Microorganisms

Bacteria, Protista, and Fungi

24

CHAPTER 24

Chapter Outline

Key Concepts	Applications
Understand the basic differences among living things.	• Identify differences between organisms at a cellular level.
Know how microbes interact with other organisms.	• List many that are harmful and the diseases they cause.
Know the characteristics of the microbes.	• Know which organisms are microbes. • List the types of environments in which these organisms live. • Describe some that live in and on all humans.

24.1 Microorganisms

Members of the bacteria, Protista, and Fungi share several characteristics that set them apart from plants and animals. These are organisms that rely primarily on asexual reproduction. Some microbes are autotrophic, whereas many others are heterotrophic. Because the majority of organisms in these kingdoms are small and cannot be seen without some type of magnification, they are called **microorganisms,** or **microbes.**

There are only the most basic forms of cooperation among the different cells of microorganisms. Some microbes are free-living, single-celled organisms; others are collections of cells that cooperate to a limited extent. The latter types are called **colonial microbes.** The limited cooperation of individual cells within a colony may take several forms. Some cells within a colony may specialize for reproduction and others do not. Some colonial microbes coordinate their activities so that the colony moves as a unit. Some cells are specialized to produce chemicals that are nutritionally valuable to other cells in the colony.

Microbes are typically found in aquatic or very moist environments; most lack the specialization required to withstand drying. Because they are small, the moist habitat does not need to be large. Microbes can maintain huge populations in very small moist places like the skin of your armpits, temporary puddles, and tiled bathroom walls. Others have the special ability to become dormant and survive long periods without water. When moistened, they become actively growing cells again. The simplest of microbes are the bacteria.

24.2 Bacteria

The Domains Archaea and Eubacteria contain microorganisms that are commonly referred to as **bacteria.** Another common name for them is *germs*. Some unusual bacteria (the Archaea) have the genetic ability to function in extreme environments such as sulfur hot springs, on glaciers, and at the openings of submarine volcanic vents. They are single-celled prokaryotes that lack an organized nucleus and other complex organelles (figure 24.1). *Bergey's Manual of Determinative Bacteriology* first published in 1923 now lists in its latest edition over 2,000 species of bacteria and describes the subtle differences among them. As investigators have discovered more bacteria, they have come to suspect that the known species may represent only 1% of all the bacteria on Earth. For general purposes, bacteria are divided into the three groups based on such features as their staining properties, ability to form endospores, shape (morphology), motility, metabolism, and reproduction (How Science Works 24.1). Table 24.1 shows the most generally accepted taxonomy of the bacteria.

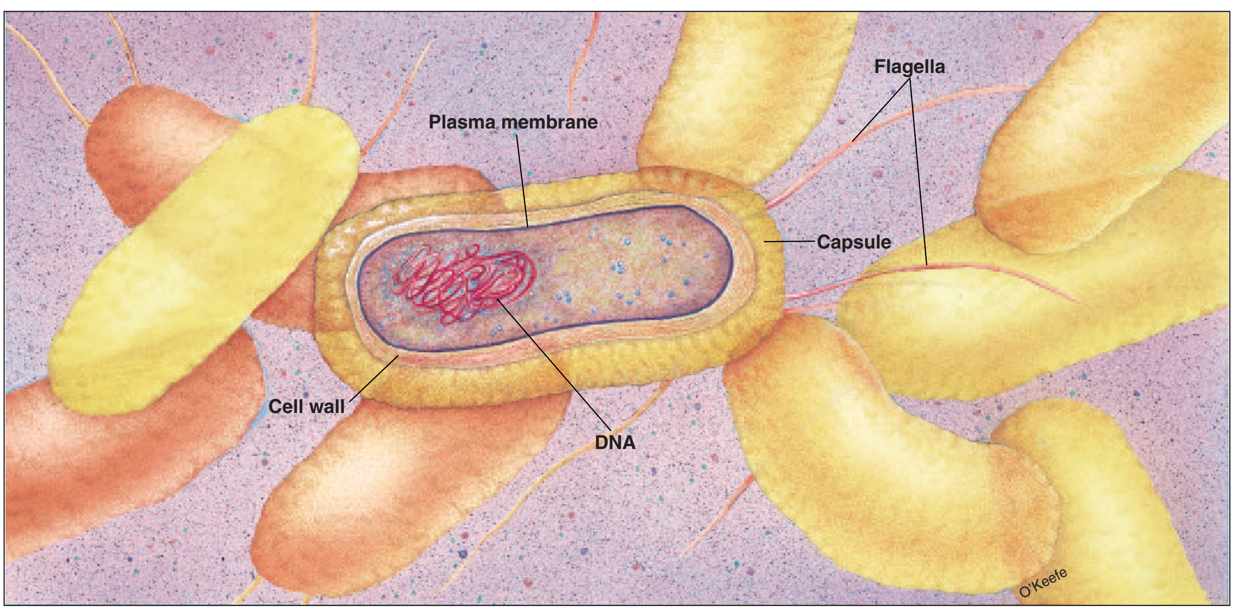


Figure 24.1

Bacteria Cell
The plasma membrane regulates the movement of material between the cell and its environment. A rigid cell wall protects the cell and determines its shape. Some bacteria, usually pathogens, have a capsule to protect them from the host's immune system. The genetic material consists of numerous replicated strands of DNA resembling an unraveled piece of twine.

Many forms of bacteria are beneficial to humans. Some forms of bacteria decompose dead material, sewage, and other wastes into simpler molecules that can be recycled. Organisms that function in this manner are called saprophytic. The food industry uses bacteria to produce cheeses, yogurt, sauerkraut, and many other foods. Alcohols, acetones, acids, and other chemicals are produced by bacterial cultures. The pharmaceutical industry employs bacteria to produce antibiotics and vitamins. Some bacteria can even metabolize oil and are used to clean up oil spills.

There are also mutualistic relationships between bacteria and other organisms. Some intestinal bacteria benefit humans by producing antibiotics that inhibit the development of pathogenic bacteria. They also compete with disease-causing bacteria for nutrients, thereby helping keep the pathogens in check. They aid digestion by releasing various nutrients. They produce and release vitamin K. Mutualistic bacteria establish this symbiotic relationship when they are ingested along with food or drink. When people travel, they consume local bacteria along with their food and drink

HOW SCIENCE WORKS 24.1

Gram Staining

Gram staining was first developed in 1843 by the Danish bacteriologist Christian Gram, who discovered that most bacteria could be divided into two main groups based on their staining reactions. Such a technique is called differential staining because it allows the microbiologist to highlight the differences between cell types. Bacteria not easily decolorized with 95% ethyl alcohol after staining with crystal violet and iodine are said to be Gram-positive. Those bacteria decolorized are Gram-negative, and thus very difficult to see through the microscope. Another stain, called a counterstain, is added to make Gram-negative cells more visible. A number of different stains can be used as a counterstain, but red is preferred because it provides the greatest contrast.

Knowing how some pathogenic bacteria react to Gram staining is of great value in determining how to handle those microbes in cases of infection. The Gram stain is probably the most widely performed diagnostic test in microbiology and can provide guidance in such matters as selecting the right antibiotic for treatment and predicting the kinds of symptoms a patient will show.

Table 24.1

MAJOR TAXONOMIC GROUPS OF THE PROKARYOTES

Type	Group	Examples
Eubacteria (true bacteria)	I Thick cell wall (Gram stains positively)	*Streptococcus pyogenes, Clostridium botulinum, Staphylococcus aureus*
	II Thin cell wall (Gram stains negatively)	*Escherichia coli, Neisseria gonorrhea, Legionella pneumophilia*
	III Bacteria lacking cell walls	*Mycoplasma pneumonia*
	IV Cyanobacteria	*Anabaena* sp., *Oscillatoria* sp.
	V Acid-fast bacteria	*Mycobacterium tuberculosis, Mycobacterium leprae*
	VI Spiral bacteria	*Treponema pallidum, Borrelia burgdorferi*
Archaea (extremophiles)	Cell walls, ribosomes, cell membranes unlike those of Eubacteria; typically found in extreme environments	*Methanococcus* sp., *Thermoplasma* sp.

and may have problems establishing a new symbiotic relationship with these foreign bacteria. Both the host and the symbionts have to make adjustments to their new environment, which can result in a very uncomfortable situation for both. Some people develop traveler's diarrhea as a result.

