1.1 The Characteristics of Life

LEARNING OUTCOMES

Upon completion of this section, you should be able to

1. Explain the basic characteristics that are common to all living organisms.
2. Describe the levels of organization of life.
3. Summarize how the terms *homeostasis, metabolism, development,* and *adaptation* all relate to living organisms.
4. Explain why the study of evolution is important in understanding life.

The science of **biology** is the study of living organisms and their environments. All living organisms (Fig. 1.1) share several basic characteristics. They (1) are organized, (2) acquire materials and energy, (3) are homeostatic, (4) respond to stimuli, (5) reproduce and grow, and (6) have an evolutionary history.

Life Is Organized

Figure 1.2 illustrates the levels of biological organization. Note that, at the bottom of the figure, **atoms** join together to form the **molecules** that make up a cell. A **cell** is the smallest structural and functional unit of an organism. Some organisms, such as bacteria, are single-celled organisms. Humans are *multicellular,* because they are composed of many different types of cells. A nerve cell is one of the types of cells in the human body. It has a structure suitable to conducting a nerve impulse.

A **tissue** is a group of similar cells that perform a particular function. Nervous tissue is composed of millions of nerve cells that transmit signals to all parts of the body. An **organ** is made up of several types of tissues, and each organ belongs to an **organ system.** The organs of an organ system work together to accomplish a common purpose. The brain works with the spinal cord to send commands to body parts by way of nerves. **Organisms,** such as trees and humans, are a collection of organ systems.

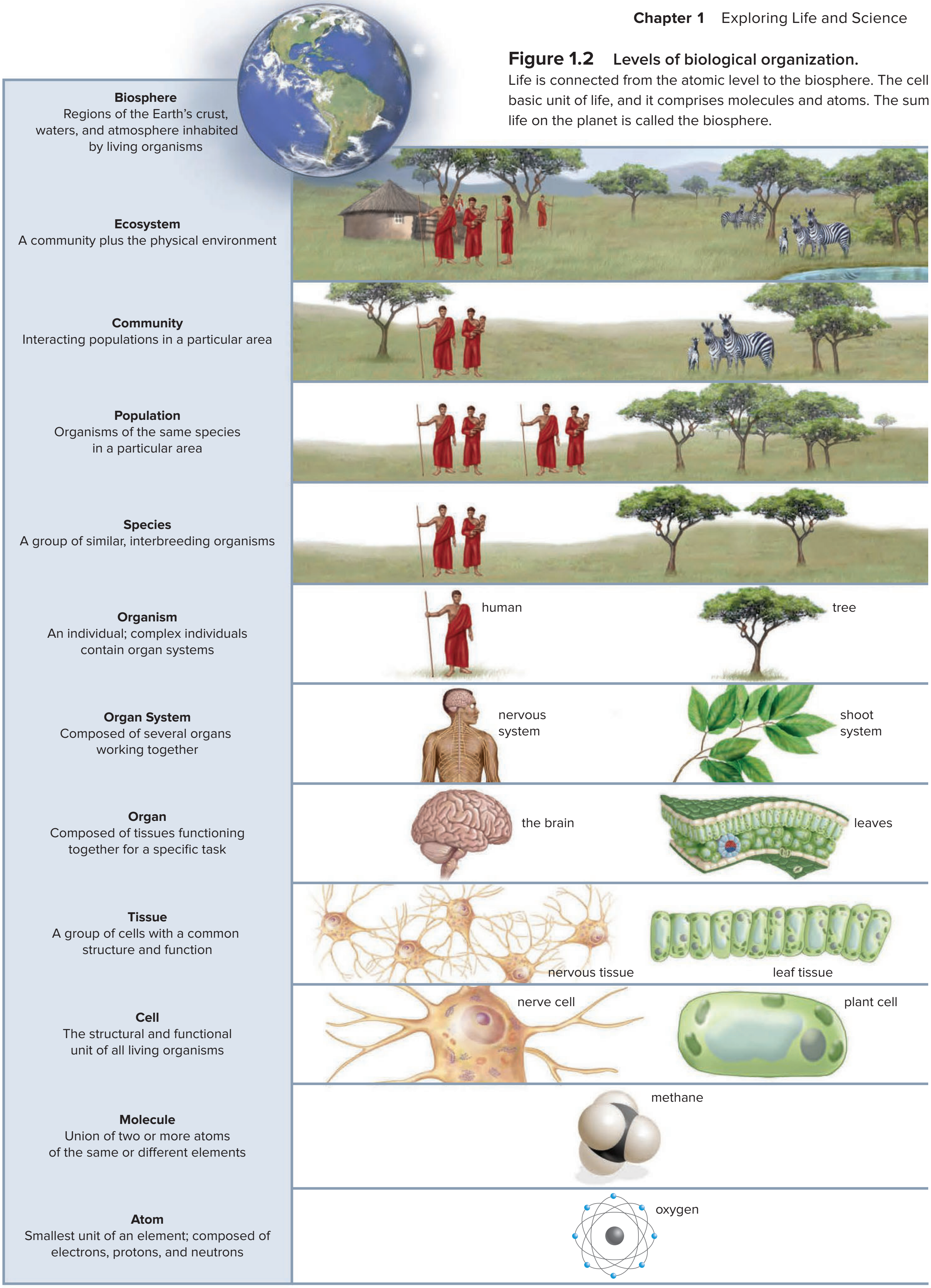
The levels of biological organization extend beyond the individual. All the members of one **species** (a group of interbreeding organisms) in a particular area belong to a **population.** A tropical grassland may have a population of zebras, acacia trees, and humans, for example. The interacting populations of the grasslands make up a **community.** The community of populations interacts with the physical environment to form an **ecosystem.** Finally, all the Earth's ecosystems collectively make up the **biosphere** (Fig. 1.2, *top*).

