CHAPTER 1

A View of Life

In the 1950s developmental biologists Robert Briggs and Thomas King, then at the Institute for Cancer Research in Philadelphia, developed techniques for cloning frogs. They removed the nucleus (the structure in the cell that contains the genetic material) of a frog egg cell and replaced it with a nucleus from the cell of a developing frog embryo. Briggs and King found that nuclei from very early embryos were able to direct development to the tadpole stage, but nuclei from more developed embryos appeared to lose that ability. In the 1960s embryologist John Gurdon, now at Cambridge University, and his colleagues, using different techniques, showed that at least some nuclei retained the ability to direct development. Gurdon removed the nucleus of a frog egg cell and replaced it with the nucleus from a tadpole cell. The egg developed into a tadpole that was a clone, a genetic duplicate, of the animal that contributed the nucleus.

The research of Briggs and King and of Gurdon challenged the long-held belief that during development, the DNA (genetic material) of each cell becomes committed to coding for a specific type of cell and can no longer direct the development of an entire organism. However, attempts to clone other species were unsuccessful and many biologists concluded that frogs were an exception. Certainly, it was thought, cloning would not be possible in humans and other mammals. With the development of more sophisticated techniques, biologists became more optimistic about cloning mammals but speculated it would be well into the 21st century before this could be accomplished.

In 1997 biologist Ian Wilmut of the Roslin Institute in Edinburgh, Scotland, and his colleagues stunned the scientific community with their report in the journal *Nature* that they had successfully cloned a sheep. These researchers transferred nuclei from cultured mammary gland cells from a six-year-old ewe into specially prepared eggs from another sheep. One of these eggs developed into the clone that was named Dolly. Dolly represented the first time that DNA from an *adult mammal* had been successfully used to create a new, genetically identical animal. Shown here is Dolly with *her* new lamb, Bonnie. Bonnie was conceived naturally, further evidence that Dolly is a fully-functioning animal. (More about cloning and the techniques used to create Dolly are discussed in Chapter 16, *Genes and Development.*) Since Dolly, fetal cells have been used to clone cows, sheep, pigs and other mammals.

The recent successes in cloning have generated a great deal of controversy about possible ethical implications. A major concern centers on the future possibility of cloning humans.

(Roslin Institute/PA News Photo Library)

Wilmut has stated that his goal in cloning Dolly was not to make copies of animals, but to develop techniques for making "precise genetic changes in cells." Already, cloning techniques have been combined with genetic engineering procedures to produce animals like Polly, a lamb that carries a human gene, and Genie, a sow that produces a human clotting protein in her milk. Such *transgenic* animals may become a routine source of relatively inexpensive human proteins needed by individuals suffering from medical conditions from hemophilia to strokes and heart attacks.

Among other applications for cloning technology are the preservation of endangered species and the development of animal strains that will be more resistant to disease or produce low-fat milk or eggs. Genetically engineered, cloned cow or pig organs might be transplanted to ailing human patients. Human tissues could be engineered to treat spinal cord injuries or human diseases like leukemia or diabetes. Society will need to balance the potential benefits to health, medicine, and conservation with the concerns about misuse of cloning techniques.

The ethical questions posed by new technology in genetics and developmental biology represent one group of issues that demand a biologically literate society. As we prepare to enter the 21st century, we face many challenges, such as the expanding human population, diminishing natural resources, decreasing biodiversity, and curing diseases such as cancer and AIDS. Meeting these challenges will require the combined efforts of biologists and other scientists, politicians, and biologically informed citizens.

Learning Objectives

After you have studied this chapter you should be able to

1. Define biology and discuss its applications to human life and society.
2. Distinguish between living and nonliving things by describing the features that characterize living organisms.
3. Relate metabolism to homeostasis and give specific examples of these life processes.
4. Summarize the importance of information transfer to living systems, giving specific examples.
5. Give a brief overview of the theory of evolution and explain why it is the principal unifying concept in biology.
6. Apply the theory of natural selection to any given adaptation, suggesting a logical explanation of how the adaptation may have evolved.
7. Construct a hierarchy of biological organization, including individual and ecological levels.
8. Demonstrate the binomial system of nomenclature using several specific examples and classify an organism (a human, for example) according to kingdom, phylum, class, order, family, genus, and species.
9. Contrast the six kingdoms of living organisms and cite examples of each group.
10. Contrast the roles of producers, consumers, and decomposers and cite examples of their interdependence.
11. Design an experiment to test a given hypothesis, using the procedure and terminology of the scientific method.

What is biology?

Biology is the science of life. More than any other discipline, biology helps us understand ourselves and the millions of other organisms with which we share our planet. As biologists continue to study interrelationships of organisms, they enhance our awareness of our own impact on our environment. Whatever your college major or career goals, a knowledge of biological concepts is a vital tool for understanding our world and for meeting many of the personal and global challenges that confront us. Applications of basic research in biology have provided us with the technology to transplant hearts, manipulate genes, and increase world food production. For example, research in molecular biology and genetics has led to new insights into disease processes, leading to the new science of gene therapy.

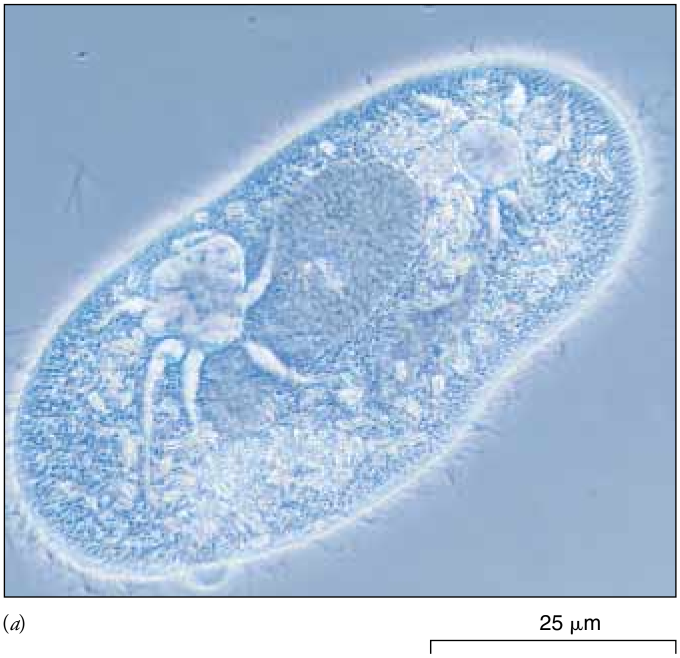
In this first chapter we will introduce three basic themes of biology: **evolution of life, transmission of information,** and **flow of energy through living systems.** Scientists have accumulated a wealth of evidence showing that the diverse life forms on our planet are related and that organisms have evolved through time from earlier life forms. The process of evolution is the framework for the science of biology and a major theme of this book.

The process of evolution, as well as the survival and function of every organism, depends on the orderly transmission of information. At the molecular level, instructions for producing and maintaining each living organism and each new generation are encoded in the DNA molecules that make up the genes. At higher levels, the activities of organisms are coordinated by many forms of chemical signaling. Animals also use chemical, as well as behavioral, signals to communicate with one another. For example, many female animals release chemical substances that attract males.

Energy is required to maintain the precise order that characterizes living systems. Maintaining the chemical transactions and cellular organization essential to life requires a continuous input of energy. We begin our study of biology by developing a more precise understanding of what life is.

Life can be defined in terms of the characteristics of organisms

We can easily recognize that an oak tree, a butterfly, and a lamb are living, whereas a rock is not. Despite their diversity, the organisms that inhabit our planet share a common set of characteristics that distinguish them from nonliving things. These features include a precise kind of organization; growth and development; self-regulated metabolism; movement; the ability to respond to stimuli; reproduction; and adaptation to environmental change. We consider each of these characteristics in the following sections.



(*a*)

(*b*)

Figure 1–1 **Unicellular and multicellular life forms.** ***(a)*** Unicellular organisms are generally smaller and consist of one intricate cell that performs all of the functions essential to life. Ciliates, such as this *Paramecium,* move about by beating their hairlike cilia. ***(b)*** Multicellular organisms, like this African buffalo *(Syncerus caffer)* and the plants on which it grazes, may consist of millions of cells specialized to perform specific functions. *(a, Roland Birke/Peter Arnold, Inc.; b, McMurray Photography)*

Organisms are composed of cells

Living organisms are highly organized, and, as discussed later in this chapter, we can identify a hierarchy of biological organization. As expressed in the **cell theory,** one of the fundamental unifying concepts of biology, all living organisms are composed of basic units called **cells.** Two German scientists are credited with the cell theory. Matthias Schleiden (in 1838) and Theodor Schwann (in 1839) were the first to report that plants and animals consist of groups of cells. Although they vary greatly in size and appearance, all organisms are composed of these small building blocks. Some of the simplest life forms, such as bacteria, are *unicellular,* meaning that each consists of a single cell. In contrast, the body of a lamb or a maple tree is made of billions of cells (Fig. 1–1). In such complex *multicellular* organisms, life processes depend on the coordinated functions of component cells that may be organized to form tissues, organs, and organ systems.

Organisms grow and develop

Some nonliving things appear to grow. For example, salt crystals form and enlarge in a supersaturated salt solution. However, this is not growth in the biological sense. Biological **growth** is an increase in the size of individual cells of an organism or in the number of cells, or both (Fig. 1–2). Growth may be uniform in the various parts of an organism, or it may be greater in some parts than in others, causing the body proportions to change as growth occurs.

Some organisms, most trees, for example, continue to grow throughout their lives. Many animals have a defined growth period that terminates when a characteristic adult size is reached.

Figure 1–2 **Biological growth.** The young African elephant *(Loxodonta africana)* eats and grows until it reaches the adult size of its parents, the largest living land animals. These elephants were photographed in Kenya. *(McMurray Photography)*

One of the remarkable aspects of the growth process is that each part of the organism continues to function as it grows.

Living organisms develop as well as grow. **Development** includes all the changes that take place during the life of an organism. Each human, like many other organisms, begins life as a fertilized egg which then grows and develops. The structures and body form that develop are exquisitely adapted to the functions the organism must perform.

Organisms regulate their metabolic processes

Within all organisms, chemical reactions and energy transformations occur that are essential to nutrition, growth and repair of cells, and conversion of energy into usable forms. The sum of all the chemical activities of the organism is its **metabolism.** Metabolic processes occur continuously in every living organism, and they must be carefully regulated to maintain **homeostasis,** a balanced internal state. When enough of some cellular product has been made, its manufacture must be decreased or turned off. When a particular substance is needed, cellular processes that produce it must be turned on. These **homeostatic mechanisms** are self-regulating control systems that are remarkably sensitive and efficient.

The regulation of glucose (a simple sugar) concentration in the blood of complex animals is a good example of a homeostatic mechanism. The circulatory system delivers glucose and other nutrients to all the cells. Most cells require a constant supply of glucose, which they break down to obtain energy. When the concentration of glucose in the blood rises above normal limits, it is stored in the liver and in muscle cells. When the concentration begins to fall (between meals), stored nutrients are converted to glucose so that the concentration in the blood returns to normal levels. When glucose becomes depleted, we also feel hungry and restore nutrients by eating.