Animals do not produce the enzymes needed for the digestion of cellulose. Methanogens, bacteria that obtain metabolic energy by reducing carbon dioxide (CO_2) to methane (CH_4), digest the cellulose consumed by herbivorous animals, such as cows, thereby permitting the cow to obtain simple sugars from the otherwise useless cellulose. There is a mutualistic relationship between the cow and the methanogens. Some methanogens are also found in the human gut and are among the organisms responsible for the production of intestinal gas. In some regions of the world methanogens are used to digest organic waste, and the methane is used as a source of fuel.

The Romans knew that bean plants somehow enriched the soil, but it was not until the 1800s that bacteria were recognized as the enriching agents. Certain types of bacteria have a symbiotic relationship with the roots of bean plants and other legumes. These bacteria are capable of converting atmospheric nitrogen into a form that is usable to the plants.

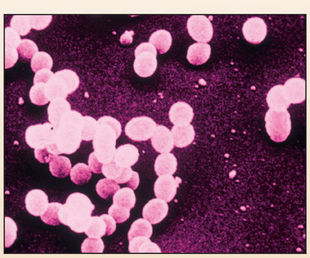
Early forms of life consisted of prokaryotic cells living in a reducing atmosphere. Photosynthetic bacteria released oxygen, and the Earth's atmosphere began to change to an oxidizing atmosphere. Photosynthetic, colonial blue-green bacteria are still present in large numbers on Earth and continue to release significant quantities of oxygen. Colonies of blue-green bacteria are found in aquatic environments, where they form long, filamentous strands commonly called *pond scum*. Some of the larger cells in the colony are capable of nitrogen fixation and convert atmospheric nitrogen, N_2, to ammonia, NH_3. This provides a form of nitrogen usable to other cells in the colony—an example of division of labor.

The word *bacteria* usually brings to mind visions of tiny things that cause diseases; however, the majority are free living and not harmful. Their roles in the ecosystem include those of decomposers, nitrogen fixers, and other symbionts. It is true that some diseases are caused by bacteria, but only a minority of bacteria are **pathogens,** microbes that cause infectious diseases. It is normal for all organisms to have symbiotic relationships with bacteria. Most organisms are lined and covered by populations of bacteria called *normal flora* (table 24.2). In fact, if an organism lacks bacteria it is considered abnormal. Some pathogenic bacteria may be associated with an organism yet do not cause disease. For example, *Streptococcus pneumoniae* may grow in the throats of healthy people without any pathogenic effects. But if a person's resistance is lowered, as after a bout with viral flu,

Table 24.2

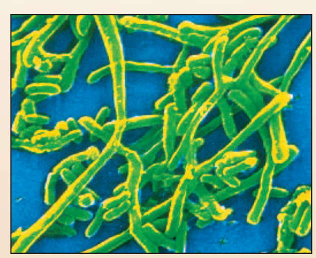
COMMON BACTERIA FOUND IN OR ON YOUR BODY

Skin	*Corynebacterium* sp., *Staphylococcus* sp., *Streptococcus* sp., *E. coli, Mycobacterium* sp.
Eye	*Corynebacterium* sp., *Neisseria* sp., *Bacillus* sp., *Staphylococcus* sp., *Streptococcus* sp.
Ear	*Staphylococcus* sp., *Streptococcus* sp., *Corynebacterium* sp., *Bacillus* sp.
Mouth	*Streptococcus* sp., *Staphylococcus* sp., *Lactobacillus* sp., *Corynebacterium* sp., *Fusobacterium* sp., *Vibrio* sp., *Haemophilus* sp.
Nose	*Corynebacterium* sp., *Staphylococcus* sp., *Streptococcus* sp.
Intestinal tract	*Lactobacillus* sp., *E. coli, Bacillus* sp., *Clostridium* sp., *Pseudomonas* sp., *Bacteroides* sp., *Streptococcus* sp.
Genital tract	*Lactobacillus* sp., *Staphylococcus* sp., *Streptococcus* sp., *Clostridium* sp., *Peptostreptococcus* sp., *E. coli*


Streptococcus


E. coli


Lactobacillus


Corynebacterium

Streptococcus pneumoniae may reproduce rapidly in the lungs and cause pneumonia; the relationship has changed from commensalistic to parasitic.

Bacteria may invade the healthy tissue of the host and cause disease by altering the tissue's normal physiology. Bacteria living in the host release a variety of enzymes that cause the destruction of tissue. The disease ends when the pathogens are killed by the body's defenses or some outside agent, such as an antibiotic. Examples are the infectious diseases strep throat, syphilis, pneumonia, tuberculosis, and leprosy (figure 24.2).

Many other bacterial illnesses are caused by toxins or poisons produced by bacteria that may be consumed with food or drink. In this case, disease can be caused even though the pathogens may never enter the host. For example, botulism is an extremely deadly disease caused by the presence of bacterial toxins in food or drink. Some other bacterial diseases are the result of toxins released from bacteria growing inside the host tissue; tetanus and diphtheria are examples. In general, toxins may cause tissue damage, fever, and aches and pains.

Bacterial pathogens are also important factors in certain plant diseases. Bacteria are the causative agents in many types of plant blights, wilts, and soft rots. Apples and other fruit trees are susceptible to fire blight, a disease that lowers the fruit yield because it kills the tree's branches. Citrus canker, a disease of citrus fruits that causes cancerlike growths, can generate widespread damage. In a three-year period, Florida citrus growers lost $2.5 billion because of this disease (figure 24.3).

Despite large investments of time and money, scientists have found it difficult to control bacterial populations. Two factors operate in favor of the bacteria: their reproductive rate and their ability to form spores. Under ideal conditions some bacteria can grow and divide every 20 minutes. If one bacterial cell and all its offspring were to reproduce at this ideal rate, in 48 hours there would be 2.2×10^{43} cells. In reality, bacteria cannot achieve such incredibly large populations because they would eventually run out of food and be unable to dispose of their wastes.

Because bacteria reproduce so rapidly, a few antibiotic-resistant cells in a population can increase to dangerous levels in a very short time. This requires the use of stronger doses of antibiotics or new types of antibiotics to bring the bacteria under control. Furthermore, these resistant strains can be transferred from one host to another. For example, sulfa drugs and penicillin, once widely used to fight infections, are now ineffective against many strains of pathogenic bacteria. As new antibiotics are developed, natural selection encourages the development of resistant bacterial strains. Therefore humans are constantly waging battles against new strains of resistant bacteria.

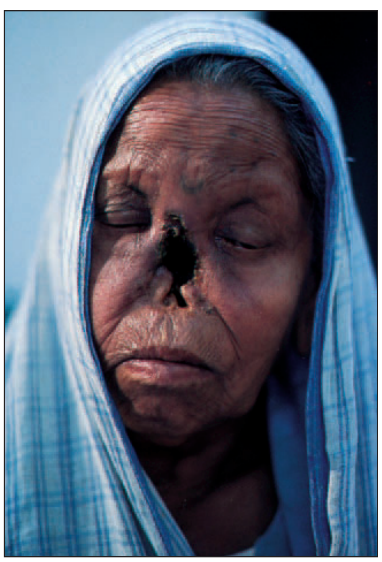


Figure 24.2

Leprosy
More than 20 million people worldwide are infected with *Mycobacterium leprae* and have leprosy (Hansen's disease). This disease alters the host's physiology, resulting in these open sores. Another species of *Mycobacterium, M. tuberculosis,* is again becoming a public health concern because it is becoming increasingly resistant to the controlling effects of antibiotics. New standards of control have been issued by the Centers for Disease Control and Prevention in Atlanta, Georgia.

Figure 24.3

Plant Disease
Citrus canker growth on an orange tree promotes rotting of the infected part of the tree.