Figure 1.1 All life shares common characteristics.

From the simplest one-celled organisms to complex plants and animals, all life shares several basic characteristics.

(leech): © St. Bartholomews Hospital/Science Source; (mushrooms): © IT Stock/age fotostock RF; (bacteria): © Science Source; (meerkats): © Jami Tarris/Getty Images; (sunflower): © Dave Thompson/Life File/Getty RF; (*Giardia*): Source: Dr. Stan Erlandsen/CDC

Figure 1.2 **Levels of biological organization.**
Life is connected from the atomic level to the biosphere. The cell is the basic unit of life, and it comprises molecules and atoms. The sum of all life on the planet is called the biosphere.



SCIENCE IN YOUR LIFE

How many cells are in your body?

The number of cells in a human body varies depending on the size of the person and whether cells have been damaged or lost. However, most estimates suggest that there are well over 100 trillion cells in a human body.

Life Requires Materials and Energy

Humans, like all living organisms, cannot maintain their organization or carry on life's activities without an outside source of materials and energy. **Energy** is the capacity to do work. Like other animals, humans acquire materials and energy by eating food (Fig. 1.3).

Food provides nutrient molecules, which are used as building blocks or for energy. It takes energy to maintain the organization of the cell and of the organism. Some nutrient molecules are broken down completely to provide the energy necessary to convert other nutrient molecules into the parts and products of cells. The term **metabolism** describes all the chemical reactions that occur within a cell.

a.

b.

Figure 1.3 Humans and other animals must acquire energy.

All life, including humans (**a**) and other animals, such as this mongoose (**b**), must acquire energy to survive. The method by which organisms acquire energy is dependent on the species.

(a): © Corbis RF; (b): © Gallo Images-Dave Hamman/Getty RF

The ultimate source of energy for the majority of life on Earth is the sun. Plants, algae, and some bacteria are able to harvest the energy of the sun and convert it to chemical energy by a process called **photosynthesis.** Photosynthesis produces organic molecules, such as sugars, that serve as the basis of the food chain for many other organisms, including humans and all other animals.

