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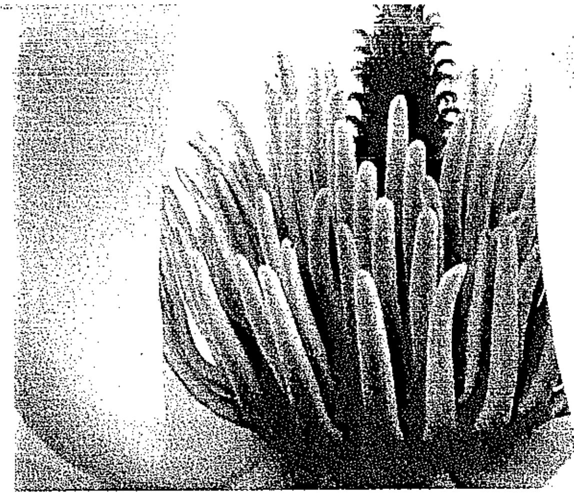
Introduction: Themes in the Study of Life



▲ **Figure 1.1 What properties of life are demonstrated by this flower?**

KEY CONCEPTS

1.1 Themes connect the concepts of biology

1.2 *The Core Theme:* Evolution accounts for the unity and diversity of life

1.3 Scientists use two main forms of inquiry in their study of nature

OVERVIEW

Inquiring About the World of Life

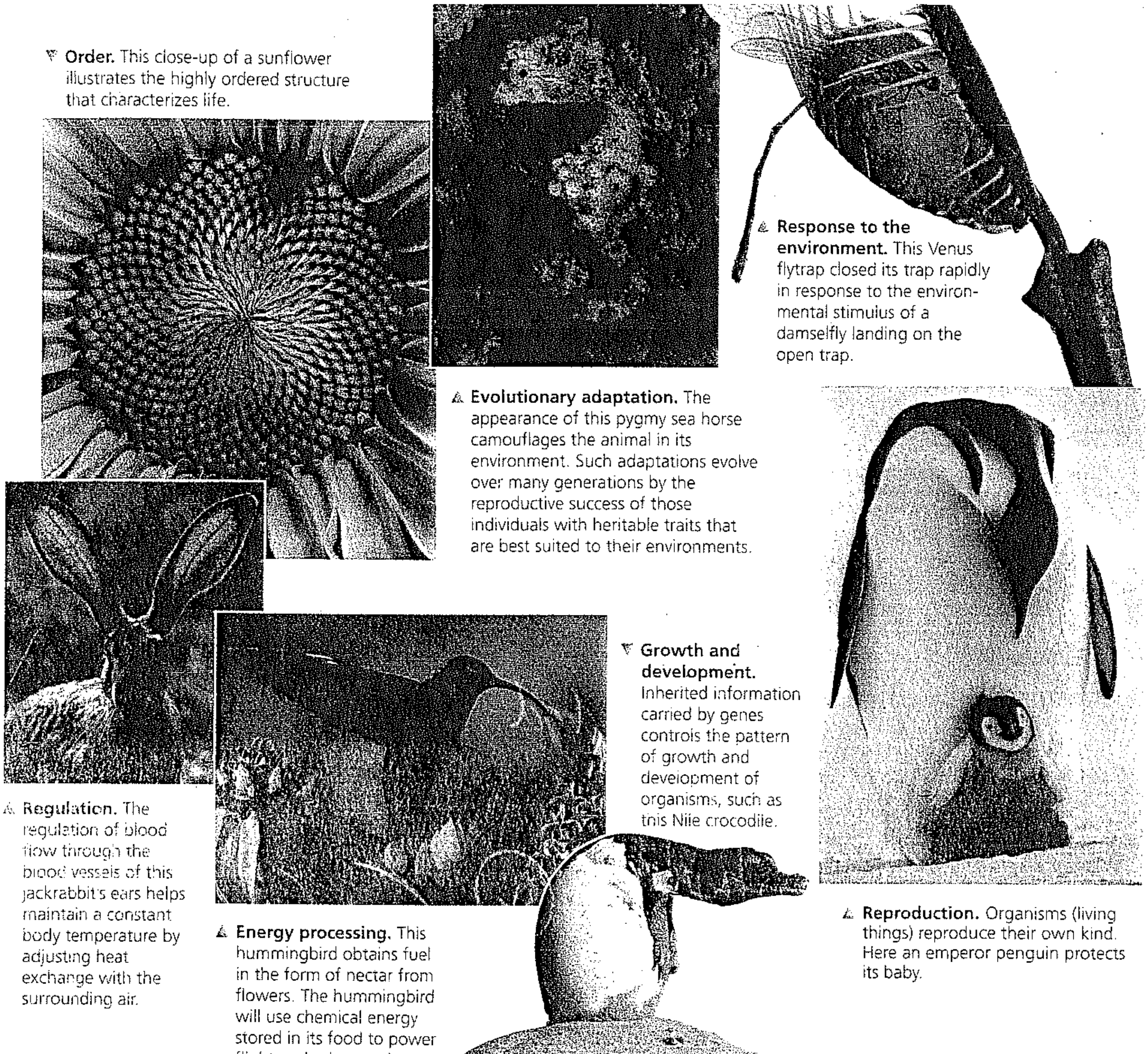
The flower featured on the cover of this book and in **Figure 1.1** is from a magnolia, a tree of ancient lineage that is native to Asian and American forests. The magnolia blossom is a sign of the plant's status as a living organism, for flowers contain organs of sexual reproduction, and reproduction is a key property of life, as you will learn later.

