Unit 6

MICROORGANISMS

CHAPTERS

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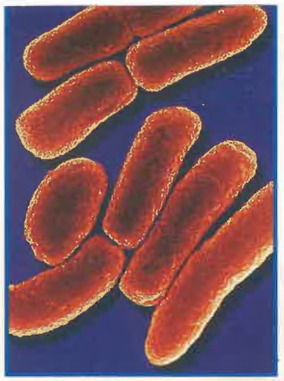
SCILINKS NSTA

National Science Teachers Association *sci*LINKS Internet resources are located throughout this unit.

"In the leaves of every forest, in the flowers of every garden, in the waters of every rivulet, there are worlds teeming with life..."

From *Thoughts on Animalcules*, or *A Glimpse of the Invisible World Revealed by the Microscope*, by G. A. Mantell, as quoted in Primo Levi's book *Other People's Trades*.

Mushrooms, members of the kingdom Fungi, are important decomposers in nature.

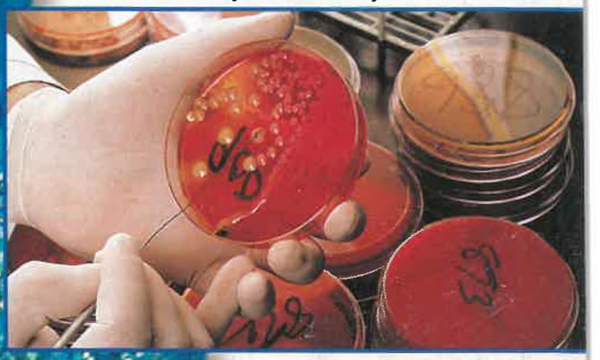


These rod-shaped bacteria are members of the kingdom Eubacteria and the species E. coli.

Diatoms, members of the phylum Protista, are unicellular, photosynthetic organisms that live in oceans and lakes.

Pelomyxa carolinensis

These Petri dishes contain bacterial cultures. Scientists often grow bacteria in the laboratory in order to study them more easily.



CHAPTER 24

BACTERIA

These bacteria are called Clostridium perfringens. *They are commonly found in soil and are the cause of the disease gas gangrene. (SEM 17,100×)*

FOCUS CONCEPT: ***Cell Structure and Function***

As you read, notice that bacteria have complex structural, nutritional, and genetic properties even though they are single-celled microorganisms.

SECTION

24-1

BACTERIAL EVOLUTION AND CLASSIFICATION

Bacteria are the most numerous organisms on Earth as well as the most ancient—they were probably the first forms of life. It is likely that all other organisms evolved from bacteria. The earliest fossils show that bacteria existed long before other forms of life evolved.

OBJECTIVES

- Define *bacteria, eubacteria,* and *archaebacteria,* and note the relationships between them.
- Describe the methods used to classify bacteria.
- Name and describe three known types of archaebacteria.
- Distinguish Gram-positive bacteria from Gram-negative bacteria.
- Describe the significance of cyanobacteria in the formation of the Earth's present atmosphere.

EVOLUTION

Bacteria are microscopic prokaryotes. Rock deposits found in Australia contain fossils of bacteria that existed on Earth about 3.5 billion years ago. Evidence in the fossil record indicates that eukaryotes are about 2.5 billion years old and modern humans arose about 100,000 years ago.

Bacteria have evolved into many different forms, and they are now a part of nearly every environment on Earth. They have even been found at the bottom of oceanic trenches 9.6 km (6 mi) below the water's surface and in Arctic and Antarctic regions. Evolution has yielded hundreds of thousands of species of bacteria that are adapted to places where no other organisms can live.

Classification

Unlike most other organisms, bacteria have few morphological differences that can be used to classify them. For example, bacteria do not vary in size and shape to the extent that other types of organisms do. Traditionally, bacteria have been grouped based on their structure, physiology, molecular composition, and reaction to specific types of stains, rather than on their evolutionary relationships. By comparing ribosomal RNA sequences, scientists have found that there are two vastly different types of bacteria. The bacteria that we generally refer to as germs are classified in the kingdom Eubacteria. In this text, members of the kingdom Eubacteria are sometimes referred to as **eubacteria** (YOO-bak-TEER-ee-uh), but more frequently, members of this kingdom are simply called bacteria. The other type of bacteria are called **archaebacteria** (AHR-kee-bak-TEER-ee-uh). These bacteria, which are more ancient than the eubacteria, are classified in the kingdom Archaebacteria.

KINGDOM ARCHAEBACTERIA

Scientists treat archaebacteria as a separate kingdom because these organisms are so different from other bacteria. For example, archaebacteria have unusual lipids in their cell membranes and have introns in their DNA. Their cell walls are also characterized by the absence of **peptidoglycan** (PEP-tuh-doh-GLIE-KAHN), a protein-carbohydrate compound found in the cell walls of eubacteria. While archaebacteria have some genes that resemble eubacterial genes, they also have genes that closely resemble those found in eukaryotes. This suggests that archaebacteria probably evolved from an ancestral organism that gave rise to other forms of life on Earth.

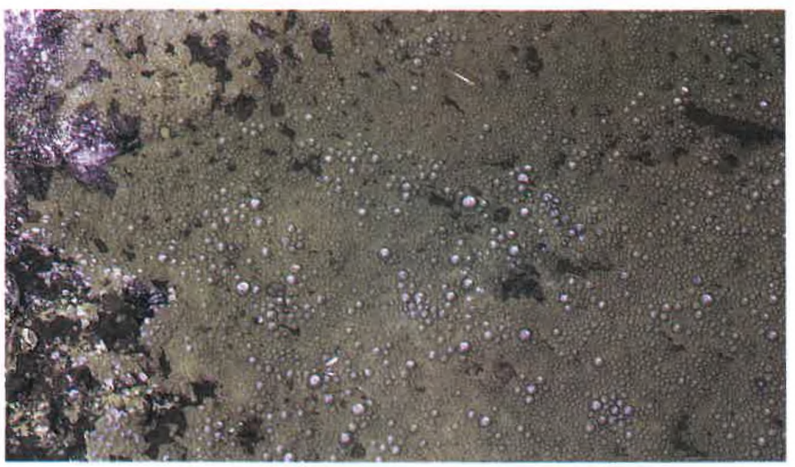
Archaebacteria were first discovered in extreme environments, such as swamps, salt lakes, and hot springs. Until recently, scientists believed that archaebacteria lived only in these extreme environments. However, by testing samples of surface water in the North Pacific and Antarctic Oceans for the presence of archaebacterial genomic sequences, scientists have discovered that archaebacteria may be more common than once thought.