Figure 24.4

Bacterial Endospore
The darker area in the cell is the endospore. It contains the bacterial DNA as well as a concentration of cytoplasmic material that is surrounded and protected by a thick wall (approx. 63,000×). Endospores thought to be *Bacillus sphaericus* and estimated to be 25 million to 40 million years old have been isolated from the intestinal tract of a bee fossilized in amber. When placed in an optimum growth environment, they germinated and grew into numerous colonies.

Another factor that enables some bacteria to survive a hostile environment is their ability to form *endospores*. An **endospore** is a unique bacterial structure with a low metabolic rate that can germinate under favorable conditions to form a new, actively growing cell (figure 24.4). For example, people who preserve food by canning often boil the food in the canning jars to kill the bacteria. But not all bacteria are killed by boiling; some of them form endospores. For example, botulism poison is usually found in foods that are improperly canned. The endospores of *Clostridium botulinum,* the bacterium that causes botulism, can withstand boiling and remain for years in the endospore state. However, endospores do not germinate and produce botulism toxin if the pH of the canned goods is in the acid range; in that case, the food remains preserved and edible. If conditions become favorable for endospores to germinate, they become actively growing cells and produce toxin. Home canning is the major source of botulism. Using a pressure cooker and heating the food to temperatures higher than 121°C for 15 to 20 minutes destroys both botulism toxin and the endospores.

24.3 Kingdom Protista

The first protists evolved about 1.5 billion years ago. Like the prokaryotes, most of the protists are one-celled organisms. However, there is a significant difference between the two kingdoms: All the protists are eukaryotic cells and all the prokaryotes are prokaryotic cells. Prokaryotic cells usually have a volume of 1 to 5 cubic micrometers. Most eukaryotic cells have a volume greater than 5,000 cubic micrometers. This means that eukaryotic cells usually have a volume at least 1,000 times greater than prokaryotic cells. The presence of membranous organelles such as the nucleus, endoplasmic reticulum, mitochondria, and chloroplasts allows protists to be larger than prokaryotes. These organelles provide a much greater surface area within the cell upon which specialized reactions may occur. This allows for more efficient cell metabolism than is found in prokaryotic cells.

Because of the great diversity within the more than 60,000 species, it is a constant challenge to separate the kingdom Protista into subgroupings as research reveals new evidence about members of this group. Usually the species are divided into three groups: **algae,** autotrophic unicellular organisms; **protozoa,** heterotrophic unicellular organisms; and funguslike protists. However, emerging evidence suggests a much more complex evolutionary pattern as noted in the cladogram seen in the table 24.3.

Plantlike Protists

Algae are protists that have a cellulose cell wall. They contain chlorophyll and can therefore carry on photosynthesis. Unicellular and colonial types occur in a variety of habitats. There are two major forms of algae in a variety of marine and freshwater habitats: planktonic and benthic. **Plankton** consists of small floating or weakly swimming organisms. **Benthic** organisms live attached to the bottom or to objects in the water. **Phytoplankton** consists of photosynthetic plankton that forms the basis for most aquatic food chains (figure 24.5). The large number of benthic and planktonic algae makes them an important source of atmospheric oxygen (O_2). It is estimated that 30% to 50% of atmospheric oxygen is produced by algae.

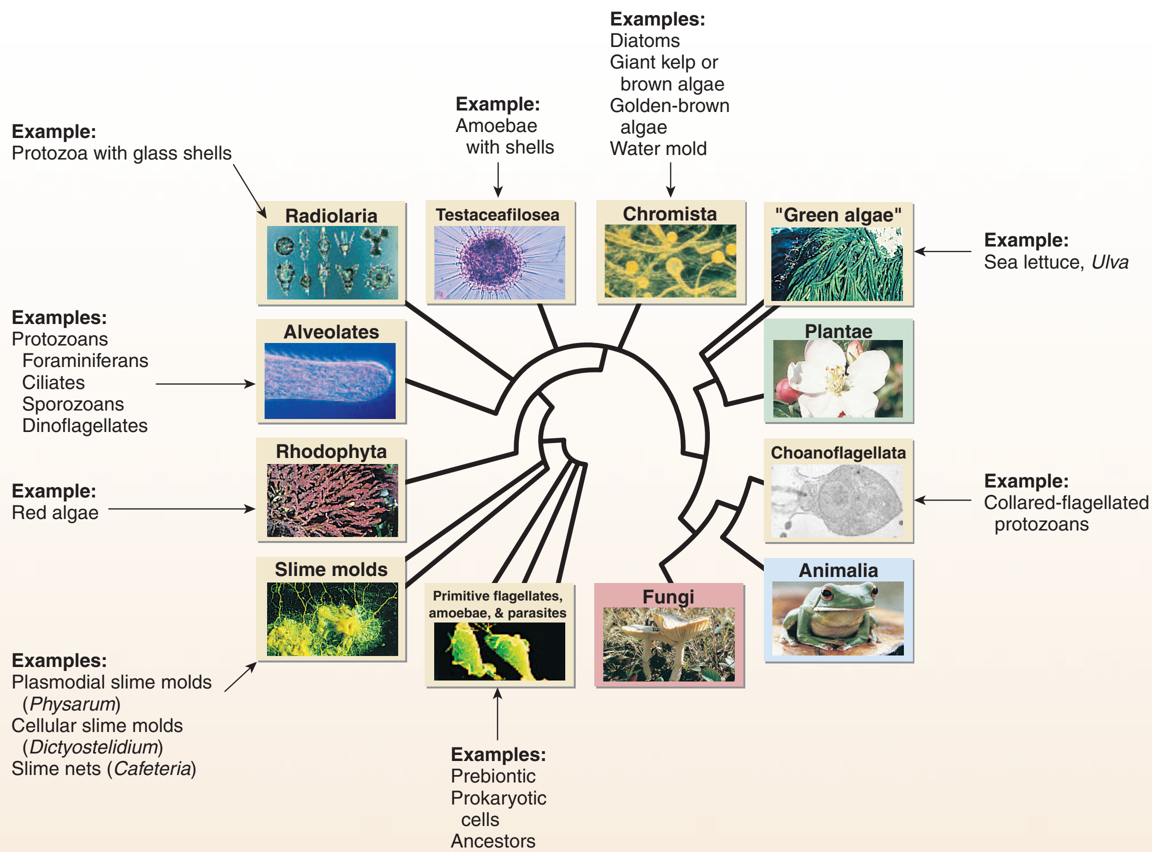
Because algae require light, phytoplankton is found only near the surface of the water. Even in the clearest water, photosynthesis does not usually occur any deeper than 100 meters. To remain near the surface, some of the phytoplankton are capable of locomotion. Others maintain their position by storing food as oil, which is less dense than water and enables the cells to float near the surface.

Three common forms of single-celled algae typically found as phytoplankton are the Euglenophyta (euglenas), and Chrysophyta (golden-brown algae = diatoms, yellow-green algae), and Pyrrophyta (dinoflagellates). *Euglena* are found mainly in freshwater. They are widely studied because they are easy to culture. Under low levels of light, these photosynthetic species can ingest food. *Euglena* can be either autotrophic or heterotrophic.

There are over 10,000 species of diatoms. Diatoms are commonly found in freshwater, marine and soil environments. They can reproduce both sexually and asexually. When conditions are favorable, asexual reproduction can

Table 24.3

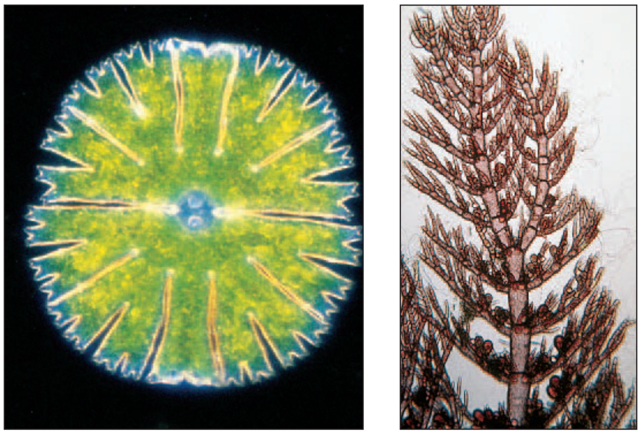
A CLADOGRAM SUGGESTING EVOLUTIONARY RELATIONSHIP AMONG THE VARIOUS GROUPS OF PROTISTS



result in what is called an algal **bloom**—a rapid increase in the population of microorganisms in a body of water. The population can become so large that the water looks murky. These algae are unique because their cell walls contain silicon dioxide (silica). The algal walls fit together like the lid and bottom of a shoe box; the lid overlaps the bottom. Because their cell walls contain silicon dioxide, they readily form fossils. The fossil cell walls have large, abrasive surface areas with many tiny holes and can be used in a number of commercial processes. They are used as filters for liquids and as abrasives in specialty soaps, toothpastes, and scouring powders.