Like all organisms, the magnolia tree in **Figure 1.2** is living in close association with other organisms, though it is a lone specimen far from its ancestral forest. For example, it depends on beetles to carry pollen from one flower to another, and the beetles, in turn, eat from its flowers. The flowers are adapted to the beetles in several ways: Their bowl shape allows easy access, and their multiple reproductive organs and tough petals (see Figure 1.1) help ensure that some survive the voracious beetles. Such adaptations are the result of **evolution**, the process of change that has transformed life on Earth from its earliest beginnings to the diversity of organisms living today. As discussed later in this chapter, evolution is the fundamental organizing principle of biology and the main theme of this book.

Although biologists know a great deal about magnolias and other plants, many mysteries remain. For instance, what exactly led to the origin of flowering plants? Posing questions about the living world and seeking science-based answers—scientific inquiry—are the central activities of **biology**, the scientific study of life. Biologists' questions can be ambitious. They may ask how a single tiny cell becomes a tree or a dog, how the human mind works, or how the different forms of life in a forest interact. Can you think of some questions about living organisms that interest you? When you do, you are already starting to think like a biologist. More than anything else, biology is a quest, an ongoing inquiry about the nature of life.

Perhaps some of your questions relate to health or to societal or environmental issues. Biology is woven into the fabric of our culture more than ever before and can help answer many questions that affect our lives. Research breakthroughs in genetics and cell biology are transforming medicine and agriculture. Neuroscience and evolutionary biology are reshaping psychology and sociology. New models in ecology are helping societies evaluate environmental issues, such as global warming. There has never been a more important time to embark on a study of life.

▲ **Figure 1.2 A magnolia tree in early spring.**



Order. This close-up of a sunflower illustrates the highly ordered structure that characterizes life.

Evolutionary adaptation. The appearance of this pygmy sea horse camouflages the animal in its environment. Such adaptations evolve over many generations by the reproductive success of those individuals with heritable traits that are best suited to their environments.

Response to the environment. This Venus flytrap closed its trap rapidly in response to the environmental stimulus of a damselfly landing on the open trap.

Regulation. The regulation of blood flow through the blood vessels of this jackrabbit's ears helps maintain a constant body temperature by adjusting heat exchange with the surrounding air.

Energy processing. This hummingbird obtains fuel in the form of nectar from flowers. The hummingbird will use chemical energy stored in its food to power flight and other work.

Growth and development. Inherited information carried by genes controls the pattern of growth and development of organisms, such as this Nile crocodile.

Reproduction. Organisms (living things) reproduce their own kind. Here an emperor penguin protects its baby.

Figure 1.3 Some properties of life.