Living Organisms Maintain an Internal Environment

For the metabolic pathways within a cell to function correctly, the environmental conditions of the cell must be kept within strict operating limits. The ability of a cell or an organism to maintain an internal environment that operates under specific conditions is called **homeostasis.** In humans, many of our organ systems work to maintain homeostasis. For example, human body temperature normally fluctuates slightly between 36.5 and 37.5°C (97.7 and 99.5°F) during the day. In general, the lowest temperature usually occurs between 2 A.M. and 4 A.M., and the highest usually occurs between 6 P.M. and 10 P.M. However, activity can cause the body temperature to rise, and inactivity can cause it to decline. A number of body systems, including the cardiovascular system and the nervous system, work together to maintain a constant temperature. The body's ability to maintain a normal temperature is also somewhat dependent on the external temperature. Even though we can shiver when we are cold and perspire when we are hot, we will die if the external temperature becomes overly cold or hot.

This text emphasizes how all the systems of the human body help maintain homeostasis. For example, the digestive system takes in nutrients, and the respiratory system exchanges gases with the environment. The cardiovascular system distributes nutrients and oxygen to the cells and picks up their wastes. The metabolic waste products of cells are excreted by the urinary system. The work of the nervous and endocrine systems is critical, because these systems coordinate the functions of the other systems. Throughout the text, the Connecting the Concepts feature at the end of each section will provide you with links to more information on homeostasis.

Living Organisms Respond

Homeostasis would be impossible without the body's ability to respond to stimuli. Response to external stimuli is more apparent to us, because it involves movement, as when we quickly remove a hand from a hot stove. Certain sensory receptors also detect a change in the internal environment, and then the central nervous system brings about an appropriate response. When you are startled by a loud noise, your heartbeat increases, which causes your blood pressure to increase. If blood pressure rises too high, the brain directs blood vessels to dilate, helping restore normal blood pressure.

All life responds to external stimuli, often by moving toward or away from a stimulus, such as the sight of food. Organisms may use a variety of mechanisms to move, but movement in humans and other animals is dependent on their nervous and musculoskeletal systems. The leaves of plants track the passage of the sun during the day; when a houseplant is placed near a window, its stems bend to face the sun. The movement of an animal, whether self-directed or in response to a stimulus, constitutes a large part of its *behavior*. Some behaviors help us acquire food and reproduce.

a. b.

Figure 1.4 **Growth and development define life.**
(**a**) A small acorn becomes a tree, and (**b**) following fertilization an embryo becomes a fetus by the process of growth and development.

Living Organisms Reproduce and Develop

Reproduction is a fundamental characteristic of life. Cells come into being only from preexisting cells, and all living organisms have parents. When organisms **reproduce,** they pass on their genetic information to the next generation. Following the fertilization of an egg by a sperm cell, the resulting zygote undergoes a rapid period of growth and development. This is common in most forms of life. Figure 1.4*a* illustrates that an acorn progresses to a seedling before it becomes an adult oak tree. In humans, growth occurs as the fertilized egg develops into a fetus (Fig. 1.4*b*). **Growth,** recognized by an increase in size and often in the number of cells, is a part of development. In multicellular organisms, such as humans, the term **development** is used to indicate all the changes that occur from the time the egg is fertilized until death. Therefore, it includes all the changes that occur during childhood, adolescence, and adulthood. Development also includes the repair that takes place following an injury.

The genetic information of all life is **DNA (deoxyribonucleic acid).** DNA contains the hereditary information that directs not only the structure of each cell but also its function. The information in DNA is contained within **genes,** short sequences of hereditary material that specify the instructions for a specific trait. Before reproduction occurs, DNA is replicated, so that an exact copy of each gene may be passed on to the offspring. When humans reproduce, a sperm carries genes contributed by a male into the egg, which contains genes contributed by a female. The genes direct both growth and development, so that the organism will eventually resemble the parents. Sometimes **mutations,** minor variations in these genes, can cause an organism to be better suited for its environment. These mutations are the basis of evolutionary change.