Along with diatoms, dinoflagellates are the most important food producers in the ocean's ecosystem. All members of this group of algae have two flagella, which is the reason for their name (*dino* = two). Many marine forms are bioluminescent; they are responsible for the twinkling lights seen at night in ocean waves or in a boat's wake.

Some species of dinoflagellates have symbiotic relationships with marine animals, such as the reef corals; the dinoflagellates provide a source of nutrients for the reef-building coral. Corals that live in the light and contain dinoflagellates grow 10 times faster than corals without this symbiont. Thus, in coral reef ecosystems, dinoflagellates form the foundation of the food chain. Some forms of dinoflagellates produce toxins that can be accumulated by such filter-feeding marine animals as clams and oysters. Filter-feeding shellfish ingest large amounts of the toxins, which has no effect on the shellfish but can cause sickness or death in animals that feed on them, such as fish, birds, and mammals. Many of the toxin-producing dinoflagellates contain red pigment. Blooms of this kind are responsible for *red tides*. Red tides usually occur in the warm months, during which people should refrain from collecting and eating oysters. The expression "Oysters 'R' in season" comes from the fact that most of the months with an R in their spelling are



(a) (b)

Figure 24.5

Algae
Algae may be found in a variety of types and colors: (*a*) a single-celled green alga, *Micrasterias;* (*b*) a colonial red alga, *Antithamnium.*

Figure 24.6

A Kelp Grove
These multicellular brown algae are attached to the ocean floor by holdfasts. Their blades may reach a length of 100 meters and float upward because they have a bladderlike sac filled with air.

cold weather months, during which oysters are safer to eat. Commercially available shellfish are tested for toxin content; if they are toxic, they are not marketed. Red tides not only have occurred off the coast of Florida in North America, but also have more recently developed off the coast of China. Hundreds of thousands of fish and other marine life have been killed as a result of toxin release, thus having a significant impact on the economy and food supply.

In recent years a new problem has surfaced caused by the dinoflagellate, *Pfiesteria piscidia.* These algae have been responsible for the death of millions of fish in estuaries of the eastern United States. These dinoflagellates release toxins that paralyze fish and feed on the fish. They have also been responsible for human and wildlife poisoning.

Multicellular algae, commonly known as *seaweed,* are large colonial forms usually found attached to objects in shallow water. Two types, red algae (Rhodophyta) and brown algae (Phaeophyta), are mainly marine forms. The green algae (Chlorophyta) are a third kind of seaweed; they are primarily freshwater species.

Red algae live in warm oceans and attach to the ocean floor by means of a holdfast structure. They may be found from the splash zone, the area where waves are breaking, to depths of 100 meters. Some red algae become encrusted with calcium carbonate and are important in reef building; other species are of commercial importance because they produce agar and carrageenin. *Agar* is widely used as a jelling agent for growth media in microbiology. *Carrageenin* is a gelatinous material used in paints, cosmetics, and baking. It is also used to make gelatin desserts harden faster and to make ice cream smoother. In Asia and Europe some red algae are harvested and used as food.

Brown algae are found in cooler marine environments than are the red algae. Most species of brown algae have a holdfast organ. Colonies of these algae can reach 100 meters in length (figure 24.6). Brown algae produce *alginates,* which are widely used as stabilizers in frozen desserts, emulsifiers in salad dressings, and as thickeners that give body to foods such as chocolate milk and cream cheeses; they are also used to form gels in such products as fruit jellies.

The Sargasso Sea is a large mat of free-floating brown algae between the Bahamas and the Azores. It is thought that this huge mass (as large as the European continent) is the result of brown algae that have become detached from the ocean bottom, have been carried by ocean currents, and accumulate in this calm region of the Atlantic Ocean. This large mass of floating algae provides a habitat for a large number of marine animals, such as marine turtles, eels, jellyfish, and innumerable crustaceans.

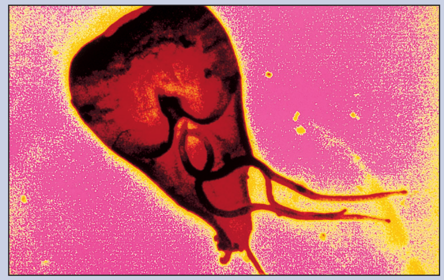
Green algae are found primarily in freshwater ecosystems, where they may attach to a variety of objects. Members of this group can also be found growing on trees, in the soil, and even on snowfields in the mountains. Like land

OUTLOOKS 24.1

Don't Drink the Water!

Giardia lamblia is a protozoan in streams and lakes throughout the world, found even in "pure" mountain water in U.S. wilderness areas. Over 40 species of animals harbor this organism in their small intestines. Its presence may cause diarrhea, vomiting, cramps, or nausea. *Giardia* may be found even if good human sanitation is practiced. No matter how inviting it may be to drink directly from that cold mountain stream, don't. Deer, beaver, or other animals could have contaminated the water with *Giardia*. Treat the water before drinking. The most effective way to eliminate the spores formed by this protozoan is to use special filters that can filter out particles as small as 1 micrometer; otherwise, boil the water for at least five minutes before drinking.

The species called *Entamoeba histolytica* (*ent* = inside; *amoeba* = amoeba; *histo* = tissue; *lytica* = destroying) is responsible for the diarrheal disease known as dysentery. People become infected with this protozoan when they travel to a foreign country and drink contaminated water. If you plan on such a trip, be sure to see your physician *several weeks* before you go! The infection can be prevented by taking an antiprotozoal antibiotic, but you must start treatment ahead of time.



Giardia lamblia

Entamoeba histolytica

(a)

(b)

Figure 24.7

Sarcodina
These protozoa range from (*a*) the *Amoeba*, which changes shape to move and feed, to (*b*) organisms that are enclosed in a shell. The extensions from the cell are called pseudopods (*pseudo* = false; *pod* = foot).

plants, green algae have cellulose cell walls and store food as starch. Green algae also have the same types of chlorophyll as do plants. Biologists believe that land plants evolved from the green algae.

Animal-like Protists

A second major group of organisms in the kingdom Protista, the protozoa, lack all types of chlorophyll. The word *protozoa* literally means "first animal." It is a descriptive term that includes all eukaryotic, heterotrophic, unicellular organisms that lack cell walls. The protozoa are classified into subgroups according to their method of locomotion.

Most members of the Zoomastigina have flagella and live in freshwater. They have no cell walls and no chloroplasts, and they can be parasitic or free living (Outlooks 24.1). There is a mutualistic relationship between some flagellates and their termite hosts. Certain protozoa live in termite guts and are capable of digesting cellulose into simple sugars that serve as food for the termite. Of the parasitic protozoa, two different species produce sleeping sickness in humans and domestic cattle. In both cases the protozoan enters the host as the result of an insect bite. The parasite develops in the circulatory system and moves to the cerebrospinal fluid surrounding the brain. When this occurs, the infected person develops the "sleeping" condition, which, if untreated, is eventually fatal. Many biologists believe that all other types of protozoa, and even the multicellular animals, evolved from primitive flagellated microorganisms similar to the Zoomastigina.

