction passes copies of an organism's **genes** to the next generation. This information directs the **development** of the organism over time.
- Have **adaptations** that make them suitable for their environment.

1.2 Evolution: The Core Concept of Biology

Evolution, or the change in a species over time, explains the unity and diversity of life. **Natural selection** is the process that results in evolution. Descent from a common ancestor explains why organisms share some characteristics, and adaptation to various ways of life explains the diversity of life-forms. An evolutionary tree is a diagram that may be used to describe how groups of organisms are related to one another.

Life may be classified into large groups called domains and kingdoms. The three domains are

- **Domain Archaea: prokaryotes** that live in extreme environments
- **Domain Bacteria:** the majority of prokaryotes
- **Domain Eukarya: eukaryotes** (plants, animals, fungi, protists)

Within domain Eukarya are four kingdoms: Protista (**protists**); **Fungi;** Plantae (**plants**); and Animalia (**animals**).

Systematics is the classification of organisms based on evolutionary relationships. The categories include **species, genus, family, order, class, phylum, kingdom,** and **domain.** A new category, called a **supergroup,** is being used to explain the evolutionary relationships of the eukaryotes.

Taxonomy is involved in naming organisms. A **binomial name** (such as *Homo sapiens*) consists of the genus (*Homo*) and the specific epithet (*sapiens*).

1.3 Science: A Way of Knowing

The scientific process uses **inductive reasoning** and includes a series of systematic steps known as the scientific method:

1. **Observations,** which use the senses and may also include studies done by others
2. A **hypothesis** that leads to a **prediction**
3. Experiments that support or refute the hypothesis
4. A **conclusion** reached by analyzing **data** to determine whether the results support or do not support the hypothesis

A hypothesis confirmed by many different studies becomes known as a **scientific theory.** Scientific theories are also referred to as **laws** or **principles.**

Experimental design is important in the scientific method. In an experiment, a single **experimental variable** is varied to measure the influence on the **responding variable.** Experiments should utilize **control groups.** Control groups may be given a **placebo** to ensure the experiment is valid. Often, scientists use model organisms and **model systems** in their experimental designs.

1.4 Challenges Facing Science

Scientific findings often lead to the development of a **technology** that can be of service to humans.

There are a number of important issues facing science in today's world. These include **emerging diseases;** human influence on ecosystems, which is resulting in a loss of **biodiversity** and **extinction;** and **global warming,** which is contributing to **climate change.**

ASSESS

Testing Yourself

Choose the best answer for each question.

1.1 The Characteristics of Life

1. A modification that helps equip organisms for their way of life is called
   a. homeostasis. **b.** natural selection. **c.** an adaptation. **d.** extinction.
2. The sum of all of the chemical reactions that occur in a cell is called
   a. homeostasis. **b.** metabolism. **c.** development. **d.** evolution.
3. Which of the following represents the lowest level of biological organization that still may be considered alive?
   a. cell **b.** molecule **c.** species **d.** tissue
4. This level of organization represents the interactions of the living organisms in a given area.
   a. ecosystem **b.** population **c.** community **d.** biosphere

1.2 Evolution: The Core Concept of Biology

5. The mechanism by which species undergo evolutionary change is called
   - **a.** development.
   - **b.** behavior.
   - **c.** natural selection.
   - **d.** metabolism.
6. Which of the following is not a domain?
   - **a.** Archaea
   - **b.** Eukarya
   - **c.** Plantae
   - **d.** Bacteria
7. A binomial name indicates
   - **a.** the domain of the organism.
   - **b.** the genus and species (specific epithet).
   - **c.** the kingdom.
   - **d.** the age of the organism.

1.3 Science: A Way of Knowing

8. A hypothesis cannot be formed without which of the following?
   - **a.** experimentation
   - **b.** observation
   - **c.** data
   - **d.** theory
9. Information collected from a scientific experiment is known as
   - **a.** a scientific theory.
   - **b.** a hypothesis.
   - **c.** data.
   - **d.** a conclusion.
10. Placebos are often used in which of the following?
   - **a.** data analysis
   - **b.** control groups
   - **c.** test groups
   - **d.** model organisms

1.4 Challenges Facing Science

11. Which of the following is the application of scientific investigations for the benefit of humans?
   - **a.** bioethics
   - **b.** evolution
   - **c.** adaptation
   - **d.** technology
12. Human influence can be associated with which of the following challenges facing science?
   - **a.** loss of biodiversity
   - **b.** climate change
   - **c.** emerging diseases
   - **d.** All of these are correct.

ENGAGE

BioNOW

Want to know how this science is relevant to your life? Check out the BioNOW video below.

- Characteristics of Life

At the end of the day, you head over to the gym for a game of basketball with your friends. Afterward, you go out to eat at a local restaurant. Explain how the characteristics of life apply to you during these activities.

Thinking Critically

1. Explain how model organisms make the study of the dependent variable in an experiment easier.
2. You are a scientist working at a pharmaceutical company and have developed a new cancer medication that has the potential for use in humans. Outline a series of experiments, including the use of a model, to test whether the cancer medication works.
3. Scientists are currently exploring the possibility that life may exist on some of the planets and moons of our solar system. Suppose you were a scientist on one of these research teams and were tasked with determining whether a new potential life-form exhibited the characteristics of behavior or adaptation. What would be your hypothesis? What types of experiments would you design?

CHAPTER

2 The Chemical Basis of Life

OUTLINE

BEFORE YOU BEGIN

Before beginning this chapter, take a few moments to review the following discussions.

Section 1.1 What are the basic characteristics of all living organisms?

Figure 1.2 What is the importance of molecules in the levels of biological organization?

Ocean Acidification

If you take a look at our planet from space, you will quickly notice we live on a water planet. In fact, not only is 71% of our planet's surface covered by water, but the physiology of every organism on the planet is based on water. While we historically have taken water for granted, the impact of climate change is beginning to increase our awareness of the importance of this resource on the health of many species, including our own.

The primary cause of climate change is the release of carbon dioxide (CO_2) gas into the atmosphere by the burning of fossil fuels by humans. Not only does that CO_2 contribute to global warming, but it also dissolves very easily in water, forming carbonic acid. In the oceans of the world, the presence of carbonic acid increases the acidity of the aquatic environment.

So why is this important? The increase in acidity decreases the amount of another compound, called carbonate, in the oceans. Carbonate plays an important role in the formation of shells of organisms, such as crabs, lobsters, and clams. As the ocean acidifies, these organisms have a harder time forming shells and other hard structures. Marine biologists have already noticed a decline not only in the amount of carbonate in shellfish, but also their abundance in the ocean's ecosystem. Because these organisms are an important part of the food chain, the loss of carbonate has a ripple effect on this ecosystem.

In this chapter, we will explore the importance of water to life as we know it, as well as the atoms that are responsible for making up the compounds of life.

As you read through this chapter, think about the following questions:

1. What elements are common in all living organisms?
2. Why is water considered to be so important to life?
3. What is the difference between an acid and a base?

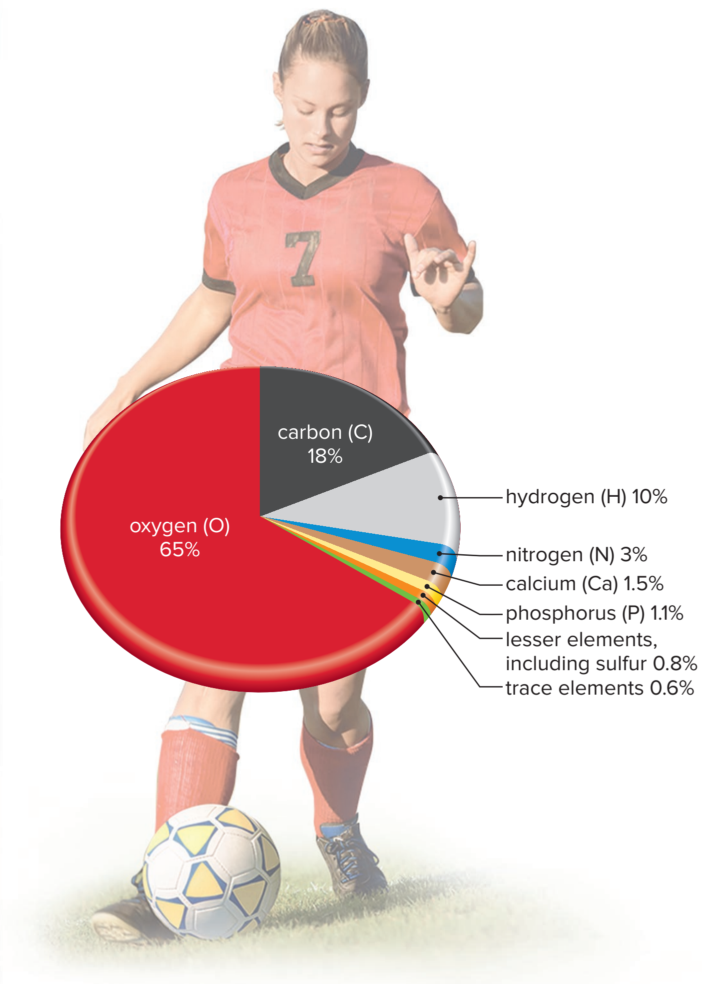


Figure 2.1 **Elements in living organisms.** If analyzed at the level of atoms, all living organisms, including humans, are mostly composed of oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus.

Connections

Where do elements come from?

We are all familiar with elements. Iron, sodium, oxygen, and carbon are all common in our lives, but where do they originate?

Normal chemical reactions do not produce elements. The majority of the heavier elements, such as iron, are produced only by the intense chemical reactions within stars. When these stars reach the end of their lives, they explode, producing supernovas. Supernovas scatter the heavier elements into space, where they are eventually involved in the formation of planets. The iron within your blood was formed by the explosions of stars. The astronomer Neil deGrasse Tyson once stated, "After all, what nobler thought can one cherish than that the universe lives within us all?"

2.1 Atoms and Atomic Bonds

Learning Outcomes

Upon completion of this section, you should be able to

1. Distinguish among the types, locations, and charges of subatomic particles.
2. Relate how the arrangement of electrons determines an element's reactivity.
3. Explain how isotopes are useful in the study of biology.
4. Contrast ionic and covalent bonds.
5. Identify the reactants and products in a chemical equation.