Methanogens (meth-AN-uh-jenz), a broad phylogenetic group of archaebacteria, are named for their unique method of harvesting energy by converting H_2 and CO_2 into methane gas. Because oxygen is a poison to them, methanogens can live only in anaerobic conditions, such as at the bottom of a swamp and in sewage, where they are the source of marsh gas, as shown in Figure 24-1. They can also be found thriving in the intestinal tracts of humans and other animals, such as cows.

Extreme halophiles (HAL-uh-FIELZ), which are salt-loving archaebacteria, live in environments with very high salt concentrations, such as the Great Salt Lake and the Dead Sea. High salt concentrations would kill most bacteria, but this high concentration is beneficial to the growth of extreme halophiles, and these organisms use salt to generate ATP.

FIGURE 24-1

Some archaebacteria, such as the methanogens that are found in the muddy bottom of this swamp, live in anaerobic conditions. Methanogens produce methane, which you can see bubbling up through the water.



Thermoacidophiles (THUHR-moh-uh-SID-oh-fielz), a third group of archaebacteria, live in extremely acidic environments that have extremely high temperatures, such as hot springs. Some thermoacidophiles thrive at temperatures up to 110°C (230°F) and at a pH of less than 2. Thermoacidophiles live near volcanic vents on land or near hydrothermal vents, cracks in the ocean floor miles below the surface that leak scalding acidic water.

Research Notes

A Geologic Hot Spot

In 1977, the submarine *Alvin* drifted slowly through the cold, dark waters off the coast of Ecuador, in the Galápagos Rift of the South Pacific. On board was a team of marine geologists from the Woods Hole Oceanographic Institution led by Robert D. Ballard. They were seeking hydrothermal vents—fissures in the Earth's crust that release heat and minerals into the surrounding water. At an ocean depth of 2550 m (8,366 ft), they found hydrothermal vents and underwater hot springs teeming with marine life.

At the time, scientists believed that no living organism could survive the harsh combination of extremely high temperatures, high pressure, and total darkness. To their surprise, when the geologists developed their film, they found ghostly images of huge clamshells and previously unknown giant tube worms thriving among the bare lava. At those depths, no sunlight penetrates to support photosynthesis. What were the vent organisms using for food?

When chemist John Edmond, who was aboard the *Alvin,* analyzed the water samples, he found that they contained a large amount of dissolved hydrogen sulfide. Later, researchers following up on Ballard's deep-sea find confirmed that bacteria from vent waters, when cultured under pressures and temperatures found in a deep-sea environment, metabolize hydrogen sulfide as an energy source in a process known as chemosynthesis. To test the idea that the larger organisms used these bacteria for food, marine biologists continued to observe the organisms living in vent communities.

These biologists discovered that the dominant vent animals—clams, mussels, and giant tube worms—have a symbiotic relationship with the vent bacteria. Using microscopes, they found that the tube worms, for example, have colonies of bacteria living in their tissues. Tube worms are red because they are filled with hemoglobin. In humans, hemoglobin transports oxygen to cells. In tube worms, hemoglobin binds with hydrogen sulfide and carries it to the bacteria. The bacteria then oxidize the hydrogen sulfide, producing carbon compounds that in turn nourish the worms.

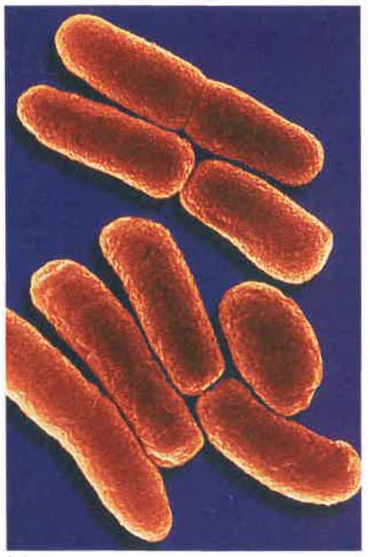
Similar communities of organisms have since been found at hundreds of geologic hot spots around the world. In December 1993, an *Alvin* expedition to the East Pacific Rise, an underwater mountain range southwest of Acapulco, Mexico, was conducted to study a recently formed hydrothermal vent.

At the site, thickets of 1.2 m (4 ft) long tube worms were found planted on the ocean floor. Measurements indicated that these tube worms grew at a rate of 84 cm (33 in.) per year, making them the fastest-growing marine organisms known.

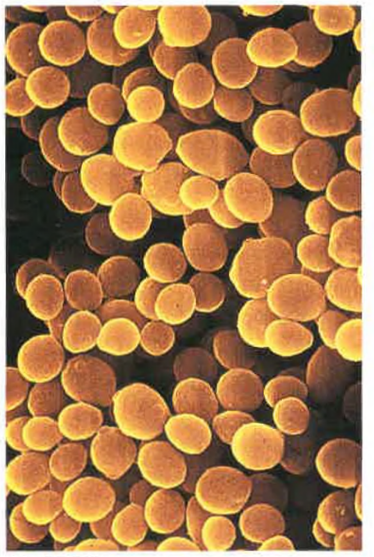
The 1993 expedition was only one in a series of dives to the East Pacific Rise. The first visit had taken place in 1989, when scientists first discovered the vent community. Then, in April 1991, the team of scientists was surprised to find another hydrothermal vent at the site. A recent volcanic eruption at the site produced the hottest hydrothermal vent ever recorded. Scientists named the site Tube Worm Barbecue after retrieving tube worms with charred flesh. One of the scientists reported that bacteria in the vent communities were so plentiful that there appeared to be a snow blizzard. After the eruption, the only living organisms that remained on the ocean floor were centimeters of bacterial mats. However, by March 1992 the bacterial mats had been replaced by new life.