Members of the group Sarcodina range from the most well-known *Amoeba*, with its constantly changing shape, to species having a rigid outer cover (figure 24.7). *Amoeba* uses pseudopods to move about and to engulf food. A pseudopod is a protoplasmic extension of the cell that contains moving cytoplasm. Many pseudopods are temporary extensions that form and disappear as the cell moves. Most amoeboid

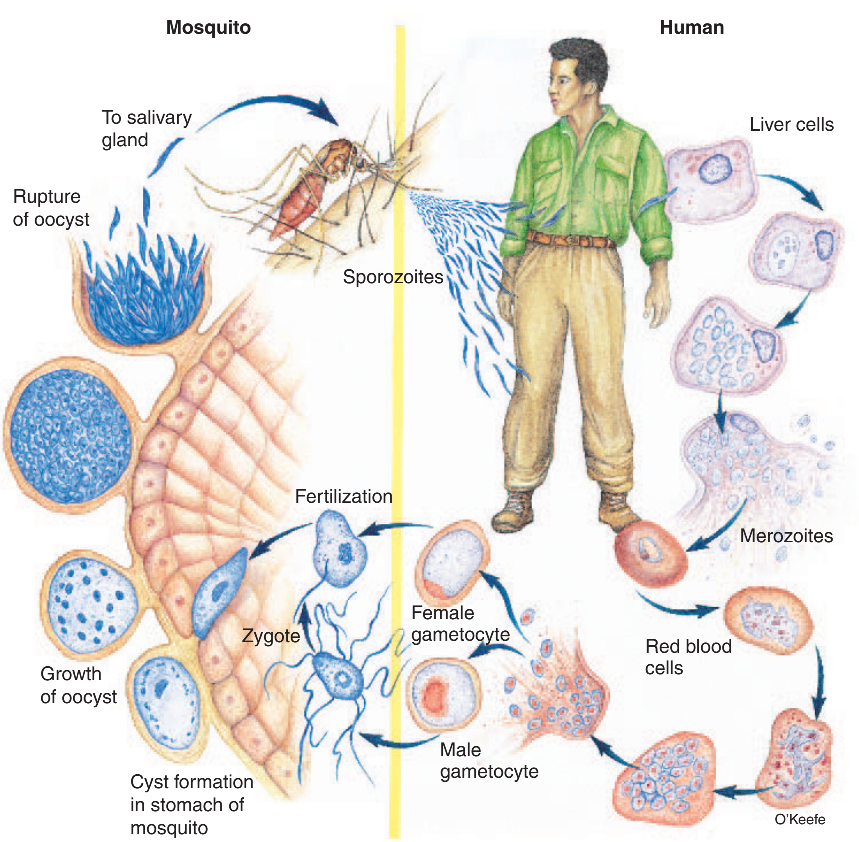


Figure 24.8

The Life Cycle of *Plasmodium vivax*
The complex life cycle of the member of the Protista that causes malaria requires two hosts, the *Anopheles* mosquito and the human. Humans get malaria when they are bitten by a mosquito carrying the larval stage of *Plasmodium.* The larva undergoes asexual reproduction and releases thousands of individuals that invade the red blood cells. Their release from massive numbers of infected red blood cells causes the chills, fever, and headache associated with malaria. Inside the red blood cell, more reproduction occurs to form male gametocytes and female gametocytes. When the mosquito bites a person with malaria, it ingests some gametocytes. Fertilization occurs and zygotes develop in the stomach of the mosquito. The resulting larvae are housed in the mosquito's salivary gland. Then, when the mosquito bites someone, some saliva containing the larvae is released into the person's blood and the cycle begins again.

protists are free living and feed on bacteria, algae, or even small multicellular organisms. Some forms are parasitic, such as the one that causes amoebic dysentery in humans.

Another member of the group Sarcodina, the foraminiferans, live in warm oceans and are enclosed in a shell. As these cells die, the shells collect on the ocean floor, and their remains form limestone. The cliffs of Dover, England, were formed from such shells. Oil companies have a vested interest in foraminiferans because they are often found where oil deposits are located.

All members of the group Sporozoa are nonmotile parasites that have a sporelike stage in their life cycles. Malaria, one of the leading causes of disability and death in the world, results from a type of sporozoan. Two billion people live in malaria-prone regions of the world. There are an estimated 150 to 300 million new cases of malaria each year, and the disease kills 2 to 4 million people annually.

Like most sporozoans, the one that causes malaria has a complex life cycle involving a mosquito vector for transmission (figure 24.8). Recall from chapter 15 that a *vector* is an organism capable of transmitting a parasite from one organism to another. While in the mosquito vector, the parasite goes through the sexual stages of its life cycle. One of the best ways to control this disease is to eliminate the vector, which usually involves using some sort of pesticide. Many of us are concerned about the harmful effects of pesticides in the environment. However, in parts of the world where malaria is common, the harmful effects of pesticides are of less concern than the harm generated by the disease. Many diseases of domestic and wild animals are also caused by members of this group.

The group Ciliophora contain the most structurally complex protozoans. They are commonly known as *ciliates* and derive their name from the fact that they have numerous short, flexible filaments called *cilia* (figure 24.9). These move in an organized, rhythmic manner and propel the cell through the water. Some types of ciliates, such as *Paramecium,* have nearly 15,000 cilia per cell and move at a rapid speed of 1 millimeter per second. Most ciliates are free-living cells found in fresh and salt water, where they feed on bacteria and other small organisms.

Funguslike Protists

Funguslike protists have a motile amoeboid reproductive stage, which differentiates them from true fungi. There are two kinds of funguslike protists: slime molds and water molds. Some slime molds, members of Myxomycota, can be

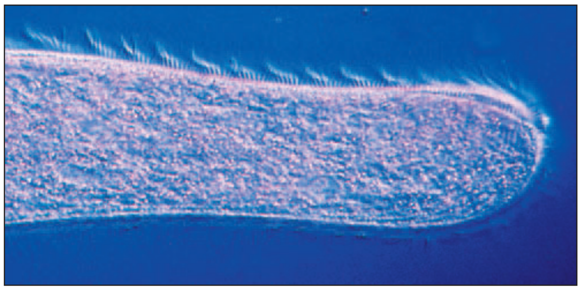


Figure 24.9

Ciliated Protozoa
The many hairlike cilia on the surface of this cell are used to propel the protozoan through the water.

Figure 24.10

Slime Mold
Slime molds grow in moist conditions and are important decomposers. As the slime mold grows, additional nuclei are produced by mitosis, but there is no cytoplasmic division. Thus, at this stage, it is a single mass of cytoplasm with many nuclei.

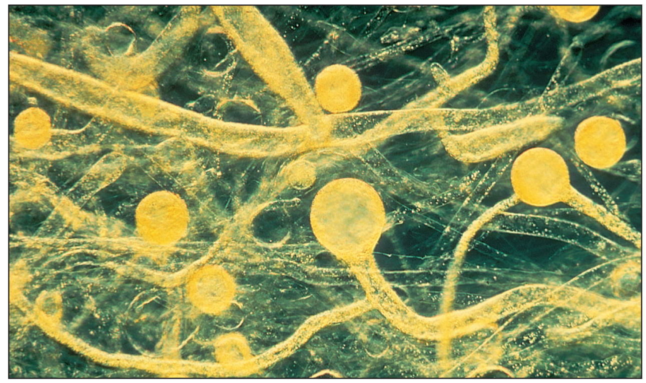


Figure 24.11

Water Mold
Rapidly reproducing water molds quickly produce a large mass of filamentous hyphae. These hyphae are the cause of fuzzy growth often seen on dead fish or other dead material in the water.

found growing on rotting damp logs, leaves, and soil. They look like giant amoebae whose nucleus and other organelles have divided repeatedly within a single large cell (figure 24.10). No cell membranes partition this mass into separate segments. They vary in color from white to bright red or yellow, and may reach relatively large sizes (45 centimeters in length) when in an optimum environment.

Other kinds of slime molds, members of Acrasiomycota, exist as large numbers of individual, amoebalike cells. These haploid cells get food by engulfing microorganisms. They reproduce by mitosis. When their environment becomes dry or otherwise unfavorable, the cells come together into an irregular mass. This mass glides along rather like an ordinary garden slug and is labeled the sluglike stage. This sluglike form may flow about for hours before it forms spores. When the mass gets ready to form spores, it forms a stalk with cells that have cell walls. At the top of this specialized structure, cells are modified to become haploid spores. When released, these spores may be carried by the wind and, if they land in a favorable place, may develop into new amoebalike cells.