As you are studying right now, everything around you, including your desk and computer, is made of matter. **Matter** may be defined as anything that takes up space and has mass. It can exist in several states, such as a solid, liquid, gas, or plasma (a form of ionized gas). Living organisms, such as ourselves, and nonliving things, such as the air we breathe, are all made of matter.

All matter is composed of elements. An **element** is a substance that cannot be broken down into other substances by ordinary chemical means. There are only 92 naturally occurring elements (see Appendix A), and each of these differs from the others in its chemical or physical properties, such as density and reactivity with other elements.

While all of the elements are present on Earth, the proportion of each element differs between living organisms and nonliving things. Four elements—carbon, hydrogen, nitrogen, and oxygen—make up about 96% of the body weight of most organisms (Fig. 2.1), from simple, one-celled organisms to complex, multicellular plants and animals. Other elements, such as phosphorus, calcium, and sulfur, may also be found in abundance in living organisms. A number of elements, including minerals such as zinc and chromium, are found at very low, or *trace,* levels. Regardless of their abundance and function in living organisms, all elements share some common characteristics.

Atomic Structure

The *atomic theory* states that elements consist of tiny particles called **atoms.** Because each element consists of only one kind of atom, the same name is given to an element and its atoms. This name is represented by one or two letters, called the **atomic symbol.** For example, the symbol H stands for an atom of hydrogen, and the symbol Na (for *natrium* in Latin) stands for an atom of sodium.

If we could look inside a single atom, we would see it is made mostly of three types of subatomic particles: **neutrons,** which have no electrical charge; **protons,** which have a positive charge; and **electrons,** which have a negative charge. Protons and neutrons are located within the center of an atom, which is called the *nucleus,* while electrons move about the nucleus.

Figure 2.2 shows the arrangement of the subatomic particles in a helium atom, which has only two electrons. In Figure 2.2*b*, the circle represents the approximate location of the electrons based on their energy state. However, electrons are in a constant state of motion, so their estimated location is often shown as a cloud (Fig. 2.2*a*). Overall, most of an atom is empty space. In fact, if we could draw an atom the size of a baseball stadium, the nucleus would be like a gumball in the center of the stadium, and the electrons would be tiny specks whirling about in the upper stands. Usually, we can indicate only where the electrons are expected to be. In our analogy, the electrons might very well stray outside the stadium at times.

Because atoms are a form of matter, you might expect each atom to have a certain mass. In effect, the **mass number** of an atom is just about equal to the sum of its protons and neutrons. Protons and neutrons are assigned one mass unit each. Electrons, being matter, have mass, but they are so small that their mass is assumed to be zero in most calculations. The term *mass* is used, rather than *weight,* because mass is constant but weight is associated with gravity and thus varies depending on an object's location in the universe.

All atoms of an element have the same number of protons. This is called the atom's **atomic number.** The number of protons makes an atom unique and may be used to identify which element the atom belongs to. As we will see, the number of neutrons may vary between atoms of an element. The average of the mass numbers for these atoms is called the **atomic mass.**

The atomic number tells you the number of positively charged protons. If the atom is electrically neutral, then the atomic number also indicates the number of negatively charged electrons. To determine the usual number of neutrons, subtract the number of protons from the atomic mass and take the closest whole number.

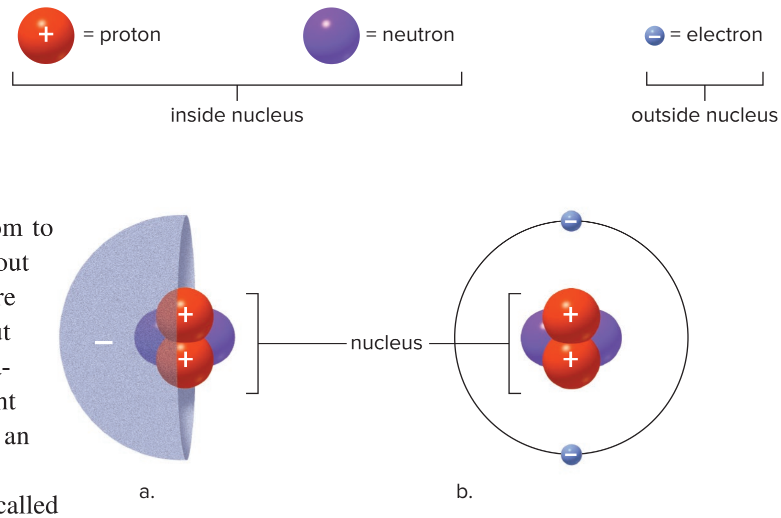
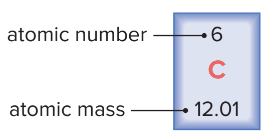


Figure 2.2 **Two models of helium (He).**
Atoms contain subatomic particles, which are located as shown in these two simplified models of helium. Protons are positively charged, neutrons have no charge, and electrons are negatively charged. Protons and neutrons are within the nucleus, and electrons are outside the nucleus. **a.** This model shows electrons as a negatively charged cloud around the nucleus. **b.** In this model, the average location of electrons is represented by a circle.

The Periodic Table

Once chemists discovered a number of the elements, they began to realize that the elements' chemical and physical characteristics recur in a predictable manner. The periodic table (Fig. 2.3) was developed as a way to display the elements, and therefore the atoms, according to these characteristics.

In a periodic table, the atomic number is written above the atomic symbol. The atomic mass is written below the atomic symbol. For example, the carbon atom is shown in this way:



Every atom is in a particular period (the horizontal rows) and in a particular group (the vertical columns). The atoms in group 8 are called the *noble gases* because they are gases that rarely react with another atom, for reasons we will discuss later in this section. In Figure 2.3, notice that helium (He) and neon (Ne) are noble gases.

Isotopes

Isotopes are atoms of the same element that differ in the number of neutrons. In other words, isotopes have the same number of protons, but they have different mass numbers. In some cases, a nucleus with excess neutrons is unstable and may decay and emit radiation. Such an isotope is said to be radioactive. However, not all isotopes are radioactive. The radiation given off by radioactive isotopes can be detected in various ways. Most

Periods \ Groups	1	2	3	4	5	6	7	8
1	1 H 1.008							2 He 4.003
2	3 Li 6.941	4 Be 9.012	5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.31	13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
4	19 K 39.10	20 Ca 40.08	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.60

Figure 2.3 **A portion of the periodic table.**
In the periodic table, the elements, and therefore the atoms that compose them, are in the order of their atomic numbers but arranged in periods (horizontal rows) and groups (vertical columns). All the atoms in a particular group have certain chemical characteristics in common. The elements highlighted in red make up the majority of matter in organic molecules (see Section 3.1). A full periodic table is provided in Appendix A.

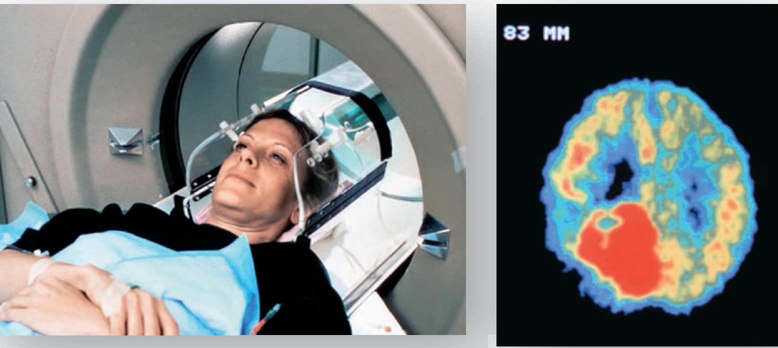


Figure 2.4 **PET scan.**
In a PET scan, red indicates areas of greatest metabolic activity and blue means areas of least activity. Computers analyze the data from different sections of an organ—in this case, the human brain.
Source: National Institutes of Health

a.

b.

Figure 2.5 **High levels of radiation.**
a. The Fukushima nuclear facility. Following a tsunami, an accident at this facility released radioactive isotopes into the environment. **b.** Radiation can also be used to sterilize items, such as mail and packages, to protect us from biological agents, such as anthrax.
(a): ©DigitalGlobe/Getty Images; (b): ©William Thomas Cain/Getty Images

people are familiar with the use of a Geiger counter to detect radiation. However, other methods to detect radiation exist that are useful in medicine and science.

Uses of Radioactive Isotopes

The importance of chemistry to biology and medicine is nowhere more evident than in the many uses of radioactive isotopes. For example, radioactive isotopes can be used as tracers to detect molecular changes or to destroy abnormal or infectious cells. Because both radioactive isotopes and stable isotopes contain the same number of electrons and protons, they essentially behave the same in chemical reactions. Therefore, a researcher can use a small amount of radioactive isotope as a tracer to detect how a group of cells or an organ is processing a certain element or molecule. For example, by giving a person a small amount of radioactive iodine (iodine-131), it is possible to determine whether the thyroid gland is functioning properly. Another example is a procedure called positron-emission tomography (PET), which utilizes tracers to determine the comparative activity of tissues. A radioactively labeled glucose tracer that emits a positron (a subatomic particle that is the opposite of an electron) is injected into the body. Positrons emit small amounts of radiation, which may be detected by sensors and analyzed by a computer. The result is a color image that shows which tissues took up glucose and are thus metabolically active (Fig. 2.4). A number of conditions, such as tumors, Alzheimer disease, epilepsy, or a stroke, may be detected using PET scans.

Radioactive substances in the environment can cause harmful chemical changes in cells, damage DNA, and cause cancer. The release of radioactive particles following a nuclear power plant accident can have far-reaching and long-lasting effects on human health. For example, a 2011 Pacific tsunami caused a release of radioactive cesium-137 from the Fukushima nuclear facility (Fig. 2.5*a*). But the effects of radiation can also be put to good use. Packets of radioactive isotopes can be placed in the body, so that the subatomic particles emitted destroy only cancer cells, with little risk to the rest of the body.

Radiation from radioactive isotopes has been used for many years to sterilize medical and dental equipment. Since the terrorist attacks in 2001, mail that is destined for the White House and congressional offices in Washington, DC, is irradiated to protect against dangerous biological agents, such as anthrax (Fig. 2.5*b*).

