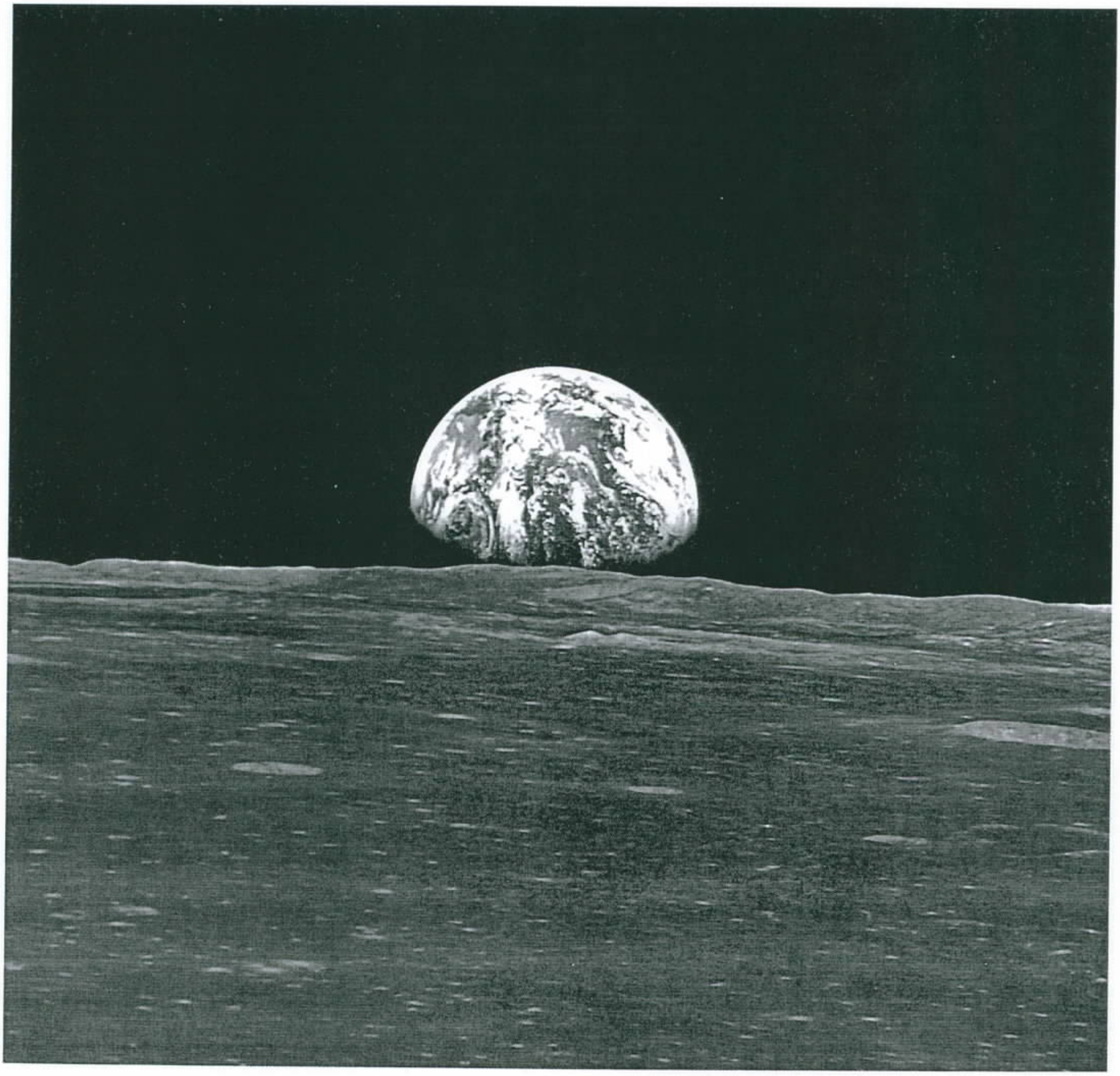
CHAPTER 1

An Introduction to Life on Earth



Life on Earth is confined to the biosphere, a thin film encompassing Earth's surface. Earth, seen here from the moon, is an oasis of life in our solar system.

AT A GLANCE

CASE STUDY Life on Earth—and Elsewhere?

1.1 How Do Scientists Study Life?
Life Can Be Studied at Different Levels of Organization
Scientific Principles Underlie All Scientific Inquiry
The Scientific Method Is the Basis for Scientific Inquiry
Communication Is Crucial to Science
Science Is a Human Endeavor

Scientific Inquiry: Controlled Experiments, Then and Now

Scientific Theories Have Been Thoroughly Tested

1.2 Evolution: The Unifying Theory of Biology
Three Natural Processes Underlie Evolution

1.3 What Are the Characteristics of Living Things?
Living Things Are Complex, Organized, and Composed of Cells

Earth Watch: Why Preserve Biodiversity?

Living Things Maintain Relatively Constant Internal Conditions Through Homeostasis
Living Things Respond to Stimuli
Living Things Acquire and Use Materials and Energy

Links to Life: The Life Around Us

Living Things Grow
Living Things Reproduce Themselves
Living Things, Collectively, Have the Capacity to Evolve

1.4 How Do Scientists Categorize the Diversity of Life?
The Domains Bacteria and Archaea Consist of Prokaryotic Cells; the Domain Eukarya Is Composed of Eukaryotic Cells
Bacteria, Archaea, and Protists Are Mostly Unicellular; Members of the Kingdoms Fungi, Plantae, and Animalia Are Primarily Multicellular
Members of the Different Kingdoms Have Different Ways of Acquiring Energy

1.5 How Does Knowledge of Biology Illuminate Everyday Life?

CASE STUDY REVISITED Life on Earth—and Elsewhere?

CASE STUDY LIFE ON EARTH—AND ELSEWHERE?

"Viewed from the distance of the moon, the astonishing thing about the earth, catching the breath, is that it is alive. The photographs show the dry, pounded surface of the moon in the foreground, dead as an old bone. Aloft, floating free beneath the moist gleaming surface of bright blue sky, is the rising earth, the only exuberant thing in this part of the cosmos."

—Lewis Thomas in *The Lives of a Cell* (1974)

WHEN LEWIS THOMAS, biomedical researcher and physician, viewed the early photographs of Earth taken by astronauts from the surface of the moon (see the photo on the opposite page), he—like most of humanity—felt a sense of awe. The dry and barren surface of the moon in the foreground reminds us of how truly special Earth is—blanketed with green plants, blue oceans, and white clouds. But is Earth itself "alive"? There is no question that life has invaded nearly every nook and cranny of Earth. The toughest life-forms are also the simplest—single-celled organisms collectively described as *extremophiles*. These "survivalist microbes" inhabit the most inhospitable environments on Earth. Some thrive in vents in the deep ocean floor, where the pressure is 30 times that on Earth's surface and which spew water at temperatures over 212°F (100°C). Others have been discovered in ice cores 1200 feet below the surface of an Antarctic lake frozen for hundreds of thousands of years. Extremophiles inhabit the highly acid environments produced by mining wastes and hot springs, and they have been discovered in rock samples taken from 4 miles beneath Earth's surface. These life-forms seem as foreign to us as alien life from another solar system. Indeed, their existence on Earth fuels guarded optimism that life may exist, or may once have existed, in the seemingly hostile conditions found on other planets. What is life? How did it evolve? Could life survive on the barren surface of the moon, or in the harsh environments of other planets?

1.1 HOW DO SCIENTISTS STUDY LIFE?

Life Can Be Studied at Different Levels of Organization

Biology utilizes the same principles and methods as other sciences. In fact, a basic tenet of modern biology is that living things obey the same laws of physics and chemistry that govern nonliving matter. Just as sand can be formed into bricks that provide the building blocks of a wall, and walls in turn provide the basis of a structure, so scientists view the living and nonliving world as a series of *levels of organization*, with each level providing the building blocks for the next level (**FIG. 1-1**).

All matter on Earth is formed of substances called **elements**, each one of them unique. An **atom** is the smallest particle of an element that retains the properties of that element. For example, a diamond is a form of the element carbon. The smallest possible unit of the diamond is an individual carbon atom. Atoms may combine in specific ways to form assemblies called **molecules**; for example, one carbon atom can combine with two oxygen atoms to form

Community	Two or more populations of different species living and interacting in the same area
Population	Members of one species inhabiting the same area
Multicellular Organism	An individual living thing composed of many cells
Organ System	Two or more organs working together in the execution of a specific bodily function
Organ	A structure usually composed of several tissue types that form a functional unit
Tissue	A group of similar cells that perform a specific function
Cell	The smallest unit of life
Molecule	A combination of atoms
Atom	The smallest particle of an element that retains the properties of that element

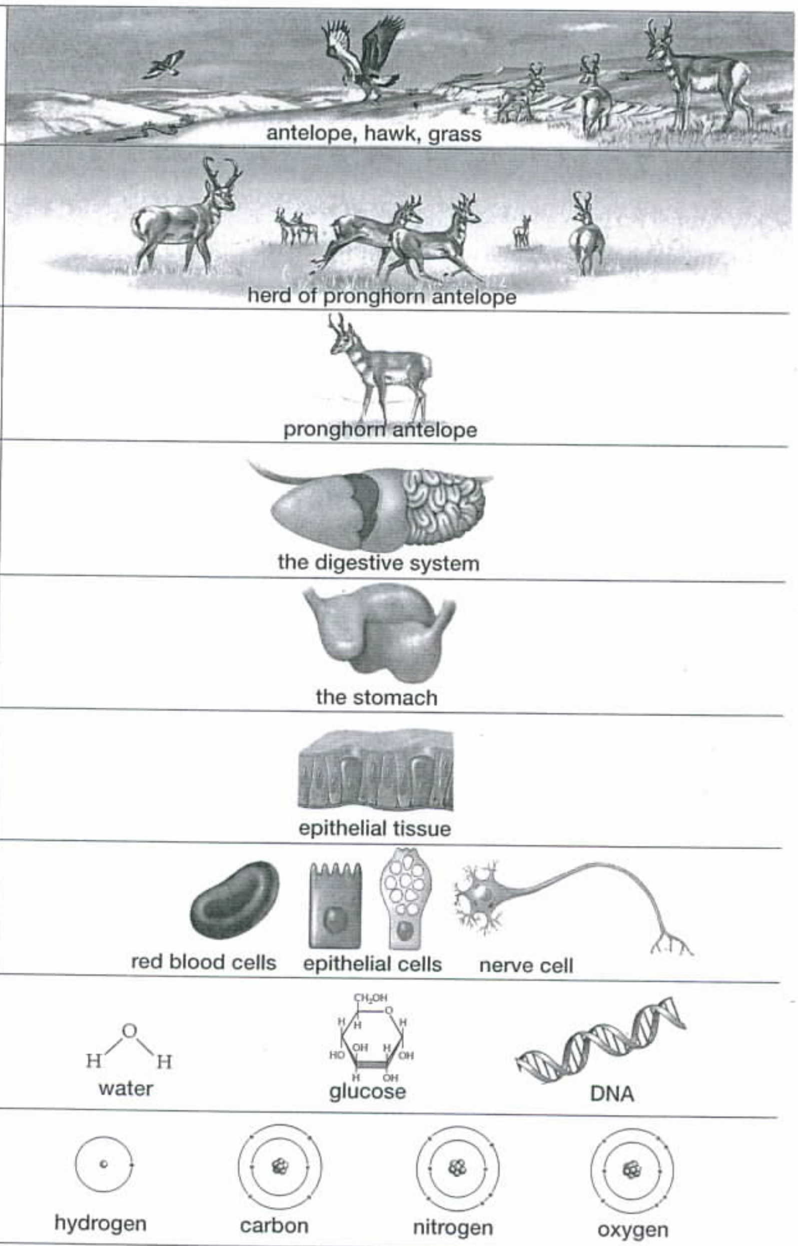


FIGURE 1-1 Levels of organization of matter
All life has a chemical basis, but the quality of life itself emerges on the cellular level. Interactions among the components of each level and the levels below it allow the development of the next-higher level of organization. **EXERCISE** Think of a scientific question that can be answered by investigating at the cell level, but that would be impossible to answer at the tissue level. Then think of one answerable at the tissue level but not the cell level. Repeat the process for two other pairs of adjacent levels of organization.

a molecule of carbon dioxide. Although many simple molecules form spontaneously, only living things manufacture extremely large and complex molecules. The bodies of living things are composed primarily of complex molecules called **organic molecules**, meaning that they contain a framework of carbon, to which at least some hydrogen is bound.

