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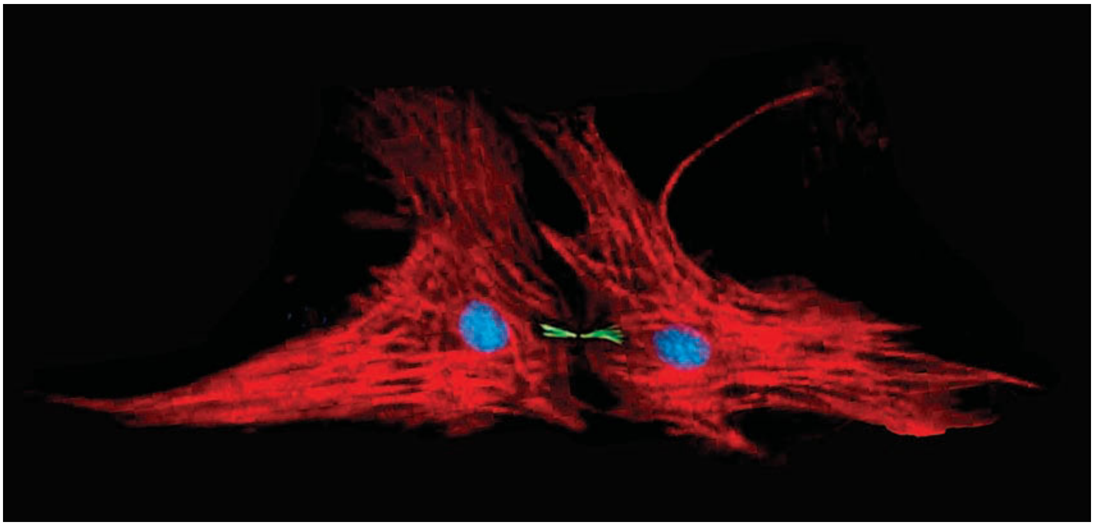
A View of Life



Felix B. Engel/Children's Hospital Boston

A cardiac muscle cell dividing into two new cells.

KEY CONCEPTS

Basic themes of biology include evolution, information transfer, and energy for life.

Characteristics of life include growth and development, self-regulated metabolism, response to stimuli, and reproduction.

Biological organization is hierarchical and includes chemical, cell, tissue, organ, organ system, and organism levels; ecological organization includes population, community, ecosystem, and biosphere levels.

The tree of life includes three major branches, or domains.

Species evolve by natural selection, adapting to changes in their environment.

Biologists ask questions, develop hypotheses, make predictions, and collect data by careful observation and experiment.

Heart disease is the leading cause of death in the United States and other developed countries. When cardiac muscle is damaged, for example, by a myocardial infarction (a "heart attack"), the injured muscle does not repair itself. Instead, the muscle is replaced by scar tissue that impairs the heart's ability to pump blood. Researcher Mark T. Keating and his team at the Howard Hughes Medical Institute at Children's Hospital Boston discovered that the small, tropical zebrafish can regenerate up to 20% of its heart muscle within two months after the tissue is injured or removed. The challenge is to find the mechanisms that stimulate regeneration and learn how to manipulate them.

Felix Engel, an investigator working with Keating, identified that a growth factor (known as fibroblast growth factor) can stimulate cardiac muscle cells to replicate their DNA. The research team also discovered that the protein known as p38 inhibits cardiac muscle growth in fetal rats. They wondered how they could inhibit the inhibitor so that cardiac muscle could repair itself. In 2005, these investigators reported that when they treated cardiac muscle cells with the growth factor in combination with a compound that inhibits p38, cardiac muscle cells activate a group of genes involved in cell division and finally divide (see photograph).

A research group in Germany is pioneering another approach to treating heart damage. This group, led by Gustav Steinhoff at the University of Rostock, injected stem cells (collected from the patient's own bone marrow) into the cardiac muscle of patients who had heart damage as a result of myocardial infarction. One year after receiving the injected stem cells, patients who had this treatment in addition to bypass surgery showed significantly better heart function compared with patients who had only surgery. Searching for ways to repair damaged hearts is one example of the thousands of new research studies in progress.