Connections

Does irradiation add radioactive particles to food?

No, the process of food irradiation exposes certain types of foods to a form of radiation called ionizing radiation. While ionizing radiation is very useful in killing bacteria on foods, it does not accumulate in or on the food. If you shine a light on a wall, the wall will not accumulate the light, nor will the wall emit light when you turn your light out. The same is true of ionizing radiation and the food irradiation process. Rather, food irradiation helps protect our food supply against disease-causing bacteria, such as *Salmonella* and *Escherichia coli* 0157:H7.

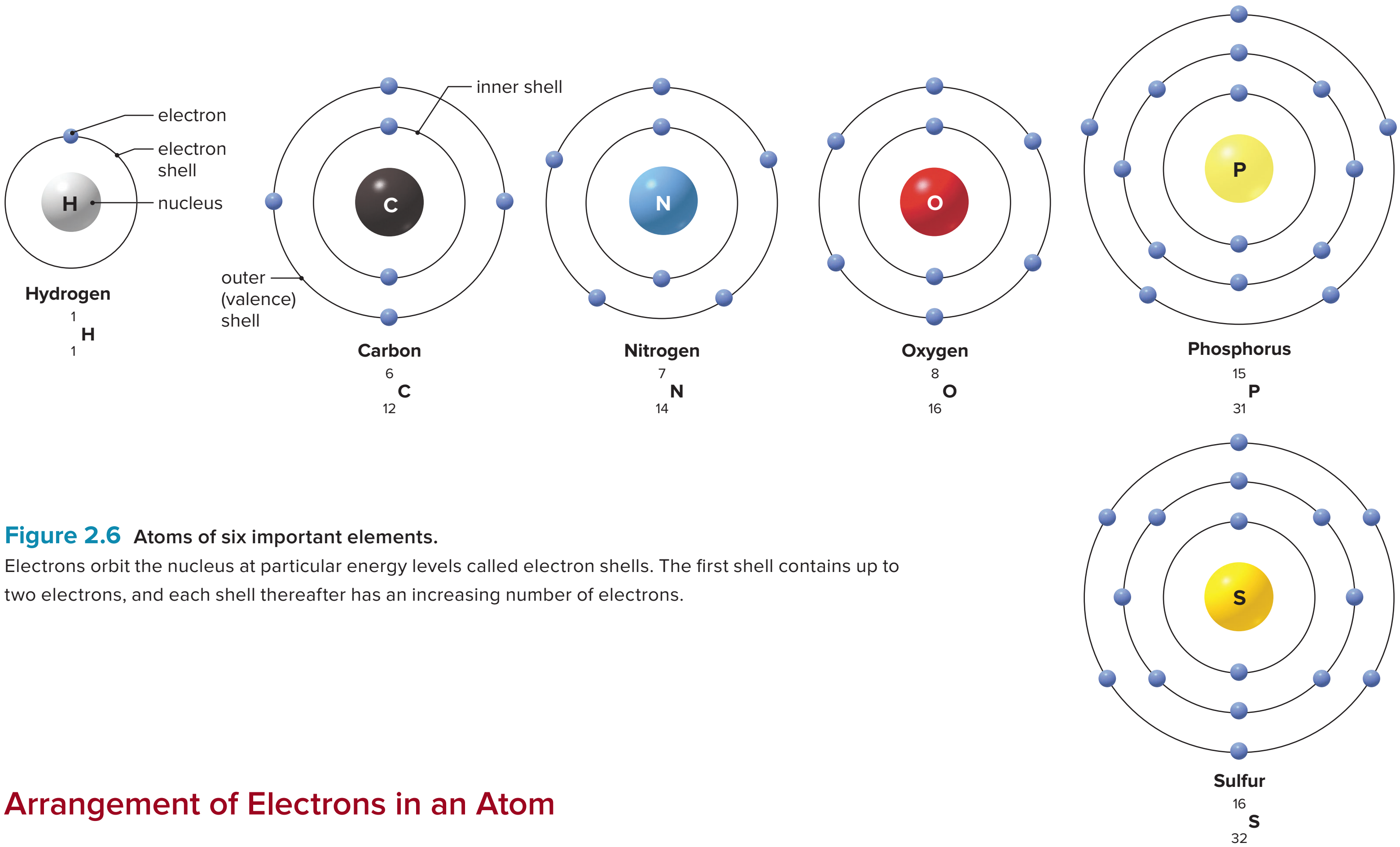


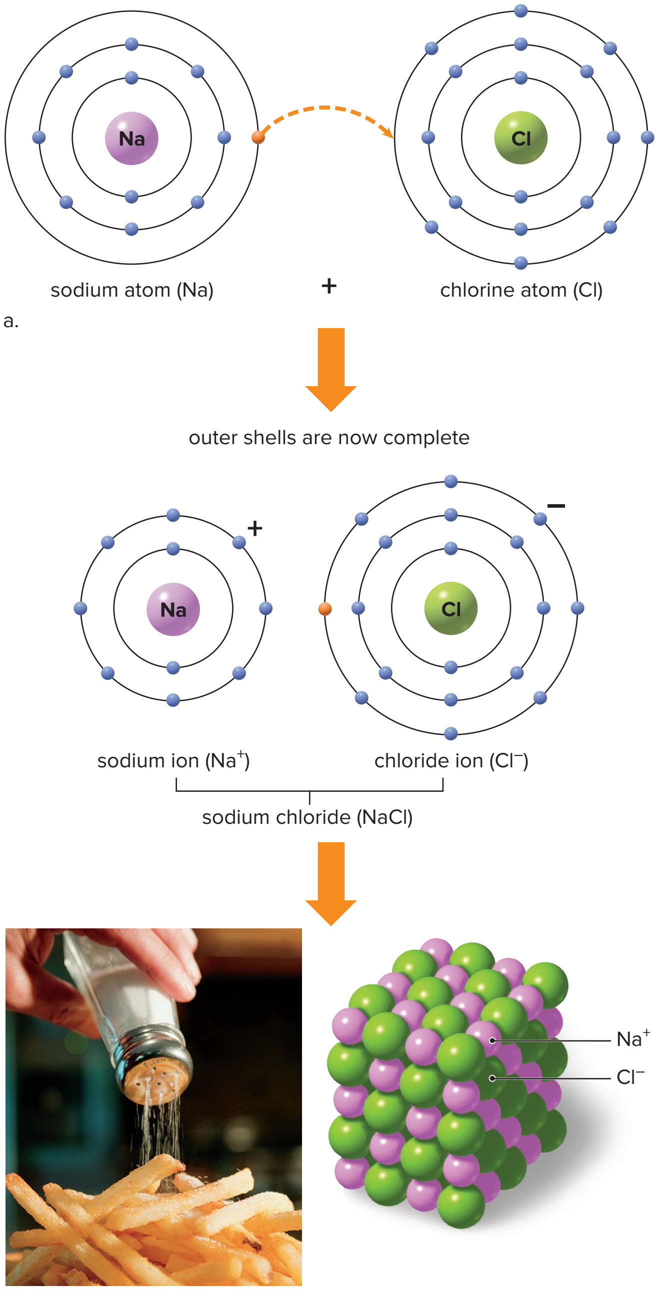
Figure 2.6 **Atoms of six important elements.**
Electrons orbit the nucleus at particular energy levels called electron shells. The first shell contains up to two electrons, and each shell thereafter has an increasing number of electrons.

Arrangement of Electrons in an Atom

Electrons in atoms are much like the blades of a ceiling fan. When the fan is moving, it is difficult to see the individual blades, and all you see is a whirling blur. When the fan is stopped, each blade has a specific location and can be seen. Likewise, the electrons of an atom are constantly moving. Although it is not possible to determine the precise location of an individual electron at any given moment, it is useful to construct models of atoms that show electrons at discrete energy levels about the nucleus (Fig. 2.6). These energy levels are commonly called **electron shells.** Because the nucleus of an atom is positively charged, negatively charged electrons require an increasing amount of energy to push them farther away from the nucleus. Electrons in outer electron shells, therefore, contain more energy than those in inner electron shells.

Each electron shell contains a certain number of electrons. In the models shown in Figure 2.6, the electron shells are drawn as concentric rings about the nucleus. These shells are used to represent the energy of the electrons, and not necessarily their physical location. The first shell closest to the nucleus can contain two electrons; thereafter, shells increase in the number of electrons that they may contain (second shell = 8, third = 16, etc.). In atoms with more than one electron shell, the lower level is generally filled with electrons first, before electrons are added to higher levels.

The sulfur atom, with an atomic number of 16, has two electrons in the first shell, eight electrons in the second shell, and six electrons in the third, or outer, shell. Notice in the periodic table (see Fig. 2.3) that sulfur is in the third period. In other words, the period tells you how many shells an atom has. Also note that sulfur is in group 6. The group tells you how many electrons an atom has in its outer shell.



b.

Figure 2.7 Formation of sodium chloride.
a. During the formation of sodium chloride, an electron is transferred from the sodium atom to the chlorine atom. At the completion of the reaction, each atom has eight electrons in the outer shell, but each also carries a charge as shown. **b.** In a sodium chloride crystal (commonly called salt), the attraction between the Na^+ and Cl^- ions causes the atoms to assume a three-dimensional lattice shape.
(b, photo): ©PM Images/Getty Images

If an atom has only one shell, the outer shell is complete when it has two electrons. If an atom has two or more shells, the outer shell is most stable when it has eight electrons; this is called the **octet rule.** We mentioned that atoms in group 8 of the periodic table are called the noble gases because they do not ordinarily undergo reactions. Atoms with fewer than eight electrons in the outer shell react with other atoms in such a way that each has a completed outer shell after the reaction. Atoms can give up, accept, or share electrons in order to have eight electrons in the outer shell. In other words, the number of electrons in an atom's outer shell, called the **valence shell,** determines its chemical reactivity. The size of an atom is also important. Both carbon (C) and silicon (Si) atoms are in group 4, and therefore they have four electrons in their valence shells. This means they can bond with as many as four other atoms in order to achieve eight electrons in their outer shells. But carbon in period 2 has two shells, and silicon in period 3 has three shells. The smaller atom, carbon, can bond to other carbon atoms and form long-chained molecules, while the larger silicon atom is unable to bond to other silicon atoms. This partially explains why carbon, and not silicon, plays an important role in building the molecules of life. Overall, the chemical properties of atoms—that is, the ways they react—are largely determined by the arrangement of their electrons.