Although atoms and molecules form the building blocks of life, the quality of life itself emerges on the level of the cell. Just as an atom is the smallest unit of an element, so the **cell** is the smallest unit of life (**FIG. 1-2**). Although many forms of life consist of single cells, in multicellular forms, cells of similar type combine to form structures known as **tissues**; for example, muscle is a type of tissue. Different tissues, in turn, can combine to form **organs** (for example, a stomach or a kidney). Organs united by a common overall function are called **organ systems** (for example, the stomach is part of the digestive system, and the kidney is part of the urinary system). A multicellular organism will generally have several organ systems.

Levels of organization extend above the individual. **Organisms** of the same type that are capable of breeding with one another are collectively called a **species**. Within a given area, a group of organisms of the same species constitutes a **population**, and a collection of different populations that interact with one another makes up a **community** (see Fig. 1-1). Note that each level of organization incorporates many members of the previous level; a community contains many populations, a population contains many organisms, and so on.

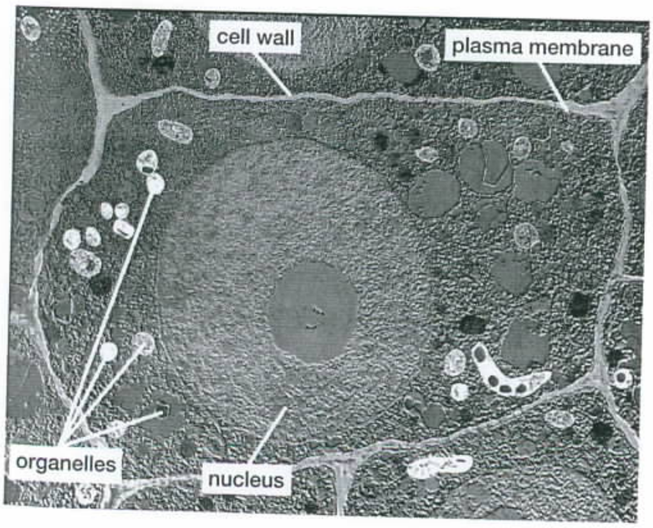


FIGURE 1-2 The cell is the smallest unit of life
This artificially colored micrograph of a plant cell shows the supporting cell wall that surrounds plant (but not animal) cells. Just inside the cell wall, the plasma membrane (found in all cells) has control over which substances enter and leave. The nucleus houses the cell's DNA. The cell also contains several types of specialized organelles. Some store food; some break down food to provide usable energy; and, in plants, some capture light energy.

Biologists work at many different levels of organization, depending on the question they are investigating. For example, to find out how antelope digest their food, a biologist might study the organs of the antelope digestive system, or at a smaller level, the cells that line the digestive tract. Delving deeper, the researcher might investigate the biological molecules secreted into the digestive tract that break down the animal's food. On the other hand, to find out whether habitat destruction is reducing the number of antelope, the scientists would investigate antelope populations as well as the interacting populations of other species that make up the community to which antelope belong. Scientists must recognize and choose the level of organization that is most appropriate to the question at hand.

Scientific Principles Underlie All Scientific Inquiry

All scientific inquiry, including biology, is based on a small set of assumptions. Although these assumptions can never be proven absolutely, they have been so thoroughly tested and validated that we might call them scientific principles. These principles are *natural causality*, *uniformity in space and time*, and *common perception*.

Natural Causality Is the Principle That All Events Can Be Traced to Natural Causes

Over the course of human history, two approaches have been taken to the study of life and other natural phenomena. The first assumes that some events happen through the intervention of supernatural forces beyond our understanding. Through the middle ages, many people believed that life arose spontaneously from nonliving matter. People of the seventeenth century believed that maggots arose from rotting meat (see "Scientific Inquiry: Controlled Experiments, Then and Now"), and that mice could be created from sweaty underwear combined with wheat husks in an open jar. The seizures of epilepsy were once thought to be the result of a visitation from the gods. In contrast, science adheres to the principle of **natural causality**: all events can be traced to natural causes that are potentially within our ability to comprehend. Today, we realize that maggots are the larval form of flies, and that epilepsy is a disease of the brain in which groups of nerve cells are uncontrollably activated. The principle of natural causality has an important corollary: the natural evidence we gather has not been deliberately distorted to fool us. This corollary may seem obvious, yet not so very long ago some people argued that fossils are not evidence of evolution; rather, they were placed on Earth by God to test our faith. The enormous accomplishments of science rely on the premise of natural causality.

The Natural Laws That Govern Events Apply Everywhere and for All Time

A second fundamental principle of science is that natural laws—laws derived from the study of nature—are uniform in space and time. The laws of gravity, the behavior of light, and the interactions of atoms, for example, are the same today as they were a billion years ago, and they hold true in Moscow as well as in New York, or even on Mars. Uniformity in space and time is especially vital to biology, because many important biological events, such as the evolution of today's diversity of living things, happened before humans were around to observe them. Some people believe that each of the different types of organisms was individually created at one time in the past by the direct intervention of God, a philosophy called *creationism*. Scientists freely admit that this idea cannot be absolutely disproved, but creationism is contrary to both natural causality and uniformity in time. The overwhelming success of science in explaining natural events through natural causes has led scientists to reject creationism as an explanation for the diversity of life on Earth.

Scientific Inquiry Is Based on the Assumption That People Perceive Natural Events in Similar Ways

A third basic assumption of science is that, generally, all human beings perceive natural events in fundamentally the same way, and that these perceptions provide us with reliable information about the natural world. Common perception is, to some extent, a principle peculiar to science. Value systems, such as those involved in the appreciation of art, poetry, and music, do not assume common perception. We may perceive the colors and shapes in a painting in a similar way (the scientific aspect of art), but we may disagree about the aesthetic value of the painting (the humanistic aspect of art; **FIG. 1-3**). Values may differ among individuals, often as a result of cultural or religious beliefs. Because value systems are subjective and not objective or measurable, science cannot answer certain types of philosophical or moral questions, such as the morality of abortion.

FIGURE 1-3 Value systems differ
Although people will generally agree about the colors and shapes in this artwork, questions such as "What does this mean?" or "Is this beautiful?" will be answered in different ways by different observers.

The Scientific Method Is the Basis for Scientific Inquiry

Given these assumptions, how do biologists study the workings of life? Scientific inquiry is a rigorous method for making observations of specific phenomena and searching for the order underlying those phenomena. Biology and other sciences commonly use the **scientific method**, which consists of six interrelated operations: *observation, question, hypothesis, prediction, experiment*, and *conclusion* (**FIG. 1-4a**). All scientific inquiry begins with an **observation** of a specific phenomenon. The observation, in turn, leads to a **question**—"How did this happen?" Then, in a flash of insight—or more typically after long, hard thought—a hypothesis is formulated. A **hypothesis** is a supposition, based on previous observations, that is offered as an answer to the question and a natural explanation for the observed phenomenon. To be useful, the hypothesis must lead to a **prediction**, typically expressed in "If … then" language. The prediction is tested by carefully controlled observations called **experiments**. These experiments produce results that either support or refute the hypothesis, allowing the scientist to reach a **conclusion** about the validity of the hypothesis. A single experiment is never an adequate basis for a conclusion; the results must be repeatable not only by the original researcher but also by others.

Simple experiments test the assertion that a single factor, or **variable**, is the cause of a single observation. To be scientifically valid, the experiment must rule out other possible variables as the cause of the observation. For this reason, scientists design **controls** into their experiments. Controls, in which all the variables not being tested remain constant, are then compared with the experimental situation, in which only the variable being tested is changed. In the early 1600s, Francesco Redi used the scientific method to test the hypothesis that flies do not arise spontaneously from rotting meat, and this method is still used today, as illustrated by Malte Andersson's experiment to test the hypothesis that female widowbirds prefer to mate with males with long tails (see "Scientific Inquiry: Controlled Experiments, Then and Now").

You probably use some variation of the scientific method to solve everyday problems (**FIG. 1-4b**). For example, late for an important date, you rush to your car, turn the ignition key, and make the *observation* that it won't start. Your *question*: Why won't the car start? immediately leads to a *hypothesis*: The battery is dead. Your hypothesis leads to the *prediction*: If the battery is dead, then a new battery will allow you to start your car. Quickly, you

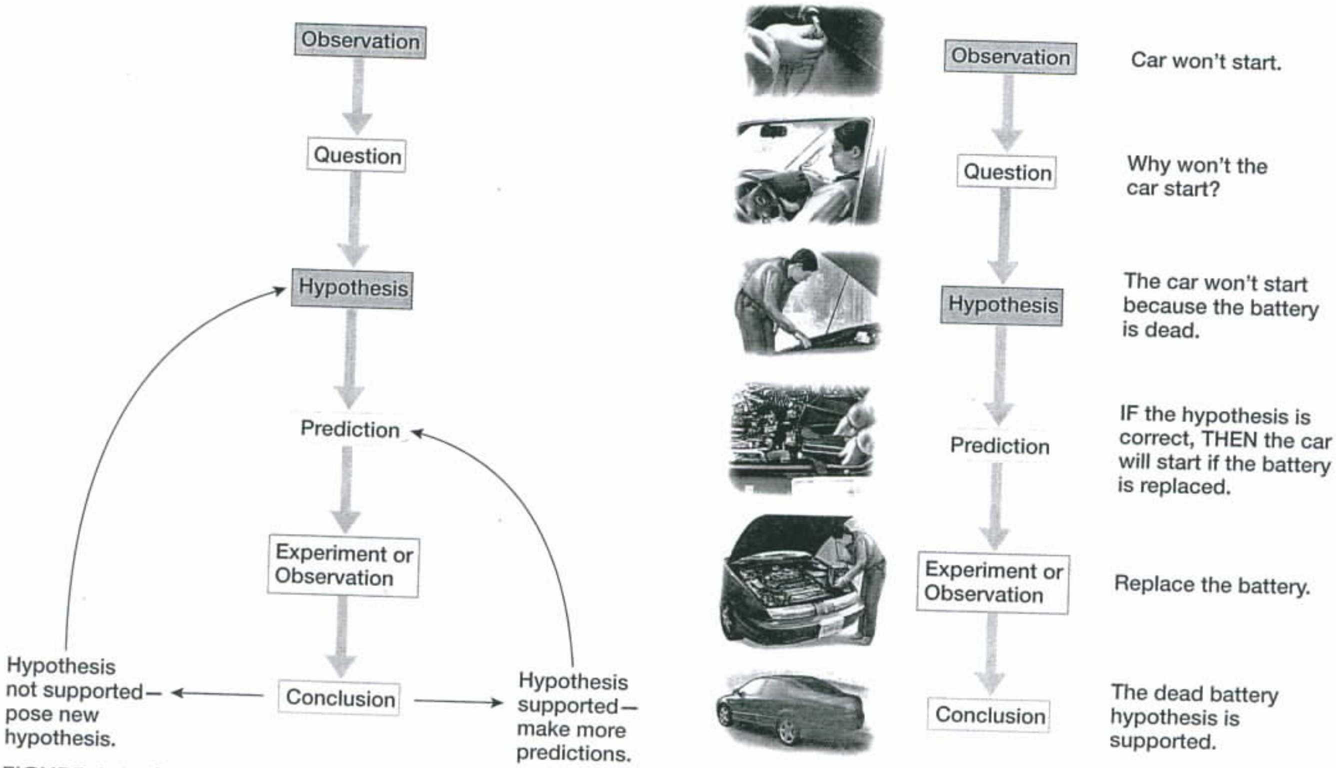


FIGURE 1-4 The scientific method
(a) The general process. **(b)** An example from everyday life.