Movement is a basic property of cells

Organisms move as they interact with the environment, and in fact the living material within their cells is in continuous motion. In some organisms, locomotion results from the slow oozing of the cell (a process called *amoeboid motion*); in others, from the beating of tiny hairlike extensions of the cell called **cilia** or longer structures called **flagella** (Fig. 1–3). Most animals move very obviously; they wiggle, crawl, swim, run, or fly by contracting muscles. A few animals, such as sponges, corals, and oysters, have free-swimming larval stages but do not move from place to place as adults. Even though these adults, described as **sessile,** remain firmly attached to some surface, they may have cilia or flagella. These structures beat rhythmically, moving the surrounding water that brings food and other necessities to the organism.

Although plants move more slowly than most animals, they do move. For example, plants orient their leaves to the sun and grow toward light. In some plants, for example the Venus flytrap, movement is obvious, even dramatic (described in the next section).

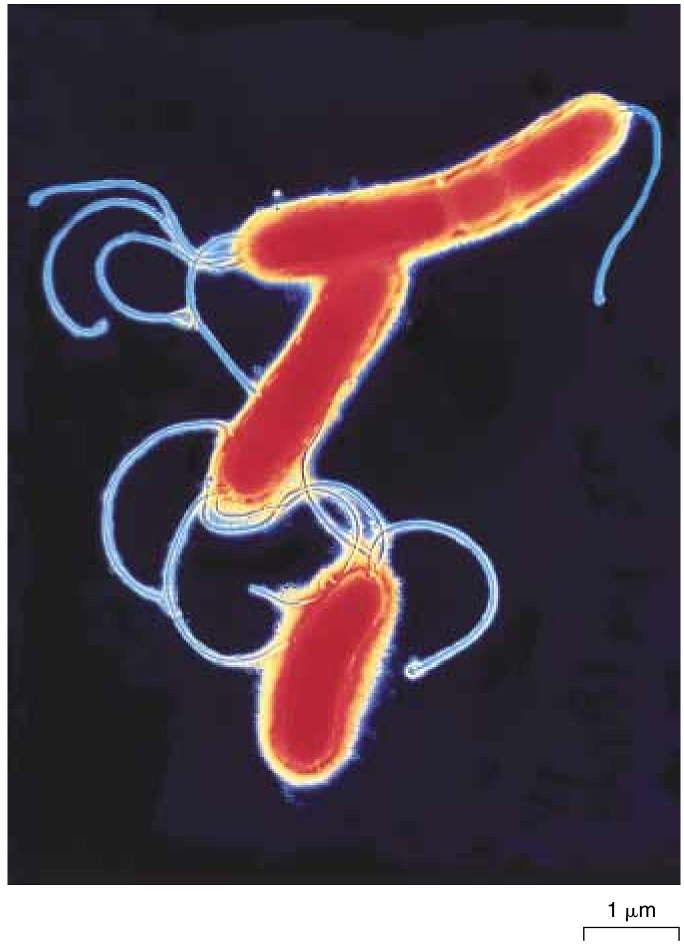


Figure 1–3 **Biological movement.** These bacteria *(Helicobacter pylori),* equipped with flagella for locomotion, have been linked to stomach ulcers. *(A. B. Dowsett/Science Photo Library/Photo Researchers, Inc.)*

Organisms respond to stimuli

All forms of life respond to **stimuli,** physical or chemical changes in their internal or external environment. Stimuli that evoke a response in most organisms are changes in the color, intensity, or direction of light; changes in temperature, pressure, or sound; and changes in the chemical composition of the surrounding soil, air, or water. In simple organisms, the entire organism may be sensitive to stimuli. Certain unicellular organisms, for example, respond to bright light by retreating. In complex animals such as polar bears or humans, certain cells of the body are highly specialized to respond to specific types of stimuli. For example, cells in the retina of the eye respond to light.

Although their responses may not be as obvious as those of animals, plants do respond to light, gravity, water, touch, and other stimuli. Many plant responses involve different rates of growth of various parts of the plant body. A few plants, such as the Venus flytrap of the Carolina swamps (Fig. 1–4), are remarkably sensitive to touch and can catch insects. Their leaves are hinged along the midrib and they have a scent that attracts insects. Trigger hairs on the leaf surface detect the arrival of an

(*a*)

(*b*)

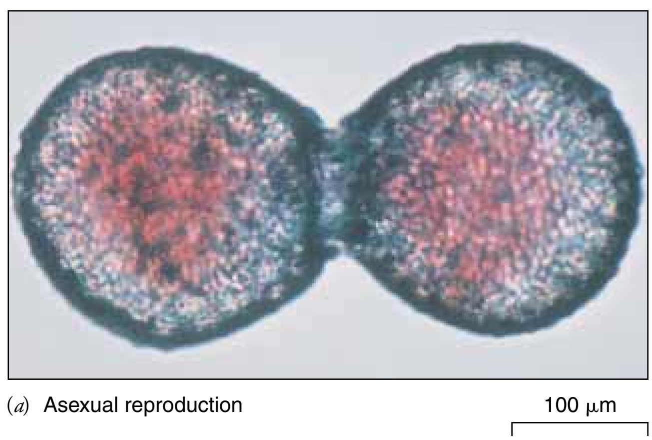
Figure 1–4 Plants respond to stimuli. ***(a)*** Hairs on the leaf surface of the Venus flytrap *(Dionaea muscipula)* detect the touch of an insect, and the leaf responds by folding. ***(b)*** The edges of the leaf come together and interlock, preventing the fly's escape. The leaf then secretes enzymes that kill and digest the insect. *(David M. Dennis/Tom Stack & Associates)*

insect and stimulate the leaf to fold. When the edges come together, the hairs interlock, preventing escape of the prey. The leaf then secretes enzymes that kill and digest the insect. The Venus flytrap is usually found in soil that is deficient in nitrogen. The plant obtains part of the nitrogen required for its growth from the insect prey it "eats."

Organisms reproduce

At one time worms were thought to arise spontaneously from horsehairs in a water trough, maggots from decaying meat, and frogs from the mud of the Nile. We now know that each can come only from previously existing organisms. If any one characteristic can be said to be the very essence of life, it is the ability of an organism to reproduce its kind.

In simple organisms such as the amoeba, reproduction may be **asexual,** that is, without the fusion of egg and sperm to form a fertilized egg (Fig. 1–5). When an amoeba has grown to a certain size, it reproduces by splitting in half to form two new amoebas. Before an amoeba divides, its hereditary material (genes) duplicate and one complete set is distributed to each new cell. Except for size, each new amoeba is similar to the parent cell. The only way that variation occurs among asex-



(*a*) Asexual reproduction

(*b*) Sexual reproduction

▶ **Figure 1–5 Asexual and sexual reproduction.** ***(a)*** Asexual reproduction in *Difflugia,* a unicellular amoeba. In asexual reproduction, one individual gives rise to two or more offspring that are similar to the parent. ***(b)*** A pair of tropical flies mating. In sexual reproduction, typically two parents each contribute a gamete (sperm or egg). Gametes join to produce the offspring, which is a combination of the traits of both parents. *(a, Visuals Unlimited/Cabisco; b, L.E. Gilbert, University of Texas at Austin/Biological Photo Service)*

Figure 1–6 **Adaptations.** These Burchell's zebras *(Equus burchelli),* photographed at Ngorongoro Crater in Tanzania, are behaviorally adapted to position themselves to watch for lions and other predators. Stripes are thought to be an adaptation for visually protecting themselves against predators. They serve as camouflage or to break up form when spotted from a distance. The zebra stomach is adapted for feeding on coarse grass passed over by other grazers, an adaptation that helps them survive when food is scarce. *(McMurray Photography)*

ually reproducing organisms is by genetic mutation, a permanent change in the genes.

In most plants and animals, **sexual reproduction** is carried out by the production of specialized egg and sperm cells that fuse to form a fertilized egg. The new organism develops from the fertilized egg. Offspring produced by sexual reproduction are the product of the interaction of various genes contributed by both the mother and the father. Such genetic variation provides raw material for the vital processes of evolution and adaptation.

Populations evolve and become adapted to the environment

The ability of a population to evolve (change over time) and adapt to its environment enables it to survive in a changing world. **Adaptations** are traits that enhance an organism's ability to survive in a particular environment. They may be structural, physiological, behavioral, or a combination of all three (Fig. 1–6). The long, flexible tongue of the frog is an adaptation for catching insects, and the thick fur coat of the polar bear is an adaptation for surviving frigid temperatures. Every biologically successful organism is a complex collection of coordinated adaptations produced through evolutionary processes.

INFORMATION MUST BE TRANSMITTED WITHIN AND BETWEEN INDIVIDUALS

In order for an organism to grow, develop, carry on self-regulated metabolism, move, respond, and reproduce, it must have precise instructions. The information an organism needs to carry on these life processes is coded and delivered in the form of chemical substances and electrical impulses.

DNA transmits information from one generation to the next

Humans give birth only to human babies, not to giraffes or rose bushes. In organisms that reproduce sexually, each offspring is a combination of the traits of its parents. In 1953, James Watson and Francis Crick worked out the structure of deoxyribonucleic acid, more simply known as **DNA.** This chemical substance makes up the **genes,** the units of hereditary material. The work of Watson and Crick led to the understanding of the genetic code that transmits information from generation to generation. This code works somewhat like our alphabet; it can spell an amazing variety of instructions for making organisms as diverse as bacteria, frogs, and redwood trees. The genetic code is a dramatic example of the unity of life because it is used to specify instructions for making every living organism (Fig. 1–7).

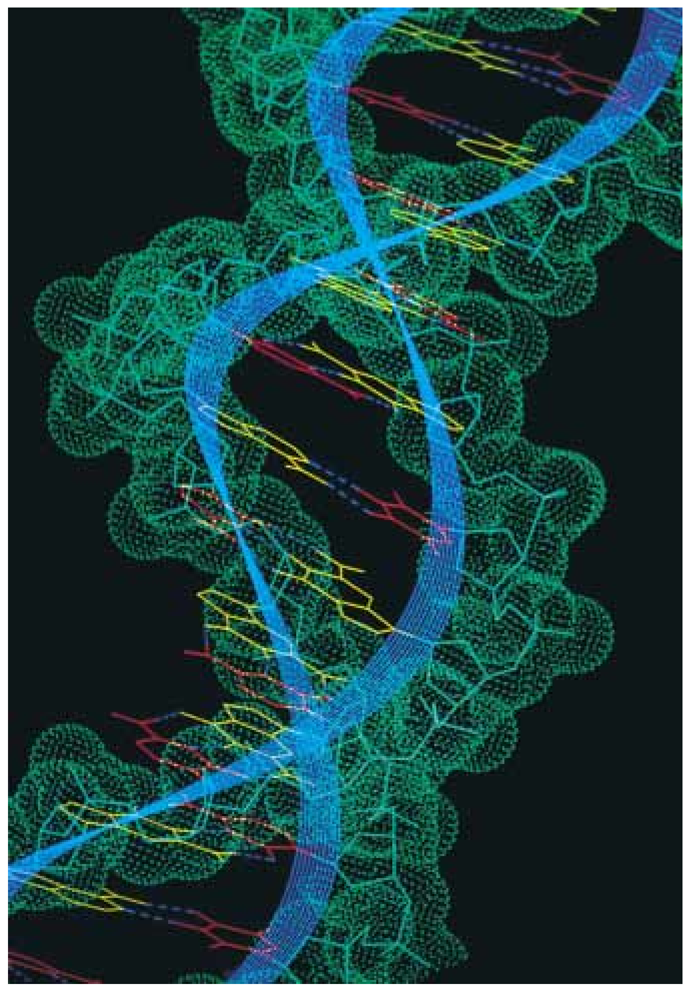


Figure 1–7 **DNA.** An organism's ability to transmit information from one generation to the next is essential to the continuity of life. In all organisms, the hereditary material is DNA. This computer-generated image shows the double-helix configuration of DNA. *(Will and Deni McIntyre/Photo Researchers, Inc.)*

Information is transmitted by chemical and electrical signals

Genes control the development and functioning of every organism. DNA contains the "recipes" for making all of the **proteins** needed by the organism. Proteins are very large molecules that are important in determining structure and function of cells and tissues. Brain cells are different from muscle cells, in large part because they have different types of proteins. Some proteins are important in communication within and among cells. Certain proteins on the surface of a cell serve as markers so that other cells "recognize" them. Other cell surface proteins serve as receptors that combine with chemical messengers.