With the discovery of hydrothermal vents, there are many questions to be asked concerning their significance. As research continues, scientists will study the light source that these vents give off and its effect on the organisms that reside there.

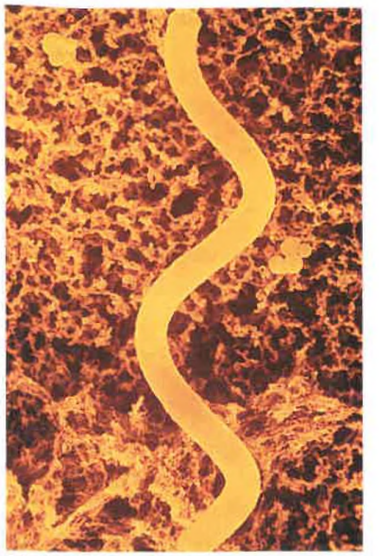
A vent-dwelling crab is spotted by the remote-operated sub Alvin.



(a) BACILLI



(b) COCCI



(c) SPIRILLA

FIGURE 24-2

The most common shapes among bacteria are represented here by (a) *Escherichia coli,* bacilli; (b) *Micrococcus luteus,* cocci (SEM 117,300×); and (c) *Spirillum volutans,* spirilla. (SEM 19,900×)

KINGDOM EUBACTERIA

Eubacteria account for most bacteria; they occur in many shapes and sizes and have distinct biochemical and genetic characteristics. Most eubacteria have one of three basic shapes, as shown in Figure 24-2. Eubacteria that are rod-shaped are called **bacilli** (buh-SIL-ie). Sphere-shaped eubacteria are called **cocci** (KAHK-sie), and spiral-shaped eubacteria are called **spirilla** (spie-RIL-uh). When cocci occur in chains, they are called **streptococci** (STREP-tuh-KAHK-sie); grapelike clusters of cocci are called **staphylococci** (STAF-uh-loh-KAHK-sie).

Eubacteria can be divided into as many as 12 different phyla according to their evolutionary relationships. Because bacteria diversified so long ago, scientists disagree on how they should be classified phylogenetically. Table 24-1 lists several generally recognized phyla of bacteria and their properties.

TABLE 24-1 *Some Phyla of Bacteria and Their Properties*

Phylum	Shape	Motility	Metabolism	Gram reaction
Cyanobacteria	bacilli, cocci	gliding; some nonmotile	aerobic, photosynthetic autotrophic	Gram-negative
Spirochetes	spirals	corkscrew motion	aerobic and anaerobic; heterotrophic	Gram-negative
Gram-positive bacteria	bacilli, cocci	flagella; some nonmotile	aerobic and anaerobic; heterotrophic, photosynthetic	mostly Gram-positive
Proteobacteria	bacilli, cocci, spiral	flagella; some nonmotile	aerobic and anaerobic; heterotrophic; unusual metabolism; and photosynthetic autotrophic	Gram-negative

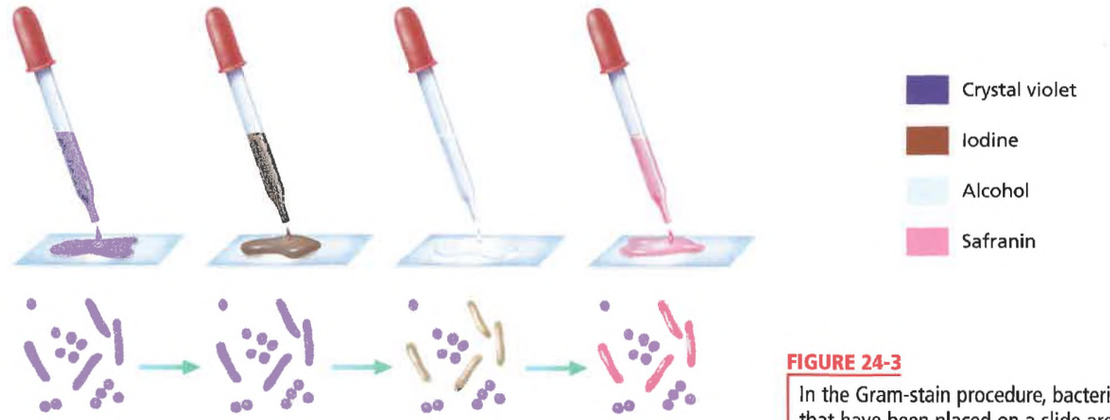


FIGURE 24-3
In the Gram-stain procedure, bacteria that have been placed on a slide are stained with a purple dye solution called crystal violet (a). The purple dye is washed off with water, and then a solution of iodine is added to the slide (b). The bacteria are rinsed with alcohol (c) and then restained with a pink dye solution called safranin (d). Gram-positive bacteria will retain the purple dye and appear purple, while Gram-negative bacteria will appear pink from the pink dye solution.

Gram Stain

Most species of eubacteria can also be grouped into two categories based on their response to a laboratory technique called the **Gram stain,** which is shown in Figure 24-3. **Gram-positive** bacteria retain the Gram stain and appear purple under the microscope. **Gram-negative** bacteria do not retain the purple stain and take up a second pink stain instead. Because Gram-positive bacteria have a thicker layer of peptidoglycan in their cell wall than Gram-negative bacteria do, they are able to retain the Gram stain. Figure 24-4 compares the cell walls of these two groups of bacteria. Gram-positive and Gram-negative bacteria also differ in several other ways. For example, they have different susceptibilities to antibacterial drugs, they produce different toxic materials, and they react differently to disinfectants. For these reasons, the Gram stain is useful for identifying and grouping eubacteria.