This is an exciting time to begin studying **biology,** the science of life. The remarkable new discoveries biologists are making almost daily affect every aspect of our lives, including our health, food, safety, relationships with humans and other organisms, and our ability to enjoy the life that surrounds us. New knowledge provides new insights into the human species and the millions of other organisms with which we share this planet.

Biology affects our personal, governmental, and societal decisions. For example, the U.S. Supreme Court abolished the death penalty for juvenile offenders in 2005, based on research findings that the brain does not complete its development until after adolescence. (At the time of this ruling, 20 states still permitted capital punishment for offenders younger than age 18.) Adolescents have not reached neurophysiological maturity and cannot be held accountable for their crimes to the same extent as adults.

Whatever your college major or career goals, knowledge of biological concepts is a vital tool for understanding this world and for meeting many of the personal, societal, and global challenges that confront us. Among these challenges are decreasing biological diversity, diminishing natural resources, the expanding human population, and prevention and cure of diseases, such as cancer, Alzheimer's disease, malaria, acquired immunodeficiency syndrome (AIDS), and avian flu. Meeting these challenges will require the combined efforts of biologists and other scientists, politicians, and biologically informed citizens.

This book is a starting point for an exploration of biology. It provides you with the basic knowledge and the tools to become a part of this fascinating science and a more informed member of society. ■

THREE BASIC THEMES

Learning Objective

1 Describe three basic themes of biology.

In this first chapter we introduce three basic themes of biology:

1. **Evolution.** Populations of organisms have evolved through time from earlier forms of life. Scientists have accumulated a wealth of evidence showing that the diverse life-forms on this planet are related and that populations have *evolved,* that is, have changed over time, from earlier forms of life. The process of *evolution* is the framework for the science of biology and is a major theme of this book.
2. **Information transfer.** Information must be transmitted within organisms and among organisms. The survival and function of every cell and every organism depend on the orderly transmission of information. Evolution depends on the transmission of genetic information from one generation to another.
3. **Energy for life.** Energy from the sun flows through living systems from producers to consumers. All life processes, including the thousands of chemical transactions that maintain life's organization, require a continuous input of energy.

Evolution, information transmission, and energy flow are forces that give life its unique characteristics. We begin our study of biology by developing a more precise understanding of the fundamental characteristics of living systems.

Review

- Why are evolution, information transfer, and energy considered basic to life?
- What does the term *evolution* mean as applied to populations of organisms?

CHARACTERISTICS OF LIFE

Learning Objective

2 Distinguish between living and nonliving things by describing the features that characterize living organisms.

We easily recognize that a pine tree, a butterfly, and a horse are living things, 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, the ability to respond to stimuli, reproduction, and adaptation to environmental change.

Organisms are composed of cells

Although they vary greatly in size and appearance, all organisms consist of basic units called **cells.** New cells are formed only by the division of previously existing cells. These concepts are expressed in the **cell theory** (discussed in Chapter 4), a fundamental unifying concept of biology.

Some of the simplest life-forms, such as protozoa, are **unicellular** organisms, meaning that each consists of a single cell (Fig. 1-1). In contrast, the body of a cat or a maple tree is made of billions of cells. In such complex **multicellular** organisms, life processes depend on the coordinated functions of component

Mike Abbey/Visuals Unlimited

(a) Unicellular organisms consist of one intricate cell that performs all the functions essential to life. Ciliates, such as this *Paramecium*, move about by beating their hairlike cilia.

McMurray Photography

(b) Multicellular organisms, such as this African buffalo (*Syncerus caffer*) and the plants on which it grazes, may consist of billions of cells specialized to perform specific functions.

Figure 1-1 Unicellular and multicellular life-forms

cells that may be organized to form tissues, organs, and organ systems.

Every cell is enveloped by a protective **plasma membrane** that separates it from the surrounding external environment. The plasma membrane regulates passage of materials between cell and environment. Cells have specialized molecules that contain genetic instructions and transmit genetic information. In most cells, the genetic instructions are encoded in deoxyribonucleic acid, more simply known as **DNA.** Cells typically have internal structures called **organelles** that are specialized to perform specific functions.