Cells use proteins and many other types of ions and molecules to communicate with one another. In a multicellular organism chemical compounds secreted by cells help regulate growth, development, and metabolic processes in other cells. The mechanisms involved in **cell signaling** are complex, often involving multistep biochemical sequences, and cell signaling is currently an area of intense research. A major focus has been the transfer of information among cells of the immune system. A better understanding of how cells communicate promises new insights into how the body protects itself against disease organisms. Learning to manipulate cell signaling may lead to new methods of delivering drugs into cells and new treatments for cancer and other diseases. Examples of cell signaling will be discussed throughout this book.

Hormones are molecules that function as chemical messengers that transmit information from one part of an organism to another. A hormone can signal cells to produce or secrete a certain protein or other substance.

Many organisms use electrical signals to transmit information. Most animals have nervous systems that transmit information by way of both electrical impulses and chemical compounds known as **neurotransmitters.** Information transmitted from one part of the body to another is important in regulating life processes. In complex animals, the nervous system transmits signals from sensory receptors like the eyes and ears to the brain, giving the animal information about its outside environment.

Information must also be transmitted from one organism to another. Mechanisms for this type of communication include release of chemicals, visual displays, and sounds.

EVOLUTION IS THE PRIMARY UNIFYING CONCEPT OF BIOLOGY

The theory of **evolution,** which explains how populations of organisms have changed over time, has become the greatest unifying concept of biology. Some element of an evolutionary perspective is present in every specialized field within biology. Biologists try to understand the structure, function, and behavior of organisms and their interactions with one another by considering them in light of the long, continuing process of evolution. Although evolution is discussed in depth in Chapters 17 through 21, we present a brief overview here to give you the background necessary to understand other aspects of biology.

Species adapt in response to changes in their environment

Every organism is the product of complex interactions between environmental conditions and the genes of its ancestors. If every organism of a species[1] were exactly like every other, any change in the environment might be disastrous to all, and the species would become extinct. Adaptation to changes in the environment involves changes in populations rather than in individual organisms. Such adaptations are the result of evolutionary processes that occur over time and involve many generations.

Natural selection is an important mechanism by which evolution proceeds

Although the concept of evolution had been discussed by philosophers and naturalists through the ages, Charles Darwin and Alfred Wallace first brought the theory of evolution to general attention and suggested a plausible mechanism, **natural selection,** to explain it. In his book *On the Origin of Species by Means of Natural Selection,* published in 1859, Darwin synthesized many new findings in geology and biology. He presented a wealth of evidence that the present forms of life on Earth descended, with modifications, from previously existing forms. Darwin's book raised a storm of controversy in both religion and science, some of which still lingers.

Darwin's theory of evolution has helped shape the biological sciences to the present day. His work generated a great wave of scientific observation and research that has provided much additional evidence that evolution is responsible for the great diversity of organisms present on our planet. Even today, the details of the process of evolution are a major focus of investigation and debate.

Darwin based his theory of natural selection on the following four observations: (1) Individual members of a species show some variation from one another. (2) Organisms produce many more offspring than will survive to reproduce (Fig. 1–8). (3) Organisms compete for necessary resources like food, sunlight, and space. Individuals who happen to have characteristics that give them some advantage are more likely to survive. (4) The survivors live to reproduce and pass their adaptations for survival on to their offspring. Thus, the best adapted individuals of a population leave, on average, more offspring than do other individuals. Because of this differential reproduction, a greater proportion of the population becomes adapted to the prevailing environmental conditions. The environment *selects* the best adapted organisms for survival.

[1]A species is a group of organisms with similar structure, function, and behavior; in nature they breed only with each other. Members of a species have a common gene pool and share a common ancestry.

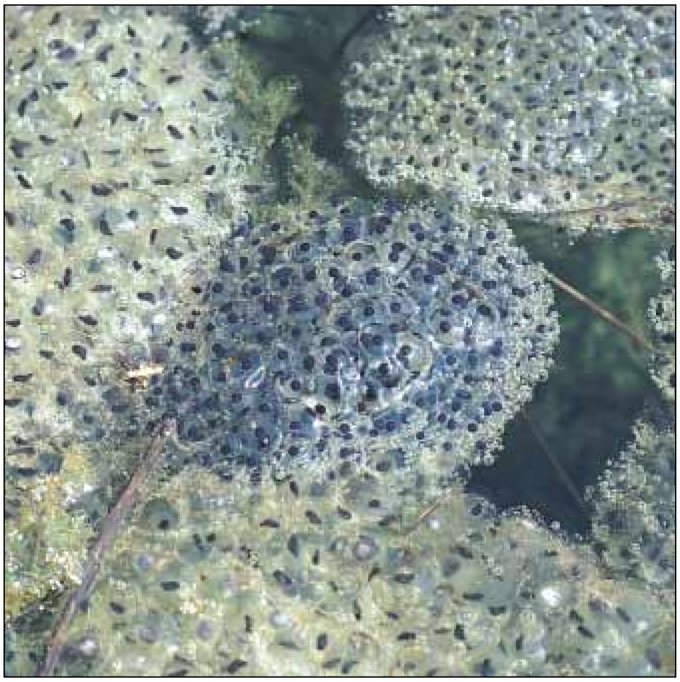


Figure 1–8 **Egg masses of the wood frog *(Rana sylvatica)*.** Many more eggs are produced than can possibly develop into adult frogs. Random events are largely responsible for determining which of these developing frogs will hatch, reach adulthood, and reproduce. However, certain traits possessed by each organism will also contribute to its probability for success in its environment. Not all organisms are as prolific as the frog, but the generalization that more organisms are produced than survive is true throughout the living world. *(J. Serrao/Photo Researchers, Inc.)*

Darwin did not know about DNA or understand the mechanisms of inheritance. We now understand that the variations among organisms are a result of different varieties of genes that code for each characteristic. The ultimate source of these variations is random **mutations,** chemical changes in DNA that persist and can be inherited. Mutations modify genes; by this process they provide the raw material for evolution.

Populations evolve as a result of selective pressures from changes in the environment

All the genes present in a population make up its gene pool. By virtue of its gene pool, a population is a reservoir of variation. Natural selection acts on individuals within a population. Selection favors individuals with genes that specify traits that enable them to cope effectively with pressures exerted by the environment. These organisms are most likely to survive and produce offspring. As these successful organisms pass on their genetic recipe for survival, their traits become more widely distributed in the population. Over time, as organisms continue to change (and as the environment itself changes, bringing different selective pressures), the members of the population become better adapted to their environment and less like their ancestors.

An interesting case of evolution in action has been documented in England since 1850. The tree trunks in a certain region of England were once white because of a type of lichen that grew on them. (A lichen is a compound organism usually consisting of an alga and fungus.) The common peppered moth was beautifully adapted for resting on these white tree trunks because its light color blended with the trunks and protected it from predatory birds (Fig. 1–9). At that time black peppered moths were rare.

Figure 1–9 **Evolution in action.** Both a dark and a light peppered moth can be seen on the tree trunk. Which is most likely to become food for the bird? Note that the tree trunk is light in color because it is covered by lichens. *(John D. Cunningham/Visuals Unlimited)*

Then humans changed the environment. They built industries that polluted the air with soot, killing the lichens and coloring the tree trunks black. The light-colored moths became easy prey to the birds. The black moths blended with the dark trunks and escaped the sharp eyes of predators. In these new surroundings, the dark moths were better adapted and were selected for survival. Eventually, more than 90% of the peppered moths in the industrial areas of England were dark. This adaptation is known as *industrial melanism.* Interestingly, with efforts to control air pollution, there has been an increase in the population of the light-colored moths.

Adaptation of the peppered moth was studied in the 1950s by H. B. D. Kettlewell of Oxford, who marked hundreds of male moths with a spot of paint under their wings and then released them in both rural and industrial areas. Observers reported that birds preyed on the moths that were more visible. After a period of time, surviving moths were recaptured by attracting them with light or females. Based on observation and on the percentage of each type of moth recaptured, these studies confirmed that significantly more dark moths survived in industrial areas and more light moths survived in rural areas.

BIOLOGICAL ORGANIZATION IS HIERARCHICAL

Whether we study a single complex organism or the world of life as a whole, we can identify a hierarchy of biological organization (Fig. 1–10). At every level, structure and function are precisely coordinated. One way to study a particular level is by looking at its components. For example, biologists can learn about cells by studying atoms and molecules. Learning about a structure by studying its parts is known as **reductionism.** However, the whole is more than the sum of its parts. Each level has **emergent properties,** characteristics not found at lower levels. For example, populations have emergent properties such as density, age structure, and birth and death rates. The individuals that make up a population lack these characteristics.

Organisms have several levels of organization

The **chemical level,** the most basic level of organization, includes atoms and molecules. An **atom** is the smallest unit of a chemical element (fundamental substance) that retains the characteristic properties of that element. For example, an atom of iron is the smallest possible amount of iron. Atoms combine chemically to form **molecules.** Two atoms of hydrogen combine with one atom of oxygen to form a single molecule of water. Although composed of two types of atoms that are gases, water is a liquid with very different properties, an example of emergent properties.

At the **cellular level** many different types of atoms and molecules associate with one another to form cells. However, a cell is much more than a heap of atoms and molecules. Its emergent properties make it the basic structural and functional unit of life, the simplest component of living matter that can carry on all of the activities necessary for life. Every cell is surrounded by a **plasma membrane** that regulates the passage of materials between the cell and its surrounding environment. All cells have specialized molecules that contain genetic instructions. Cells typically have internal structures called **organelles** that are specialized to perform specific functions.

Two fundamentally different types of cells are known. Bacteria have **prokaryotic cells.** All other organisms are characterized by their **eukaryotic cells.** Unlike the structurally simpler prokaryotic cells, eukaryotic cells typically contain a variety of membrane-bounded organelles, including a **nucleus** which houses DNA.

During the evolution of multicellular organisms, cells associated to form **tissues.** For example most animals have muscle tissue and nervous tissue, and plants have epidermis (a tissue that serves as a protective covering). In most complex organisms, tissues organize into functional structures, called **organs,** such as the heart and stomach in animals and roots and leaves in plants. In animals, each major group of biological functions is performed by a coordinated group of tissues and organs called an **organ system.** The circulatory and digestive systems are examples of organ systems. Functioning together with great precision, organ systems make up a complex multicellular **organism.** Again, emergent properties are evident. An organism is much more than its component organ systems.