Types of Chemical Bonds

A group of atoms bonded together is called a **molecule.** When a molecule contains atoms of more than one element, it can be called a **compound.** Compounds and molecules contain two primary types of chemical bonds: ionic and covalent. The type of bond that forms depends on whether two bonded atoms share electrons or whether one has given electrons to the other. For example, in hydrogen gas (H_2), the two hydrogen atoms are sharing electrons in order to fill the valence shells of both atoms. When sodium chloride (NaCl) forms, however, the sodium atom (Na) gives an electron to the chlorine (Cl) atom, and in that way, each atom has eight electrons in the outer shell.

Ionic Bonding

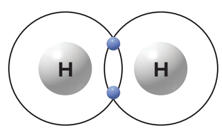
An **ionic bond** forms when two atoms are held together by the attraction between opposite charges. The reaction between sodium and chlorine atoms is an example of how an ionic bond is formed. Consider that sodium (Na), with only one electron in its third shell, usually gives up an electron (Fig. 2.7*a*). Once it does so, the second shell, with eight electrons, becomes its outer shell. Chlorine (Cl), on the other hand, tends to take on an electron, because its outer shell has seven electrons. If chlorine gets one more electron, it has a completed outer shell. So, when a sodium atom and a chlorine atom react, an electron is transferred from sodium to chlorine. Now both atoms have eight electrons in their outer shells.

This electron transfer causes these atoms to become **ions,** or charged atoms. The sodium ion has one more proton than it has electrons; therefore, it has a net charge of +1 (symbolized by Na^+). The chloride ion has one more electron than it has protons; therefore, it has a net charge of –1 (symbolized by Cl^-). Negatively charged ions often have names that end in "ide," and thus Cl^- is called a chloride ion. In the periodic table (see Fig. 2.3), atoms in groups 1 and 2 and groups 6 and 7 become ions when they react with other atoms. Atoms in groups 2 and 6 always transfer two electrons. For example, calcium becomes Ca^{2+}, while oxygen becomes O^{2-}.

Ionic compounds are often found as **salts,** solid substances that usually separate and exist as individual ions in water. A common example is sodium chloride (NaCl), or table salt. A sodium chloride crystal illustrates the solid form of a salt (Fig. 2.7*b*). When sodium chloride is placed in water, the ionic bonds break, causing the Na^+ and Cl^- ions to dissociate. Ionic compounds are most commonly found in this dissociated (ionized) form in biological systems because these systems are 70–90% water.

Covalent Bonding

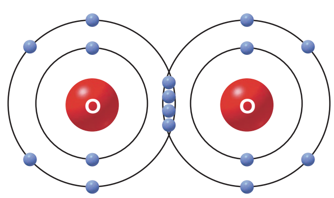
A **covalent bond** results when two atoms share electrons in order to have a completed outer shell. In a hydrogen atom, the outer shell is complete when it contains two electrons. If hydrogen is in the presence of a strong electron acceptor, it gives up its electron to become a hydrogen ion (H^+). But if this is not possible, hydrogen can share with another atom, and thereby have a completed outer shell. For example, one hydrogen atom can share with another hydrogen atom. In this case, the two orbitals overlap and the electrons are shared between them—that is, you count the electrons as belonging to both atoms:



Hydrogen gas (H_2)

Rather than drawing an orbital model like the one above, scientists often use simpler ways to indicate molecules. A *structural formula* uses straight lines, as in H—H. The straight line is used to indicate a pair of shared electrons. A *molecular formula* omits the lines that indicate bonds and simply shows the number of atoms involved, as in H_2.

Sometimes, atoms share more than two electrons to complete their octets. A double covalent bond occurs when two atoms share two pairs of electrons, as in this molecule of oxygen gas:



Oxygen gas (O_2)

In order to show that oxygen gas (O_2) contains a double bond, the structural formula is written as O═O to indicate that two pairs of electrons are shared between the oxygen atoms.

It is also possible for atoms to form triple covalent bonds, as in nitrogen gas (N_2), which can be written as N≡N. Single covalent bonds between atoms are quite strong, but double and triple bonds are even stronger.

A single atom may form bonds with more than one other atom. For example, the molecule methane results when carbon binds to four hydrogen atoms (Fig. 2.8*a*). In methane, each bond actually points to one corner of a four-sided structure called a tetrahedron (Fig. 2.8*b*). The best model to show this arrangement is a ball-and-stick model (Fig. 2.8*c*). Space-filling

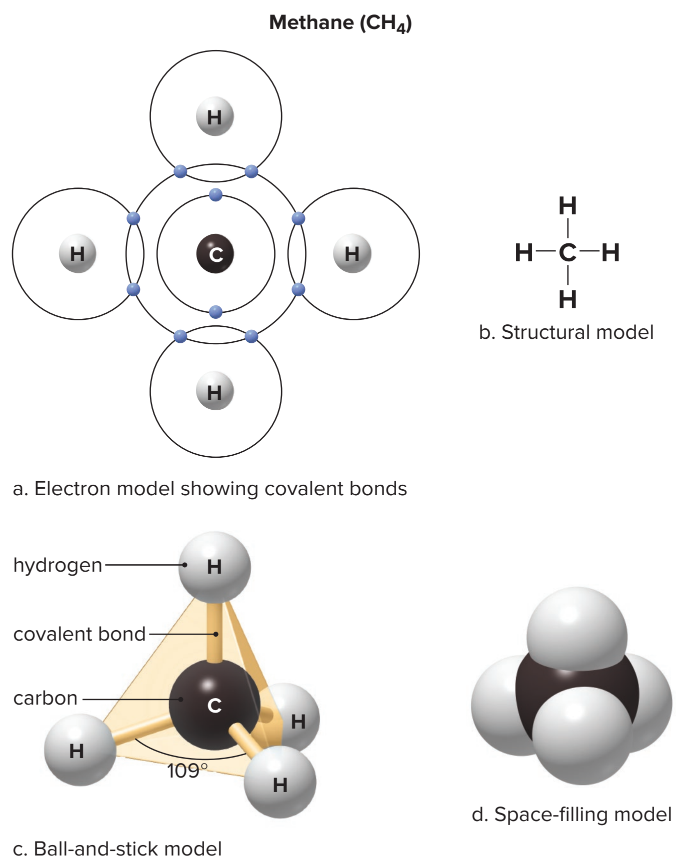
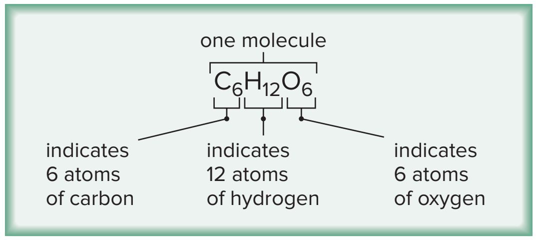


Figure 2.8 **Shapes of covalently bonded molecules.** An electron model (**a**) and a structural model (**b**) show that methane (CH_4) contains one carbon atom bonded to four hydrogen atoms. **c.** The ball-and-stick model shows that, when carbon bonds to four other atoms, as in methane, each bond actually points to one corner of a tetrahedron. **d.** The space-filling model is a three-dimensional representation of the molecule.

models (Fig. 2.8*d*) come closest to showing the actual shape of a molecule. The shapes of molecules help dictate the functional roles they play in organisms.

Chemical Formulas and Reactions

Chemical reactions are very important to organisms. In a chemical reaction, the molecules are often represented by a chemical formula, such as the one below for the energy molecule glucose.



Notice how the chemical formula for glucose indicates the type and quantity of each element that is found in the molecule. Chemical formulas do not indicate the arrangement of these elements. As we will see later, they are sometimes several different structures that can be formed based on a chemical formula.

We have already noted that the process of photosynthesis enables plants to make molecular energy available to themselves and other organisms. An overall equation for photosynthesis indicates that some bonds are broken and others are formed:

$$\underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water}}{6\,H_2O} \longrightarrow \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\,O_2}$$

CONNECTING THE CONCEPTS

2.1 Subatomic particles determine how elements bond to form molecules and compounds.

This equation says that six molecules of carbon dioxide react with six molecules of water to form one glucose molecule and six molecules of oxygen. The **reactants** (molecules that participate in the reaction) are shown on the left of the arrow, and the **products** (molecules formed by the reaction) are shown on the right. Notice that the equation is "balanced"—that is, the same number of each type of atom occurs on both sides of the arrow.

Check Your Progress 2.1

1. Describe the structure of an atom, including the charge of each subatomic particle.
2. Define the term *isotope*, and list a few beneficial uses of radioactive isotopes.
3. Explain the differences between covalent and ionic bonds.
4. Summarize the octet rule, and explain how it relates to an element's reactivity.
5. Distinguish between reactants and products in a chemical equation.

2.2 Water's Importance to Life

Learning Outcomes

Upon completion of this section, you should be able to

1. Describe the general structure of a water molecule.
2. List the properties of water that are important to life.
3. Understand the importance of hydrogen bonds to the properties of water.

The history of life starts in water, and water is the single most important molecule on Earth. All organisms are 70–90% water; their cells consist of membranous compartments enclosing aqueous solutions. The structure of a water molecule gives it unique properties. These properties play an important role in how living organisms function.

The Structure of Water

The electrons shared between two atoms in a covalent bond are not always shared equally. Atoms differ in their **electronegativity**—that is, their affinity for electrons in a covalent bond. Atoms that are more electronegative tend to hold shared electrons more tightly than do those that are less electronegative. This unequal sharing of electrons causes the bond to become **polar,** meaning that the atoms on both sides of the bond are partially charged, even though the overall molecule itself bears no net charge.

For example, in a water molecule, oxygen shares electrons with two hydrogen atoms. Oxygen is more electronegative than hydrogen, so the two bonds are polar. The shared electrons spend more time orbiting the oxygen nucleus than the hydrogen nuclei, and this unequal sharing of electrons makes water a polar molecule. The covalent bonds are angled, and the molecule is bent roughly into a ∧ shape. The point of the ∧ (oxygen) is the negative (–) end, and the two hydrogens are the positive (+) end (Fig. 2.9*a*).