design an *experiment*: you replace your battery with the battery from your roommate's new car and try to start your car again. The result supports your hypothesis, because your car starts immediately. But wait! You haven't provided controls for several variables. Perhaps the battery cable was loose and simply needed to be tightened. Realizing the need for a good *control*, you replace your old battery, making sure the cables are secured tightly, and attempt to restart the car. If your car repeatedly refuses to start with the old battery and tightened cables but then starts immediately when you put in your roommate's new battery, you have isolated a single *variable*, the battery. Although you are very late for your date, you can now safely draw the *conclusion* that your old battery is dead.

The scientific method is powerful, but it is important to recognize its limitations. In particular, scientists can seldom be sure that they have controlled *all* the variables other than the one they are trying to study. Therefore, scientific conclusions must always remain tentative and are subject to revision if new observations or experiments demand it.

Communication Is Crucial to Science

A final important element of science is *communication*. No matter how well designed an experiment is, it is useless if it is not communicated thoroughly and accurately. Redi's experimental design and conclusions survive today only because he carefully recorded his methods and observations. If experiments are not communicated to other scientists in enough detail, they cannot be repeated to verify the conclusions. Without verification, scientific findings cannot be safely used as the basis for new hypotheses and further experiments.

A fascinating aspect of scientific inquiry is that whenever a scientist reaches a conclusion, the conclusion immediately raises further questions that lead to further hypotheses and more experiments (why did your battery die?). Science is a never-ending quest for knowledge.

Science Is a Human Endeavor

Scientists are real people. They are driven by the same ambitions, pride, and fears as other people, and they sometimes make mistakes. As you will read in Chapter 9, ambition played an important role in the discovery of the structure of DNA by James Watson and Francis Crick. Accidents, lucky guesses, controversies with competing scientists, and, of course, the intellectual powers of individual scientists contribute greatly to scientific advances. To illustrate what we might call "real science," let's consider an actual case.

To study bacteria, microbiologists use pure *cultures*—that is, plates of bacteria that are free from contamination by other bacteria or molds. Only by studying a single type at a time can they learn about the properties of that

SCIENTIFIC INQUIRY Controlled Experiments, Then and Now

A classic experiment by the Italian physician Francesco Redi (1621–1697) beautifully demonstrates the scientific method and helps to illustrate the principle of natural causality, on which modern science is based. Redi investigated why maggots (which are the larval form of flies) appear on spoiled meat. In Redi's time, the appearance of maggots on meat was considered to be evidence of *spontaneous generation*, the production of living things from nonliving matter.

Redi *observed* that flies swarm around fresh meat and that maggots appear on meat left out for a few days. He formed a testable *hypothesis*: The flies produce the maggots. In his *experiment*, Redi wanted to test just one variable—the access of flies to the meat. Therefore, he took two clean jars and filled them with similar pieces of meat. He left one jar open (the *control* jar) and covered the other with gauze to keep out flies (the *experimental* jar). He did his best to keep all the other variables the same (for example, the type of jar, the type of meat, and the temperature). After a few days, he observed maggots on the meat in the open jar, but saw none on the meat in the covered jar. Redi *concluded* that his hypothesis was correct and that maggots are produced by flies, not by the nonliving meat (**FIG. E1-1**). Only through controlled experiments could the age-old hypothesis of spontaneous generation be laid to rest.

More than 300 years after Redi's experiment, today's scientists still use the same approach to design their experiments. Consider the experiment that Malte Andersson designed to investigate the long tails of male widowbirds. Andersson *observed* that male, but not female, widowbirds have extravagantly long tails, which they display while flying across African grasslands (**FIG. E1-2**). This observation led Andersson to ask the *question*: Why do the males, and only the males, have such long tails? His *hypothesis* was that males have long tails because females prefer to mate with long-tailed males, which therefore have more offspring than shorter-tailed males. From this hypothesis, Andersson *predicted* that if his hypothesis were true, then more females would build nests on the territories of males with artificially lengthened tails than would build nests on the territories of males with artificially shortened tails. He then captured some males, trimmed their tails to about half their original length, and released them (*experimental* group 1). Another group of males had the tail feathers that had been removed from the first group glued on as tail extensions (*experimental* group 2). Finally, Andersson had two *control* groups. In one, the tail was cut and then glued back in place (to control for the ef-

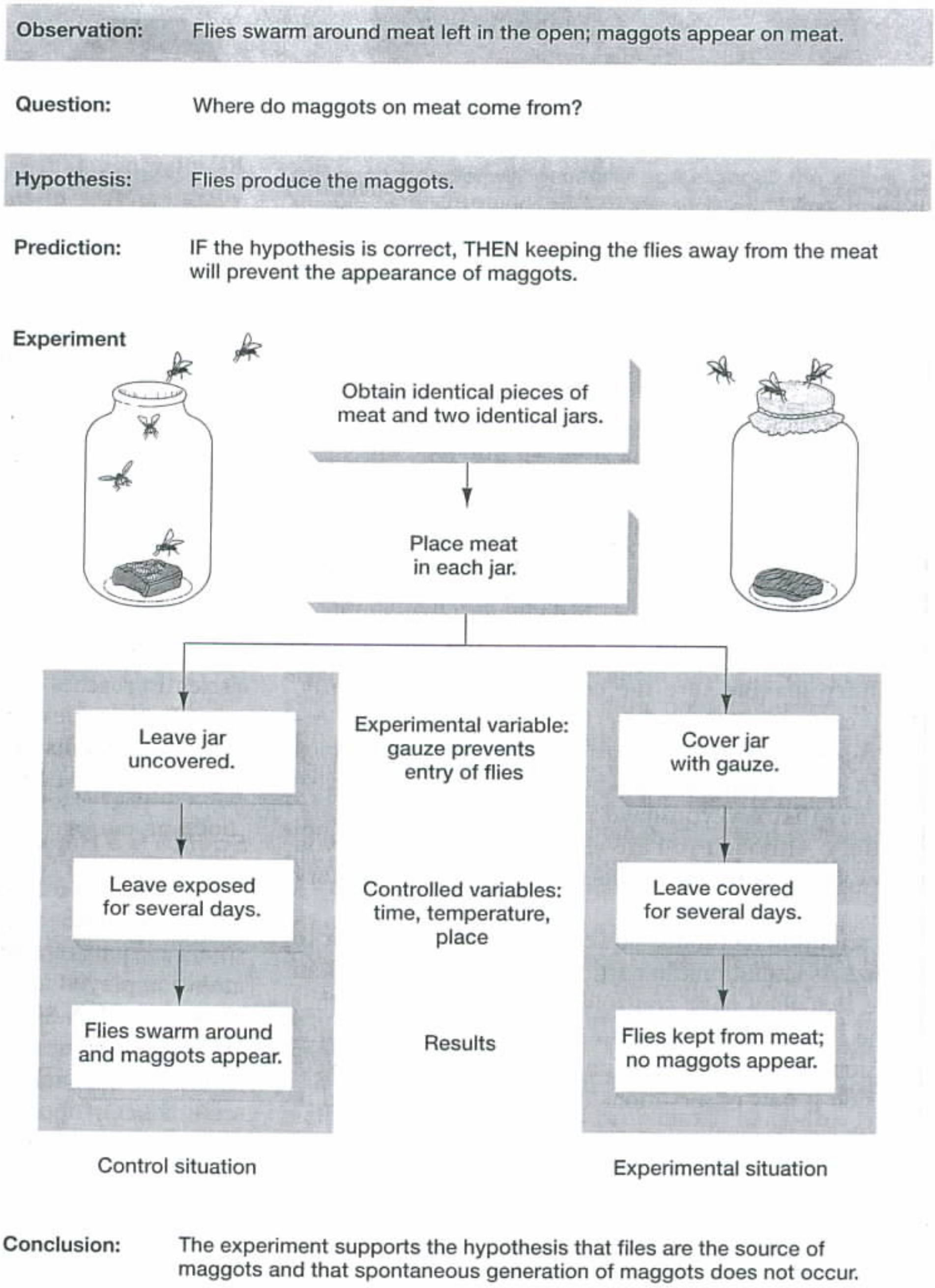


FIGURE E1-1 The experiments of Francesco Redi
QUESTION Redi's experiment falsified spontaneous generation, but did his experiment conclusively demonstrate that flies cause maggots? What kind of follow-up experiment would be necessary to better determine the source of maggots?

fects of capturing the birds and manipulating their feathers). In the other, the birds were simply captured and released. The experimenter was doing his best to make sure that tail length was the only variable that was changed. After a few days, Andersson counted the number of nests that females had built on each male's territory. He found that males with lengthened tails had the most nests on their territories, males with shortened tails had the fewest, and control males (with normal-length tails) had an intermediate number (**FIG. E1-3**). Andersson *concluded* that his hypothesis was correct, and that female widowbirds prefer to mate with males that have long tails.