Several levels of ecological organization can be identified

Organisms interact to form still more complex levels of biological organization. All of the members of one species that live in the same geographic area at the same time make up a **population.** The populations of organisms that inhabit a particular area and interact with one another form a **community.** A community can consist of hundreds of different types of organisms. As populations within a community evolve, the community changes.

A community together with its nonliving environment is referred to as an **ecosystem.** An ecosystem can be as small as a pond (or even a puddle) or as vast as the Great Plains of North America or the Arctic tundra. All of planet Earth's ecosystems together are known as the **biosphere.** The biosphere includes all of Earth that is inhabited by living organisms—the atmosphere, the hydrosphere (water in any form), and the lithosphere (Earth's crust). The study of how organisms relate to one another and to their physical environment is called **ecology** (derived from the Greek *oikos,* meaning "house").

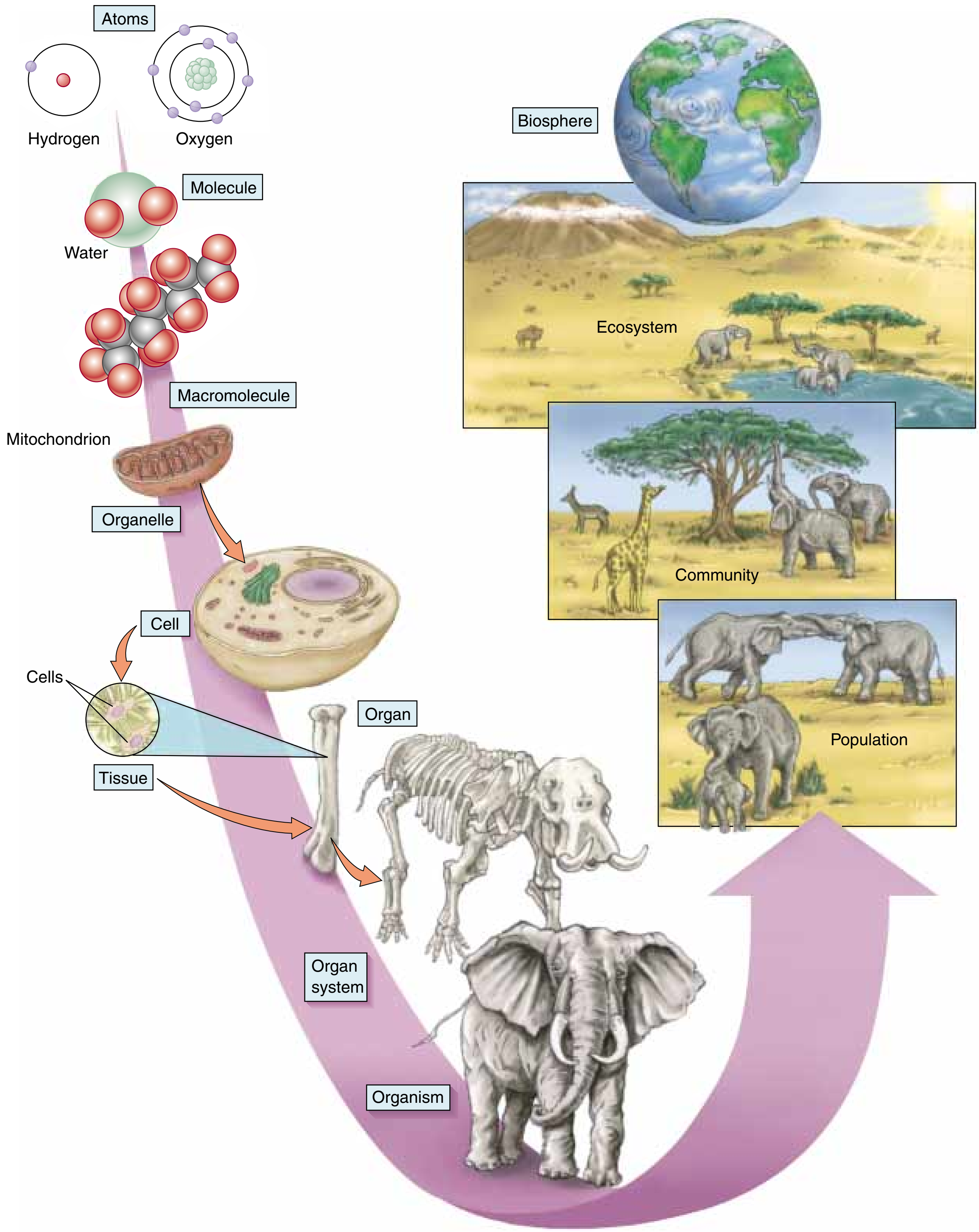


Figure 1–10 **Biological organization.** Atoms join to form molecules of varying size, including very large molecules, or macromolecules. Atoms and molecules form organelles such as the nucleus or mitochondrion (the site of many energy transformations) of the cell. Cells associate to form tissues, such as bone tissue. Tissues form organs, such as bones, which, in turn, make up organ systems. The skeletal system and other organ systems work together to make up the functioning organism. A population is composed of organisms of the same species. The populations of different species that inhabit a particular area make up a community, which together with the nonliving environment, form an ecosystem. Planet Earth and all of its communities make up the biosphere.

TABLE 1–1 Classification of Domestic Cat, Human, and White Oak

Category	Classification of Cat	Classification of Human	Classification of White Oak
Kingdom	Animalia	Animalia	Plantae
Phylum	Chordata	Chordata	Anthophyta
Subphylum	Vertebrata	Vertebrata	None
Class	Mammalia	Mammalia	Dicotyledones
Order	Carnivora	Primates	Fagales
Family	Felidae	Hominidae	Fagaceae
Genus and specific epithet	*Felis catus*	*Homo sapiens*	*Quercus alba*

MILLIONS OF SPECIES HAVE EVOLVED

About 1.75 million species of extant (currently living) organisms have been scientifically identified, and biologists estimate that millions more remain to be discovered. In order to study life, we need a system for organizing, naming, and classifying its myriad forms. That system is part of **taxonomy,** the science of naming and classifying organisms. Biologists who specialize in classification are **taxonomists.**

Biologists use a binomial system for naming organisms

In the 18th century Carolus Linnaeus, a Swedish botanist, developed a hierarchical system of naming and classifying organisms that, with some modification, is still used today. The basic unit of classification is the **species.** Closely related species are grouped together in the next higher level of classification, the **genus** (pl. *genera*).

The Linnaean system of naming species is referred to as the **binomial system of nomenclature** because each species is assigned a two-part name. The first part of the name is the genus, and the second part, the **specific epithet,** designates a particular species belonging to that genus. The specific epithet is often a descriptive word expressing some quality of the organism. It is always used together with the full or abbreviated generic name preceding it. The generic name is always capitalized; the specific epithet is generally not capitalized. Both names are always italicized or underlined. For example, the dog, *Canis familiaris* (abbreviated *C. familiaris*), and the timber wolf, *Canis lupus (C. lupus),* belong to the same genus. The cat, *Felis catus,* belongs to a different genus. The scientific name of the American white oak is *Quercus alba,* whereas the name of the European white oak is *Quercus robur*. Another tree, the white willow, *Salix alba,* belongs to a different genus. The scientific name for our own species is *Homo sapiens* ("wise man").

Taxonomic classification is hierarchical

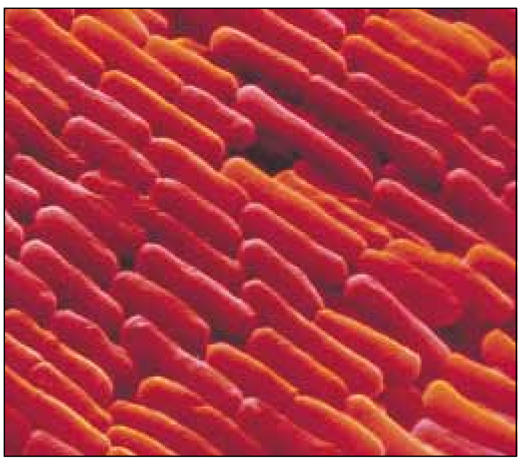
Just as species may be grouped together in a common genus, a number of related genera can be grouped in a more inclusive group, a **family** (Table 1–1). In turn, families may be grouped into **orders,** orders into **classes,** and classes into **phyla.** Note that each group is more inclusive. The family Canidae, which includes all doglike carnivores (animals that eat mainly meat), consists of 12 genera and about 34 living species. Family Canidae, along with family Ursidae (bears), family Felidae (catlike animals), and several other families that eat mainly meat, is placed in order Carnivora. Order Carnivora, order Primates (the order to which humans belong), and several other orders belong to class Mammalia (mammals). Class Mammalia, class Aves (birds), class Reptilia (reptiles), and four other classes are grouped together as subphylum Vertebrata. The vertebrates belong to phylum Chordata, which is part of kingdom Animalia.

Organisms can be assigned to six kingdoms

In the system of classification used in this book, every organism is assigned to one of six **kingdoms:** Archaebacteria, Eubacteria, Protista, Fungi, Plantae, or Animalia (Fig. 1–11). Bacteria are unicellular, and they differ from all other organisms in that they are prokaryotes; their cells lack a discrete nucleus and other membrane-bounded organelles. Among the prokaryotes two very distinct groups have been recognized, so in the

▶ **Figure 1–11** **A survey of the kingdoms of life.** ***(a)*** These bacteria (*Methanosarcina mazei*) members of kingdom Archaebacteria, produce methane. ***(b)*** The large rod-shaped bacterium *Bacillus anthracis,* a member of kingdom Eubacteria, is the causative agent of anthrax, a disease of cattle and sheep that can infect humans. ***(c)*** Unicellar protozoa (*Tetrahymena* sp.) are classified in kingdom Protista. ***(d)*** Mushrooms, such as these fly agaric mushrooms *(Amanita muscaria),* belong to kingdom Fungi. ***(e)*** The plant kingdom claims many beautiful and diverse forms such as the lady's slipper *(Phragmipedium caricinum)*. ***(f)*** Among the fiercest members of the animal kingdom, lions *(Panthero leo)* are also among the most sociable. The largest of the big cats, lions live in prides (groups). *(a, R. Robinson/Visuals Unlimited, b, CNRI/Science Photo Library/Photo Researchers, Inc.; c, David M. Phillips/Visuals Unlimited; d, Ulf Sjostedt/FPG International; e, John Arnaldi; f, McMurray Photography.)*

(*a*) 5 μm



(*b*) 1 μm

(*c*) 10 μm

(*d*)

(*e*)

(*f*)

six-kingdom system, bacteria are assigned to two kingdoms, **Archaebacteria** and **Eubacteria.** Kingdom **Protista** consists of protozoa, algae, water molds, and slime molds. These are single-celled or simple multicellular organisms. Some protists are adapted to carry out **photosynthesis,** the process in which light energy is converted to the chemical energy of food molecules.

Kingdom **Fungi** is composed of the yeasts, mildews, molds, and mushrooms. These organisms do not photosynthesize. They obtain their nutrients by secreting digestive enzymes into food and then absorbing the predigested food.

Members of kingdom **Plantae** are complex multicellular organisms adapted to carry out photosynthesis. Among characteristic plant features are the *cuticle* (a waxy covering over aerial parts that reduces water loss), *stomata* (tiny openings in stems and leaves for gas exchange), and multicellular *gametangia* (organs that protect developing reproductive cells). Kingdom Plantae includes both nonvascular plants (mosses) and vascular plants (ferns, conifers, and flowering plants).

