It is important to remember that all living things are either prokaryotes or eukaryotes. Note, however, that viruses are neither, since they are not living organisms. Viruses are fragments of nucleic acid packaged in a protein shell. Nevertheless we consider them "microorganisms" because of their infectious nature. In the following sections, we shall summarize other significant properties of the major groups of microorganisms.

BACTERIA

The term **bacteria** is a plural form of the Latin *bacterium,* meaning "staff" or "rod." Bacteria are prokaryotes and are among the most abundant organisms on Earth. The vast majority play a positive role in nature: They digest sewage into simple chemicals, they extract nitrogen from the air and make it available to plants for protein production, they break down the remains of all that die and recycle the carbon and other elements, and they produce foods for human consumption and products for industrial technology. Many biologists believe that life as we know it would be impossible without the bacteria.

Toxin:
a chemical substance poisonous to body tissues.

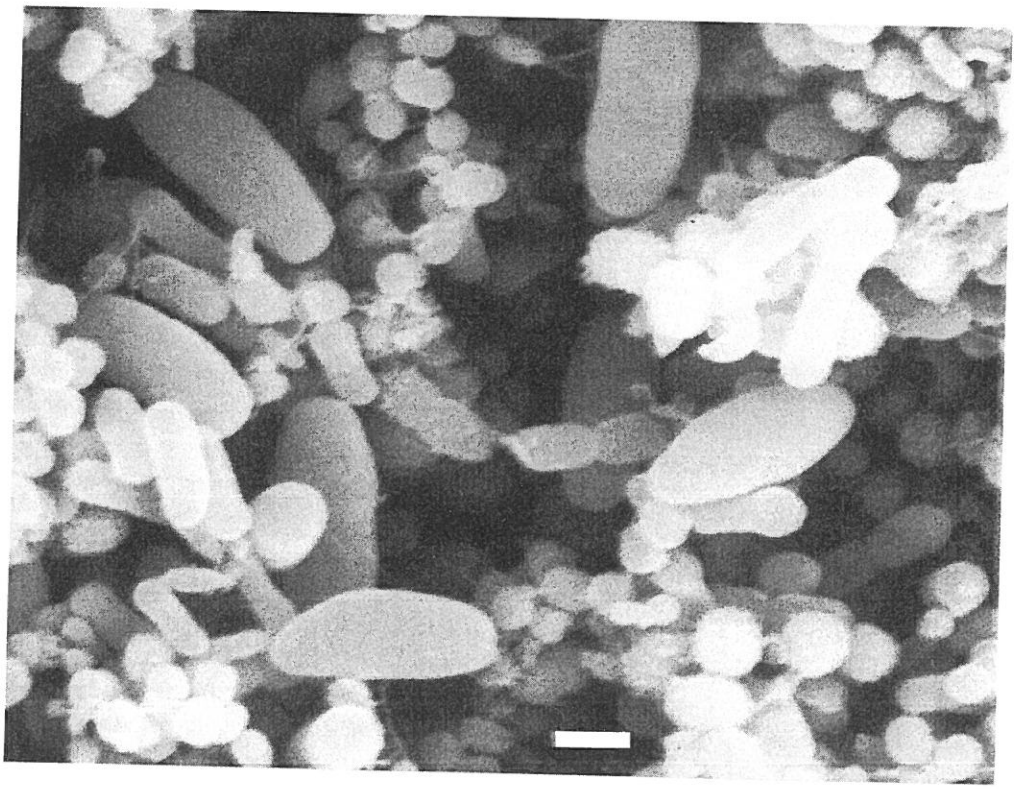
Of course, some bacteria are harmful. Certain species multiply within the human body, where they digest the tissues or produce toxins that result in disease. Other bacteria infect plant crops and animal herds. Disease-causing bacteria (i.e., pathogenic bacteria) are a global threat to all forms of life.

Bacteria have adapted to more different living conditions than any other group of organisms. They inhabit the air, soil, and water, and they exist in enormous numbers on the surfaces of virtually all plants and animals. They can be isolated from Arctic ice, thermal hot springs, the fringes of space, and the tissues of animals (FIGURE 3.2). Some can withstand the searing acid in volcanic ash, the crushing pressures of ocean trenches, and the powerful activity of digestive enzymes. Other bacteria sur-

FIGURE 3.2

Mixed Bacteria

An electron microscopic view of mixed bacteria from the gastrointestinal tract of a lamb. Rod and spherical forms in various sizes and shapes are visible. (Bar = 1 μm.)