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TOPIC: Eubacteria
GO TO: www.scilinks.org
KEYWORD: HM471

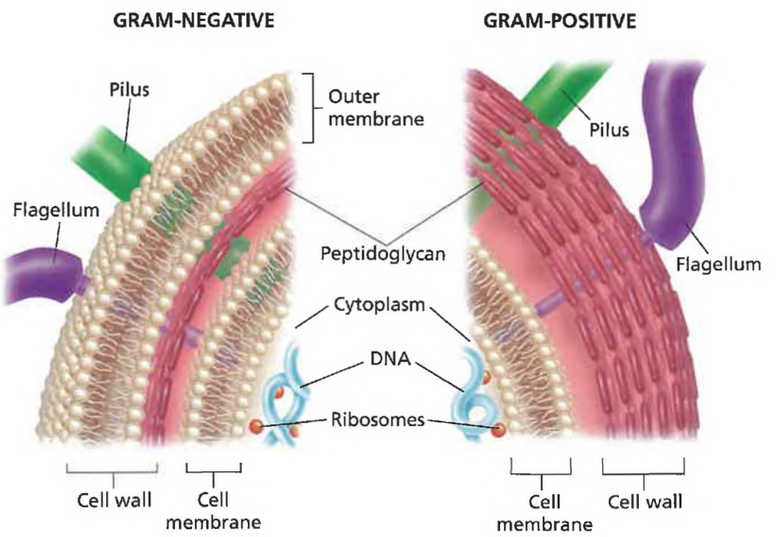


FIGURE 24-4
The drawing demonstrates the similarities and differences between Gram-negative bacteria and Gram-positive bacteria.

Word Roots and Origins

heterocyst

from the Greek *hetero,* meaning "other or different," and *kystis,* meaning "sac or bladder"

Quick Lab

Predicting the Spread of Disease

Materials disposable gloves, lab apron, and safety goggles; clear plastic cup with liquid

Procedure

1. Put on your disposable gloves, lab apron, and safety goggles.
2. Obtain a cup of liquid from your teacher.
3. Pour the contents of your cup into a classmate's cup. Have the classmate pour half the liquid back into your cup. Circulate around the room and repeat this step with two other classmates at random. Choose classmates you do not know well, and do not touch hands with anyone.
4. If one of your classmates had a highly contagious bacterial disease, predict how likely it is that you have "caught" the disease. Then your teacher will test the liquid in each student's cup to see who else has caught the disease. Count the number of students who are "infected."

Analysis How did the actual results compare with your prediction? How many students became infected? Was direct contact needed?

Phylum Cyanobacteria

The cyanobacteria are photosynthetic; that is, they use photosynthetic chemicals to capture sunlight, harvest the energy to produce carbohydrates, and give off oxygen as a waste product. Recall that the atmosphere of early Earth was filled with the oxygen produced by cyanobacteria, which allowed aerobic organisms to develop.

Cyanobacteria, once classified as blue-green algae, are now considered eubacteria because they lack a membrane-bound nucleus and chloroplasts. Unlike other eubacteria, however, the cyanobacteria are encased in a jellylike substance and often cling together in colonies.

Certain cyanobacteria grow in chains. Some of these cells form specialized cells called **heterocysts.** Heterocysts contain enzymes for fixing atmospheric nitrogen. Cyanobacteria that form heterocysts make nitrogen available to plants in a form that plants can use.

Cyanobacteria, such as *Anabaena,* thrive on phosphates and nitrates that accumulate in a body of water. The sudden increase in the number of cyanobacteria due to a high availability of nutrients is called **eutrophication** (YOO-troh-fuh-KAY-shuhn), or **population bloom.** Following eutrophication, many of the cyanobacteria die and are decomposed by heterotrophic bacteria. The increasing population of heterotrophic bacteria consume available oxygen in the water, causing other organisms in the water, such as fish, to die from lack of oxygen.

Phylum Spirochetes

Spirochetes (SPIE-roh-KEETS) are Gram-negative, spiral-shaped heterotrophic bacteria. Some spirochetes are aerobic, and some are anaerobic. They all move by means of a corkscrew-like rotation. Spirochetes live freely, symbiotically, or parasitically. One well-known spirochete is *Treponema pallidum,* which causes the sexually transmitted disease syphilis.

Phylum Gram-Positive Bacteria

Despite its name, not all members of this phylum are Gram-positive. A few species of Gram-negative bacteria are also grouped in this phylum because they share molecular similarities with Gram-positive bacteria. Members of this phylum include the species of streptococci that causes strep throat.

Milk becomes yogurt when certain Gram-positive bacilli grow in milk and produce lactic acid. Gram-positive bacilli are also found in the oral cavity and in the intestinal tract, where they retard the growth of disease-causing bacteria. Lactobacilli, Gram-positive bacilli found on the teeth, are known to cause tooth decay through the release of acid.

Actinomycetes (AK-tuh-noh-MIE-seets) are Gram-positive bacteria that form branching filaments. They grow in the soil and produce many **antibiotics,** chemicals that inhibit the growth of or kill other microscopic organisms.

Phylum Proteobacteria

The proteobacteria make up one of the largest and most diverse phylum among bacteria. This group is divided into several subdivisions, including enteric bacteria, chemoautotrophic bacteria, and nitrogen-fixing bacteria.

Enteric bacteria are Gram-negative heterotrophic bacteria that inhabit animal intestinal tracts and can live in either aerobic or anaerobic conditions. This group includes the well-known organism *Escherichia coli* (abbreviated *E. coli*). *E. coli* lives in the human intestine where it produces vitamin K and assists enzymes in the breakdown of foods. Other genera of enteric bacteria are responsible for many diseases. For example, bacteria in the genus *Salmonella* are responsible for many cases of food poisoning.