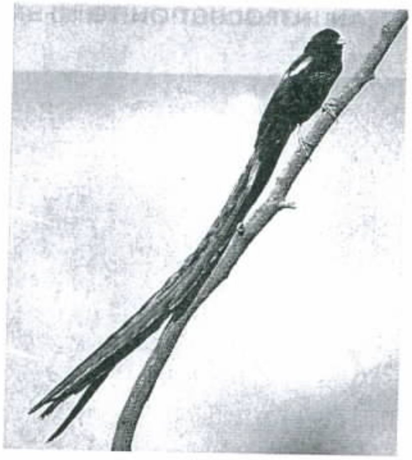


FIGURE E1-2 A male widowbird

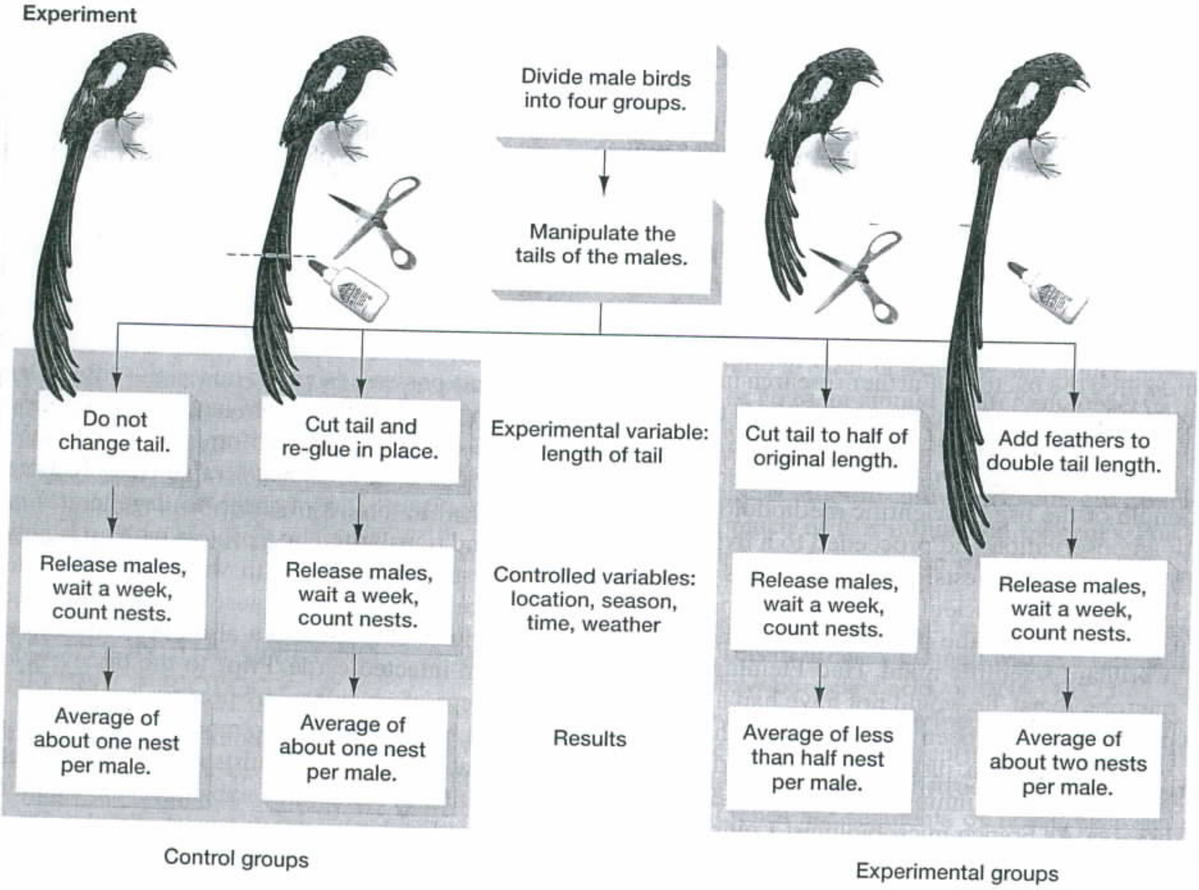
Observation: Male widowbirds have extremely long tails.

Question: Why do males, but not females, have such long tails?

Hypothesis: Males have long tails because females prefer to mate with long-tailed males.

Prediction: If females prefer long-tailed males, males with artificially lengthened tails will attract more mates.

Experiment



Conclusion: The hypothesis that widowbirds do prefer to mate with long-tailed males (and avoid mating with short-tailed males) is supported.

FIGURE E1-3 The experiments of Malte Andersson

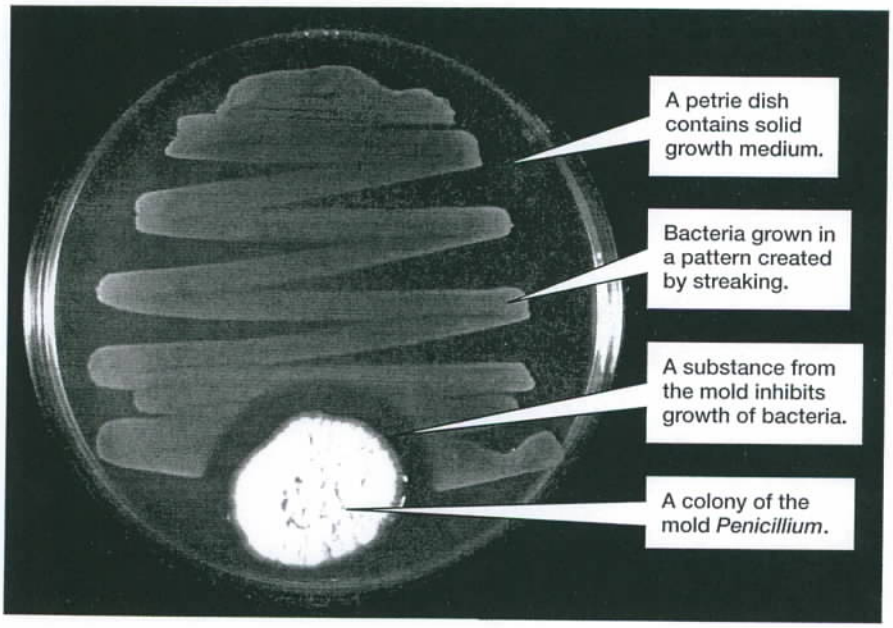


FIGURE 1-5 Penicillin kills bacteria
A fuzzy white colony of the mold *Penicillium* has inhibited the growth of colonies of the disease-causing bacteria *Staphlococcus aureus,* which have been smeared back and forth across this plate of jellylike growth medium. Both the mold and the bacteria are visible only when they grow at high densities, as in the colonies seen here. QUESTION Why do some molds produce substances that are toxic to bacteria?

particular bacterium. Consequently, at the first sign of contamination, a culture is usually thrown out, often with mutterings about sloppy technique. On one such occasion however, in the late 1920s, Scottish bacteriologist Alexander Fleming turned a ruined bacterial culture into one of the greatest medical advances in history.

One of Fleming's bacterial cultures became contaminated with a patch of a mold called *Penicillium.* Before throwing out the culture dish, Fleming observed that no bacteria were growing near the mold (**FIG. 1-5**). Why not? Fleming hypothesized that perhaps *Penicillium* releases a substance that kills off bacteria growing nearby. To test this hypothesis, Fleming grew some pure *Penicillium* in a liquid nutrient broth. He then filtered out the *Penicillium* mold and applied the liquid in which the mold had grown to an uncontaminated bacterial culture. Sure enough, something in the liquid killed the bacteria. Further research into these mold extracts resulted in the production of the first *antibiotic*—penicillin, a bacteria-killing substance that has since saved millions of lives. Fleming's experiments are a classic example of the use of scientific methodology. They began with an observation and proceeded to a hypothesis, followed by experimental tests of the hypothesis that led to a conclusion. But the scientific method alone would have been useless without the lucky combination of accident and a brilliant scientific mind. Had Fleming been a "perfect" microbiologist, he would not have had any contaminated cultures. Had he been less observant, the contamination would have been just another spoiled culture dish. Instead, it was the beginning of antibiotic therapy for bacterial diseases. As French microbiologist Louis Pasteur said, "Chance favors the prepared mind."

Scientific Theories Have Been Thoroughly Tested

Scientists use the word *theory* in a way that is different from its everyday usage. If Dr. Watson were to ask Sherlock Holmes, "Do you have a theory as to the perpetrator of this foul deed?" in scientific terms, he would be asking Holmes for a hypothesis—an "educated guess" based on observable evidence, or clues. A **scientific theory** is far more general and more reliable than a hypothesis. Far from being an educated guess, a scientific theory is a general explanation of important natural phenomena, developed through extensive and reproducible observations. In common English, it is more like a *principle* or a *natural law*. For example, scientific theories such as the atomic theory (that all matter is composed of atoms) and the theory of gravitation (that objects exert attraction for one another) are fundamental to the science of physics. Likewise, the *cell theory* (that all living things are composed of cells) and the *theory of evolution* are fundamental to the study of biology. Scientists describe fundamental principles as "theories" rather than "facts" because a basic premise of scientific inquiry is that it must be performed with an open mind. If compelling evidence arises, a theory will be modified.

A modern example of the need to keep an open mind in the light of new scientific evidence is the discovery of *prions*, which are infectious proteins (see the Case Study for Chapter 3). Before the early 1980s, all known infectious disease agents possessed genetic material—either DNA or the related molecule, RNA. When neurologist Stanley Prusiner from the University of California at San Francisco published evidence in 1982 that scrapie (an infectious disease that causes the brains of sheep to degenerate) is actually caused and transmitted by a protein with no genetic material, his results were met with widespread disbelief. Prions have since been found to cause "mad cow disease," which has killed not only cattle but also over 150 people who ate beef from infected cattle. Prior to the discovery of prions, the concept of an infectious protein was unknown to science. But by being willing to modify accepted beliefs to accommodate new data, scientists maintained the integrity of the scientific process while expanding their understanding of disease. For his pioneering work, Stanley Prusiner was awarded the Nobel Prize in Physiology or Medicine in 1997.

Science Is Based on Reasoning

Scientific theories arise through inductive reasoning. **Inductive reasoning** is the process of creating a generalization as a result of making many observations that support it, and none that contradict it. Simplistically, the theory that Earth exerts gravitational forces on objects arose from repeated observations of objects falling down toward Earth and from a complete lack of observations of objects "falling up." Likewise, the cell theory arises from the observation that all organisms that have the attributes of life are composed of one or more cells, and that nothing that is not composed of cells shares all these attributes.

Once a scientific theory has been formulated, it can be used to support deductive reasoning. In science, **deductive reasoning** is the process of generating hypotheses about how a specific experiment or observation will turn out, based on a well-supported generalization such as a scientific theory. For example, based on the cell theory, if a new organism is found that shares all the attributes of life, scientists can confidently deduce or hypothesize that it will be composed of cells. Of course, the new organism must be carefully scrutinized under the microscope to determine its cellular structure; if compelling new evidence arises, a theory can be modified.

Scientific Theories Are Formulated in Ways That Can Potentially Be Disproved

A major difference between a scientific theory and a belief based on faith is that a scientific theory can be disproved or *falsified*, while a faith-based assertion cannot. The potential to be falsified is why scientists continue to refer to basic precepts of science as "theories." For example, let's look at the existence of elves. The scientific approach to elves is that no solid evidence of their existence can be detected, and therefore elves do not exist. People who have faith in the existence of elves might describe them as creatures so secretive that they can never be captured, observed, or otherwise detected. Alternatively, these believers might claim that elves manifest themselves only to people who believe in them. The scientific theory that elves do not exist could easily be falsified if someone caught one or provided other repeatable, objective evidence of their existence. In contrast, the faith-based assertion that elves exist, as well as other faith-based assertions such as creationism, are formulated in ways that can never be disproved. For this reason, they are articles of faith rather than science.

1.2 EVOLUTION: THE UNIFYING THEORY OF BIOLOGY

In the words of biologist Theodosius Dobzhansky, "Nothing in biology makes sense, except in the light of evolution." Why don't snakes have legs? Why are there dinosaur fossils but no living dinosaurs? Why are monkeys so like us, not only in appearance but also in the structure of their genes and proteins? The answers to those questions, and thousands more, lie in the processes of evolution (examined in detail in Unit Three). Evolution is so vital to our understanding and appreciation of biology that we introduce its major principles here in our opening chapter.