MicroFocus 3.2

AN UNKNOWN WORLD

Practically everyone is familiar with the word *bacteria*, but it may surprise you that hardly anyone really knows the bacteria. Yes, bacteria have been thoroughly studied in medicine, ecology, and molecular genetics, but the vast majority of bacteria remain unknown to science.

Hold a pinch of rich soil in the palm of your hand. You are now face to face with an estimated billion bacteria representing some 10,000 different species. If you were to try cultivating them using the most sophisticated methods available, perhaps 500 species might grow. That leaves 9500 species unknown until the right combinations of nutrients and environmental conditions are established in the laboratory.

Traditionally, *Bergey's Manual* has been the most authoritative guide to bacterial species. About 4000 species are listed in this book, a far cry from the thousands more believed to exist. Those who believe there are no more worlds to conquer should take note.

vive in oxygen-free environments, boiling water, and extremely dry locations. Bacteria have so completely invaded every part of the Earth that the mass of bacterial cells is estimated to outweigh the mass of all plants and animals combined (MicroFocus 3.2). Chapters 4, 5, and 6 are devoted to the structure, growth, biochemistry, and genetics of bacteria, and Chapters 7 through 10 discuss the diseases they cause.

RICKETTSIAE, CHLAMYDIAE, AND MYCOPLASMAS

Rickettsiae (sing., rickettsia), chlamydiae, and mycoplasmas are also prokaryotes. Until the early 1970s these microorganisms were considered apart from the bacteria, but contemporary microbiologists now classify them as "small bacteria." Unfortunately, old habits linger and some microbiologists still think of them as distinct groups, which is why we separate them here.

Rickettsiae were first described by Howard Taylor Ricketts in 1909. These tiny bacteria can barely be seen with the most sophisticated light microscope and they are transmitted among humans primarily by arthropods such as ticks and lice. They are cultivated only in living tissues such as fertilized eggs, and different species cause a number of important diseases, including Rocky Mountain spotted fever and typhus fever. Chapter 9 contains a more thorough description of their properties.

rik-et'se-e

Arthropods: animals with jointed appendages and a hard outer skeleton; examples are mosquitoes, ticks, and fleas.

Chlamydiae (sing., chlamydia) are roughly half the size of the rickettsiae and are so small that they cannot be seen with the light microscope. The chlamydiae can be cultivated within living cells, and one species causes the gonorrhealike disease known as chlamydia. This and several other chlamydial diseases are described in Chapters 7 and 10.

klah-mid'e-a

Mycoplasmas are another notch smaller than chlamydiae and are possibly the smallest known bacteria (TABLE 3.2). They can be cultivated outside living tissues in artificial laboratory media, and, although they are prokaryotes, they do not have cell walls like other bacteria. One form of pneumonia is caused by a mycoplasma (Chapter 7) and one sexually transmitted disease (Chapter 10) is a mycoplasmal illness.

CYANOBACTERIA

In older textbooks, **cyanobacteria** were known as blue-green algae. Today these microorganisms are considered bacteria because structural and biochemical properties are similar. However, cyanobacteria are not unique because of fundamental differences in how they form carbohydrates in photosynthesis (Chapter 5).

si'ah-no-bak-ter'e-ah

Photosynthesis:
a chemical process in which light energy is used to form chemical bonds in carbohydrate molecules.

Cyanobacteria are prokaryotes. They possess light-trapping pigments that function in photosynthesis taking place in the cell. Many of the pigments are blue, but some are black, yellow, green, or red. The periodic redness of the Red Sea, for example, is due to a species of cyanobacteria whose members contain large amounts of red pigment.

Cyanobacteria may occur as unicellular or filamentous organisms. Many species are able to incorporate atmospheric nitrogen (they "fix" nitrogen) into organic compounds useful to plants, thereby filling an important ecological niche. Cyanobacteria inhabit freshwater as well as marine environments. When ponds or lakes contain a rich supply of nutrients, the organisms may "bloom" and convert the water to a pea-soup green with a foul odor. Swimming pools and aquaria experience this problem if algicide is not used regularly.