Chemoautotrophs (KEEM-oh-AW-toh-TROHFS) are Gram-negative bacteria that can extract energy from minerals by oxidizing the chemicals in these minerals. For example, iron-oxidizing bacteria, live in freshwater ponds that contain a high concentration of iron salts. The iron bacteria oxidize the iron in the salts to obtain energy.

As you learned in Chapter 22, nitrogen-fixing bacteria, which include some Gram-negative rods, live both freely and symbiotically with plants. *Rhizobium* is one example of nitrogen-fixing bacteria that live symbiotically with plants.

Nitrogen-fixing bacteria are vital to the success of many ecosystems. Although almost 80 percent of Earth's atmosphere is composed of nitrogen gas, N_2, plants and animals are unable to use it. *Rhizobium* is able to convert nitrogen gas to a form of nitrogen that plants can most easily use. Nitrogen-fixing bacteria colonize many plants, such as beans, soybeans, peas, alfalfa, and clover. By inducing plants to form nodules on their roots, nitrogen-fixing bacteria receive organic compounds that they need while providing the plants with nitrogen in a form they can use. *Rhizobium* is considered a major microbial source of soil nitrogen. *Rhizobium* can produce about 250 kg (114 lb) of fixed nitrogen per hectare (2.5 acres) of alfalfa in a single year, whereas the free-living nitrogen-fixing *Azotobacter* genus can produce only 2.5 kg (1.1 lb) of fixed nitrogen per hectare of alfalfa in a year.

SECTION 24-1 REVIEW

1. **Explain how the terms *bacteria, eubacteria,* and *archaebacteria* relate to one another.**
2. **List the characteristics that are used to classify bacteria.**
3. **List the habitats of three types of archaebacteria.**
4. **Distinguish between Gram-positive bacteria and Gram-negative bacteria.**
5. **Describe the significance of cyanobacteria in the formation of the Earth's atmosphere.**
6. **CRITICAL THINKING Why are methanogens and cyanobacteria unable to live in the same environment?**

SECTION

24-2

OBJECTIVES

- Describe the structure of a bacterial cell.
- Describe three ways that bacteria move.
- Compare the heterotrophic modes of nutrition in bacteria with the autotrophic modes.
- Discuss the various types of environments that bacteria occupy.
- List three types of genetic recombination used by bacteria.

BIOLOGY OF BACTERIA

Viewed through a light microscope, bacteria appear to be relatively simple rods, spheres, and other forms. However, the electron microscope reveals a great amount of detailed structure within each form. These detailed structures are responsible for the activities carried out by bacteria.

STRUCTURE

Bacteria are typically composed of a cell wall, a cell membrane, and cytoplasm. Some bacteria have distinctive structures, such as endospores, capsules, and outer membranes. The variety of structures among bacteria is due to adaptations to individual niches. A summary of bacterial structures is presented in Table 24-2.

Cell Wall

With a few exceptions, both eubacteria and archaebacteria have a cell wall. Unlike plant cell walls, eubacterial cell walls are made of peptidoglycan. Peptidoglycan is composed of short chains of amino acids, or peptides, and carbohydrates. Archaebacterial cell walls are composed of a different compound. In Gram-negative eubacteria, the cell wall includes an outer membrane that is composed of a layer of lipids and sugars. The outer membrane protects these bacteria against some kinds of antibiotics by preventing their entry into the cell. Thus, many antibiotics have no effect on Gram-negative bacteria.

Cell Membrane and Cytoplasm

The bacterial cell membrane, which is composed of a lipid bilayer, is similar to the eukaryotic cell membrane. However, in bacteria, the cell membrane contains the enzymes that catalyze the reactions of cellular respiration. Because bacteria do not have mitochondria, they use their cell membranes to create proton gradients and to carry out cellular respiration.

The cell membranes of photosynthetic bacteria have internal foldings called thylakoids. These structures are homologous to the thylakoids found in plant chloroplasts. Like those in plant chloroplasts, bacterial thylakoids contain photosynthetic pigments and carry out the function of harvesting light energy.

Unlike eukaryotic cells, bacterial cells do not contain membrane-bound organelles. The cytoplasm of bacterial cells is made of a viscous solution of ribosomes and DNA. The bacterial DNA is arranged

TABLE 24-2 Structural Characteristics of a Bacterial Cell

Structure	Function
Cell wall	protects the cell and gives it shape
Outer membrane	protects the cell against some antibiotics (only present in Gram-negative cells)
Cell membrane	regulates movement of materials into and out of the cell; contains enzymes important to cellular respiration
Cytoplasm	contains DNA, ribosomes, and organic compounds required to carry out life processes
Chromosome	carries genetic information inherited from past generations
Plasmid	contains some genes obtained through genetic recombination
Capsule and slime layer	protect the cell and assist in attaching the cell to other surfaces
Endospore	protects the cell against harsh environmental conditions, such as heat and drought
Pilus	assists the cell in attaching to other surfaces, which is important for genetic recombination
Flagellum	moves the cell

in a single, closed loop. In addition to the main chromosome, some species of bacteria also have plasmids, self-replicating loops of DNA, in their cytoplasm.

Capsules and Pili

Many bacterial species produce an outer covering called a **capsule.** The capsule is made of polysaccharides that cling to the surface of the cell and protect it against drying or harsh chemicals. It also protects an invading bacterium from the host body's white blood cells, which could otherwise engulf it. When a capsule consists of a fuzzy coat of sticky sugars, it is called a **glycocalyx** (GLIE-koh-KAY-liks). The glycocalyx enables bacteria to attach to the surface of host cells and tissues.

Pili (PIL-ee) are short, hairlike protein structures found on the surface of some species of bacteria. Pili help bacteria adhere to host cells. Pili are also used to transfer genetic material from one bacterium to another.