Evolution not only explains the origin of diverse forms of life but accounts for the remarkable similarities among different life-forms as well. Ever since the theory of evolution was formulated in the mid-1800s by two English naturalists, Charles Darwin and Alfred Russel Wallace, it has been supported by fossil finds, geological studies, radioactive dating of rocks, genetics, molecular biology, biochemistry, and breeding experiments. People who refer to evolution as "just a theory" profoundly misunderstand what scientists mean by the word "theory."

Three Natural Processes Underlie Evolution

The scientific theory of **evolution** states that modern organisms descended, with modification, from preexisting life-forms. The most important force in evolution is **natural selection**, the process by which organisms with specific traits that help them cope with the rigors of their environment reproduce more successfully than do others that lack these traits. The changes that occur during evolution are a result of natural selection acting on the inherited variation that occurs among individuals in a population, causing changes in the population over successive generations. The variation upon which natural selection acts is a result of small differences in the genetic makeup of the individuals within the population.

Evolution arises as a consequence of three natural processes: *genetic variation* among members of a population owing to differences in their DNA, *inheritance* of those variations by offspring of parents who carry the variation, and *natural selection*, the enhanced reproduction of organisms with variations that help them cope with their environment.

Genetic Variability Among Organisms Is Inherited

Look around at your classmates and notice how different they are, or go to an animal shelter and observe the differences among the dogs in size, shape, and coat color. Although some of this variation (particularly among your classmates) is due to differences in environment and lifestyles, much of it is influenced by genes. For example, most of us could pump iron for the rest of our lives and never develop a body like that of "Mr. Universe."

But what are genes? The hereditary information of all known forms of life is contained within a type of molecule called **deoxyribonucleic acid**, or **DNA** (FIG. 1-6). An organism's DNA, which is contained in **chromosomes** in each cell, is the cell's genetic blueprint or molecular instruction manual, a guide to the construction and the operation of its body. Genes are segments of DNA; each gene directs the formation of one of the crucial molecular components of the organism's body. When an organism reproduces, it passes a copy of its chromosomes containing DNA to its offspring.

The accuracy of the DNA copying process is astonishingly high; in people only about 25 mistakes, called **mutations**, occur for every billion bits of information copied. Mutations

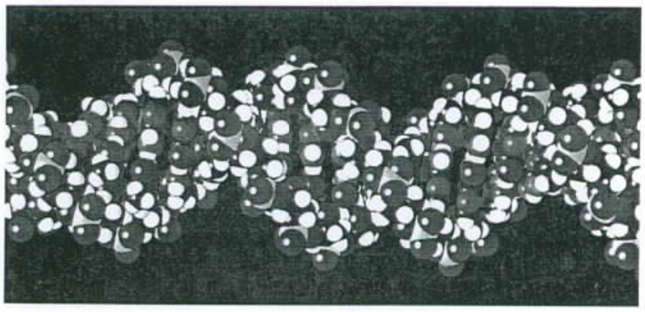


FIGURE 1-6 DNA
A computer-generated model of DNA, the molecule of heredity. As James Watson, its codiscoverer, put it: "A structure this pretty just had to exist."

can also result from damage to DNA, for example by ultraviolet light, radioactive particles, or toxic chemicals such as those in cigarette smoke. These occasional errors alter the information in genes or alter the collections of genes within chromosomes. Most mutations have no effect or are harmful. For example, mutations in skin cells caused by too much ultraviolet light can cause skin cancer. Mutations in lung cells caused by poisons in cigarette smoke can cause lung cancer. On very rare occasions, however, a mutation will occur when a sperm or egg cell is being formed, allowing it to be passed to the organism's offspring. As a result, each cell in the new individual's body will carry this *hereditary mutation*. Some of these will prevent the new organism from developing, while other changes in genetic material cause diseases such as Down syndrome. Still other mutations, many of which occurred millions of years ago and have been passed from parent to offspring through countless generations, account for differences such as height, body proportions, facial features, and the color of skin, hair, and eyes.

Natural Selection Tends to Preserve Genes That Help an Organism Survive and Reproduce

On average, organisms that best meet the challenges of their environment will leave the most offspring; these offspring will inherit the genes that made their parents successful. Thus, natural selection preserves genes that help organisms flourish in their environment. To create a hypothetical example, a mutated gene that caused ancestral beavers to grow larger teeth allowed those with this mutation to chew down trees more efficiently, build bigger dams and lodges, and eat more bark than "ordinary" beavers could. Because these big-toothed beavers obtained more food and better shelter, they were able to raise more offspring who inherited their parents' genes for larger teeth. Over time, less-successful, smaller-toothed beavers became increasingly scarce; after many generations, all beavers had large teeth.

Structures, physiological processes, or behaviors that aid in survival and reproduction in a particular environment are called **adaptations**. Most of the features that we admire so much in our fellow life-forms, such as the long limbs of deer, the wings of eagles, and the mighty trunks of redwood trees, are adaptations molded by millions of years of natural selection acting on random mutations.

Over millennia, the interplay of environment, genetic variation, and natural selection inevitably results in evolution: a change in the genetic makeup of species. This change has been documented innumerable times both in laboratory settings and in the wild. For example, antibiotics have acted as agents of natural selection on bacterial populations, causing the evolution of antibiotic-resistant forms. Lawn mowers have caused changes in the genetic makeup of populations of dandelions, favoring those that produce flowers on very short stems. Scientists have documented the spontaneous emergence of entirely new species of plants due to mutations that alter their chromosome number.

What helps an organism survive today can become a liability tomorrow. If environments change—for example, as global warming occurs—the genetic makeup that best adapts organisms to their environment will also change over time. When random new mutations increase the fitness of an organism in the altered environment, these mutations will spread throughout the population. Populations within a species that live in different environments will be subjected to different types of natural selection. If the differences are great enough and continue for long enough, they may eventually cause the populations to become sufficiently different from one another to prevent interbreeding—a new species will have evolved.

If, however, favorable mutations do not occur, a changing environment may doom a species to extinction. Dinosaurs (**FIG. 1-7**) are extinct not because they were failures—after all, they flourished for 100 million years—but because they could not adapt rapidly enough to changing conditions.

Within particular habitats, diverse organisms have evolved complex interrelationships with one another and with their nonliving surroundings. The diversity of species and the interactions that sustain them are encompassed by the term **biodiversity**. In recent decades, the rate of environmental change has been drastically accelerated by human activities. Many wild species are unable to adapt to this rapid change. In habitats most affected by humans, many species are being driven to extinction. This concept is explored further in "Earth Watch: Why Preserve Biodiversity?"

1.3 WHAT ARE THE CHARACTERISTICS OF LIVING THINGS?

What is life? If you look up *life* in a dictionary, you will find definitions such as "the quality that distinguishes a vital and functioning being from a dead body," but you won't find out what that "quality" is. Life emerges as a result of incredibly complex, ordered interactions among nonliving molecules. How did life originate? Although scientists have several hypotheses as to how life on Earth first arose (see Chapter 17), there are no scientific theories that describe the origin of life. Life is an intangible quality that defies simple definition, but we can describe some of the

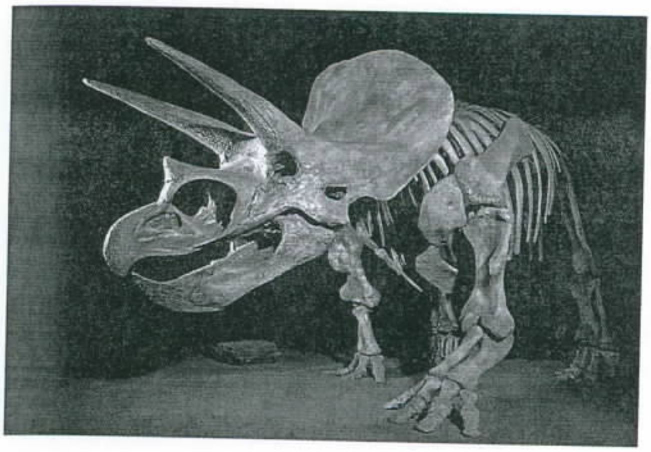


FIGURE 1-7 A fossil of *Triceratops*
This *Triceratops* died in what is now Montana about 70 million years ago. No one is certain what caused the extinction of the dinosaurs, but we do know that they were unable to evolve new adaptations to keep up with changes in their habitat.

characteristics of living things. Taken together, these attributes are not shared by nonliving objects. As you walk outside, you can observe many of these attributes (see "Links to Life: The Life Around Us"). Characteristics of life include the following:

- Living things are composed of cells that have a complex, organized structure.
- Living things respond to stimuli from their environment.
- Living things actively maintain their complex structure and their internal environment, a process called *homeostasis*.
- Living things acquire and use materials and energy from their environment and convert them into different forms.
- Living things grow.
- Living things reproduce themselves, using the molecular blueprint of DNA.
- Living things, as a whole, have the capacity to evolve.

Let's explore these characteristics in more detail.

Living Things Are Complex, Organized, and Composed of Cells

In Chapter 4 you will learn how researchers in the early 1800s, observing life with primitive microscopes, devised the **cell theory**, which states that the cell is the basic unit of life. Even a single cell has an elaborate internal structure (see Fig. 1-2). All cells contain **genes**, units of heredity that provide the information needed to control the life of the cell, and small structures called **organelles** that are specialized to carry out specific functions such as moving the cell, obtaining energy, or synthesizing large molecules. Cells are always surrounded by a thin **plasma membrane** that encloses the **cytoplasm** (organelles and the fluid surrounding them) and separates the cell from the outside world. Some life-forms, mostly invisible to the naked eye, consist of just one cell. Your body—and the bodies of organisms that are most familiar to us—is composed of many cells that are specialized and elaborately organized to perform specific functions. The water flea beautifully illustrates the complexity found in a multicellular form of life far smaller than the letter "o" in this text (**FIG. 1-8**).

Living Things Maintain Relatively Constant Internal Conditions Through Homeostasis

Complex, organized structures are not easy to maintain. Whether we consider the molecules of your body or the books and papers on your desk, organization tends to disintegrate into chaos unless energy is used to sustain it (we explore this concept further in Chapter 6). To stay alive and function effectively, organisms must keep the conditions within their bodies fairly constant; in other words, they must maintain **homeostasis** (derived from Greek words meaning "to stay the same"). For example, organisms must precisely regulate the amount of water and salts within their cells. Their bodies must also be maintained at appropriate temperatures for biological functions to occur. Among warm-blooded animals, vital organs such as the brain and heart are kept at a warm, constant temperature despite wide fluctuations in outside temperature. Homeostasis is

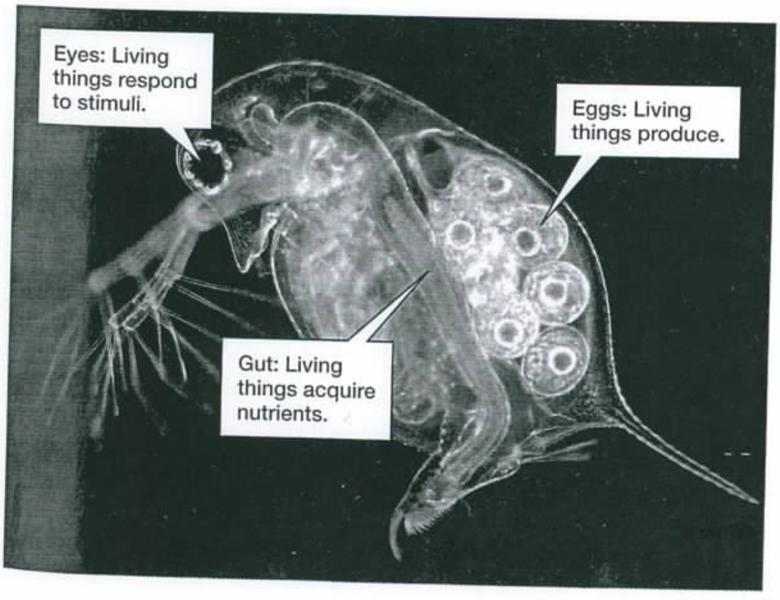


FIGURE 1-8 Life is both complex and organized
The water flea, *Daphnia longispina*, is only 1 millimeter long (1/1000 meter), yet it has legs, a mouth, a digestive tract, reproductive organs, light-sensing eyes, and even a rather impressive brain in relation to its size.