PROTOZOA

Protozoa (sing., protozoan) are single-celled eukaryotes, most of which lack cell walls, ingest food particles, and move about freely. Many protozoal species join with other microorganisms to decompose dead organisms and recycle nutrients. Indeed, numerous species are important links in the food chain as they convert nutritionally inaccessible materials into protozoal substances easily digested by other organisms. In some plant-eating animals (e.g., cattle, goats, and other ruminants), protozoa live in the digestive tract and, along with bacteria, enable the animals to use grass and other high-cellulose foods they could not otherwise digest.

Cellulose:
a polysaccharide of plant cell walls normally indigestible by humans.

Protozoa exhibit a bewildering assortment of shapes, sizes, and structural components (FIGURE 3.3). A few species have the necessary pigments for photosynthesis and can therefore synthesize their own foods. Most protozoal species, however, must obtain nutrients from preformed organic matter. Protozoa are classified into groups according to how they move. Some have whiplike flagella, others possess hairlike cilia, and still others move by means of cytoplasmic extensions called pseudopodia ("false feet").

soo'do-po'de-ah

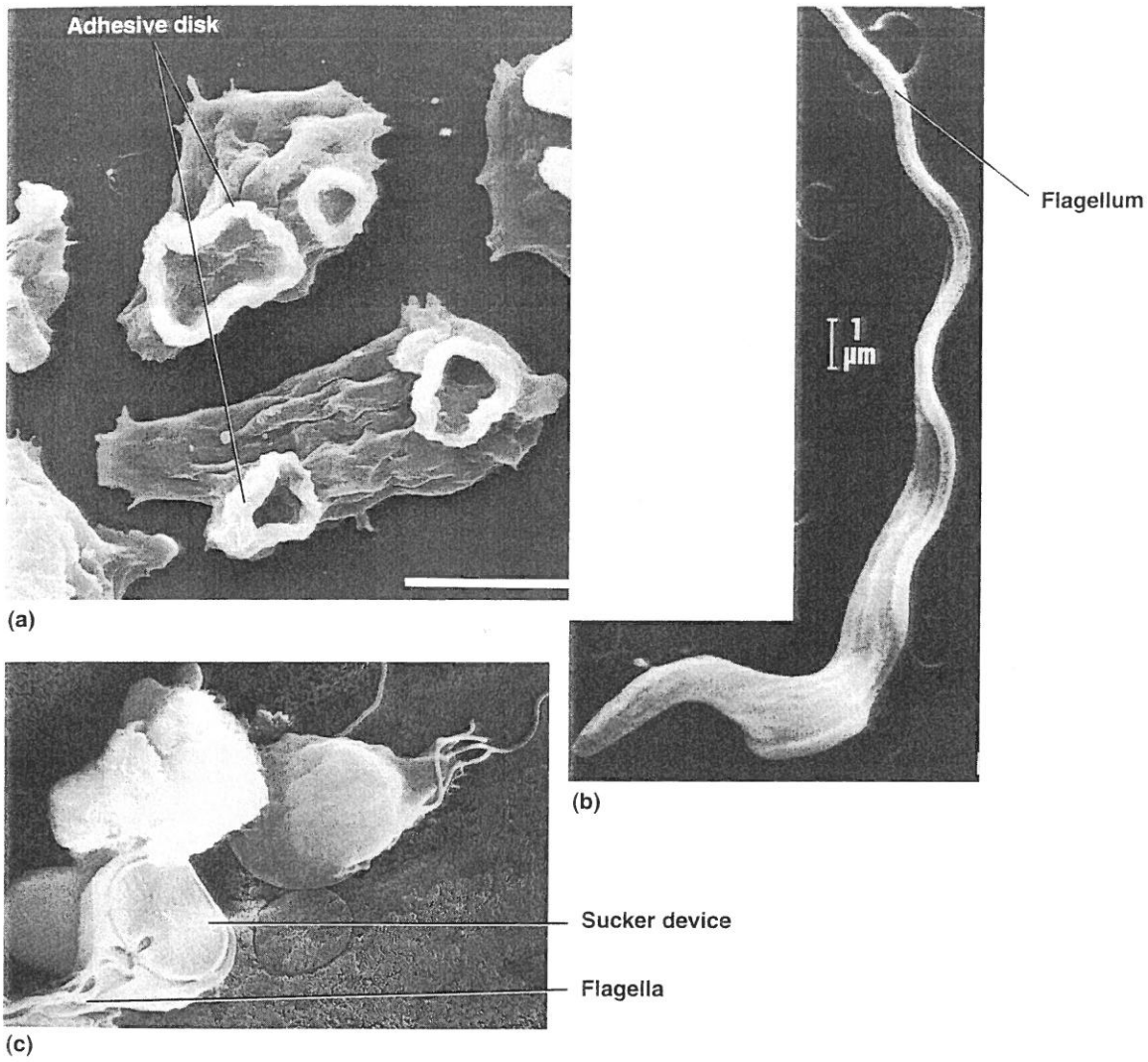


FIGURE 3.3

Three Species of Protozoa

Electron micrographs of three species of protozoa illustrating differences in shape and size. (a) The amoeba *Naegleria fowleri*, a cause of meningitis in humans. Note the irregular shape of this organism. (Bar = 5 µm.) (b) A protozoan called a trypanosome. The elongated shape and hairlike appendage (flagellum) are apparent. This organism causes African sleeping sickness. (c) Another flagellated protozoan, *Giardia lamblia* (×8026). The organism has a flat shape with multiple flagella extending toward the rear. The protozoan on the left shows the sucker device on its lower surface for holding fast to tissue. *Giardia* causes diarrhea in humans.

Although most protozoa are harmless to humans, some species are feared because they are pathogenic. Among the more notorious protozoal species are those that cause malaria of the blood and sleeping sickness in the nervous system. Other species are waterborne and cause such diseases as giardiasis, amoebic dysentery, and cryptosporidiosis (FIGURE 3.4). In recent years, the protozoan *Pneumocystis carinii* has been thrust into the headlines as a major cause of death in people with AIDS. We shall study protozoal diseases in depth in Chapter 15.

Malaria:
a mosquitoborne blood disease in which protozoa multiply within and destroy red blood cells.