Kingdom **Animalia** is made up of multicellular organisms that must eat other organisms for nourishment. Complex animals have high degrees of tissue specialization and body organization; these have evolved along with motility, complex sense organs, nervous systems, and muscular systems.

A more detailed presentation of the kingdoms can be found in Chapters 22 through 30, and classification is summarized in Appendix C. We refer to these groups repeatedly throughout this book as we consider the many kinds of challenges faced by living organisms and the various adaptations that have evolved in response to these challenges.

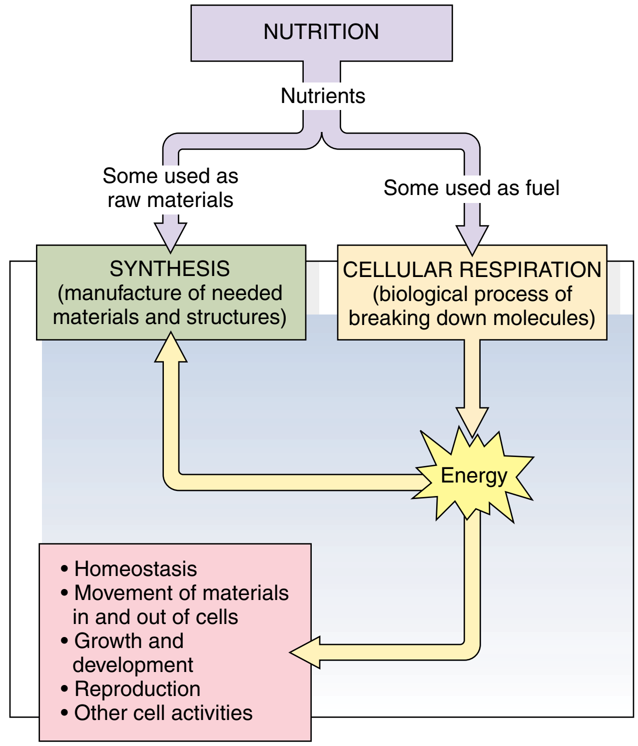


Figure 1–12 Relationships of metabolic processes. These processes occur continuously in every living organism. Some of the nutrients in food are used to synthesize needed materials and cell parts. Other nutrients are used as fuel for cellular respiration, a process that releases energy stored in food. This energy is needed for synthesis and for other forms of cellular work.

LIFE DEPENDS ON CONTINUOUS INPUT OF ENERGY

A continuous input of energy from the Sun enables life to exist. Every activity of a living cell or organism requires energy. Whenever energy is used to perform biological work, some is converted to heat and dispersed into the environment.

Energy flows through cells and organisms

Recall that all of the energy transformations and chemical processes that occur within an organism are referred to as metabolism. Energy is necessary in order to carry on the metabolic activities essential for growth, repair, and maintenance. Each cell of an organism requires nutrients. Some nutrients are used as fuel for **cellular respiration,** a process during which some of the energy stored in the nutrient molecules is released for use by the cells (Fig. 1–12). This energy can be used for cellular work or for synthesis of needed materials such as new cellular components.

Energy flows through ecosystems

Like individual organisms, ecosystems depend on a continuous input of energy. A self-sufficient ecosystem contains three types of organisms—producers, consumers, and decomposers—and has a physical environment appropriate for their survival. These organisms depend on each other and on the environment for nutrients, energy, oxygen, and carbon dioxide. However, there is a one-way flow of energy through ecosystems. Organisms can neither create energy nor use it with complete efficiency. During every energy transaction, some energy is lost to biological systems as it is dispersed into the environment as heat (Fig. 1–13).

Producers manufacture their own food

Producers, or **autotrophs,** are plants, algae, and certain bacteria that can produce their own food from simple raw materials. Most of these organisms use sunlight as an energy source and carry out photosynthesis, in which complex molecules are synthesized from carbon dioxide and water. The light energy is transformed into chemical energy, which is stored within the chemical bonds of the food molecules produced. Oxygen, which is required not only by plant cells but also by the cells

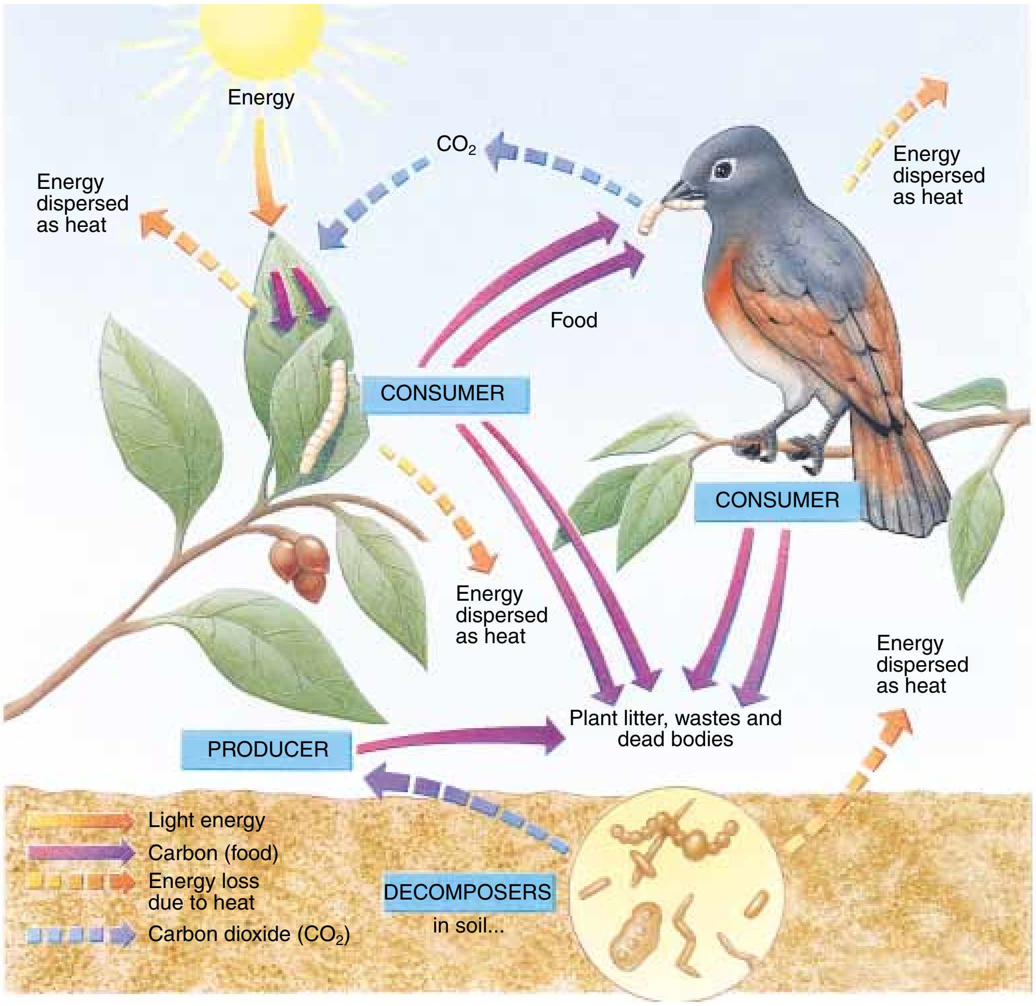


Figure 1–13 **Energy flow.** Continuous energy input from the Sun operates the biosphere. During photosynthesis, producers use the energy from sunlight to make complex molecules from carbon dioxide and water. Consumers obtain energy, carbon, and other needed materials when they eat producers. Wastes and dead organic material supply decomposers with energy and carbon. During every energy transaction some energy is lost to biological systems as it is dispersed as heat.

of most other organisms, is produced as a byproduct of photosynthesis:

Carbon dioxide + Water + Energy ⟶ Sugars (food) + Oxygen

Consumers obtain energy by eating producers

Animals are **consumers,** or **heterotrophs,** organisms that depend on producers for food, energy, and oxygen. Consumers obtain energy by breaking down sugars and other food molecules originally produced during photosynthesis. Recall that the biological process of breaking down sugars and other fuel molecules is known as cellular respiration. When chemical bonds are broken during cellular respiration, their stored energy is made available for life processes.

Sugars (and other fuel molecules) + Oxygen ⟶ Carbon dioxide + Water + Energy

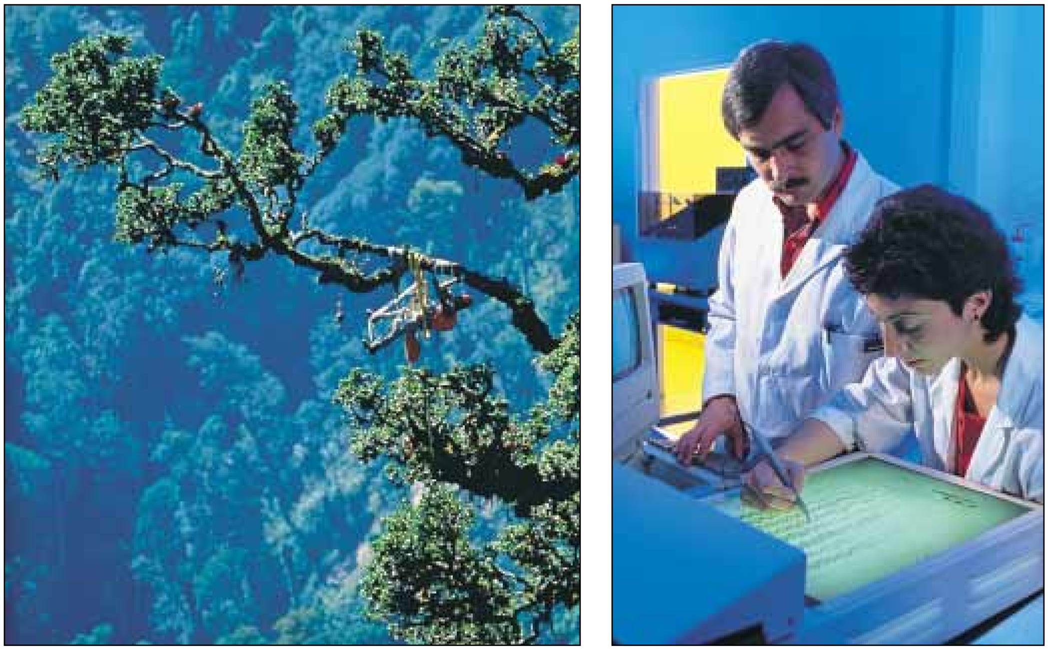
Consumers contribute to the balance of the ecosystem. For example, consumers produce carbon dioxide needed by producers. The metabolism of consumers and producers helps maintain the life-sustaining mixture of gases in the atmosphere.

Decomposers obtain energy from wastes and dead organisms

Bacteria and fungi are **decomposers,** heterotrophs that obtain nutrients by breaking down wastes, dead leaves, and the bodies of dead organisms. In their process of obtaining energy, decomposers make the components of wastes and dead organisms available for reuse. If decomposers did not exist, nutrients would remain locked up in dead bodies, and the supply of elements required by living systems would soon be exhausted.