Another group of funguslike protists includes the water molds (figure 24.11). This group, the Oomycota, has reproductive cells with two flagella. A wide variety of water molds are saprophytes, which are usually found growing in a moist environment. They differ in structure from the true fungi in that some filaments have no cross walls, thus allowing the cell contents to flow from cell to cell.

Water molds are important saprophytes and parasites in aquatic ecosystems. They are often seen as fluffy growths on dead fish or other organic matter floating in water. A parasitic form of this fungus is well known to people who rear tropical fish; it causes a cottonlike growth on the fish. Although these organisms are usually found in aquatic habitats, they are not limited to this environment. Some species cause downy mildew on plants such as grapes. In the 1880s this mildew almost ruined the French wine industry when it spread throughout the vineyards. A copper-based fungicide called *Bordeaux mixture*—the first chemical used against plant diseases—was used to save the vineyards. A water mold was also responsible for the Irish potato blight. In the nineteenth century, potatoes were the staple of the Irish diet. Cool, wet weather in 1845 and 1847 damaged much of the potato crop, and more than a million people died of starvation. Nearly one-third of the survivors left Ireland and moved to Canada or the United States.

24.4 Multicellularity in the Protista

The three major types of the kingdom Protista (algae, protozoa, and funguslike protists) include both single-celled and multicellular forms. Biologists believe that there has been a similar type of evolution in all three of these groups. The most primitive organisms in each group are thought to have been single-celled, and to have given rise to the more advanced multicellular forms. Most protozoan organisms are single-celled; however, there is a group that contains numerous colonial forms. The multicellular forms of funguslike protists are the slime molds, which have both single-celled and multicellular stages. Perhaps the most widely known example of this trend from a single-celled to a multicellular condition is found in the green algae. A very common single-celled green alga is *Chlamydomonas*, which has a cell wall and two flagella. It looks just like the individual cells of the colonial green algae *Volvox*. *Volvox* can be composed of more than half a million cells (figure 24.12). All the flagella of each cell in the colony move in unison, allowing the colony to move in one direction. Many of the cells cannot reproduce sexually; other cells assume this function for the colony. In some *Volvox* species, certain cells have even specialized to produce sperm or eggs. Biologists believe that the division of labor seen in colonial protists represents the beginning of specialization that led to the development of true multicellular organisms with many different kinds of specialized cells. Three types of multicellular organisms—fungi, plants, and animals—eventually developed.

24.5 Kingdom Fungi

Members of the kingdom Fungi are nonphotosynthetic eukaryotic organisms with rigid cell walls. The majority are multicellular, but a few, like yeasts, are single-celled. The majority also do not move. All of these organisms are heterotrophs; that is, they must obtain nutrients from organic sources. Most secrete chemicals that digest large molecules into smaller units that are absorbed. Fungi can be either free living or parasitic. Fungi that are free living, like mushrooms, decompose dead organisms as they absorb nutrients. Fungi that are parasitic are responsible for athlete's foot, vaginal yeast infections, ringworm, as well as many plant diseases. There is no unanimity regarding the divisions within the kingdom Fungi. Originally, fungi were thought to be members of the Plantae kingdom. In fact, the term *division* is used with this kingdom because this is the term used by botanists in place of *phylum*.

Even though fungi are nonmotile, they successfully survive and disperse because of their ability to form spores, which some produce sexually and others produce asexually. Spores may be produced internally or externally (figure 24.13). An

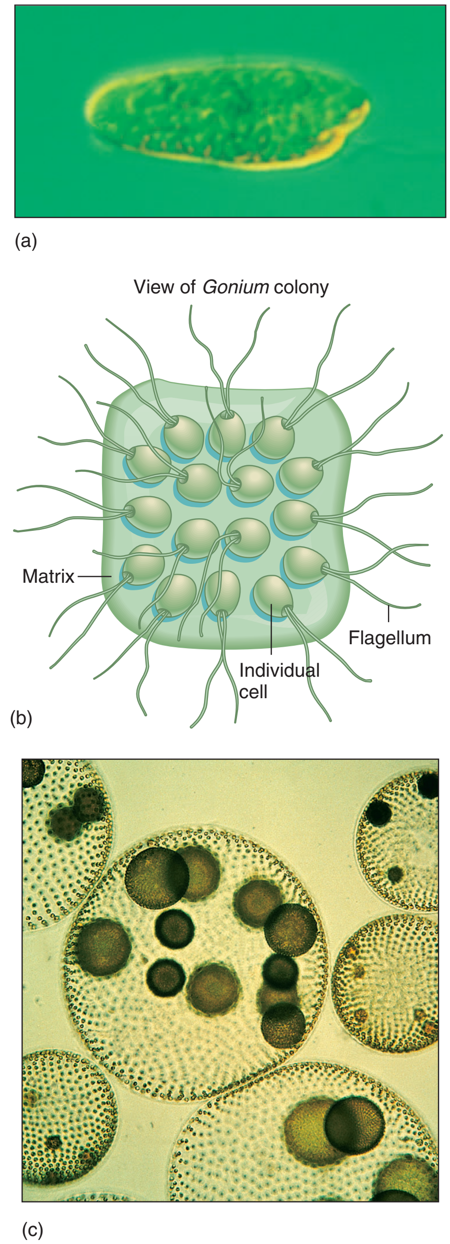


Figure 24.12

Algae
(*a*) *Chlamydomonas* is a green, single-celled alga containing the same type of chlorophyll as that found in green plants. (*b*) *Gonium,* a green alga similar to *Chlamydomonas,* forms colonies composed of 4 to 32 cells. (*c*) *Volvox,* another green alga, is a more complex form in the evolution of colonial green algae.

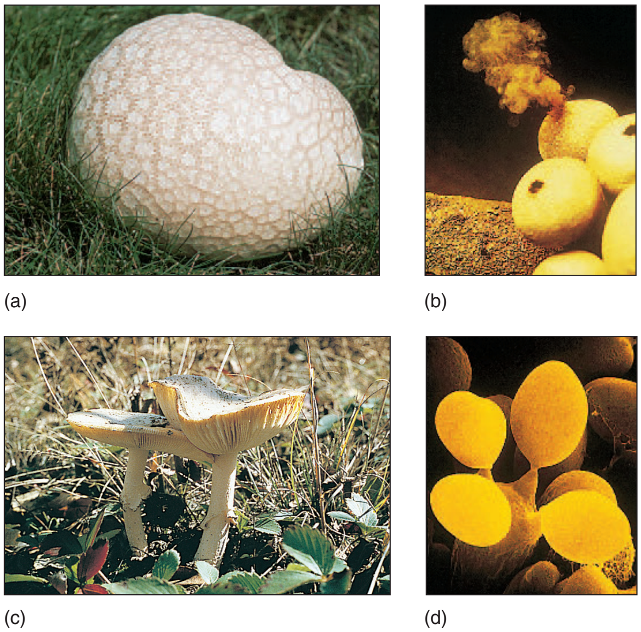


Figure 24.13

Spore Production
Some fungi, like the puffball (*a*), produce spores on the inside. The puffball must be broken (*b*) to release the spores. Other forms, like the club fungus (*c*), have exposed gills with spore-producing basidia (*d*).

average-sized mushroom can produce over 20 billion spores; a good-sized puffball can produce as many as 8 trillion spores. When released, the spores can be transported by wind or water. Because of their small size, spores can remain in the atmosphere a long time and travel thousands of kilometers. Fungal spores have been collected as high as 50 kilometers above the Earth.

In a favorable environment, a fungus produces dispersal spores, which are short-lived and germinate quickly under suitable conditions. If the environment becomes unfavorable—too cold or hot, or too dry—the fungus produces survival spores. These may live for years before germinating. Fungi are so prolific that their spores are almost always present in the air; as soon as something dies, fungal spores settle on it, and decomposition usually begins.

Fungi play a variety of roles. They are used in the processing of food and are vital in the recycling processes within ecosystems. As decomposers, they destroy billions of dollars worth of material each year; as pathogens, they are responsible for certain diseases. They are beneficial in the production of antibiotics and other chemicals used in the treatment of diseases. *Penicillium chrysogenum* is a mold that produces the antibiotic penicillin, which was the first commercially available antibiotic and is still widely used (How Science Works 24.2).