Organisms Have an Evolutionary History

Evolution is the process by which a population changes over time. The mechanism by which evolution occurs is **natural selection** (see Section 23.2). When a new variation arises that allows certain members of a population to capture more resources, these members tend to survive and have more offspring than the other, unchanged members. Therefore, each successive generation will include more members with the new variation, which represents an **adaptation** to the environment. Consider, for example, populations of humans who live at high altitudes, such as the cultures living at elevations of over 4,000 meters (m) (14,000 ft) in the Tibetan Plateau. This environment is very low in oxygen. As the Science feature "Adapting to Life at High Elevations" investigates, these populations have evolved an adaptation that reduces the amount of hemoglobin, the oxygen-carrying pigment in the blood. As the feature explains, this adaptation makes life at these altitudes possible.

Evolution, which has been going on since the origin of life and will continue as long as life exists, explains both the unity and the diversity of life. All organisms share the same characteristics of life because their ancestry can be traced to the first cell or cells. Organisms are diverse because they are adapted to different ways of life.

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Adapting to Life at High Elevations

Humans, like all other organisms, have an evolutionary history. This means not only that we share common ancestors with other animals but also that over time we demonstrate adaptations to changing environmental conditions. One study of populations living in the high-elevation mountains of Tibet (Fig. 1A) demonstrates how the processes of evolution and adaptation influence humans.

Figure 1A
Individuals living at high elevations, such as these Tibetans, have become adapted to their environment.

Normally when a person moves to a higher altitude, his or her body responds by making more hemoglobin, the component of blood that carries oxygen, which thickens the blood. For minor elevation changes, this does not present much of a problem. But for people who live at extreme elevations (some people in the Himalayas can live at elevations of over 13,000 ft, or close to 4,000 m), excess hemoglobin can present a number of health problems, including chronic mountain sickness, a disease that affects people who live at high altitudes for extended periods of time. The problem is that, as the amount of hemoglobin increases, the blood thickens and becomes more viscous. This can cause elevated blood pressure, or hypertension, and an increase in the formation of blood clots, both of which have negative physiological effects.

Because high hemoglobin levels would be a detriment to people at high elevations, it makes sense that natural selection would favor individuals who produce less hemoglobin at high elevations. Such is the case with the Tibetans in this study. Researchers have identified an allele of a gene that reduces hemoglobin production at high elevations. Comparisons between Tibetans at both high and low elevations strongly suggest that selection has played a role in the prevalence of the high-elevation allele.

The gene is *EPSA1,* located on chromosome 2 of humans. *EPSA1* produces a transcription factor, which basically regulates which genes are turned on and off in the body, a process called gene expression. The transcription factor produced by *EPSA1* has a number of functions in the body. For example, in addition to controlling the amount of hemoglobin in the blood, this transcription factor also regulates other genes that direct how the body uses oxygen.

When the researchers examined the variations in *EPSA1* in the Tibetan population, they discovered that the Tibetan version greatly reduces the production of hemoglobin. Therefore, the Tibetan population has lower hemoglobin levels than people living at lower altitudes, allowing these individuals to escape the consequences of thick blood.

How long did it take for the original population to adapt to living at higher elevations? Initially the comparison of variations in these genes between high-elevation and low-elevation Tibetan populations suggested that the event may have occurred over a 3,000-year period. But researchers were skeptical of that data because it suggested a relatively rapid rate of evolutionary change. Additional studies of genetic databases yielded an interesting finding—the *EPSA1* gene in Tibetans was identical to a similar gene found in an ancient group of humans called the Denisovans (see Section 23.5). Scientists now believe that the *EPSA1* gene entered the Tibetan population around 40,000 years ago, either through interbreeding between early Tibetans and Denisovans, or from one of the immediate ancestors of this now-lost group of early humans.

Questions to Consider

1. What other environments do you think could be studied to look for examples of human adaptation?
2. In addition to hemoglobin levels, do you think that people at high elevations may exhibit other adaptations?

CHECK YOUR PROGRESS 1.1

1. List the basic characteristics of life.
2. Summarize the levels of biological organization.
3. Explain the relationship between adaptations and evolutionary change.

CONNECTING THE CONCEPTS

Both homeostasis and evolution are central themes in the study of biology. For more examples of homeostasis and evolution, refer to the following discussions:

Section 4.8 explains how body temperature is regulated.

Section 11.4 explores the role of the kidneys in fluid and salt homeostasis.

Section 23.3 examines the evolutionary history of humans.