BIOETHICS EARTH WATCH

Why Preserve Biodiversity?

"The loss of species is the folly our descendants are least likely to forgive us."
—E. O. Wilson, Professor, Harvard University

What is biodiversity, and why should we be concerned with preserving it? *Biodiversity* refers to the total number of species within a given region and to the resulting complexity of interactions among them. Over the 3.5-billion-year history of life on Earth, evolution has produced an estimated 8 to 10 million unique and irreplaceable species. Of these, scientists have named only about 1.4 million, and only a tiny fraction of this number have been studied. Evolution has not, however, merely churned out millions of independent species. Over thousands of years, organisms in a given area have been molded by forces of natural selection exerted by other living species as well as by the nonliving environment in which they live. The outcome is the community, a highly complex web of interdependent life-forms whose interactions sustain one another. By participating in the natural cycling of water, oxygen, and other nutrients, and by producing rich soil and purifying wastes, these communities contribute to the sustenance of human life as well. The concept of biodiversity has emerged as a result of our increasing concern over the loss of countless forms of life and the habitats that sustain them.

The tropics are home to the vast majority of all the species on Earth, perhaps 7 or 8 million of them, living in complex communities. The rapid destruction of habitats in the tropics—from rain forests to coral reefs—as a result of human activities is producing high rates of extinction of many species (**FIG. E1-4**). Most of these species have never been named, and others never even discovered. Aside from ethical concerns over eradicating irreplaceable forms of life, as we drive unknown organisms to extinction, we lose potential sources of medicine, food, and raw materials for industry.

For example, a wild relative of corn that is not only very disease-resistant but also *perennial* (that is, lasts more than one growing season) was found growing only on a 25-acre plot of land in Mexico that was scheduled to be cut and burned within a week of the discovery. The genes of this plant might one day enhance the disease resistance of corn or create a perennial corn plant. The rosy periwinkle, a flowering plant found in the tropical forest of the island of Madagascar (off the eastern coast of Africa) produces two substances that are now widely marketed for the treatment of leukemia and Hodgkin's disease, a cancer of the lymphatic organs. Only about 3 percent of the world's flowering plants have been examined for substances that might fight cancer or other diseases. Closer to home, loggers of the Pacific Northwest frequently cut and burned the Pacific yew tree as a "nuisance species" until the active ingredient that has since gone into making the anticancer drug Taxol® was discovered in its bark.

Many conservationists are also concerned that as species are eliminated, either locally or through total extinction, the communities of which they were a part might change, becoming less stable and more vulnerable to damage by diseases or adverse environmental conditions. Some experimental evidence supports this viewpoint, but the interactions within communities are so complex that these hypotheses are difficult to test. Clearly, some species have a much larger role than others in preserving the stability of a given ecosystem. Which species are most crucial in each ecosystem? No one knows. Human activities have increased the natural rate of extinction by a factor of at least 100 and possibly by as much as 1000 times the prehuman rate. By reducing biodiversity to support increasing numbers of humans and wasteful standards of living, we have ignorantly embarked on an uncontrolled global experiment, using planet Earth as our laboratory. In their book *Extinction* (1981), Stanford ecologists Paul and Anne Ehrlich compare the loss of biodiversity to the removal of rivets from the wing of an airplane. The rivet-removers continue to assume that there are far more rivets than needed, until one day, when the airplane takes off, they are proven tragically wrong. As human activities drive species to extinction while we have little knowledge of the role each plays in the complex web of life, we run the risk of removing "one rivet too many."

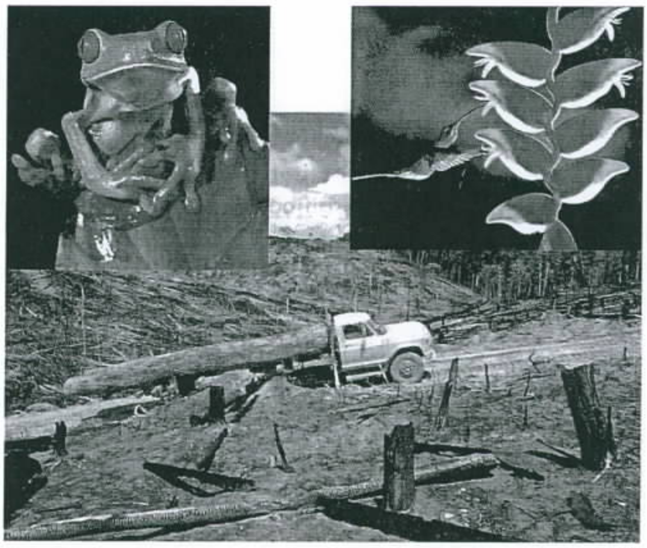


FIGURE E1-4 Biodiversity threatened
Destruction of tropical rain forests by indiscriminate logging threatens Earth's greatest storehouse of biological diversity. Interrelationships such as those that have evolved between this *Heliconia* flower and its hummingbird pollinator, and this frog and the bromeliad on which it lives, sustain these diverse communities and are threatened by human activities.

maintained by a variety of mechanisms. In the case of temperature regulation, these include sweating during hot weather and exercise, dousing oneself with cool water (**FIG. 1-9**), metabolizing more food in cold weather, basking in the sun, or even adjusting a thermostat.

Of course, not everything stays the same throughout an organism's life. Major changes, such as growth and reproduction, occur; but these are not failures of homeostasis. Rather, they are specific, genetically programmed parts of the organism's life cycle.

Living Things Respond to Stimuli

In order to stay alive, reproduce, and maintain homeostasis, organisms must perceive and respond to stimuli in their internal and external environments. Animals have evolved elaborate sensory organs and muscular systems that allow them to detect and respond to light, sound, touch, chemicals, and many other stimuli from their surroundings. Internal stimuli are perceived by receptors for stretch, temperature, pain, and various chemicals. For example, when you feel hungry, you perceive contractions of your empty stomach and low levels of sugars and fats in your blood. You then respond to external stimuli by choosing appropriate objects to eat, such as a sandwich rather than a plate. Yet animals, with their elaborate nervous systems and motile bodies, are not the only organisms that perceive and respond to stimuli. The plants on your windowsill grow toward light, and even the bacteria in your intestines manufacture different digestive enzymes depending on whether you drink milk, eat candy, or both.

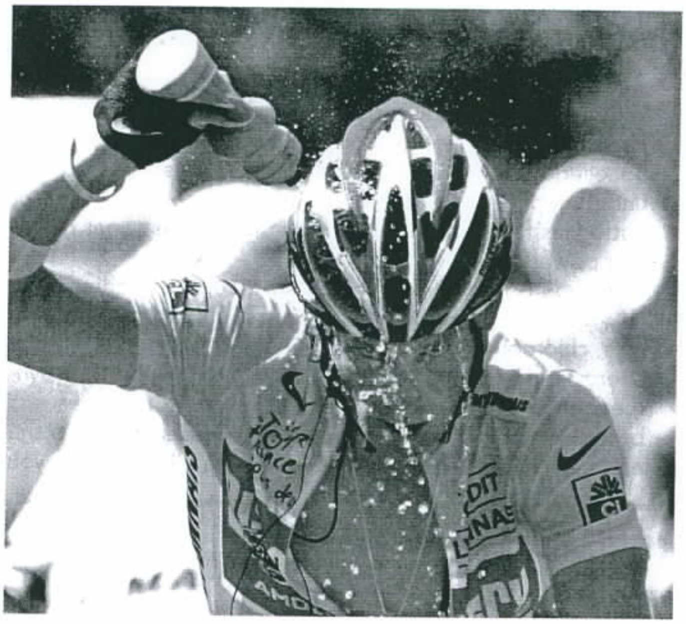


FIGURE 1-9 Living things maintain homeostasis
Evaporative cooling by water, both from sweat and from a bottle, helps Lance Armstrong (seven-time winner of the Tour de France bicycle race) maintain temperature homeostasis. QUESTION In addition to reducing body temperature, how else does sweating affect homeostasis?

Living Things Acquire and Use Materials and Energy

Organisms need materials and energy to maintain their high level of complexity and organization, to grow, to maintain homeostasis, and to reproduce (see Fig. 1-8). Organisms acquire the materials they need, called **nutrients**, from air, water, or soil, or from other living things. Nutrients include minerals, oxygen, water, and all the other chemical building blocks that make up biological molecules. These nutrients are obtained from the environment, where they are continuously exchanged and recycled among living things and their nonliving surroundings (**FIG. 1-10**).

To sustain life, organisms must obtain **energy**—the ability to do work, such as carrying out chemical reactions, growing leaves in the spring, or contracting a muscle. Ultimately, the energy that sustains nearly all life comes from sunlight. Plants and some single-celled organisms capture the energy of sunlight directly and store it in energy-rich molecules, such as sugars, using a process called **photosynthesis**. These organisms are called **autotrophs**, meaning "self-feeders." Organisms that cannot photosynthesize, such as animals and fungi, must acquire energy prepackaged in the molecules of the bodies of other organisms; hence, these organisms are called **heterotrophs**, meaning "other-feeders." Thus, energy flows in a one-way path from the sun through nearly all forms of life. That energy is eventually released again as heat, which cannot be used to power life (see Fig. 1-10).

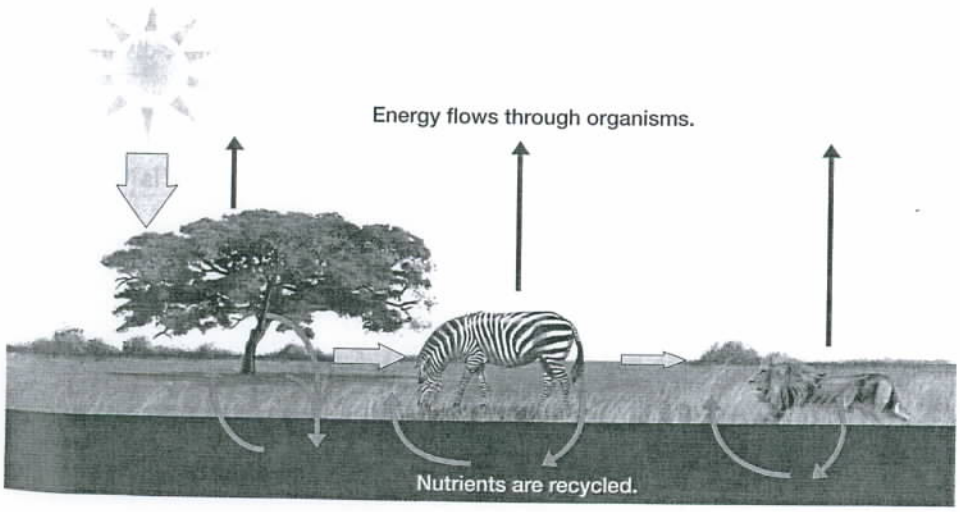


FIGURE 1-10 The flow of energy and the recycling of nutrients
Nutrients are recycled among organisms and their nonliving environment. In contrast, energy is acquired from sunlight, transferred through heterotrophs (yellow arrows), and lost as heat (red arrows) in a one-way flow. Photosynthetic organisms (autotrophs) capture solar energy and obtain nutrients from soil and water. Other forms of life (heterotrophs) obtain their energy and most of their nutrients from autotrophs either directly (in the case of herbivores) or indirectly by consuming other heterotrophs (in the case of carnivores).