The polarity of water molecules causes them to be attracted to one another. The positive hydrogen atoms in one molecule are attracted to the negative oxygen atoms in other water molecules. This attraction is called a **hydrogen bond,** and each water molecule can engage in as many as four hydrogen bonds (Fig. 2.9*b*). The covalent bond is much stronger than a hydrogen bond, but the large number of hydrogen bonds in water make for a strong attractive force. The properties of water are due to its polarity and its ability to form hydrogen bonds.

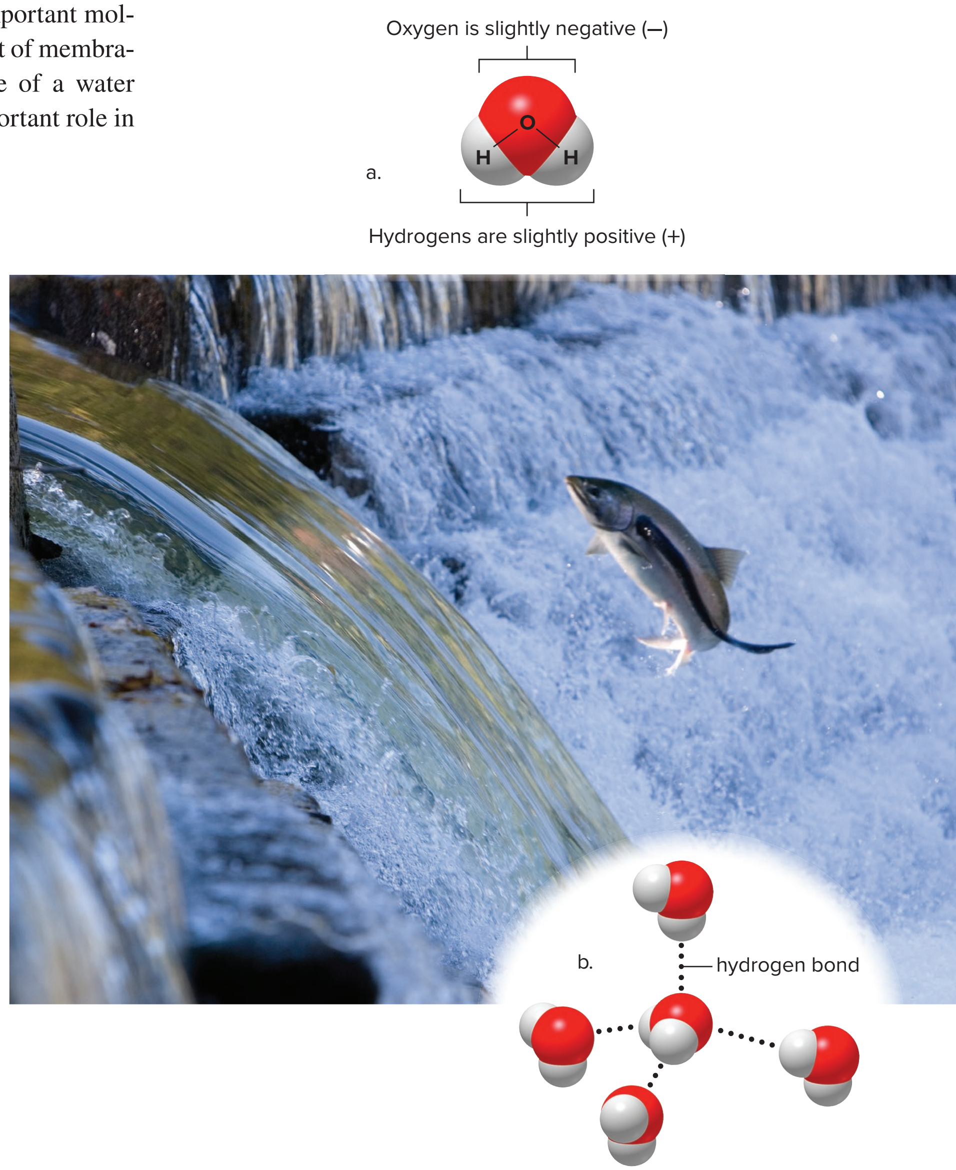


Figure 2.9 **The structure of water.**
The properties of water play an important role in all life, including the fish shown here. **a.** The space-filling model shows the ∧ shape of a water molecule. Oxygen attracts the shared electrons more than hydrogen atoms do, and this causes the molecule to be polar: The oxygen carries a slightly negative charge and the hydrogens carry a slightly positive charge. **b.** The positive hydrogens form hydrogen bonds with the negative oxygen in nearby molecules.

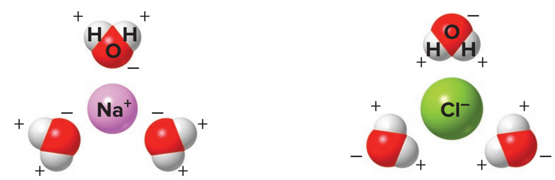
Properties of Water

We often take water for granted, but without water, life as we know it would not exist. The properties of water that support life are solvency, cohesion and adhesion, high surface tension, high heat capacity, and varying density.

Water Is a Solvent

Because of its polarity and hydrogen-bonding ability, water dissolves a great number of substances. Molecules that are attracted to water are said to be **hydrophilic** (*hydro,* water; *phil,* love). Polar and ionized molecules are usually hydrophilic. Nonionized and nonpolar molecules that are not attracted to water are said to be **hydrophobic** (*hydro,* water; *phob,* fear).

When a salt such as sodium chloride (NaCl) is put into water, the negative ends of the water molecules are attracted to the sodium ions, and the positive ends of the water molecules are attracted to the chloride ions. This attraction causes the sodium ions and the chloride ions to break up, or dissociate, in water:



The salt NaCl dissociates in water.

Water may also dissolve polar nonionic substances, such as long chains of glucose, by forming hydrogen bonds with them. When ions and molecules disperse in water, they move about and collide, allowing reactions to occur. The interior of our cells is composed primarily of water, and the ability of water to act as a solvent allows the atoms and molecules within each cell to readily interact and participate in chemical reactions.

Water Molecules Are Cohesive and Adhesive

Cohesion refers to the ability of water molecules to cling to each other due to hydrogen bonding. Because of cohesion, water exists as a liquid under ordinary conditions of temperature and pressure. The strong cohesion of water molecules is apparent because water flows freely, yet the molecules do not separate from each other. **Adhesion** refers to the ability of water molecules to cling to other polar surfaces. This ability is due to water's polarity. The positive and negative poles of water molecules cause them to adhere to other polar surfaces.

Due to cohesion and adhesion, liquid water is an excellent transport system (Fig. 2.10). Both within and outside the cell, water assists in the transport of

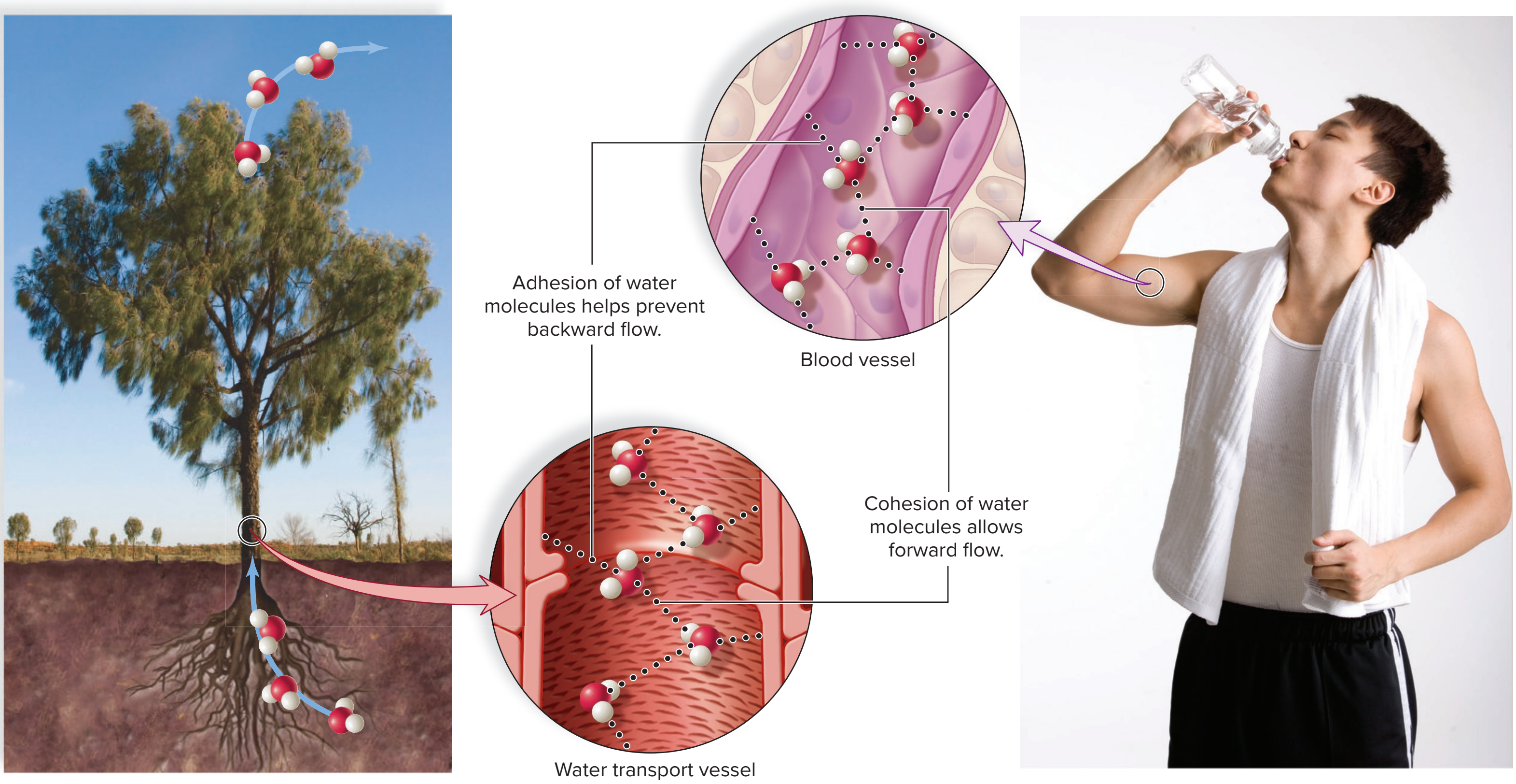


Figure 2.10 Cohesion and adhesion of water molecules. Water's properties of cohesion and adhesion make it an excellent transport medium in both trees and humans.