BIOLOGY IS STUDIED USING THE SCIENTIFIC METHOD

This book is a starting point for your exploration of biology. It will provide you with tools to become a part of this fascinating science and a more informed inhabitant of our planet. Biologists work both in laboratories and out in the field (Fig. 1–14). Their investigations range from the study of molecu-



(*a*) (*b*)

Figure 1–14 Biologists at work. *(a)* This biologist studying the rainforest canopy in Costa Rica is part of an international effort to study and preserve tropical rain forests. Researchers study the interactions of organisms and the effects of human activities on the rain forests. *(b)* These researchers, working on developing an AIDS vaccine, are examining a DNA sequencing autoradiogram over a light box. *(a, Mark Moffett/Minden Pictures; b, Hank Morgan/Photo Researchers, Inc.)*

lar biology and viruses to the interactions of the communities of our biosphere. Perhaps you will decide to become a research biologist and help unravel the complexities of the human brain; discover new hormones that cause plants to flower; identify new species of animals or bacteria; or develop new treatments for diseases such as cancer, AIDS, or heart disease. Or perhaps you will choose to enter an applied field of biology such as forestry, dentistry, medicine, or veterinary medicine.

Biology is a **science.** The word *science* comes from a Latin word meaning "to know." Science is a way of thinking and a method of investigating the world around us in a systematic manner. Science enables us to uncover ever more about the world we live in and leads us to an expanded appreciation of our universe.

The **process of science** is investigative, dynamic, and often controversial. It changes over time as it is influenced by cultural, social, and historical contexts as well as by the personalities of scientists themselves. The observations made, the range of questions posed, and the design of experiments depend on the creativity of the individual scientist. In contrast, the **scientific method** involves a series of ordered steps and is a framework used by most scientists.

Using the scientific method, scientists make careful observations, ask critical questions, develop **hypotheses** (testable statements), make predictions that can be tested, and perform experiments to test their predictions (Fig. 1–15). They interpret the results of their experiments and draw conclusions from them. Even results that do not support the hypothesis may be valuable and may lead to new hypotheses. If the results support a hypothesis, a scientist may use them to generate related hypotheses.

Science is systematic. Scientists organize, and often quantify, knowledge, making it readily accessible to all who wish to build on its foundation. In this way science is both a personal and a social endeavor. Science is not mysterious. Anyone who understands its rules and procedures can take on its challenges. What distinguishes science is its insistence on rigorous methods to examine a problem. Science seeks to give us precise knowledge about those aspects of the world that are accessible to its methods of inquiry. It is not a replacement for philosophy, religion, or art. Being a scientist does not prevent one from participating in other fields of human endeavor, just as being an artist does not prevent one from practicing science.

Science requires systematic thought processes

Two types of systematic thought processes used by scientists are deduction and induction. With **deductive reasoning,** we begin with supplied information, called *premises,* and draw conclusions on the basis of that information. Deduction proceeds from general principles to specific conclusions. For example, if we accept the premise that all birds have wings, and the second premise that sparrows are birds, we can conclude deductively that sparrows have wings (Fig. 1–16). Deduction helps us discover relationships among known facts. The **hypothetico-deductive approach** emphasizes the use of deductive reasoning to test hypotheses.

Scientists also use a **hypothetico-inductive approach** that focuses on discovering new general principles. **Inductive reasoning** is the opposite of deduction. We begin with specific observations and draw a conclusion or discover a general prin-

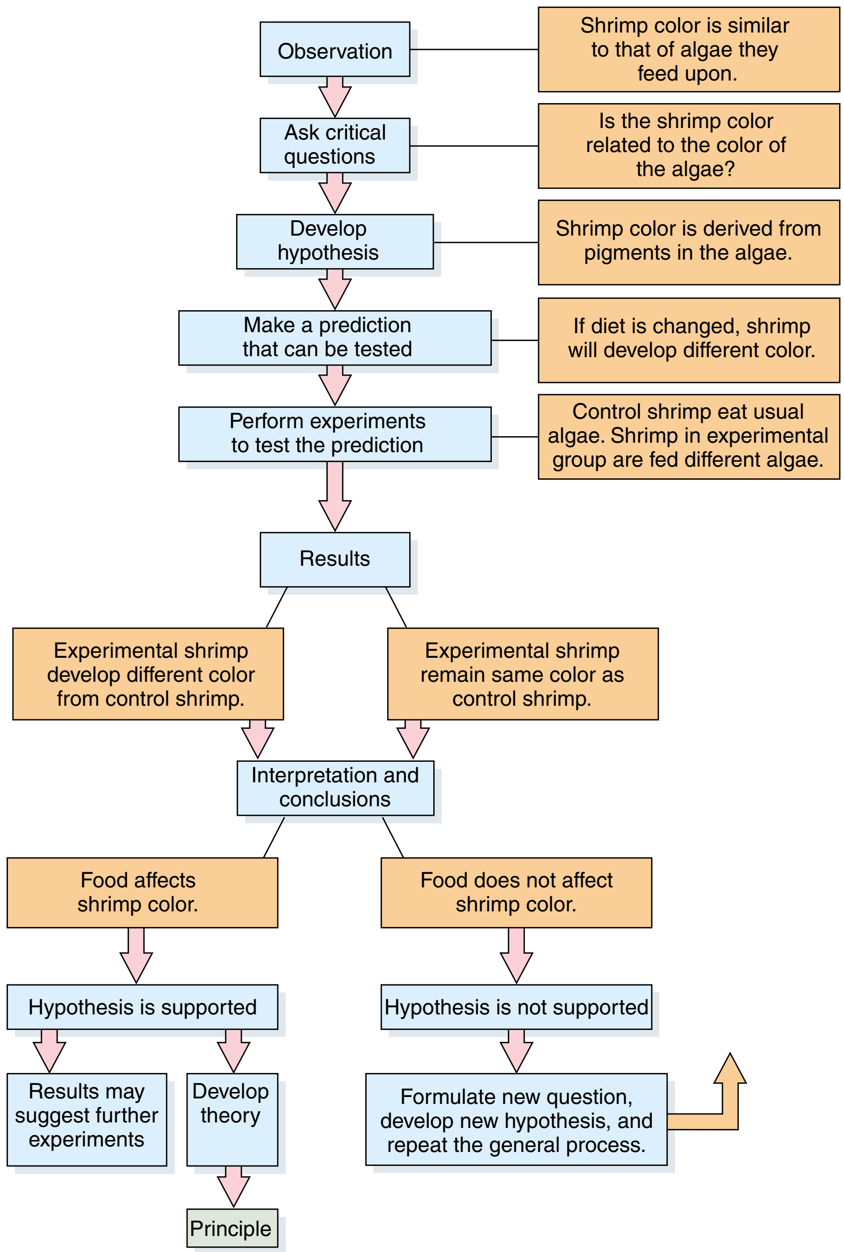


Figure 1–15 **The scientific method.** Scientists use the scientific method as a framework for their research.

ciple. For example, if we know that sparrows have wings and are birds, and we know that robins, eagles, pigeons, and hawks have wings and are birds, we might induce that all birds have wings. In this way, the inductive method can be used to organize raw data into manageable categories by answering the question, What do all these facts have in common?

A weakness of inductive reasoning is that conclusions generalize the facts to all possible examples. We go from many observed examples to all possible examples when we formulate the general principle. This is known as the **inductive leap.** Without it, we could not arrive at generalizations. However, we must be sensitive to exceptions and to the possibility that the conclusion is not valid. For example, the kiwi bird of New Zealand does not have functional wings! The generalizations that inductive conclusions contain come from the creative insight of the human mind, and creativity, however admirable, is not infallible.

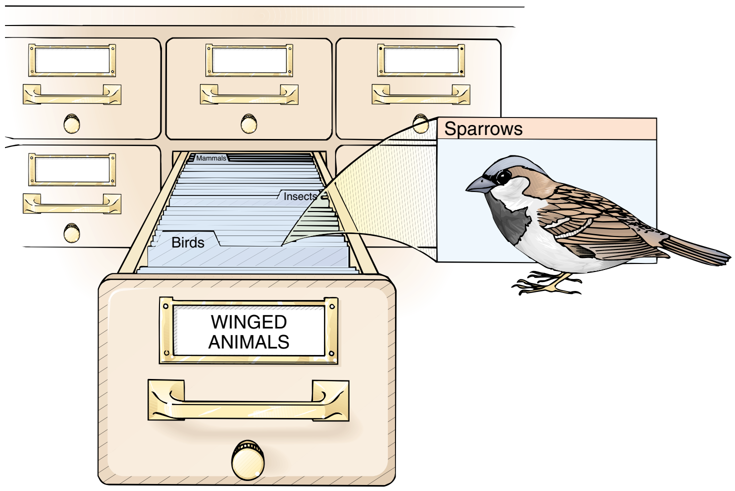


Figure 1–16 **All birds have wings.** A diagrammatic example of a syllogism, the classic form of deductive reasoning.

Scientists make careful observations and ask critical questions

Significant discoveries are usually made by those who are in the habit of looking critically at nature. Chance and luck are often involved in recognizing a phenomenon or problem. In 1928 the British bacteriologist Alexander Fleming observed that one of his bacterial cultures had become invaded by a blue mold. He almost discarded it, but before he did, he noticed that the area contaminated by the mold was surrounded by a zone where bacterial colonies did not grow well.

The bacteria were disease organisms of the genus *Staphylococcus,* which can cause boils and skin infections. Anything that could kill them was interesting! Fleming saved the mold, a variety of *Penicillium* (blue bread mold). It was subsequently discovered that the mold produced a substance that slowed reproduction of the bacterial population but was usually harmless to laboratory animals and humans. The substance was penicillin, one of the first antibiotics.

We may wonder how many times the same type of mold grew on the cultures of other bacteriologists who failed to make the connection and simply threw away their contaminated cultures. Fleming benefited from chance, but his mind was prepared to make observations and formulate critical questions, and his pen was prepared to publish them. It was left to others, however, to develop the practical applications. Though Fleming recognized the potential practical benefit of penicillin, he did not vigorously promote it, and more than ten years passed before the drug was put to significant use.

A hypothesis is a testable statement

In the early stages of an investigation, a scientist typically thinks of many possible hypotheses and hopes that the right one is among them. He or she then decides which, if any, could and should be subjected to experimental test. Why not test them all? Time and money are important considerations in conducting research. We must establish priority among the hypotheses in order to decide which to test first. Fortunately, some guidelines do exist. A good hypothesis exhibits the following:

1. It is reasonably consistent with well established facts.
2. It is capable of being tested; that is, it should generate definite predictions, whether the results are positive or negative. Test results should also be repeatable by independent observers.
3. It is falsifiable, which means it can be proved false.

A hypothesis cannot really be proved true, but in theory (though not necessarily in practice) a well stated hypothesis can be proved false. If one believes in an unfalsifiable hypothesis (e.g., the existence of invisible and undetectable angels), it must be on grounds other than scientific ones.

Consider the following hypothesis: All female mammals (animals that have hair and produce milk for their young) bear live young. The hypothesis was based on the observations that dogs, cats, cows, lions, and humans are all mammals and all bear live young. Consider further that a new species, species X, was identified as a mammal. Biologists predicted that females of species X would bear live young. When a female of the new species gave birth to offspring, this supported the hypothesis. Yet it did not really *prove* the hypothesis.