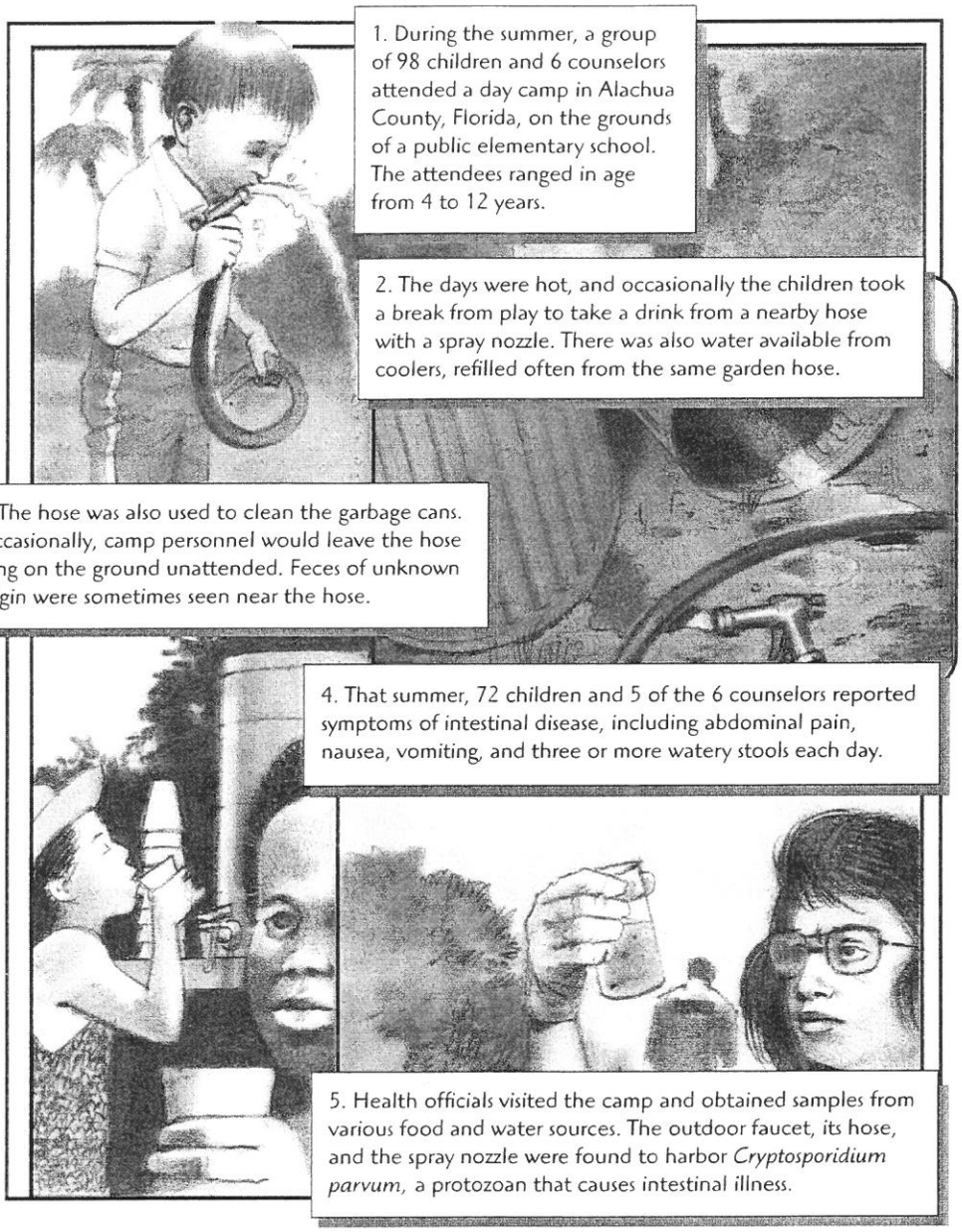
ji-ar-di'a-sis

nu'mo-sis'tis car-in'i-i

FIGURE 3.4

An Outbreak of Intestinal Disease at a Summer Day Camp

This outbreak occurred in Florida during July and August 1996. Health officials recommended measures to restrict access to the hose believed to be the source of the outbreak.



TEXTBOOK CASES

FUNGI

fun'jī

kī'tin
Chitin:
a carbohydrate substance found in the cell wall of fungi.

Because of their distinctive cell walls, **fungi** were once considered members of the plant kingdom (indeed, many botany books and courses still discuss the fungi in detail). However, researchers have found the carbohydrate chitin in the fungal cell wall but not in the plant cell wall. Moreover, fungi do not synthesize nutrients by photosynthesis; instead they use preformed organic matter from the environment as a nutritional strategy. These characteristics, among others, separate them from plants.

Fungi are eukaryotic organisms often spoken of in two broad groups: the yeasts and the molds (FIGURE 3.5). **Yeasts** are unicellular organisms larger than bacteria. They play a vital role in the fermentation of wine and beer and the production of bread. **Molds** are long chains of cells often seen as fuzzy or fluffy masses on bread and other food products, especially acidic products. Commonly the molds assume vivid colors from the pigments in spores they produce for reproductive purposes. The chains of cells are called hyphae (sing., hypha). Cells of the hypha are highly efficient exploiters of available nutrients—during periods of peak growth, a mold can grow more than a half-mile of new hyphae in a single day. (Incidentally, the word *mold* has no technical significance, but we use it because it is ingrained in the English language.)

hi'fā

Fungi are among the major decomposers of organic matter in the world. Yet a few fungal species do not wait for an organism to die before they start consuming it. These are the pathogenic fungi, which cause some of the most common and persistent challenges to modern medicine. More than 20 percent of the world's population suffers from fungal disease, ranging from irritating maladies of the skin and mucous membranes (e.g., athlete's foot and yeast infection) to life-threatening diseases such as cryptococcosis. Chapter 14 discusses these diseases in more detail.

krip'to-kok-o'sis

UNICELLULAR ALGAE

The word **algae** (sing., alga) refers to any plantlike organisms that practice photosynthesis and differ structurally from typical land plants such as mosses, ferns, and seed plants. Two types of unicellular algae, the diatoms and the dinoflagellates, are important in microbiology.