There are over 100 species of *Penicillium,* and each characteristically produces spores in a brushlike border; the word *penicillus* means "little brush." Members of this group do more than produce antibiotics; they are also widely used in processing food. Many people are familiar with the blue, cottony growth that sometimes occurs on citrus fruits. The *P. italicum* growing on the fruit appears to be blue because of the pigment produced in the spores. The blue cheeses, such as Danish, American, and the original Roquefort, all have this color. Each has been aged with *P. roquefortii* to produce the color, texture, and flavor. Differences in the cheeses are determined by the kinds of milk used and the conditions under which the aging occurs. Roquefort cheese is made from sheep's milk and aged in Roquefort, France, in particular caves. American blue cheese is made from cow's milk and aged in many places around the United States. The blue color has become a very important feature of these cheeses. The same research laboratory that first isolated *P. chrysogenum* also found a mutant species of *P. roquefortii* that would produce spores having no blue color. The cheese made from this mold is "white" blue cheese. The flavor is exactly the same as "blue" blue cheese, but commercially it is worthless: People want the blue color.

Fungi and their by-products have been used as sources of food for centuries. When we think of fungi and food, mushrooms usually come to mind. The common mushroom found in the grocer's vegetable section is grown in many countries and has an annual market value in the billions of dollars. But there are other uses for fungi as food. *Shoyu* (soy sauce) was originally made by fermenting a mixture of wheat, soybeans, and an ascomycote fungus for a year. Most of the soy sauce used today is made by a cheaper method of processing soybeans with hydrochloric acid. True connoisseurs still prefer soy sauce made the original way. Another mold is important to the soft-drink industry. The citric acid that gives a soft drink its sharp taste was originally produced by squeezing juice from lemons and purifying the acid. Today, however, a mold is grown on a nutrient medium with table sugar (sucrose) to produce great quantities of citric acid at a low cost.

All fungi are capable of breaking down organic matter to provide themselves with the energy and building materials they need. This may be either beneficial or harmful, depending on what is being broken down. In order for any ecosystem to survive, it must have a source of carbon, nitrogen, phosphorus, and other elements that can be incorporated into new carbohydrates, fats, proteins, and other molecules necessary for growth. The fungi, along with bacteria, are the primary recycling agents for these elements in ecosystems. Spores are an efficient method of dispersal, and when they land in a favorable environment with moist conditions, they germinate and begin the process of decomposition. As

HOW SCIENCE WORKS 24.2

Penicillin

The discovery of the antibiotic penicillin is an interesting story. In 1928 Dr. Alexander Fleming was working at St. Mary's Hospital in London. As he sorted through some old petri dishes on his bench, he noticed something unusual. The mold *Penicillium notatum* was growing on some of the petri dishes. Apparently, the mold had found its way through an open window and onto a bacterial culture of *Staphylococcus aureus.* The bacterial colonies that were growing at a distance from the fungus were typical, but there was no growth close to the mold. Fleming isolated the agent responsible for this destruction of the bacteria and named it *penicillin.*

Through Fleming's research efforts and those of several colleagues, the chemical was identified and used for about 10 years in microbiological work in the laboratory. Many suspected that penicillin might be used as a drug, but the fungus could not produce enough of the chemical to make it worthwhile. When World War II began, and England was being firebombed, there was an urgent need for a drug that would control bacterial infections in burn wounds. Two scientists from England were sent to the United States to begin research into the mass production of penicillin.

Their research in isolating new forms of *Penicillium* and purifying the drug were so successful that cultures of the mold now produce over 100 times more of the drug than the original mold discovered by Fleming. In addition, the price of the drug dropped considerably—from a 1944 price of $20,000 per kilogram to a current price of less than $250.00. The species of *Penicillium* used to produce penicillin today is *P. chrysogenum,* which was first isolated in Peoria, Illinois, from a mixture of molds found growing on a cantaloupe. The species name, *chrysogenum,* means "golden" and refers to the golden-yellow droplets of antibiotic that the mold produces on the surface of its hyphae. The spores of this mold were isolated and irradiated with high dosages of ultraviolet light, which caused mutations to occur in the genes. When some of these mutant spores were germinated, the new hyphae were found to produce much greater amounts of the antibiotic.

decomposers, fungi cause billions of dollars worth of damage each year. Clothing, wood, leather, and all types of food are susceptible to damage by fungi. One of the best ways to protect against such damage is to keep the material dry, because fungi grow best in a moist environment. Millions of dollars are spent each year on fungicides to limit damage that is due to fungi.

Some fungi have a symbiotic relationship with plant roots; **mycorrhiza** usually grow inside a plant's root-hair cells—the cells through which plants absorb water and nutrients. The hyphae from the fungus grow out of the root-hair cells and greatly increase the amount of absorptive area (figure 24.14). Plants with mycorrhizal fungi can absorb as much as 10 times more minerals than those without the fungi. Some types of fungi also supply plants with growth hormones, while the plants supply carbohydrates and other organic compounds to the fungi. Mycorrhizal fungi are found in 80% to 90% of all plants.

In some situations, mycorrhizae may be essential to the life of a plant. Botanists are investigating a correlation between mycorrhizae and acid-rain damage to trees. Acid-rain conditions can leach certain necessary plant minerals from the soil, making them less accessible to plants. The increased soil acidity also makes certain toxic chemicals,

Figure 24.14

Mycorrhiza
The symbiotic relationship between fungi and the roots of the two plants on the right increases the intake of water and nutrients into the plant. As a result these plants have more growth than the control plant on the left.

Figure 24.15

Fairy Ring
Legend tells us that fairies danced in a circle in the moonlight and rested on the mushrooms. Mycologists tell us that the mushrooms began to grow in the center; as the organic material was consumed, the mushrooms grew in an ever-widening circle and formed this "fairy ring."

Figure 24.16

Corn Smut
Most people who raise corn have seen corn smut. Besides being unsightly, it decreases the corn yield.

such as copper, more accessible to plants. When the roots of trees suspected of being killed by acid rain are examined, there is often no evidence of the presence of mycorrhizal fungi, whereas a healthy tree growing next to a dead one has the root fungus.

One of the most interesting formations caused by mushroom growth can be seen in soil that is rich in mushroom hyphae, such as in lawns, fields, and forests. These formations, known as *fairy rings,* result from the expanding growth of the mushrooms (figure 24.15). The inner circle is normal grass and vegetation. The mushroom population originally began to grow at the center, but grew out from there because it exhausted the soil nutrients necessary for fungal growth. As the microscopic hyphae grow outward from the center, they stunt the growth of grass, forming a ring of short, inhibited grass. Just to the outside of this growth ring, the grass is luxuriant because the hyphae excrete enzymes that decompose soil material into rich nutrients for growth. The name *fairy ring* comes from an old superstition that such rings were formed by fairies tramping down the grass while dancing in a circle.

There are also pathogenic fungi that feed on living organisms; those that cause ringworm and athlete's foot are two examples. A number of diseases are caused by fungi that grow on human mucus membranes, such as those of the vagina, lungs, and mouth. Plants are also susceptible to fungal attacks. Chestnut blight and Dutch elm disease almost caused these two species of trees to become extinct. The fungus that causes Dutch elm disease is a parasite that kills the tree; then it functions as a saprophyte and feeds on the dead tree. Fungi also damage certain domestic crops. Wheat rust gets its common name because infected plants look as if they are covered with rust. Corn smut is also due to a fungal pathogen of plants (figure 24.16).

A number of fungi produce deadly poisons called **mycotoxins.** There is no easy way to distinguish those that are poisonous from those that are safe to eat. The poisonous forms are sometimes called *toadstools* and the nonpoisonous ones, *mushrooms*. However, they are all properly called mushrooms. The origin of the name toadstools is unclear. One idea is that toadstools are mushrooms on which toads sit; another is that the word is derived from the German *todstuhl,* "seat of death." The most deadly of these, *Amanita verna,* is known as "the destroying angel" and can be found in woodlands during the summer. Mushroom hunters must learn to recognize this deadly, pure white species. This mushroom is believed to be so dangerous that food accidentally contaminated by its spores can cause illness and possible death. Another mushroom, *Psilocybe mexicana,* has been used for centuries in religious ceremonies by certain Mexican tribes because of the hallucinogenic chemical that it produces. These mushrooms have been grown in culture, and the drug psilocybin has been isolated. In the past, it was used experimentally to study schizophrenia. *Claviceps purpurea,* a sac fungus, is a parasite on rye and other grains. The metabolic activity of *C. purpurea* produces a toxin that can cause hallucinations, muscle spasms, insanity, or even death.