Before the Southern Hemisphere was explored, most individuals would probably have accepted the hypothesis without question, because all known furry, milk-giving animals did, in fact, bear live young. But it was discovered that two Australian animals (the duck-billed platypus and the spiny anteater) had fur, produced milk for their young, but laid eggs (Fig. 1–17). The hypothesis, as stated, was false no matter how

Figure 1–17 **Is this animal a mammal?** The duck-billed platypus is classified as a mammal because it has fur and produces milk for its young. However, unlike most mammals, it lays eggs. *(Tom McHugh/Photo Researchers, Inc.)*

many times it had previously been supported. As a result, biologists either had to consider the platypus and the spiny anteater as nonmammals, or to broaden their definition of mammals to include them (they chose the latter).

A hypothesis is not true just because some of its predictions (the ones we happen to have thought of or have thus far been able to test) have been shown to be true. After all, they could be true by coincidence. Failure to observe a predicted outcome does not make a hypothesis false, but it does not show that the hypothesis is true, either.

A prediction is a logical consequence of a hypothesis

A hypothesis is an abstract idea, so there is no way to test it directly. But hypotheses suggest certain logical consequences, that is, observable things that cannot be false if the hypothesis is true. On the other hand, if the hypothesis is, in fact, false, other definite predictions should disclose that. As used here, then, a **prediction** is a deductive, logical consequence of a hypothesis. It does not have to be a future event.

Predictions can be tested by experiment

A prediction can be tested by controlled experiments. Early biologists observed that the nucleus was the most prominent part of the cell, and they hypothesized that it might be essential for the well-being of the cell. They predicted that if the nucleus were removed from the cell, the cell would die. Experiments were performed in which the nucleus of a single-celled amoeba was removed surgically with a micro-loop. After this surgery, the amoeba continued to live and move but it did not grow, and after a few days it died. These results suggested that the nucleus is necessary for the metabolic processes that provide for growth and cell reproduction (Fig. 1–18).

But, the investigators asked, what if the operation itself and not the loss of the nucleus caused the amoeba to die? They performed a *controlled* experiment in which two groups of amoebas were subjected to the same operative trauma. However, in the **experimental group** the nucleus was removed, whereas in the **control group** it was not. An experimental group ideally differs from a control group only with respect to the variable being studied. In the control group, a micro-loop was inserted into each amoeba and pushed around inside the cell to simulate the removal of the nucleus; then the needle was withdrawn, leaving the nucleus inside. Amoebas treated with such a sham operation recovered and subsequently grew and divided, but the amoebas without nuclei died. This experiment provided data that it was the removal of the nucleus and not simply the operation that caused the death of the amoebas. The data supported the hypothesis that the nucleus is essential for the well-being of the cell.

Let us consider another example of a scientific study. Steven N. Blair and his colleagues reported in 1996 in the *Journal of the American Medical Association* the results of their study of the relationship between cardiac fitness and cardiovascular disease. The subjects were more than 25,000 men and 7,000 women, ages 20 to 88 years, who had completed a preventive medical examination. The investigators used treadmill time to group participants into fitness categories and then followed these subjects over several years. Outcome measures were cardiovascular disease and mortality from all causes. The investigators reported that low fitness and cigarette smoking were significant predictors of mortality in men and women. Moderately fit men and women had a significantly lower death rate compared to those in the low-fitness group.

In scientific studies, care must be taken to avoid **bias.** For example, to prevent bias, most medical experiments today are carried out in **double-blind** fashion. When a drug is being tested, one group of patients is given the new medication, while a second similar group of patients is given a placebo, a harmless starch pill similar in size, shape, color, and taste to the pill being tested. This is a double-blind study because neither the patient nor the physician knows who is getting the experimental drug and who is getting the placebo. The pills or treatments are coded in some way, and only after the experiment

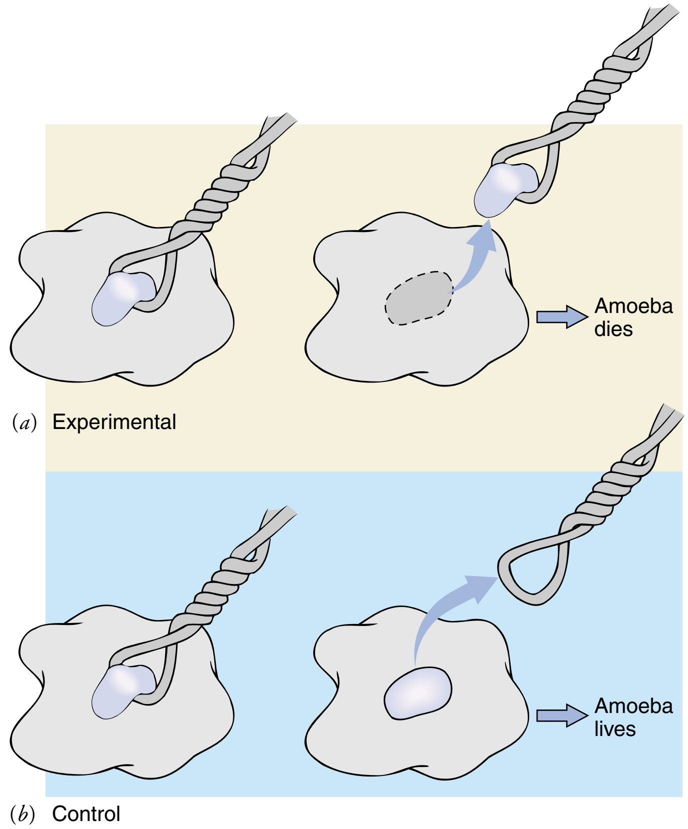


Figure 1–18 **Testing a prediction.** A controlled experiment tested the prediction that if the nucleus is removed from a cell, the cell would die. The data gathered from this and similar experiments provided support for the hypothesis that the nucleus is essential for the well-being of the cell. ***(a)*** When its nucleus is surgically removed with a micro-loop, the amoeba dies. ***(b)*** Control amoebas subjected to similar surgical procedures (including insertion of a micro-loop), but without actual removal of the nucleus, do not die.

is over and the results are recorded is the code broken. Not all experiments can be so neatly designed; for one thing, it is often difficult to establish appropriate controls.

Scientists interpret the results of experiments and make conclusions

Scientists gather data in an experiment, interpret their results, and then formulate conclusions. For example, in the amoeba experiment described above, investigators concluded that the nucleus was essential for the well-being of the cell. One reason for inaccurate conclusions is **sampling error.** Since *all* cases of what is being studied cannot be observed or tested (scientists cannot study every amoeba), we must be content with a sample, or subset, of them. Yet how can we know whether that sample is truly representative of whatever we are studying? In the first place, if the sample is too small, it may be different due to random factors. A study with only two, or even ten, amoebas might not yield reliable data that could be generalized to other amoebas. This problem can usually be solved by using large numbers of subjects and applying the mathematics of statistical analysis (Fig. 1–19).

We must also ensure that the sample is typical of the group that we intend to study. Scientists use statistical techniques to ensure that there is no consistent bias in the way that experimental samples are chosen.

Even if a conclusion is based on results from a carefully designed experiment, it is still possible that new observations or results from other experiments can challenge the conclusion. If we test a large number of cases, we are more likely to draw accurate scientific conclusions. The scientist seeks to state with confidence that any specific conclusion has a certain statistical probability of being correct.

Experiments must also be replicated. Approximately one year after Wilmut (see Chapter Opener) reported that he had cloned a lamb from adult DNA, some biologists challenged his work. Wilmut's critics were concerned that he had not repeated his experiment and that his results had not yet been replicated by other biologists. They pointed out that Wilmut himself reported that his cloning efforts had been successful only once out of about 400 attempts. Before scientists fully accept the experimental results, the study must be repeated in at least one other laboratory.

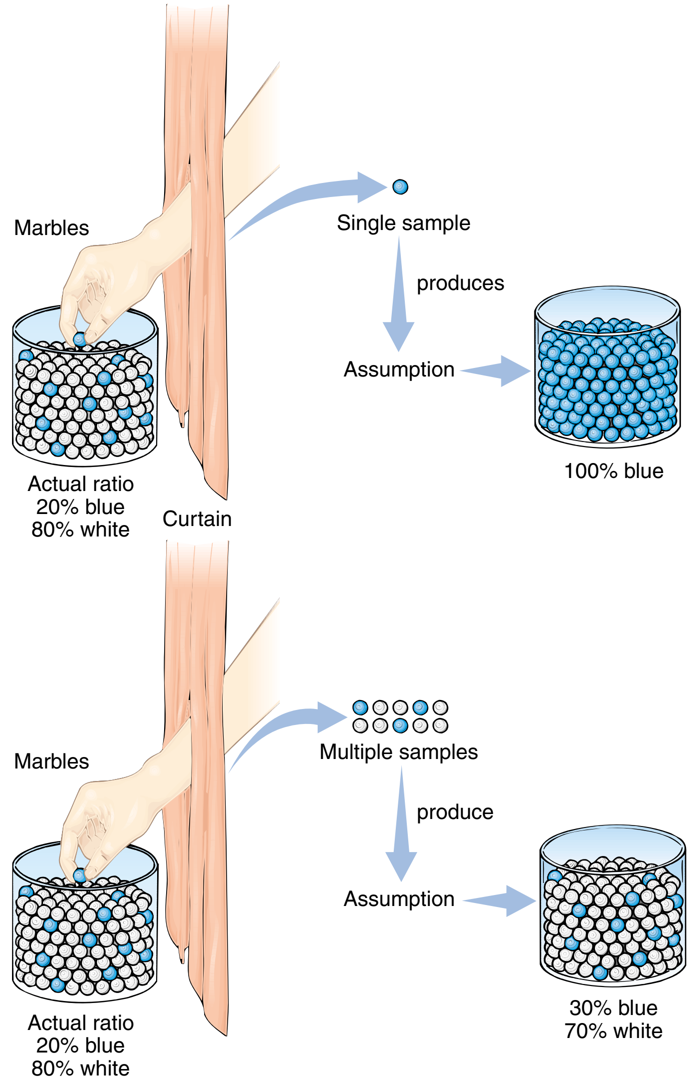


Figure 1–19 **Statistical probability.** Taking a single sample can result in sampling error. The greater the number of samples we take of an unknown, the more likely we can make valid assumptions about it.

A well-supported hypothesis may lead to a theory

Nonscientists often use the word *theory* incorrectly to refer to a hypothesis. A **theory** can be developed only when a hypothesis has been supported by consistent results from many observations or experiments. A good theory relates facts that previously appeared to be unrelated. A good theory grows, building on additional facts as they become known. It predicts new facts and suggests new relationships among phenomena. It may even suggest practical applications.

A good theory, by showing the relationships among classes of facts, simplifies and clarifies our understanding of natural phenomena. As Einstein wrote, "In the whole history of science from Greek philosophy to modern physics, there have been constant attempts to reduce the apparent complexity of natural phenomena to simple, fundamental ideas and relations."

A theory that, over a long period of time, has yielded true predictions and is thus almost universally accepted is referred to as a scientific **principle.** The term **law** is sometimes used for a principle judged to be of great basic importance, such as the law of gravity.

Science has ethical dimensions

Researchers who publish their work in scientific journals describe their experiments in sufficient detail to be independently performed by others. This permits objective observers to detect errors or bias in the original study and helps to guard against the occasional odd result caused by random or uncontrolled factors, as well as those tainted by dishonesty on the part of the original researcher.