(tree): ©Paul Davies/Alamy Stock Photo; (man): ©Asiaselects/Getty Images nutrients and waste materials. Many multicellular animals contain internal vessels in which water assists the transport of materials. The liquid portion of blood, which transports dissolved and suspended substances within the body, is 90% water. The cohesion and adhesion of water molecules allow blood to fill the tubular vessels of the cardiovascular system, making transport possible. Cohesion and adhesion also contribute to the transport of water in plants. Plants have their roots anchored in the soil, where they absorb water, but the leaves are uplifted and exposed to solar energy. Water evaporating from the leaves is immediately replaced with water molecules from transport vessels that extend from the roots to the leaves. Because water molecules are cohesive, a tension is created that pulls a water column up from the roots. Adhesion of water to the walls of the vessels also helps prevent the water column from breaking apart.

Water Has a High Surface Tension

Because the water molecules at the surface are more strongly attracted to each other than to the air above, water molecules at the surface cling tightly to each other. Thus, we say that water exhibits surface tension. The stronger the force between molecules in a liquid, the greater the surface tension. Hydrogen bonding is the main force that causes water to have a high surface tension. If you slowly fill a glass with water, you may notice that the level of the water forms a small dome above the top of the glass. This is due to the surface tension of water.

Connections

How do some insects walk on water?

Anyone who has visited a pond or stream has witnessed insects walking on the surface of the water. These insects, commonly called water striders, have evolved this ability by adapting to two properties of water—its surface tension and the fact that water is a polar molecule. By trapping small air bubbles in the hairs on their legs, water striders are able to remain buoyant and not break the surface tension of the water molecules. Many water striders also secrete a nonpolar wax, which further repels the water molecules and keeps the insect afloat.

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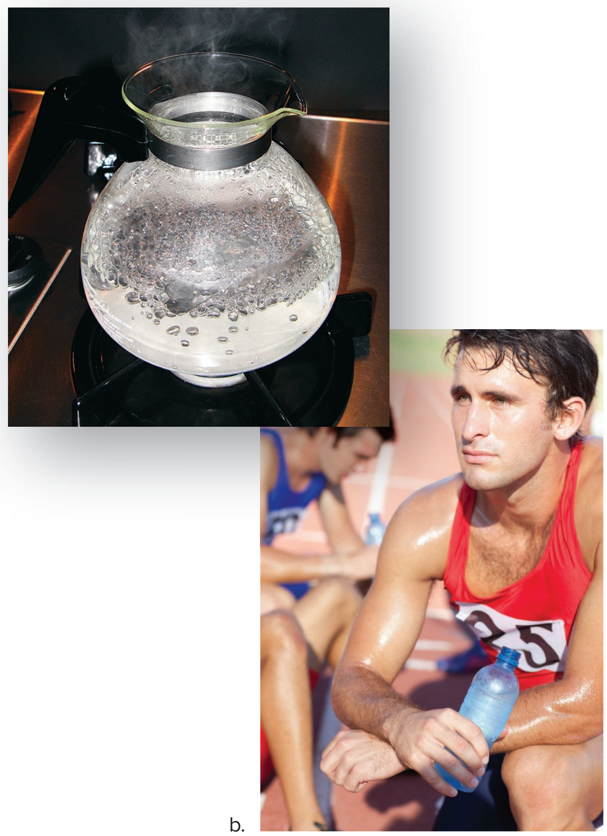
Water Has a High Heat Capacity

The many hydrogen bonds that link water molecules allow water to absorb heat without greatly changing in temperature. Water's high heat capacity is important not only for aquatic organisms but for all organisms. Because the temperature of water rises and falls slowly, terrestrial organisms are better able to maintain their normal internal temperatures and are protected from rapid temperature changes.

Water also has a high heat of vaporization: It takes a great deal of heat to break the hydrogen bonds in water so it becomes gaseous and evaporates into the environment. If the heat given off by our metabolic activities were to go directly into raising our body temperature, death would follow. Instead, the heat is dispelled as sweat evaporates (Fig. 2.11).

Because of water's high heat capacity and high heat of vaporization, the oceans of the planet play an important role in regulating the climate of the planet. For example, the temperatures along the majority of Earth's coasts are



a. b.

Figure 2.11 Heat capacity and heat of vaporization. At room temperature, water is a liquid. **a.** Water takes a large amount of heat to vaporize at 100°C. **b.** It takes much body heat to vaporize sweat, which is mostly liquid water, and the vaporization helps keep our bodies cool when the temperature rises.

(a): ©McGraw-Hill Education/Jill Braaten, photographer; (b): ©Clerkenwell/Getty Images

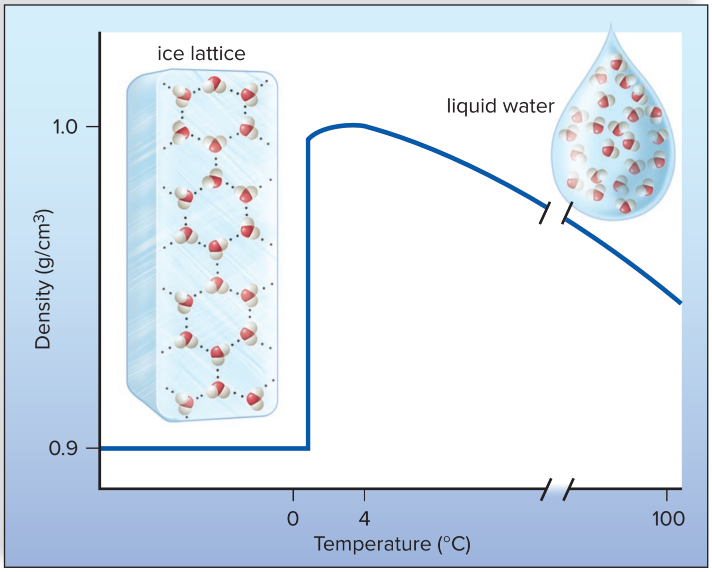


Figure 2.12 **Properties of ice.**
The geometric requirements of hydrogen bonding of water molecules cause ice to be less dense than liquid water.

2.2 CONNECTING THE CONCEPTS
The properties of water are important to life due to water's ability to form hydrogen bonds.

generally moderate. During the summer, the ocean absorbs and stores solar heat; during the winter, the ocean releases it slowly. However, as we will see in our discussion about climate change in Section 31.2, the ability of the world's oceans to absorb heat comes with considerable consequences.

Ice Is Less Dense than Water

Unlike other substances, water expands as it freezes, which explains why cans of soda burst when placed in a freezer and how roads in northern climates become bumpy because of "frost heaves" in the winter. Because water expands as it freezes, ice is less dense than liquid water, and therefore ice floats on liquid water (Fig. 2.12).

Connections

Why is it important that ice is less dense than water?


©Jeff Vanuga/Corbis/Getty Images

If ice were more dense than water, it would sink, and ponds, lakes, and perhaps even the oceans would freeze solid, making life impossible in water, as well as on land. Instead, bodies of water always freeze from the top down. When a body of water freezes on the surface, the ice acts as an insulator to prevent the water below it from freezing. This protects aquatic organisms, so they can survive the winter. As ice melts in the spring, it draws heat from the environment, helping prevent a sudden change in temperature that might be harmful to life.

Check Your Progress 2.2

1. Explain how the structure of a water molecule gives it unique properties.
2. Describe how the properties of water make it an important molecule for life.
3. Explain how hydrogen bonds relate to the properties of water.

2.3 Acids and Bases

Learning Outcomes

Upon completion of this section, you should be able to

1. Distinguish between an acid and a base.
2. Interpret the pH scale.
3. Explain the purpose of a buffer.

While water plays a central role in life as we know it, water molecules can break apart (or dissociate), releasing hydrogen ions (H^+) and hydroxide ions (OH^-).

$$\underset{\text{water}}{H{-}O{-}H} \rightleftharpoons \underset{\text{hydrogen ion}}{H^+} + \underset{\text{hydroxide ion}}{OH^-}$$

The concentration of each of these ions in a solution determines whether the solution of water is acidic or basic.

Acidic Solutions

Lemon juice, vinegar, tomato juice, and coffee are all acidic solutions. Acidic solutions have a sharp or sour taste, and therefore we sometimes associate them with indigestion. **Acids** are solutions that have a high hydrogen ion (H^+) concentration, meaning that they either release hydrogen ions or take up hydroxide ions (OH^-). For example, an important acid is hydrochloric acid (HCl), which dissociates in this manner:

$$\underset{\text{hydrochloric acid}}{HCl} \longrightarrow \underset{\text{hydrogen ion}}{H^+} + \underset{\text{chloride ion}}{Cl^-}$$

Acidic solutions have a higher concentration of H^+ ions than OH^- ions. The acidity of a substance depends on how fully it dissociates in water. HCl dissociates almost completely; therefore, it is called a strong acid. If hydrochloric acid is added to a beaker of water, the number of hydrogen ions (H^+) increases greatly.

Connections

How strong is the acid in your stomach?


©Dwight Smith/Shutterstock

Within the gastric juice of the stomach is hydrochloric acid (HCl), which has a pH value between 1.0 and 2.0. This acid makes the contents of your stomach around 1 million times more acidic than water and 100 times more acidic than vinegar. While, theoretically, the gastric juice in your stomach is able to dissolve metals, such as steel, in reality the contents of your stomach are exposed to these extreme pH values for only a short period of time before moving into the remainder of the intestinal tract, where the acid levels are quickly neutralized.