(a)

(b)

Figure 24.17

Lichens
Lichens grow in a variety of habitats: (*a*) the shrubby lichen is growing on soil; (*b*) the crustlike lichen is growing on rock. The different coloring is due to the different species of algae or cyanobacteria in the lichens.

However it is also used to treat high blood pressure, to stop bleeding after childbirth, and to treat migraine headaches.

Lichens

Lichens are usually classified with the Fungi, but they actually represent a very close mutualistic relationship between a fungus and an algal protist or a cyanobacterium. Algae and cyanobacteria require a moist environment. Certain species of these photosynthetic organisms grow surrounded by fungus. The fungal covering maintains a moist area, and the photosynthesizers in turn provide nourishment for the fungus. These two species growing together are what we call a **lichen** (figure 24.17). Lichens grow slowly; a patch of lichen may grow only 1 centimeter per year in diameter.

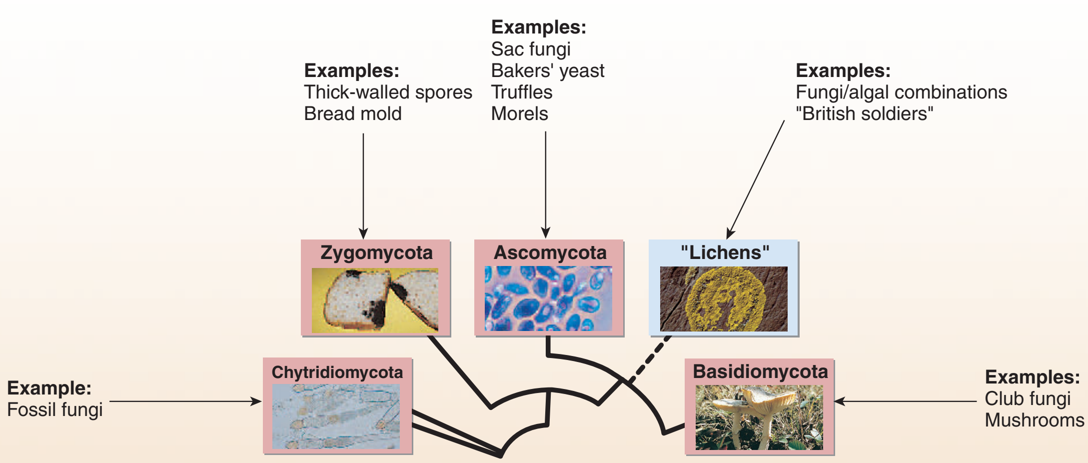
Because the fungus provides a damp environment and the algae produce the food, lichens require no soil for growth. For this reason, they are commonly found growing on bare rock, and are the pioneer organisms in the process of succession. Lichens are important in the process of soil formation. They secrete an acid that weathers the rock and makes minerals available for use by plants. When lichens die, they provide a source of humus—dead organic material—that mixes with the rock particles to form soil.

Lichens are found in a wide variety of environments, ranging from the frigid arctic to the scorching desert. One reason for this success is their ability to withstand drought conditions. Some lichens can survive with only 2% water by weight. In this condition they stop photosynthesis and go into a dormant stage, remaining so until water becomes available and photosynthesis begins again.

Another factor in the success of lichens is their ability to absorb minerals. However, because air pollution increases

Table 24.4

A CLADOGRAM SUGGESTING EVOLUTIONARY RELATIONSHIP AMONG THE VARIOUS GROUPS OF FUNGI



the amounts of minerals they absorb, many lichens are damaged. Some forms of lichens absorb concentrations of sulfur 1,000 times greater than those found in the atmosphere. This increases the amount of sulfuric acid in the lichen, resulting in damage or death. For this reason, areas with heavy air pollution are "lichen deserts." Because they can absorb minerals, certain forms of lichens have been used to monitor the amount of various pollutants in the atmosphere, including radioactivity. The absorption of radioactive fallout from Chernobyl by arctic lichens made the meat of the reindeer that fed on them unsafe for human consumption (table 24.4).

SUMMARY

Organisms in the Domains Archaea and Eubacteria, and the kingdoms Protista and Fungi rely mainly on asexual reproduction, and each cell usually satisfies its own nutritional needs. In some species, there is minimal cooperation between cells. The bacteria have the genetic ability to function in various environments. Most species of bacteria are beneficial, although some are pathogenic.

Members of the kingdom Protista are one-celled organisms. They differ from the prokaryotes in that they are eukaryotic cells, whereas the prokaryotes are prokaryotic cells. Protists include algae, autotrophic cells that have a cell wall and carry on photosynthesis; protozoa, which lack cell walls and cannot carry on photosynthesis; and funguslike protists, whose motile, amoeboid reproductive stage distinguishes them from true fungi. Some species of Protista developed a primitive type of specialization, and from these evolved the multicellular fungi, plants, and animals.

The kingdom Fungi consists of nonphotosynthetic, eukaryotic organisms with cell walls. Most species are multicellular. Fungi are nonmotile organisms that disperse by producing spores. Lichens are a combination of organisms involving a mutualistic relationship between a fungus and an algal protist or cyanobacterium.

THINKING CRITICALLY

Throughout much of Europe there has been a severe decline in the mushroom population. On study plots in Holland, data collected since 1912 indicate that the number of mushroom species has dropped from 37 to 12 per plot in recent years. Along with the reduction in the number of species there is a parallel decline in the number of individual plants; moreover, the surviving plants are smaller.

The phenomenon of the disappearing mushrooms is also evident in England. One study noted that in 60 fungus species, 20 exhibited declining populations. Mycologists are also concerned about a decline in the United States; however there are no long-term studies, such as those in Europe, to provide evidence for such a decline.

Consider the niche of fungi in the ecosystem. How would an ecosystem be affected by a decline in their numbers?

CONCEPT MAP TERMINOLOGY

Construct a concept map to show relationships among the following concepts.

algae
archaea
bacteria
colony
endospore
eukaryotic
microorganism
prokaryotic
protozoa

KEY TERMS

algae
bacteria
benthic
bloom
colonial microbes
endospore
lichen
microorganisms (microbes)
mycorrhiza
mycotoxin
pathogen
phytoplankton
plankton
protozoa

e—LEARNING CONNECTIONS *www.mhhe.com/enger10*

Topics	Questions	Media Resources
24.1 Microorganisms	1. What is meant by the term bloom? 2. What is a pathogen? Give two examples. 3. Name a disease caused by each of the following: bacteria, fungi, protozoa. 4. Name two beneficial results of fungal growth and activity. 5. Define the term saprophytic. 6. Give an example of a symbiotic relationship.	**Quick Overview** • Grouping bacteria, protists, and fungi **Key Points** • Microorganisms **Experience This!** • Useful microbes!
24.2 Bacteria	7. What is a bacterial endospore?	**Quick Overview** • Bacteria **Key Points** • Bacteria
24.3 Kingdom Protista	8. Why are the protozoa and the algae in different subgroups of the kingdom Protista? 9. What is phytoplankton? 10. Name three commercial uses of algae. 11. What is the best method to prevent the spread of malaria?	**Quick Overview** • Protists **Key Points** • Kingdom Protista
24.4 Multicellularity in the Protista		**Quick Overview** • Single cells? **Key Points** • Multicellularity in the Protista
24.5 Kingdom Fungi	12. What types of spores do fungi produce?	**Quick Overview** • Fungi **Key Points** • Kingdom Fungi **Interactive Concept Maps** • Text concept map • Beneficial microbes • Problem microbes **Review Questions** • Prokaryotes, protists, and fungus