Is a gasoline-powered lawn mower alive? Which of these properties does it have? Which properties does it lack?

But what is life? Even a small child realizes that a dog or a plant is alive, while a rock is not. Yet the phenomenon we call life defies a simple, one-sentence definition. We recognize life by what living things do. **Figure 1.3** highlights some of the properties and processes we associate with life.

While limited to a handful of images, Figure 1.3 reminds us that the living world is wondrously varied. How do biologists make sense of this diversity and complexity? This opening chapter sets up a framework for answering this question. The first part of the chapter provides a panoramic view of the biological "landscape," organized around some unifying themes. We then focus on biology's overarching theme, evolution, with an introduction to the reasoning that led Charles Darwin to his explanatory theory. Finally, we look at scientific inquiry—how scientists raise and attempt to answer questions about the natural world.

Themes connect the concepts of biology

Biology is a subject of enormous scope, and anyone who follows the news knows that biological knowledge is expanding at an ever-increasing rate. Simply memorizing the factual details of this huge subject is not a reasonable option. How, then, can you, as a student, go beyond the facts to develop a coherent view of life? One approach is to fit the many things you learn into a set of themes that pervade all of biology—ways of thinking about life that will still apply decades from now. Focusing on a few big ideas will help you organize and make sense of all the information you'll encounter as you study biology. To help you, we have selected seven unifying themes to serve as touchstones as you proceed through this book.

Evolution, the Overarching Theme of Biology

Evolution is biology's core theme—the one idea that makes sense of everything we know about living organisms. Life has been evolving on Earth for billions of years, resulting in a vast diversity of past and present organisms. But along with the diversity we find many shared features. For example, while the sea horse, jackrabbit, hummingbird, crocodile, and penguins in Figure 1.3 look very different, their skeletons are basically similar. The scientific explanation for this unity and diversity—and for the suitability of organisms to their environments—is evolution: the idea that the organisms living on Earth today are the modified descendants of common ancestors. In other words, we can explain traits shared by two organisms with the idea that they have descended from a common ancestor, and we can account for differences with the idea that heritable changes have occurred along the way. Many kinds of evidence support the occurrence of evolution and the theory that describes how it takes place. We'll return to evolution later in the chapter, after surveying some other themes and painting a fuller picture of the scope of biology.

Theme: New properties emerge at each level in the biological hierarchy

The study of life extends from the microscopic scale of the molecules and cells that make up organisms to the global scale of the entire living planet. We can divide this enormous range into different levels of biological organization.

Imagine zooming in from space to take a closer and closer look at life on Earth. It is spring, and our destination is a forest in Ontario, Canada, where we will eventually explore a maple leaf right down to the molecular level. **Figure 1.4** (on the next two pages) narrates this journey into life, with the circled numbers leading you through the levels of biological organization illustrated by the photographs.

Emergent Properties

If we now zoom back out from the molecular level in Figure 1.4, we can see that novel properties emerge at each step, properties that are not present at the preceding level. These **emergent properties** are due to the arrangement and interactions of parts as complexity increases. For example, if you make a test-tube mixture of chlorophyll and all the other kinds of molecules found in a chloroplast, photosynthesis will not occur. Photosynthesis can take place only when the molecules are arranged in a specific way in an intact chloroplast. To take another example, if a serious head injury disrupts the intricate architecture of a human brain, the mind may cease to function properly even though all of the brain parts are still present. Our thoughts and memories are emergent properties of a complex network of nerve cells. At a much higher level of biological organization—at the ecosystem level—the recycling of chemical elements essential to life, such as carbon, depends on a network of diverse organisms interacting with each other and with the soil, water, and air.

Emergent properties are not unique to life. We can see the importance of arrangement in the distinction between a box of bicycle parts and a working bicycle. And while graphite and diamonds are both pure carbon, they have very different properties because their carbon atoms are arranged differently. But compared to such nonliving examples, the unrivaled complexity of biological systems makes the emergent properties of life especially challenging to study.