There are two fundamentally different types of cells: prokaryotic and eukaryotic. **Prokaryotic cells** are exclusive to bacteria and to microscopic organisms called *archaea.* All other organisms are characterized by their **eukaryotic cells.** These cells typically contain a variety of organelles enclosed by membranes, including a **nucleus,** which houses DNA. Prokaryotic cells are structurally simpler; they do not have a nucleus or other membrane-enclosed organelles.

Organisms grow and develop

Biological growth involves an increase in the size of individual cells of an organism, in the number of cells, or in both. 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. An intriguing aspect of the growth process is that each part of the organism typically continues to function as it grows.

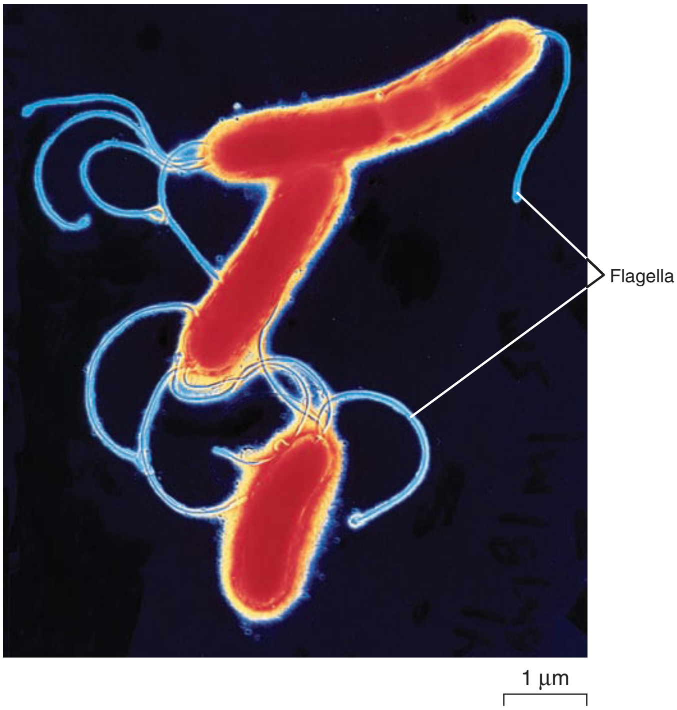
Living organisms develop as well as grow. **Development** includes all the changes that take place during an organism's life. Like many other organisms, every human begins life as a fertilized egg that then grows and develops. The structures and body form that develop are exquisitely adapted to the functions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

Organisms regulate their metabolic processes

Within all organisms, chemical reactions and energy transformations occur that are essential to nutrition, the growth and repair of cells, and the 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 organism, and they must be carefully regulated to maintain **homeostasis,** an appropriate, balanced internal environment. When enough of a cell product has been made, its manufacture must be decreased or turned off. When a particular substance is required, cell 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. Your cells require a constant supply of glucose, which they break down to obtain energy. The circulatory system delivers glucose and other nutrients to all the cells. When the concentration of glucose in the blood rises above normal limits, glucose is stored in the liver and in muscle cells. When you have not eaten for a few hours, the glucose concentration begins to fall. Your body converts stored nutrients to glucose, bringing the glucose concentration in the blood back to normal levels. When the glucose concentration decreases, you also feel hungry and restore nutrients by eating.



A. B. Dowsett/Science Photo Library/Photo Researchers, Inc.

Figure 1-2 Biological movement

These bacteria (*Helicobacter pylori*), equipped with flagella for locomotion, have been linked to stomach ulcers. The photograph was taken using a scanning electron microscope. The bacteria are not really red and blue. Their color has been artificially enhanced.