Basic Solutions

Milk of magnesia and ammonia are common basic (alkaline) solutions that most people are familiar with. Basic solutions have a bitter taste and feel slippery when in water. **Bases** are solutions that have a low hydrogen ion (H^+) concentration, meaning they either take up hydrogen ions or release hydroxide ions (OH^-). For example, an important base is sodium hydroxide (NaOH), which dissociates in this manner:

$$\underset{\text{sodium hydroxide}}{NaOH} \longrightarrow \underset{\text{sodium ion}}{Na^+} + \underset{\text{hydroxide ion}}{OH^-}$$

Basic solutions have a higher concentration of OH^- ions than H^+ ions. Like acids, the strength of a base is determined by how fully it dissociates. Dissociation of sodium hydroxide is almost complete; therefore, it is called a strong base. If sodium hydroxide is added to a beaker of water, the number of hydroxide ions increases.

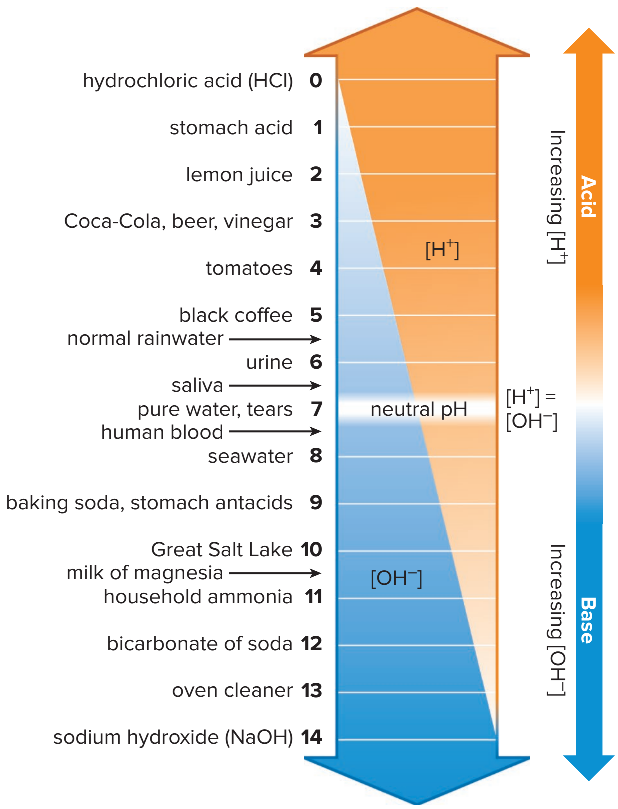


Figure 2.13 The pH scale.
The proportionate amount of hydrogen ions to hydroxide ions is indicated by the diagonal line. Any solution with a pH above 7 is basic, while any solution with a pH below 7 is acidic.

Many strong bases, such as ammonia, are useful household cleansers. Ammonia has a poison symbol and carries a strong warning not to ingest the product. Neither acids or bases should be tasted because they are quite destructive to cells.

pH and the pH Scale

pH[1] is a mathematical way of indicating the number of hydrogen ions in a solution. The **pH scale** is used to indicate the acidity or basicity of a solution. The pH scale ranges from 0 to 14 (Fig. 2.13). A pH of 7 represents a neutral state in which the hydrogen ion and hydroxide ion concentrations are equal, as in pure water. A pH below 7 is acidic because the hydrogen ion concentration, commonly expressed in brackets as $[H^+]$, is greater than the hydroxide concentration, $[OH^-]$. A pH above 7 is basic because $[OH^-]$ is greater than $[H^+]$. Further, as we move down the pH scale from pH 7 to pH 0, each unit has 10 times the acidity $[H^+]$ of the previous unit. As we move up the scale from 7 to 14, each unit has 10 times the basicity $[OH^-]$ of the previous unit.

The pH scale was devised to eliminate the use of cumbersome numbers. For example, the hydrogen ion concentrations of several solutions are given on the left, and the pH is on the right:

$[H^+]$ (moles per liter)			pH
0.000001	=	1×10^{-6}	6 (acid)
0.0000001	=	1×10^{-7}	7 (neutral)
0.00000001	=	1×10^{-8}	8 (base)

The effect of pH on organisms is dramatically illustrated by the phenomenon known as acid precipitation. When fossil fuels are burned, sulfur dioxide and nitrogen oxides are produced, and they combine with water in the atmosphere to form acids. These acids then come in contact with organisms and objects, leading to damage or even death.

Buffers and pH

A **buffer** is a chemical or a combination of chemicals that keeps pH within established limits. Buffers resist pH changes because they can take up excess hydrogen ions (H^+) or hydroxide ions (OH^-). In the human body, pH needs to be kept within a narrow range in order to maintain homeostasis. Diseases such as diabetes and congestive heart failure may bring on a condition called acidosis, in which the body is unable to buffer the excessive production of H^+ ions. If left untreated, acidosis can cause a number of health problems and may result in coma or death.

2.3 CONNECTING THE CONCEPTS
The acidity of water is based on the concentration of hydrogen ions (H^+) in a solution.

Check Your Progress 2.3

1. Distinguish between an acid and a base.
2. Explain what information can be gathered by a given pH of a solution.
3. Summarize how buffers are used to regulate the pH of the human body.

[1] pH is defined as the negative log of the hydrogen ion concentration, or $-\log[H^+]$. A log is the power to which 10 must be raised to produce a given number.

SUMMARIZE

All life is composed of a similar set of elements. These elements may be combined using chemical bonds to form more complex molecules and compounds. Knowledge of this basic chemistry provides a foundation for understanding biology.

- Subatomic particles determine how elements bond to form molecules and compounds.
- The properties of water are important to life due to water's ability to form hydrogen bonds.
- The acidity of water is based on the concentration of hydrogen ions (H+) in a solution.

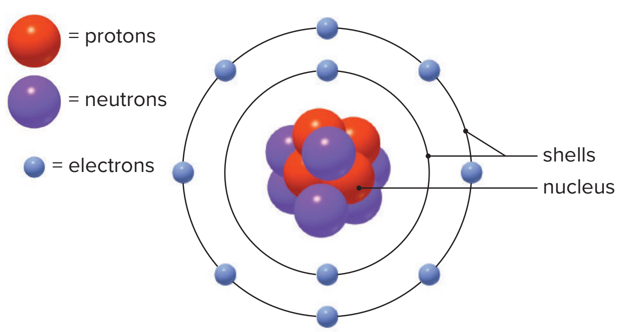
2.1 Atoms and Atomic Bonds

Both living organisms and nonliving things are composed of **matter** consisting of **elements.** The major elements in living organisms are carbon, hydrogen, nitrogen, and oxygen. Elements consist of **atoms,** which in turn contain subatomic particles. **Protons** have positive charges, **neutrons** are uncharged, and **electrons** have negative charges. Electrons are found outside the nucleus in energy levels called **electron shells.**

Protons and neutrons in the nucleus determine the **mass number** of an atom. The **atomic number** indicates the number of protons in the nucleus. In an electrically neutral atom, the atomic number also indicates the number of electrons. **Isotopes** are atoms of a single element that differ in their number of neutrons. Radioactive isotopes have many uses, including serving as tracers in biological experiments and medical procedures.

The number of electrons in the **valence shell** (outer energy level) determines the reactivity of an atom. The first electron shell is complete when it is occupied by two electrons. Atoms are most stable when the valence shell contains eight electrons. The **octet rule** states that atoms react with one another in order to have a completed valence shell.

Atoms are often bonded together to form **molecules.** If the elements in a molecule are different, it is called a **compound.** Molecules and compounds may be held together by ionic or covalent bonds. **Ionic bonds** are formed by an attraction between oppositely charged ions. **Ions** form when atoms lose or gain one or more electrons to achieve a completed outer shell. **Covalent bonds** occur when electrons are shared between two atoms. There are single covalent bonds (sharing one pair of electrons), double (sharing two pairs of electrons), and triple (sharing three pairs of electrons).



2.2 Water's Importance to Life

The two covalent O—H bonds of water are **polar** because the electrons are not shared equally between oxygen and hydrogen. This is because oxygen has a higher **electronegativity** than hydrogen. The positively and negatively charged ends of the molecules are attracted to each other to form **hydrogen bonds.** Hydrogen bonds explain the chemical characteristics of water, including its **cohesive** and **adhesive** properties.

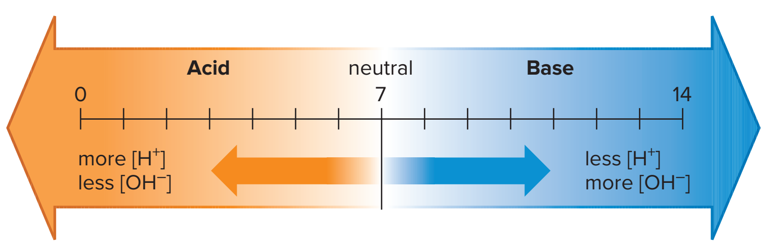
The polarity of water causes the attraction of **hydrophilic** molecules. Molecules that are not attracted to water are **hydrophobic.** The polarity and hydrogen bonding in water account for its unique properties, which are summarized in Table 2.1.

Table 2.1 Properties of Water

Properties	Chemical Reason(s)	Effect
Water is a solvent.	Polarity	Water facilitates chemical reactions.
Water is cohesive and adhesive.	Hydrogen bonding; polarity	Water serves as a transport medium.
Water has a high surface tension.	Hydrogen bonding	The surface tension of water is hard to break.
Water has a high heat capacity and heat of vaporization.	Hydrogen bonding	Water protects organisms from rapid changes in temperature and from overheating.
Water varies in density.	Hydrogen bonding	Ice is less dense than liquid water and therefore ice floats on liquid water.

2.3 Acids and Bases

Water dissociates to produce an equal number of hydrogen ions (H^+) and hydroxide ions. This is neutral **pH. Acids** increase the H^+ concentration of a solution, while **bases** decrease the H^+ concentration. This **pH scale** shows the range of acidic and basic solutions:



Cells are sensitive to pH changes. Biological systems contain **buffers** that help keep the pH within a normal range.

ASSESS

Testing Yourself

Choose the best answer for each question.