Endospores

A bacterial **endospore** is a dormant structure that is produced by some Gram-positive bacterial species that are exposed to harsh environmental conditions. Endospores consist of a thick outer covering that surrounds the cell's DNA. Although the original cell may be destroyed by harsh conditions, its endospore will survive. Endospores are not reproductive cells. Instead, they help bacteria resist high temperatures, harsh chemicals, radiation, drying, and other environmental extremes. When conditions become favorable, the endospore will open, allowing the living bacterium to emerge and to begin multiplying. Endospores can be formed by species of the genera *Bacillus* and *Clostridium.*

Word Roots and Origins

pili

from the Latin *pilus,* meaning "hair"

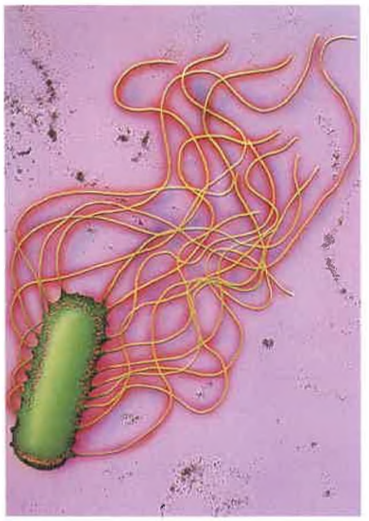


FIGURE 24-5
Some bacteria, such as this Gram-negative *Salmonella,* move by means of flagella.

Movement Structures

Many bacteria use flagella to move. Flagella, which are made of protein, turn and propel the bacterium in an erratic, "run-and-tumble" motion. Bacteria can have a single flagellum or a tuft of flagella. Some species of bacteria have flagella at both ends of the cell, and other species of bacteria are completely surrounded by flagella, as is the bacterium shown in Figure 24-5.

The bacteria that lack flagella have other methods of movement. For example, myxobacteria produce a layer of slime and then glide through it. Wavelike contractions of the outer membrane propel the organism through the slime. Some spiral-shaped bacteria move by a corkscrew-like rotation. These organisms have flexible cell walls and filaments within the cell walls that, when contracted, cause the bacterium to turn and move ahead.

NUTRITION AND GROWTH

Depending on the species, bacteria may be heterotrophic or autotrophic. Heterotrophic bacteria use organic matter as a source of nutrition. Heterotrophic bacteria that feed on dead and decaying material are called **saprophytes** (SAP-ruh-FIETS). Autotrophic bacteria obtain their energy from sunlight or minerals.

Bacteria that use sunlight as an energy source, such as cyanobacteria, are called **photoautotrophs** (FOH-toh-AW-toh-trohfs). These autotrophs use light-trapping compounds similar to those used by plants to obtain energy. As you learned in the previous section, chemoautotrophs, another group of autotrophic organisms, oxidize inorganic compounds to obtain energy. For example, members of the genus *Nitrosomonas* oxidize ammonia, NH_3, to form nitrite, NO_2, and harvest the resulting energy.

Many bacteria are **obligate anaerobes** (AHB-luh-git AN-uhr-OHBZ), which means they cannot survive in the presence of oxygen. The obligate anaerobe *Clostridium tetani* causes tetanus. **Facultative anaerobes** (FAK-uhl-TAY-tiv AN-uh-ROHBZ) can live with or without oxygen. *Escherichia coli,* which is common in the human digestive tract, is a facultative anaerobe. Bacteria that cannot survive without oxygen are called **obligate aerobes.** The obligate aerobe *Mycobacterium tuberculosis* lives in the lungs and causes tuberculosis.

Bacteria have varying temperature requirements for growth. Some bacteria grow best in cold temperatures of 0–20°C (32–68°F). Other bacteria grow best in temperatures that range from 20°C (68°F) to 40°C (104°F). **Thermophilic** (THUHR-moh-FIL-ik) bacteria grow best in temperatures between 40°C (104°F) and 110°C (230°F). Most bacterial species grow best at a pH of 6.5 to 7.5 (7.0 is neutral). Certain species, such as those used to produce yogurt and sour cream, prefer acidic environments of a pH of 6.0 or lower.

TABLE 24-3 *A Comparison of Three Genetic Recombination Methods*

Characteristic	Transformation	Conjugation	Transduction
Method of DNA transfer	across cell wall and cell membrane of recipient	through a conjugation bridge between two cells	by a virus
Plasmid transfer	yes	yes	not likely
Chromosome transfer	no	sometimes	no
Antibiotic resistance acquired	yes	yes	sometimes

GENETIC RECOMBINATION

Table 24-3 summarizes three nonreproductive ways that bacteria can acquire and express new combinations of genetic material. **Transformation** occurs when a bacterial cell takes in DNA from its external environment. The new DNA is then substituted for a similar DNA fragment in the chromosome of the bacterial cell.

Bacterial **conjugation** is the process by which two living bacteria bind together and one bacterium transfers genetic information to the other. In order for conjugation to take place, the genetic donor must have a specialized plasmid and pilus. The specialized pilus binds to a recipient bacterium that does not have the specialized plasmid and forms a **conjugation bridge,** a passageway for the transfer of the genetic information. The plasmid replicates in the donor bacterium, and one copy of the plasmid passes through the conjugation bridge to the recipient bacterium. After the DNA transfer, the cells detach.

In **transduction,** a virus obtains a fragment of DNA from a host bacterium. As the viruses replicate inside the bacterium, they produce new copies of the bacterial DNA fragment. After the newly formed viruses have been released, they carry the bacterial gene to a new bacterium, where it can be expressed by the recipient bacterium.

SECTION 24-2 REVIEW

1. List the various structures of the bacterial cell, and describe their function.
2. Describe three types of movement among bacteria.
3. What specific terms are used to describe the oxygen requirements of bacteria?
4. In what key way do photoautotrophs and chemoautotrophs differ?
5. List and summarize three methods of genetic recombination in bacteria.
6. **CRITICAL THINKING** What eukaryotic structures are functionally similar to the bacterial cell membrane and its infoldings?