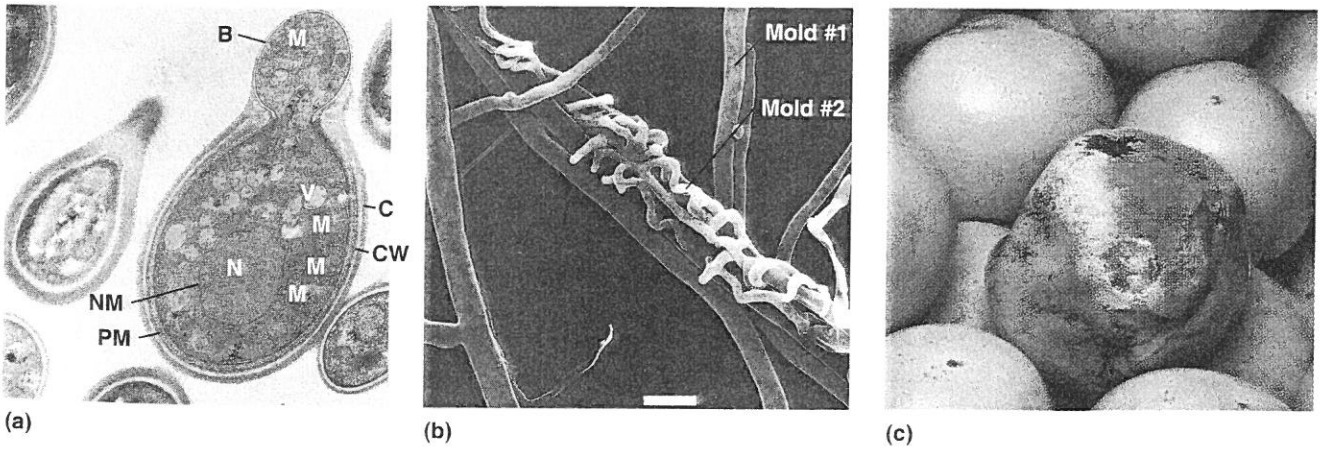


FIGURE 3.5

Three Views of Fungi

(a) A transmission electron micrograph of a yeast cell showing typical eukaryotic features. Note the cell wall (CW), capsule (C), and plasma membrane (PM) on the cell surface. In the cytoplasm, clear bodies called vacuoles (V) and mitochondria (M) may be seen. The nucleus (N) is surrounded by a nuclear membrane (NM). In the upper portion of the photograph, a reproductive structure, the bud (B), is growing out from the parent cell. (b) Two molds, one wrapped around the other, in a parasitic relationship. The long filamentous form of each mold and the many branches are visible (Bar = 10 μm.) (c) A mold growing on a grapefruit.

di'ah-tomz

Diatoms are eukaryotic microorganisms and an important source of food in the world's oceans. Through photosynthesis, they trap the sun's energy and manufacture carbohydrates, which are passed on to other marine organisms as food. The cell walls of diatoms are impregnated with silicon dioxide, a glasslike substance. When diatoms die, their remains accumulate on the seafloor as diatomaceous earth. The latter is gathered and used to produce filters. **Dinoflagellates** are a group of photosynthetic eukaryotes composed of amoebas encased in hard shells (hence the name *dino*). Dinoflagellates are important members of the world's food chains. They also cause the periodic red tides occurring in the oceans. Both diatoms and dinoflagellates are discussed in Chapter 25.

Diatomaceous earth: the remains of diatoms used in filtering materials.

VIRUSES

Viruses are neither prokaryotes nor eukaryotes, as we noted previously. Many microbiologists even question whether viruses are living organisms because they are noncellular. They do not grow, nor do they display any nutritional patterns. Viruses have no observable activity except replication, and they accomplish this function only within living cells. Indeed, outside a living cell, a virus is no more alive than a grain of sand.

Viruses are smaller than the tiniest bacteria, so small that an electron microscope is necessary to see them. The simplest forms consist of nothing more than nucleic acid and protein. The nucleic acid is either DNA or RNA, but not both. Constituting as few as seven genes, the nucleic acid is packed inside the protein, and it is released when the virus penetrates its host cell. By commandeering the host cell's structures and enzymes, the virus then replicates itself many hundreds of times, often destroying the cell in the process. As nearby cells are penetrated and destroyed, the tissues disintegrate. Tissue disintegration is common to all viral diseases, including influenza, AIDS, hepatitis, chickenpox, herpes simplex, and rabies (FIGURE 3.6). We shall pay considerable attention to the structure and physiology of viruses in Chapter 11 and survey their diseases in Chapters 12 and 13.

Nucleic acid: a major organic substance composed of a carbohydrate (ribose or deoxyribose), a phosphate group, and any of five nitrogenous bases.

To this point . . .

We have begun our study of microbiology by placing microorganisms into the panorama of living things as prokaryotes or eukaryotes. Knowing whether an organism is a prokaryote or a eukaryote is important because it enables us to see microorganisms in relation to plants and animals, while giving us a glimpse of their properties. We then developed brief sketches of different microorganisms to observe the spectrum of forms studied in the chapters ahead. Viruses were included because they are important agents of disease, even though they are neither prokaryotes nor eukaryotes.

We shall now focus on some general properties that apply to all microorganisms. Included here are such properties as classification, nomenclature, and size. This study will serve as a prelude to studying individual characteristics of the groups of microorganisms in other chapters.