2.1 Atoms and Atomic Bonds

1. The mass number of an atom depends primarily on the number of
   a. protons and neutrons. **c.** neutrons and electrons.
   b. positrons. **d.** protons and electrons.
2. The most abundant element by weight in the human body is
   a. carbon. **c.** oxygen.
   b. hydrogen. **d.** nitrogen.
3. Isotopes of an element vary in their number of
   a. electrons. **c.** protons.
   b. neutrons. **d.** Both a and c are correct.
4. A covalent bond in which electrons are not shared equally is called
   a. polar. **c.** nonpolar.
   b. normal. **d.** neutral.
5. Refer to Figure 2.3. Which element has the same number of valence electrons as nitrogen (N)?
   a. carbon (C) **c.** neon (Ne)
   b. phosphorus (P) **d.** oxygen (O)

2.2 Water's Importance to Life

6. Water flows freely but does not separate into individual molecules because water is
   a. cohesive. **c.** hydrophobic.
   b. hydrophilic. **d.** adhesive.
7. Compounds having an affinity for water are said to be
   a. cohesive. **c.** hydrophobic.
   b. hydrophilic. **d.** adhesive.
8. Water freezes from the top down because
   a. water has a high surface tension.
   b. ice has a high heat capacity.
   c. ice is less dense than water.
   d. ice is less cohesive than water.
9. Water can absorb a large amount of heat without much change in temperature because it has a high
   a. surface tension.
   b. heat capacity.
   c. hydrogen ion (H^+) concentration.
   d. hydroxide ion (OH^-) concentration.

2.3 Acids and Bases

10. A pH of 9 is
    a. basic. **c.** acidic.
    b. neutral. **d.** a buffer.
11. These contribute hydrogen ions (H^+) to a solution.
    a. bases **c.** acids
    b. isotopes **d.** buffers
12. To maintain a constant pH, many organisms use ____________ to regulate the hydrogen ion concentration.
    a. buffers **c.** acids
    b. bases **d.** isotopes

ENGAGE

BioNOW

Want to know how this science is relevant to your life? Check out the BioNOW video below.

- Properties of Water

What characteristic of water do you think is most important to a living organism such as yourself?

Thinking Critically

1. On a hot summer day, you decide to dive into a swimming pool. Before you begin your dive, you notice that the surface of the water is smooth and continuous. After the dive, you discover that some water droplets are clinging to your skin and that your skin temperature feels cooler. Explain these observations based on the properties of water.
2. Like carbon, silicon has four electrons in its outer shell, yet life evolved to be carbon-based. What is there about silicon's structure that might prevent it from sharing with four other elements and prevent it from forming the many varied shapes of carbon-containing molecules?
3. Antacids are a common over-the-counter remedy for heartburn, a condition caused by an overabundance of H^+ ions in the stomach. Based on what you know regarding pH, how do the chemicals in antacids work?
4. Acid precipitation is produced when atmospheric water is polluted by sulfur dioxide and nitrous oxide emissions. These emissions are mostly produced by the burning of fossil fuels, particularly coal. In the atmosphere, these compounds are converted to sulfuric and nitric acids, and are absorbed into water droplets in the atmosphere. Eventually, they fall back to Earth as acid precipitation. How do you think acid precipitation can negatively influence an ecosystem?

CHAPTER

3

The Organic Molecules of Life

What Is Gluten?

On any trip to the grocery store, you may notice a wide abundance of foods that are labeled "gluten-free," and almost every restaurant has a gluten-free section of the menu. So, what exactly is gluten?

Contrary to what most people believe, gluten is not a carbohydrate. Instead, it is a type of protein that is commonly found in wheat, rye, and barley. For most of us, gluten is processed by the digestive system in the same manner as any other protein, meaning it is broken down into amino acids and absorbed into the circulatory system.

However, for about 1 out of every 100 individuals, the body misidentifies gluten as a foreign pathogen. The result is celiac disease, a disorder of the lining of the small intestine. In celiac disease, an example of an autoimmune response, the body's reaction to gluten causes inflammation and loss of the intestinal linings. The damage to the intestines causes malnutrition and other health problems. Individuals with celiac disease must eliminate gluten from their diet. Interestingly, a gluten-free diet does not seem to have health benefits for individuals who do not suffer from celiac disease.

In this chapter, you will learn about the structure and function of the major classes of organic molecules, including carbohydrates, lipids, proteins, and nucleic acids.

As you read through this chapter, think about the following questions:

1. What is the difference in the structure of a carbohydrate and a protein?
2. What are the roles of proteins in the body?
3. How does the body determine which proteins to make?

OUTLINE

BEFORE YOU BEGIN

Before beginning this chapter, take a few moments to review the following discussions.

Section 2.1 What is a covalent bond?

Section 2.2 What is the difference between hydrophobic and hydrophilic molecules?

Figure 2.8 How are molecules represented in a diagram?

3.1 Organic Molecules

Learning Outcomes

Upon completion of this section, you should be able to

1. Distinguish between organic and inorganic molecules.
2. Recognize the importance of functional groups in determining the chemical properties of an organic molecule.

The study of chemistry can be divided into two major categories: organic chemistry and inorganic chemistry. The difference between the two is relatively simple. Organic chemistry is the study of organic molecules. An **organic** molecule contains atoms of carbon and hydrogen. Organic molecules make up portions of cells, tissues, and organs (Fig. 3.1). An inorganic molecule does not contain a combination of carbon and hydrogen. Water (H_2O) and table salt (NaCl) are examples of inorganic molecules. This chapter focuses on the diversity and functions of organic molecules in cells, also commonly referred to as **biological molecules,** or simply biomolecules.

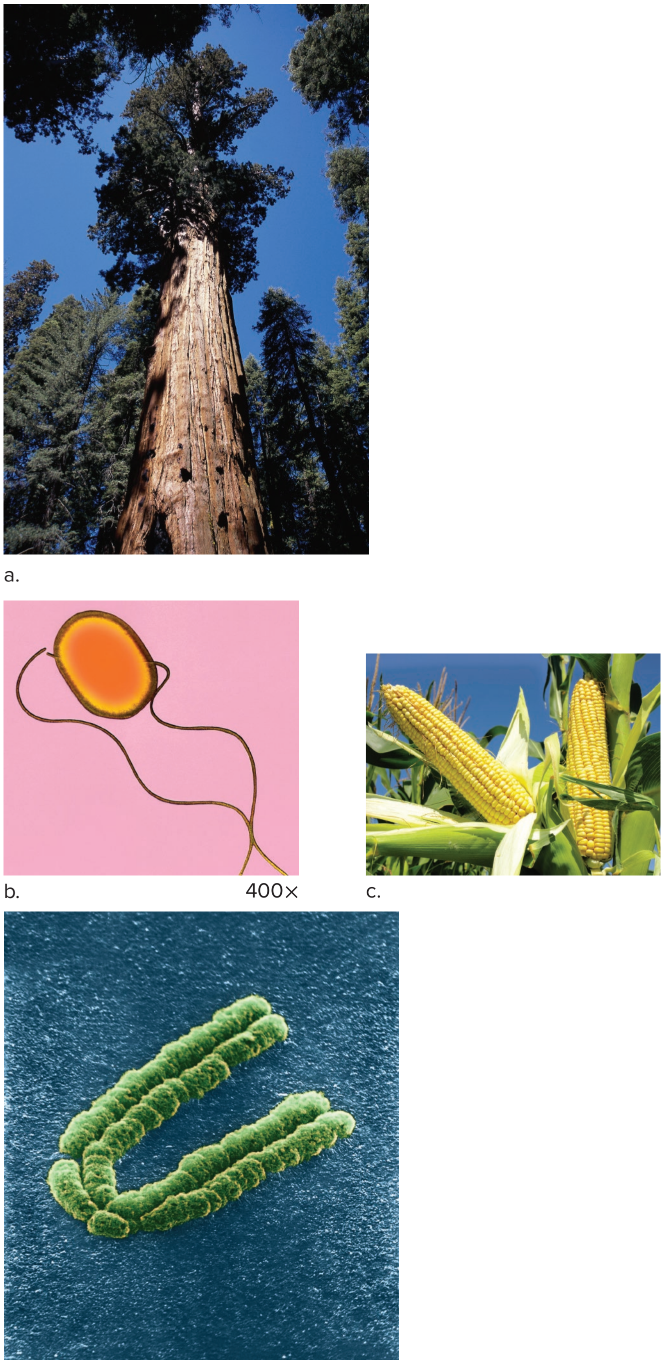


Figure 3.1 **Organic molecules have a variety of functions.** **a.** Carbohydrates form fiber that provides support to plants. **b.** Proteins help form the cell walls of bacteria. **c.** Lipids, such as the oil within these corn plants, are used for energy storage for plants. **d.** Nucleic acids form DNA which acts to store genetic information.

(a): ©SuperStock/Alamy Stock Photo; (b): ©Science Photo Library/Alamy Stock Photo; (c): ©Zeljko Radojko/Getty Images; (d): ©Adrian T. Sumner/Science Source

Connections

Is there a connection between organic molecules and organic produce?

As you just learned, organic molecules are those that contain carbon and hydrogen. Vegetables and fruits are all organic in that they contain these elements. The use of the term *organic* when related to farming means that there are certain production standards in place when growing the food. Normally, it means no pesticides or herbicides with harsh chemicals were used and the crop was grown as naturally as possible. So, as you can see, there are two different ways that the term *organic* may be used.

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The Carbon Atom

A microscopic bacterial cell can contain thousands of different organic molecules. In fact, there appears to be an almost unlimited variation in the structure of organic molecules. What is there about carbon that makes organic molecules so diverse and so complex? Recall that carbon, with a total of six electrons, has four electrons in the outer shell (see Fig. 2.8). In order to acquire four electrons to complete its outer shell, a carbon atom almost always shares electrons, and typically with the elements hydrogen, nitrogen, and oxygen—the elements that make up most of the weight of living organisms (see Section 2.1).

Because carbon is small and needs to acquire four electrons, carbon can bond with as many as four other elements. Carbon atoms most often share electrons with other carbon atoms. The C—C bond is stable, and the result is that carbon chains can be quite long. *Hydrocarbons* are chains of carbon atoms that are also bonded only to hydrogen atoms. Any carbon atom of a hydrocarbon