SECTION

24-3

OBJECTIVES

- Describe the ways that bacteria can cause disease in humans.
- Specify how antibiotic resistance has come about, and describe ways that bacteria resist antibiotics.
- List three ways that bacteria are helpful to humans.

BACTERIA AND HUMANS

Much of our knowledge about bacteria is a result of the study of the diseases they cause in humans. In addition to what we have learned about pathogenic bacteria and how they cause disease, we have also learned how bacteria benefit us. Bacteria are used in food preparation and in environmental, chemical, and mining processes.

BACTERIA AND DISEASE

The scientific study of disease is called **pathology** (path-AHL-uh-jee). Bacteria that cause disease are called pathogens. Some diseases caused by bacteria are listed in Table 24-4.

Some bacteria cause disease by producing poisons called **toxins** (TAHK-sins). **Exotoxins** (EKS-oh-TAHK-sins) are toxins that are made of protein. Exotoxins are produced by Gram-positive bacteria and are secreted into the surrounding environment. For example, tetanus is a disease caused by an exotoxin.

TABLE 24-4 *A Summary of Bacterial Diseases*

Disease	Pathogen	Areas affected	Mode of transmission
Botulism	*Clostridium botulinum*	nerves	improperly preserved foods
Cholera	*Vibrio cholerae*	intestine	contaminated water
Dental caries (tooth decay)	*Streptococcus mutans, sanguis,* and *salivarius*	teeth	bacteria enter the mouth from the environment
Gonorrhea	*Neisseria gonorrhoeae*	urethra, fallopian tubes, epididymis	person-to-person by sexual contact
Lyme disease	*Borrelia burgdorferi*	skin, joints, heart	tick bite
Rocky Mountain spotted fever	*Rickettsia ricketsii*	blood, skin	tick bite
Salmonella food poisoning	*Salmonella*	intestine	contaminated water and food
Strep throat	*Streptococcus pyogenes*	upper respiratory tract, blood, skin	person-to-person by sneezes, coughs, or direct contact
Tetanus	*Clostridium tetani*	nerves at synapses	contaminated wounds
Tuberculosis	*Mycobacterium tuberculosis*	lung, bones, other organs	person-to-person by coughs

Endotoxins, toxins made of lipids and carbohydrates, are associated with the outer membrane of Gram-negative bacteria, such as *E. coli.* While exotoxins are steadily released by living Gram-positive bacteria, endotoxins are not released by Gram-negative bacteria until the bacteria die. Once released, endotoxins cause fever, body aches, and weakness, and they damage the vessels of the circulatory system.

Bacteria also cause disease by destroying body tissues. As bacteria adhere to cells, they secrete digestive enzymes. These enzymes allow further tissue invasion. For example, some *Streptococci* bacteria produce a blood-clot-dissolving enzyme that allows infectious bacteria to spread to other tissues.

Word Roots and Origins

endotoxin

from the Greek *endon,* meaning "within," and *toxicon,* meaning "poison"

Antibiotics

Antibiotics are drugs that combat bacteria by interfering with various cellular functions. For example, **penicillin** interferes with cell-wall synthesis. **Tetracycline** (TE-truh-SIE-klin) interferes with bacterial protein synthesis. Many antibiotics are derived from chemicals that bacteria and fungi produce. Antibiotics protect bacteria and fungi from other microscopic invaders. Other antibiotics, such as **sulfa drugs,** are synthesized in laboratories. Many antibiotics are able to affect a wide variety of organisms; they are called **broad-spectrum antibiotics.** Some antibiotics, their mechanisms of action, and target bacteria are listed in Table 24-5.

Antibiotic Resistance

When a population of bacteria is exposed to an antibiotic, the bacteria that are most susceptible to the antibiotic die first. However, a few mutant bacteria that are resistant to the antibiotic may continue to grow. A resistant population then grows from these mutant bacteria through reproduction and genetic recombination. In this

TABLE 24-5 *A Summary of Common Antibiotics*

Antibiotic or synthetic drug	Mechanism of action	Target bacteria
Penicillin	inhibits cell-wall synthesis	Gram-positive bacteria
Ampicillin	inhibits cell-wall synthesis	broad spectrum
Bacitracin	inhibits cell-wall synthesis	Gram-positive bacteria; used as a skin-ointment
Cephalosporin	inhibits cell-wall synthesis	Gram-positive bacteria
Tetracycline	inhibits protein synthesis	broad spectrum
Streptomycin	inhibits protein synthesis	Gram-negative bacteria, tuberculosis
Sulfa drug	inhibits cell metabolism	bacterial meningitis, urinary-tract infections
Rifampin	inhibits RNA synthesis	Gram-positive bacteria and some Gram-negative bacteria
Quinolines	inhibit DNA synthesis	urinary-tract infections

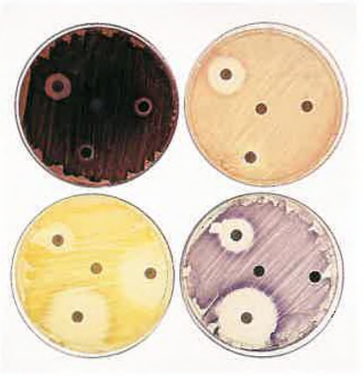


FIGURE 24-6

Bacteria can be tested for their sensitivity to antibiotics by growing them in a Petri dish with paper disks containing different antibiotics. As the antibiotics diffuse into the agar, the bacteria's growth will be inhibited by the antibiotic if the bacteria are sensitive to that antibiotic.

way, antibiotics provide a selective advantage to antibiotic-resistant bacteria. Because antibiotics have been overused, many diseases that were once easy to treat are becoming more difficult to treat.

The mechanisms of antibiotic resistance vary. In some bacteria, cell walls prevent passage of the antibiotic. Still other bacteria secrete enzymes that destroy or alter the antibiotic, as penicillin-resistant bacteria do. Figure 24-6 shows a method of testing bacterial resistance and sensitivity toward antibiotics.