LINKS TO LIFE The Life Around Us

The next time you walk across campus, look at the astonishing array of creatures thriving in a place as domesticated as a college campus. During the right seasons, you will undoubtedly pass beds of flowers and see honeybees or butterflies flitting among them, gathering the sweet nectar that powers their flight.

As you observe life, think about the "why" behind what you see. The plants' green color is due to a unique molecule, chlorophyll, that absorbs specific wavelengths of solar energy and uses them to power the life of the plant and synthesize the sugar in the nectar gathered by the bees and butterflies. Showy flowers evolved to entice insects to the energy-rich nectar. Why? If you look carefully at a bee, you may see yellow pollen clinging to its legs or to the hairs coating its body. The plants "use" the insects to fertilize each other, and both benefit. The sugar in nectar is assembled by chemical reactions that combine carbon dioxide and water, releasing oxygen as a waste product. So as you breathe out air rich in carbon dioxide, you are nourishing the plants with your "waste gas." Conversely, with each breath you take, you are inhaling the life-sustaining "waste gas" from the plants around you: oxygen. Wherever you look, if you look in the right way, you'll see evidence of the interdependence of living things, and you will never take life on Earth for granted.

Living Things Grow

At some time in its life cycle, every organism becomes larger—that is, it *grows*. Although this characteristic is obvious in most animals and plants, even single-celled bacteria grow to about double their original size before they divide. In all cases, growth involves the conversion of materials acquired from the environment into the specific molecules of the organism's body.

Living Things Reproduce Themselves

Organisms reproduce, giving rise to offspring of the same type and creating continuity of life. The processes by which this occurs vary, but the result is the same—the perpetuation of the parents' genes.

Living Things, Collectively, Have the Capacity to Evolve

Populations of organisms evolve in response to changing environments. Although the genetic makeup of a single organism remains essentially the same over its lifetime, the genetic makeup of a population will change over time as a result of natural selection.

1.4 HOW DO SCIENTISTS CATEGORIZE THE DIVERSITY OF LIFE?

Although all living things share the general characteristics discussed earlier, evolution has produced an amazing variety of life-forms. Organisms can be grouped into three major categories, called **domains**: Bacteria, Archaea, and Eukarya. This classification reflects fundamental differences among the cell types that compose these organisms. Members of both the Bacteria and the Archaea usually consist of single, simple cells. Members of the Eukarya have bodies composed of one or more highly complex cells. This domain includes three major subdivisions or **kingdoms**: the Fungi, Plantae, and Animalia, as well as a diverse collection of mostly single-celled organisms collectively known as "protists" (**FIG. 1-11**). There are exceptions to any simple set of criteria used to characterize the domains and kingdoms, but three characteristics are particularly useful: cell type, the number of cells in each organism, and how it acquires energy (Table 1-1).

Categories within the various kingdoms are phylum, class, order, family, genus, and species. These groupings form a hierarchy in which each category includes all of those below it. Within the final category, the species, all members are so similar that they can interbreed. Biologists use a **binomial system** for naming species. As the word "binomial" suggests, each type of organism is assigned a scientific name that consists of two parts: its genus and its species. The genus name is always capitalized, and the species name is not; both are shown in italics. So *Daphnia longispina*, the water flea in Figure 1-8, is in the genus *Daphnia* (which includes many other "water fleas") and the species *longispina* (which refers to the long spine protruding from its tail end). People are classified as *Homo sapiens*; we are the only members of this genus and species. This binomial system of naming organisms allows scientists worldwide to communicate very precisely about any given organism. In the following paragraphs, we provide a brief introduction to the domains and kingdoms of life. You will learn far more about life's incredible diversity and how it evolved in Unit Three.

The Domains Bacteria and Archaea Consist of Prokaryotic Cells; the Domain Eukarya Is Composed of Eukaryotic Cells

There are two fundamentally different types of cells: **prokaryotic** and **eukaryotic**. *Karyotic* refers to the **nucleus** of a cell, a membrane-enclosed sac containing the cell's genetic material (see Fig. 1-2). *Eu* means "true" in Greek; eukaryotic cells possess a "true" membrane-enclosed nucleus. Eukaryotic cells are generally larger than prokaryotic cells and contain a variety of other organelles, many surrounded by membranes. *Pro* means "before" in Greek; prokaryotic

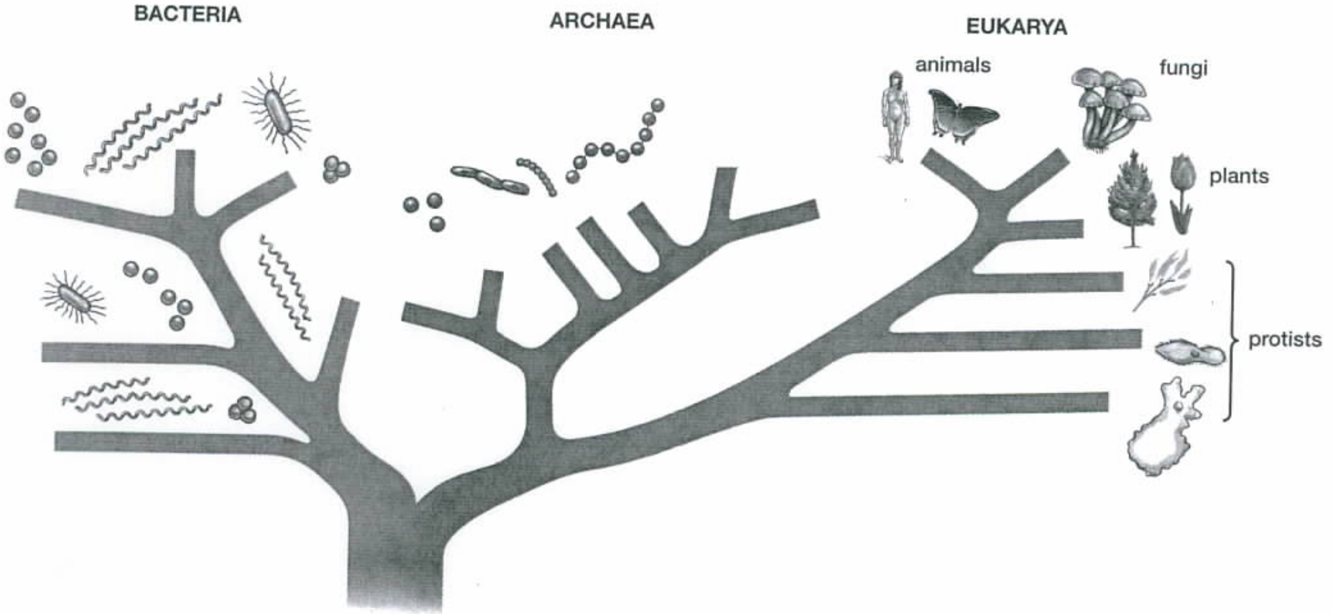


FIGURE 1-11 The domains and kingdoms of life

cells almost certainly evolved before eukaryotic cells (and, as we will see in Chapter 17, eukaryotic cells almost certainly evolved from prokaryotic cells). Prokaryotic cells do not have a nucleus; their genetic material resides in their cytoplasm. They are usually small—only 1 or 2 micrometers in diameter—and lack membrane-bound organelles. The domains Bacteria and Archaea consist of prokaryotic cells; as its name implies, the cells of Eukarya are eukaryotic.

Bacteria, Archaea, and the Protists Are Mostly Unicellular; Members of the Kingdoms Fungi, Plantae, and Animalia Are Primarily Multicellular

Most members of the domains Bacteria and Archaea and the protists from the domain Eukarya are single-celled, or **unicellular**, although a few live in strands or mats of cells with little communication, cooperation, or organization among them. Most members of the kingdoms Fungi, Plantae, and Animalia are many-celled, or **multicellular**; their lives depend on intimate communication and cooperation among many specialized cells.

Members of the Different Kingdoms Have Different Ways of Acquiring Energy

Photosynthetic organisms—including plants, some bacteria, and some protists—are autotrophic, meaning "self-feeding." Organisms that cannot photosynthesize are heterotrophic, meaning "other-feeding." Many archaea, bacteria, protists, and all fungi and animals are heterotrophs. Heterotrophs differ in the size of the food they eat. Some, such as bacteria and fungi, absorb individual food molecules from outside their bodies; others, including most animals, take in chunks of food (*ingestion*) and break them down to molecules in their digestive tracts.

1.5 HOW DOES KNOWLEDGE OF BIOLOGY ILLUMINATE EVERYDAY LIFE?

Some people regard science as a "dehumanizing" activity, thinking that too deep an understanding of the world robs us of vision and awe. Nothing could be farther from the truth, as we repeatedly discover anew in our own lives.

Table 1-1 Some Characteristics Used in Classification of Organisms

Domain	Kingdom	Cell Type	Cell Number	Energy Acquisition
Bacteria	(Under discussion)	Prokaryotic	Unicellular	Autotrophic or heterotrophic (absorb nutrients)
Archaea	(Under discussion)	Prokaryotic	Unicellular	Heterotrophic (absorb)
Eukarya	Fungi	Eukaryotic	Multicellular	Heterotrophic (absorb)
	Plantae	Eukaryotic	Multicellular	Autotrophic
	Animalia	Eukaryotic	Multicellular	Heterotrophic (ingest)
	"protists"*	Eukaryotic	Uni- and multicellular	Autotrophic or heterotrophic (ingest or absorb)

*The "protists" are a diverse collection of organisms that includes several kingdoms under discussion.