Scientific investigation depends on commitment to such practical ideals as truthfulness and the obligation to communicate results. Honesty is particularly important in science. Consider the great (though temporary) damage done whenever an unprincipled or even desperate researcher, whose career might depend on publication of a research study, knowingly disseminates false data. Until the deception is uncovered, researchers might devote many thousands of dollars or hours of precious professional labor to futile lines of research inspired by erroneous reports.

Fortunately, science tends to be self-correcting through the consistent use of the scientific process itself. Sooner or later, someone's experimental results are bound to cast doubt on false data.

Scientists face many important ethical issues surrounding such issues as cloning, research on human embryos, human and animal experimentation, and applications of genetic engineering. Many of these concerns will be discussed in this book.

SUMMARY WITH KEY TERMS

I. **Biology** is the study of life. Basic themes of biology include the evolution of life, the transmission of information, and the flow of energy through organisms.

II. A living organism is able to grow and develop, carry on self-regulated metabolism, move, respond to stimuli, and reproduce. In addition, species evolve and adapt to their environment.
   - A. All living organisms are composed of one or more **cells.**
   - B. Organisms grow by increasing the size and number of their cells.
   - C. **Metabolism** refers to all the chemical activities that take place in the organism, including the chemical reactions essential to nutrition, growth and repair, and the conversion of energy to usable forms. **Homeostasis** is the tendency of organisms to maintain a constant internal environment.
   - D. Movement, although not necessarily locomotion, is characteristic of living organisms. Some organisms use tiny extensions of the cell called **cilia,** or longer **flagella,** to move from place to place. Other organisms are **sessile** and remain rooted to some surface.
   - E. Organisms respond to **stimuli,** physical or chemical changes in their external or internal environment.
   - F. In **asexual reproduction** offspring are typically identical to the single parent; in **sexual reproduction** offspring are typically the product of genes contributed by two parents.
   - G. Populations evolve and become adapted to their environment. **Adaptations** are traits that increase an organism's ability to survive in its environment.

III. Organisms transmit information chemically, electrically, and behaviorally.
   - A. DNA, which makes up the **genes,** contains the instructions for the development of an organism and for carrying out life processes.
     1. Information encoded in **DNA** is transmitted from one generation to the next.
     2. DNA codes for **proteins,** which are important in determining the structure and function of cells and tissues.
   - B. **Hormones** are chemical messengers that transmit messages from one part of an organism to another.
   - C. Many organisms use electrical signals to transmit information; most animals have nervous systems that transmit electrical impulses and release **neurotransmitters.**

IV. **Evolution** is the process by which populations of organisms change over time in response to changes in the environment.
   - A. **Natural selection,** the mechanism by which evolution proceeds, favors organisms with traits that enable them to cope with environmental changes. These organisms are most likely to survive and to produce offspring.
   - B. Charles Darwin based his theory of natural selection on his observations that individuals of a species vary; organisms produce more offspring than survive to reproduce; individuals that are best adapted to their environment are more likely to survive and reproduce; as successful organisms pass on their genes, their traits become more widely distributed in the population.
   - C. The source of variation in a population is random **mutation.**

V. Biological organization is hierarchical.
   - A. A complex **organism** is organized at the **chemical, cellular, tissue, organ,** and **organ system levels.**
   - B. The basic unit of ecological organization is the **population.** Various populations form **communities;** a community and its physical environment are referred to as an **ecosystem;** all of our planet's communities and ecosystems together make up the **biosphere.**

VI. Millions of species have evolved on our planet.
   - A. Taxonomic classification is hierarchical; it includes **species, genus, family, order, class, phylum,** and **kingdom.**
   - B. Biologists use a **binomial system of nomenclature** in which the name of each species includes a genus name and a **specific epithet.**
   - C. Bacteria have **prokaryotic cells;** all other organisms have **eukaryotic cells.**
   - D. Organisms can be classified into six kingdoms: **Archaebacteria, Eubacteria, Protista** (protozoa, algae, water molds, and slime molds), **Fungi** (molds and yeasts), **Plantae,** and **Animalia.**

VII. Life depends on continuous energy input from the Sun. Activities of living cells require energy.
   - A. During **photosynthesis** plants and many other types of producers use the energy of sunlight to synthesize complex molecules from carbon dioxide and water.
   - B. During **cellular respiration,** cells capture the energy stored in nutrients by producers. Some of that energy is then used to synthesize needed materials or to carry on other cell activities.
   - C. A self-sufficient ecosystem includes **producers,** or **autotrophs,** that make their own food, **consumers** that eat producers or organisms that have eaten producers, and **decomposers** that obtain energy by breaking down wastes and dead organisms. Consumers and decomposers are **heterotrophs,** organisms that depend on producers as an energy source and for food and oxygen.

VIII. The **process of science** is a dynamic approach to investigation. The **scientific method** is a framework that scientists use in their work; it includes observing, recognizing a problem or stating a critical question, developing a hypothesis, making a prediction that can be tested, performing experiments, interpreting results, and drawing conclusions that support or falsify the hypothesis.

A. **Deductive reasoning** and **inductive reasoning** are two categories of systematic thought processes that can be used in the scientific method.
B. A **hypothesis** is a testable statement about the nature of an observation or relationship.
C. A properly designed scientific experiment includes both a **control group** and an **experimental group,** and must be as free as possible from **bias.** The experimental group differs from a control group only with respect to the variable being studied.
D. When a hypothesis has been supported by conclusions from many experiments, scientists may develop a **theory** based on it. A well established and tested theory may be referred to as a scientific **principle.**
E. Science has important ethical dimensions.

POST-TEST

1. Metabolism (a) is the sum of all the chemical activities of an organism (b) results from an increase in the number of cells (c) is characteristic of plant and animal kingdoms only (d) refers to chemical changes in an organism's environment (e) does not take place in producers
2. Homeostasis (a) is the tendency of organisms to maintain a constant internal environment (b) generally depends on the action of cilia (c) is the long-term response of organisms to changes in their environment (d) occurs at the ecosystem level, not in cells or organisms (e) may be sexual or asexual
3. Structures used by some organisms for locomotion are (a) cilia (b) flagella (c) nuclei (d) answers a, b, and c are correct (e) answers a and b only are correct
4. The splitting of an amoeba into two is best described as an example of (a) locomotion (b) neurotransmission (c) asexual reproduction (d) sexual reproduction (e) metabolism
5. Cells (a) are the building blocks of living organisms (b) always have nuclei (c) are not found among the bacteria (d) answers a, b, and c are correct (e) answers a and b only are correct
6. An increase in size or number of cells best describes (a) homeostasis (b) biological growth (c) the chemical level of organization (d) asexual reproduction (e) adaptation
7. DNA (a) makes up the genes (b) transmits information from one species to another (c) cannot be changed (d) is a neurotransmitter (e) is produced during cellular respiration
8. Cellular respiration (a) is a process whereby sunlight is used to synthesize cellular components with the release of energy (b) occurs in heterotrophs only (c) is carried on by both autotrophs and heterotrophs (d) causes chemical changes in DNA (e) occurs in response to environmental changes
9. Which of the following is a correct sequence of levels of biological organization? (a) cellular, organ, tissue, organ system (b) chemical, cellular, organ, tissue (c) chemical, cellular, tissue, organ (d) tissue, organ, cellular, organ system (e) chemical, cellular, population, species
10. Which of the following is a correct sequence of levels of biological organization? (a) organism, population, ecosystem, community (b) organism, population, community, ecosystem (c) population, biosphere, ecosystem, community (d) species, population, ecosystem, community (e) population, species, community, biosphere
11. Darwin suggested that evolution takes place by (a) mutation (b) changes in the individuals of a species (c) natural selection (d) interaction of hormones (e) homeostatic responses to each change in the environment
12. Protozoa are assigned to kingdom (a) Protista (b) Fungi (c) Archaebacteria (d) Animalia (e) Plantae
13. Yeasts and molds are assigned to kingdom (a) Protista (b) Fungi (c) Archaebacteria (d) Animalia (e) Plantae
14. In the binomial system of nomenclature, the first part of an organism's name designates the (a) specific epithet (b) genus (c) class (d) kingdom (e) phylum
15. Which of the following is a correct sequence of levels of classification? (a) genus, species, family, order, class, phylum, kingdom (b) genus, species, order, phylum, class, kingdom (c) genus, species, order, family, class, phylum, kingdom (d) species, genus, family, order, class, phylum, kingdom (e) species, genus, order, family, class, kingdom, phylum
16. A testable statement is a(an) (a) theory (b) hypothesis (c) principle (d) inductive leap (e) critical question
17. Ideally, an experimental group differs from a control group (a) only with respect to the hypothesis being tested (b) only with respect to the variable being studied (c) by being less subject to bias (d) because it is less vulnerable to sampling error (e) because its subjects are more reliable.

REVIEW QUESTIONS

1. Contrast a living organism with a nonliving object.
2. In what ways might the metabolisms of an oak tree and a tiger be similar? Relate these similarities to the biological themes of transmission of information, energy, and evolution.
3. What would be the consequences if an organism's homeostatic mechanisms failed? Explain your answer.
4. What components do you think might be present in a balanced forest ecosystem? In what ways are consumers dependent on producers? On decomposers? Include energy considerations in your answer.
5. Why do you suppose that the binomial system of nomenclature has survived for more than 200 years and is still used by biologists?
6. How might you explain the sharp claws and teeth of tigers in terms of natural selection?
7. What is meant by a "controlled" experiment?
8. Make a prediction and devise a suitably controlled experiment to test each of the following hypotheses: (a) A type of mold found in your garden does not produce an effective antibiotic. (b) The rate of growth of a bean seedling is affected by temperature. (c) Estrogen alleviates the symptoms of Alzheimer's disease in elderly women.

YOU MAKE THE CONNECTION

1. How might a firm understanding of evolutionary processes be helpful to a biologist who is doing research in (a) animal behavior, (b) ecology, and (c) the development of a vaccine against HIV, the virus that causes AIDS?
2. If you could influence U. S. policy on continuing cloning research, what position would you take? Explain. What would be your position on the use of gene-modified animals for producing drugs like insulin or blood-clotting factors?

RECOMMENDED READINGS

Cohen, J. "Can Cloning Help Save Beleaguered Species?" *Science,* Vol. 276, 30 May, 1997. A brief discussion of the benefits and concerns of cloning endangered species.

Mirsky, S., and J. Rennie. "What Cloning Means for Gene Therapy," *Scientific American,* Vol. 276, Jun. 1997. A special report about the benefits of combining cloning technology with other biotechnologies.

Moore, J.A. *Science as a Way of Knowing: The Foundations of Modern Biology.* Harvard University Press, Cambridge, 1993. An account of scientific thought as related to the history of modern biology.

Science, Vol. 277, 25 Jul. 1997. Special Issue: Human-Dominated Ecosystems. The authors examine the global consequences of human activity on several ecosystems.

Scientific American, Vol. 273, No. 3, Sep. 1995. Special Issue: Key Technologies for the 21st Century. This issue includes several interesting articles on medical technology and on "Energy and the Environment."

Velander. W.H., Lubon, H., and W.N. Drohan. "Transgenic Livestock as Drug Factories," *Scientific American,* Vol. 276, No. 1, Jan. 1997. A discussion of some exciting new medical applications of genetic techniques.

- Visit our website at **http://www.saunderscollege.com/lifesci/titles.html** and click on Solomon/Berg/Martin Biology for links to chapter-related resources on the World Wide Web.