The Power and Limitations of Reductionism

Because the properties of life emerge from complex organization, scientists seeking to understand biological systems confront a dilemma. On the one hand, we cannot fully explain a higher level of order by breaking it down into its parts. A dissected animal no longer functions; a cell reduced to its chemical ingredients is no longer a cell. Disrupting a living system interferes with its functioning. On the other hand, something as complex as an organism or a cell cannot be analyzed without taking it apart.

Reductionism—the reduction of complex systems to simpler components that are more manageable to study—is a powerful strategy in biology. For example, by studying the molecular structure of DNA that had been extracted from cells, James Watson and Francis Crick inferred, in 1953, how this molecule could serve as the chemical basis of inheritance. The central role of DNA in cells and organisms became better understood, however, when scientists were able to study the interactions of DNA with other molecules. Biologists must balance the reductionist strategy with the larger-scale, holistic objective of understanding emergent properties—how the parts of cells, organisms, and higher levels of order, such as ecosystems, work together. At the cutting edge of research today is the approach called systems biology.

Exploring Levels of Biological Organization

◄ 1 The Biosphere

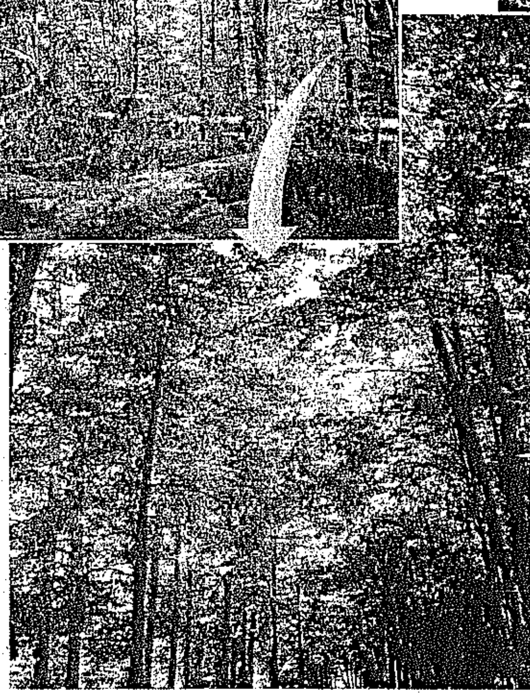
As soon as we are near enough to Earth to make out its continents and oceans, we begin to see signs of life—in the green mosaic of the planet's forests, for example. This is our first view of the biosphere, which consists of all the environments on Earth that are inhabited by life. The biosphere includes most regions of land, most bodies of water, and the atmosphere to an altitude of several kilometers.

◄ 2 Ecosystems

As we approach Earth's surface for an imaginary landing in Ontario, we can begin to make out a forest with an abundance of deciduous trees (trees that lose their leaves in one season and grow new ones in another). Such a deciduous forest is an example of an ecosystem. Grasslands, deserts, and the ocean's coral reefs are other types of ecosystems. An ecosystem consists of all the living things in a particular area, along with all the nonliving components of the environment with which life interacts, such as soil, water, atmospheric gases, and light. All of Earth's ecosystems combined make up the biosphere.

► 3 Communities

The entire array of organisms inhabiting a particular ecosystem is called a biological community. The community in our forest ecosystem includes many kinds of trees and other plants, a diversity of animals, various mushrooms and other fungi, and enormous numbers of diverse microorganisms, which are living forms, such as bacteria, that are too small to see without a microscope. Each of these forms of life is called a *species.*



► 4 Populations

A population consists of all the individuals of a species living within the bounds of a specified area. For example, our Ontario forest includes a population of sugar maple trees and a population of white-tailed deer. We can now refine our definition of a community as the set of populations that inhabit a particular area.

▲ 5 Organisms

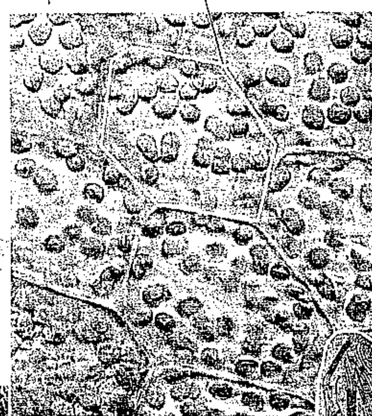
Individual living things are called organisms. Each of the maple trees and other plants in the forest is an organism, and so is each forest animal, such as a frog, squirrel, deer, and beetle. The soil teems with microorganisms such as bacteria.