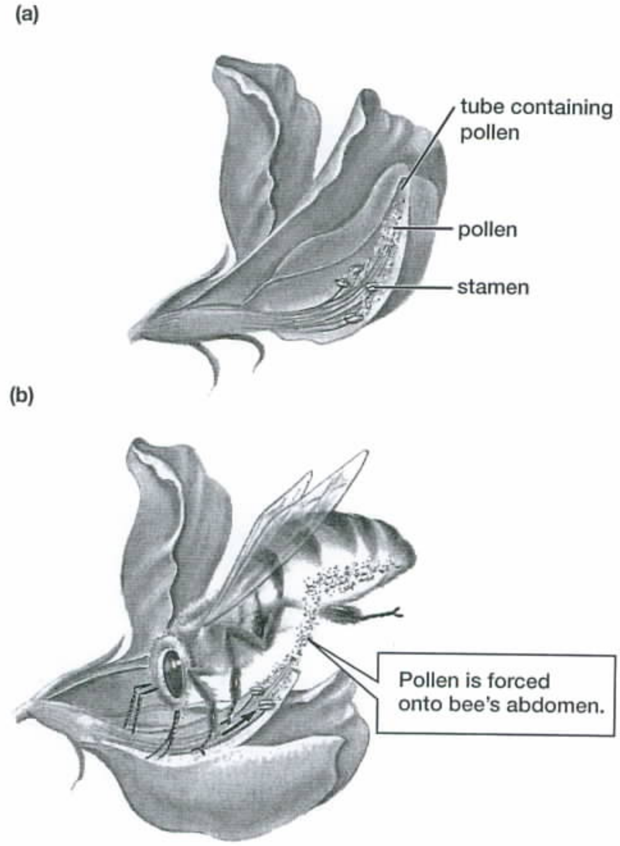


FIGURE 1-12 Complex adaptations help ensure pollination **(a)** In young lupine flowers, the lower petals form a tube enclosing the reproductive structures, including the male stamens, that shed pollen within the tube. **(b)** The weight of a foraging bee compresses the tube, thrusting the reproductive structures forward and forcing pollen out of the tube onto the bee's abdomen. Some pollen adheres to the abdomen and may come off on the sticky female stigma of the next flower that the bee visits, thus pollinating the flower.

FIGURE 1-13 Wild lupines and subalpine fir trees Thousands of people visit Hurricane Ridge in Washington State's Olympic National Park each summer to gaze in awe at Mt. Olympus, but few bother to investigate the wonders at their feet.

Years ago, we watched a bee foraging at a spike of lupine flowers. Members of the pea family, lupines have a complicated structure, with two petals on the lower half of the flower enclosing the pollen-laden male reproductive parts (*stamens*) and sticky pollen-capturing female reproductive parts (*stigma*) within a tubelike structure. We had recently learned that in young lupine flowers (**FIG. 1-12a**), the weight of a bee pushing on these petals compresses the stamens, pushing pollen out of the tube and onto the bee's abdomen (**FIG. 1-12b**). In flowers that are ready to be fertilized, the stigma protrudes through the lower petals; when a pollen-dusted bee visits, it usually leaves behind a few grains of pollen.

Did our newfound insights into the functioning of lupine flowers detract from our appreciation of them? Far from it. Rather, we now looked on lupines with new delight, understanding something of the interplay of form and function, bee and flower, that shaped the evolution of the lupine. A few months later we ventured atop Hurricane Ridge in Olympic National Park in Washington State, where the alpine meadows burst with color in August (**FIG. 1-13**). As we crouched beside a wild lupine, an elderly man stopped to ask what we were looking at so intently. He listened with interest as we explained the structure to him; he then went off to another patch of lupines to watch the bees foraging. He too felt the increased sense of wonder that comes with understanding.

Throughout this text, we try to convey to you that sense of understanding and wonder. We also emphasize that biology is not a completed work but an exploration that has really just begun. As Lewis Thomas, a physician and natural philosopher, eloquently stated: "The only solid piece of scientific truth about which I feel totally confident is that we are profoundly ignorant about nature. Indeed, I regard this as the major discovery of the past hundred years of biology … but we are making a beginning."

We cannot urge you strongly enough, even if you are not contemplating a career in biology, to join in the journey of biological discoveries throughout your life. Don't think of biology as just another course to take, just another set of facts to memorize. Biology is a pathway to a new understanding of yourself and of the life on Earth around you.

CASE STUDY REVISITED LIFE ON EARTH—AND ELSEWHERE?

Is there life on the moon? NASA was not taking any chances. When the *Apollo 11* astronauts who had spent 2.5 hours on the lunar surface splashed down in the ocean on July 24, 1969, a decontamination specialist met them and had them don biological isolation suits while still in the *Apollo 11* module. After the astronauts left the spacecraft, he sterilized the outsides of their isolation suits and the hatch of the spacecraft with disinfectant. The astronauts then stayed in a mobile decontamination unit aboard the recovery ship for four days, until they reached the Johnson Space Center in Houston, Texas. There they remained in quarantine for an additional three weeks.

No foreign microorganisms were found on the astronauts or on the moon rocks they carried back with them. The only microbes found on the moon were discovered by *Apollo 12* astronauts in November 1969. Visiting the unmanned spacecraft *Surveyor 3* that had landed on the moon in 1967, they collected material from inside *Surveyor 3* in a sterile container. From this sample, scientists back on Earth cultured bacteria of the genus *Streptococcus*; ironically, this resident of the human mouth, nose, and throat may have been deposited by a NASA technician who sneezed as he assembled the spacecraft before it was launched. Normally residing in the warm, moist conditions inside the human body, these amazing microbes had, for two years, survived the vacuum of outer space and temperatures as low as –170°F (–110°C).

Astronomers estimate that there may be billions of Earth-like planets in the universe. Thus, the probability is very high that life has evolved elsewhere, although the likelihood of intelligent life is far less certain—and hotly debated. But as an intelligent species, we have hardly begun to understand the diversity, the complexity, and the incredible versatility of life on our own home planet.

Consider This In the late 1970s and 1980s, Dr. James Lovelock, a British chemist, published the controversial and provocative "Gaia hypothesis" (named after the Greek goddess who is said to have brought forth the living world from chaos). Lovelock suggested the living and nonliving components of Earth together constitute a superorganism—an enormous living thing. He noted that the interconnectedness among all forms of life and their environment and the way that living things modify their nonliving surroundings helps maintain conditions conducive to life. Research Lovelock's Gaia hypothesis, either in the library or on the Internet, and discuss how the definition of *life* given in this chapter would need to be changed to accommodate his ideas. Do you believe that Gaia is a useful hypothesis? Is it falsifiable? Should it be elevated to the status of a scientific theory? Explain your answer.

CHAPTER REVIEW

SUMMARY OF KEY CONCEPTS

1.1 How Do Scientists Study Life?

Scientists identify a hierarchy of levels of organizations, as illustrated in Figure 1-1. Biology is based on the scientific principles of natural causality, uniformity in space and time, and common perception. Knowledge in biology is acquired through application of the scientific method, which starts with an observation leading to a question, which leads to a hypothesis. The hypothesis leads to a prediction that is tested by controlled experiments. The experimental results, which must be repeatable, either support or refute the hypothesis, leading to a conclusion about the validity of the hypothesis. A scientific theory is a general explanation of natural phenomena, developed through extensive and reproducible experiments and observations.

Web Tutorial 1.1 Hypothesis Formation and Testing

Web Tutorial 1.2 Spontaneous Generation

1.2 Evolution: The Unifying Theory of Biology

Evolution is the scientific theory that modern organisms descended, with modification, from preexisting life-forms. Evolution occurs as a consequence of genetic variation among members of a population, caused by mutation, inheritance of those variations by offspring, and natural selection of the variations that best adapt an organism to its environment.

1.3 What Are the Characteristics of Living Things?

Organisms possess the following characteristics: their structure is complex and organized; they maintain homeostasis; they acquire energy and materials from the environment; they respond to stimuli; they grow; they reproduce; and they have the capacity to evolve. Most autotrophic organisms capture and store the energy of sunlight in energy-rich molecules by means of photosynthesis. Autotrophs obtain nutrients from their nonliving environment. Heterotrophs obtain all of their energy and most of their nutrients from the bodies of other organisms.

Web Tutorial 1.3 Defining Life

1.4 How Do Scientists Categorize the Diversity of Life?

Organisms can be grouped into three major categories, called domains: Archaea, Bacteria, and Eukarya. Within the Eukarya are three kingdoms, Fungi, Plantae, and Animalia, and unicellular eukaryotes known collectively as "protists." Features used to classify organisms include the cell type (eukaryotic or prokaryotic), cell number (unicellular or multicellular), and energy acquisition (autotrophic or heterotrophic). The genetic material of eukaryotic cells is enclosed within a membrane-bound nucleus. Prokaryotic cells do not have a nucleus. Food obtained by heterotrophic organisms is either ingested in chunks or absorbed molecule by molecule from the environment. The features of the domains and kingdoms are summarized in Table 1-1.

1.5 How Does Knowledge of Biology Illuminate Everyday Life?

The more you know about living things, the more fascinating they become!

KEY TERMS

adaptation *page 10*
atom *page 2*
autotroph *page 13*
binomial system *page 14*
biodiversity *page 10*
cell *page 3*
cell theory *page 11*
chromosomes *page 9*
community *page 3*
conclusion *page 4*
control *page 4*
cytoplasm *page 11*
deductive reasoning *page 9*
deoxyribonucleic acid (DNA) *page 9*
domain *page 14*
element *page 2*
energy *page 13*
eukaryotic *page 14*
evolution *page 9*
experiment *page 4*
gene *page 11*
heterotroph *page 13*
homeostasis *page 11*
hypothesis *page 4*
inductive reasoning *page 8*
kingdom *page 14*
molecule *page 2*
multicellular *page 15*
mutation *page 9*
natural causality *page 3*
natural selection *page 9*
nucleus *page 14*
nutrient *page 13*
observation *page 4*
organ *page 3*
organelle *page 11*
organic molecule *page 3*
organism *page 3*
organ system *page 3*
photosynthesis *page 13*
plasma membrane *page 11*
population *page 3*
prediction *page 4*
prokaryotic *page 14*
question *page 4*
scientific method *page 4*
scientific theory *page 8*
species *page 3*
tissue *page 3*
unicellular *page 15*
variable *page 4*

THINKING THROUGH THE CONCEPTS

1. List the hierarchy of organization of life from an atom to a multicellular organism, briefly explaining each level.
2. What is the difference between a scientific theory and a hypothesis? Explain how scientists use each operation. Why do scientists refer to basic principles as "theories," not "facts"?
3. Explain the differences between inductive and deductive reasoning, and provide an example, real or hypothetical, of each.
4. Describe the scientific method. In what ways do you use the scientific method in everyday life?
5. What are the differences between a salt crystal and a tree? Which is living? How do you know?
6. Define and explain the terms *natural selection*, *evolution*, *mutation*, *creationism*, and *population*.
7. What is evolution? Briefly describe how evolution occurs.
8. Define *homeostasis*. Why must organisms continuously acquire energy and materials from the external environment to maintain homeostasis?

APPLYING THE CONCEPTS

1. Review the properties of life, and then discuss whether humans are unique.
2. Design an experiment to test the effects of a new dog food, "Super Dog," on the thickness and water-shedding properties of the coats of golden retrievers. Include all the parts of a scientific experiment. Design objective methods to assess coat thickness and water-shedding ability.
3. Science is based on principles, including uniformity in space and time and common perception. Assume that humans encounter intelligent beings from a planet in another galaxy where they evolved under very different conditions. Discuss the two principles just mentioned, and explain how they would affect the nature of scientific observations on the different planets as well as communications about these observations.
4. Identify two different types of organisms that you have seen interacting, for example, a caterpillar on a plant such as a milkweed, or a beetle in a flower. Now, form a single, simple hypothesis about this interaction. Use the scientific method and your imagination to design an experiment that tests this hypothesis. Be sure to identify variables and control for them.
5. Explain an instance in which understanding a phenomenon enhances your appreciation of it.

FOR MORE INFORMATION

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