Organisms respond to stimuli

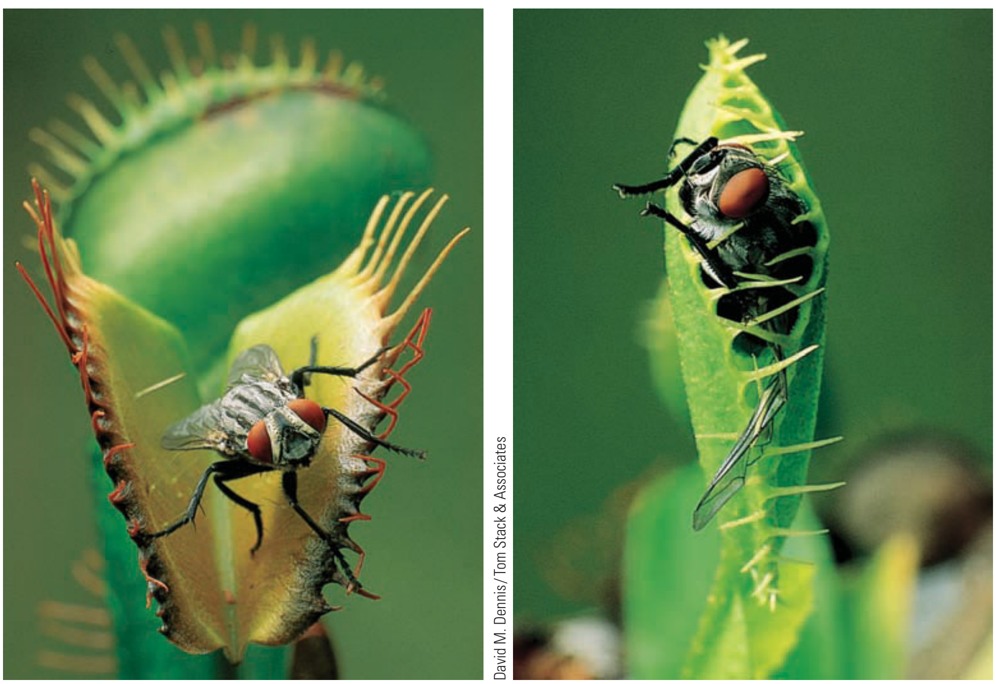
All forms of life respond to **stimuli,** physical or chemical changes in their internal or external environment. Stimuli that evoke a response in most organisms are changes in the color, intensity, or direction of light; changes in temperature, pressure, or sound; and changes in the chemical composition of the surrounding soil, air, or water. Responding to stimuli involves movement, though not always locomotion (moving from one place to another).

In simple organisms, the entire individual may be sensitive to stimuli. Certain unicellular organisms, for example, respond to bright light by retreating. In some organisms, locomotion is achieved by the slow oozing of the cell, the process of *amoeboid movement.* Other organisms move by beating tiny, hairlike extensions of the cell called **cilia** or longer structures known as **flagella** (Fig. 1-2). Some bacteria move by rotating their flagella.

Most animals move very obviously. They wiggle, crawl, swim, run, or fly by contracting muscles. Sponges, corals, and oysters have free-swimming larval stages, but most are **sessile** as adults, meaning that they do not move from place to place. In fact, they may remain firmly attached to a surface, such as the sea bottom or a rock. Many sessile organisms have cilia or flagella that beat rhythmically, moving the surrounding water, which contains the food and oxygen the organisms require. Complex animals, such as grasshoppers, lizards, and humans, have highly specialized cells that respond to specific types of stimuli. For example, cells in the retina of the human 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. For example, plants orient their leaves to the sun and grow toward light. Many plant responses involve different growth rates of various parts of the plant body.

A few plants, such as the Venus flytrap of the Carolina swamps, are very sensitive to touch and catch insects (Fig. 1-3). 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 insect and stimulate the leaf to fold. When the edges come together, they interlock, preventing the insect's escape. The leaf then secretes enzymes that kill and digest the insect. The Venus flytrap usually grows in soil deficient in nitrogen. The plant obtains part of the nitrogen required for its growth from the insects it "eats."



David M. Dennis/Tom Stack & Associates

David M. Dennis/Tom Stack & Associates

(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.

Figure 1-3 Plants respond to stimuli