▾ 6 Organs and Organ Systems

The structural hierarchy of life continues to unfold as we explore the architecture of the more complex organisms. A maple leaf is an example of an organ, a body part consisting of two or more tissues (which we'll see upon our next scale change). An organ carries out a particular function in the body. Stems and roots are the other major organs of plants. Examples of human organs are the brain, heart, and kidney. The organs of humans, other complex animals, and plants are organized into organ systems, each a team of organs that cooperate in a specific function. For example, the human digestive system includes such organs as the tongue, stomach, and intestines.

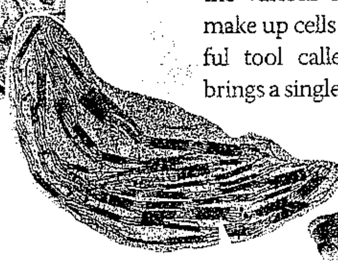
▾ 8 Cells

The cell is life's fundamental unit of structure and function. Some organisms, such as amoebas and most bacteria, are single cells. Other organisms, including plants and animals, are multicellular. Instead of a single cell performing all the functions of life, a multicellular organism has a division of labor among specialized cells. A human body consists of trillions of microscopic cells of many different kinds, such as muscle cells and nerve cells, which are organized into the various specialized tissues. For example, muscle tissue consists of bundles of muscle cells. In the photo below, we see a more highly magnified view of some of the cells in a leaf tissue. Each of the cells is only about 25 micrometers (µm) across. It would take more than 700 of these cells to reach across a penny. As small as these cells are, you can see that each contains numerous green structures called chloroplasts, which are responsible for photosynthesis.

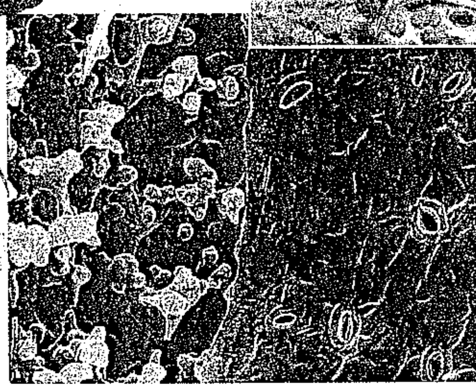


▾ 9 Organelles

Chloroplasts are examples of organelles, the various functional components that make up cells. In this image, a very powerful tool called an electron microscope brings a single chloroplast into sharp focus.

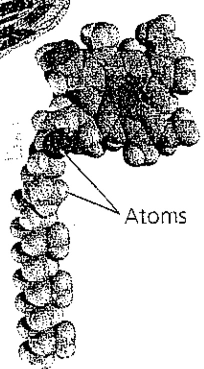


▸ 7 Tissues



Our next scale change—to see a leaf's tissues—requires a microscope. The leaf shown here has been cut on an angle. The honeycombed tissue in the interior of the leaf (left portion of photo) is the main location of photosynthesis, the process that converts light energy to the chemical energy of sugar and other food. We are viewing the sliced leaf from a perspective that also enables us to see the jigsaw puzzle–like tissue called epidermis, the "skin" on the surface of the leaf (right part of photo). The pores through the epidermis allow the gas carbon dioxide, a raw material for sugar production, to reach the photosynthetic tissue inside the leaf. At this scale, we can also see that each tissue has a cellular structure. In fact, each kind of tissue is a group of similar cells.

▸ 10 Molecules



Our last scale change vaults us into a chloroplast for a view of life at the molecular level. A molecule is a chemical structure consisting of two or more small chemical units called *atoms*, which are represented as balls in this computer graphic of a chlorophyll molecule. Chlorophyll is the pigment molecule that makes a maple leaf green. One of the most important molecules on Earth, chlorophyll absorbs sunlight during the first step of photosynthesis. Within each chloroplast, millions of chlorophylls and other molecules are organized into the equipment that converts light energy to the chemical energy of food.