USEFUL BACTERIA

Bacteria affect our lives in many positive ways. In sewage treatment, for example, bacteria break down the remains of organic matter in dead plant and animal waste, recycling carbon and nitrogen. Bacteria also turn sewage into simpler organic compounds. Bacteria, along with other microorganisms, recycle compounds from dead organisms, making them available to other organisms through the process of decay. Many bacteria are also able to fix carbon dioxide and create organic compounds.

Bacteria are also useful in producing and processing food. For example, bacteria ferment the lactose in milk to produce sour-milk products such as buttermilk, sour cream, and yogurt. Other species of bacteria digest the protein in milk and produce unripened cheeses such as ricotta and cottage cheese. Fermented foods are also produced by bacteria. Sauerkraut is produced when bacteria digest the carbohydrates in cabbage, and pickles result from the fermentation of cucumbers.

Bacteria are also used in industrial chemical production. They produce organic chemicals and fuels. Some are useful in mining for minerals and in petroleum recovery, while other bacteria and their products are used as insecticides. Bacteria are also used to help clean up environmental disasters caused by humans, such as chemical and oil spills.

SECTION 24-3 REVIEW

1. Describe ways that bacteria cause human disease.
2. Describe the function of antibiotics in nature.
3. List three antibiotics used to treat disease and the mechanism of action of each.
4. List some of the positive uses of bacteria.
5. Explain how antibiotic resistance arises in bacteria and how bacteria resist antibiotics.
6. **CRITICAL THINKING** Why would a pickle processor carry out the preparation of pickles in anaerobic conditions?

CHAPTER 24 REVIEW

SUMMARY/VOCABULARY

24-1

- Bacteria are prokaryotic single-celled organisms. They occur in several variations of three basic shapes: rods, spheres, and spirals.
- Bacteria are the oldest and most populous organisms. They are believed to have existed on Earth for about 3.5 billion years.
- Bacteria are classified in two kingdoms: Archaebacteria, which includes ancient forms of life, and Eubacteria, which includes most bacteria.
- The archaebacteria include the methanogens, which produce methane gas; the extreme halophiles, which live in very salty environments; and the thermoacidophiles, which live in extremely acidic environments at extremely high temperatures.
- The Gram stain is used to group bacteria into two groups; Gram-positive and Gram-negative bacteria.
- The cyanobacteria are photosynthetic bacteria that probably produced much of the oxygen in the Earth's atmosphere.

Vocabulary

actinomycete (472)
antibiotic (472)
archaebacterium (467)
bacillus (470)
chemoautotroph (473)
coccus (470)
enteric bacterium (473)
eubacterium (467)
eutrophication (472)
extreme halophile (468)
Gram-negative (471)
Gram-positive (471)
Gram stain (471)
heterocyst (472)
methanogen (468)
peptidoglycan (468)
population bloom (472)
spirillum (470)
spirochete (472)
staphylococcus (470)
streptococcus (470)
thermoacidophile (468)

24-2

- The major structures of the bacterial cell include a cell wall, a cell membrane, cytoplasm, a capsule, pili, endospores, ribosomes, and movement structures.
- Aerobic and anaerobic bacteria differ in whether they need an oxygen-rich environment or an oxygen-free environment. Different species live under different temperature conditions, ranging from 0°C to 110°C. Most bacterial species grow best at a neutral pH.
- Genetic recombination in bacteria can occur through transformation, conjugation, and transduction.

Vocabulary

capsule (475)
conjugation (477)
conjugation bridge (477)
endospore (475)
facultative anaerobe (476)
glycocalyx (475)
obligate aerobe (476)
obligate anaerobe (476)
photoautotroph (476)
pilus (475)
saprophyte (476)
thermophilic (476)
transduction (477)
transformation (477)

24-3

- Many bacteria are pathogens. Diseases may result from toxins produced by bacteria, from the destruction of body tissues, or from bacterial enzymes interfering with normal body processes.
- Antibiotics inhibit the growth of bacteria. Antibiotic-resistant bacteria destroy antibiotics, or prevent entry of the antibiotic into the cytoplasm.
- Helpful bacteria are used to convert sewage into simpler organic compounds, to produce and process food, to produce industrial chemicals, to mine for minerals, to produce insecticides, and to clean up chemical and oil spills.

Vocabulary

broad-spectrum antibiotic (479)
endotoxin (479)
exotoxin (478)
pathology (478)
penicillin (479)
sulfa drug (479)
tetracycline (479)
toxin (478)

REVIEW

Vocabulary

In each of the following sets, choose the term that does not belong, and explain why it does not belong.

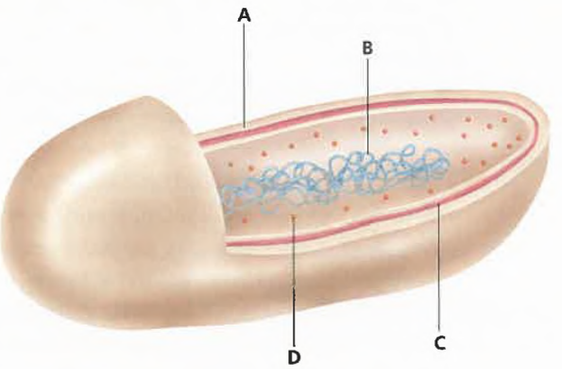
1. heterotroph, saprophyte, chemoautotroph
2. methanogen, spirochetes, enteric bacteria
3. archaebacterium, exotoxin, pathogen
4. pilus, conjugation, endospore
5. cyanobacterium, anaerobe, enteric bacteria

Multiple Choice

6. Bacteria produce yogurt from milk by (a) conjugation (b) aerobic respiration (c) fermentation (d) fixing nitrogen.
7. Rod-shaped bacteria are called (a) cocci (b) bacilli (c) halophiles (d) spirilla.
8. Thermoacidophiles are (a) eubacteria (b) cyanobacteria (c) archaebacteria (d) spirochetes.
9. Gram-positive bacteria stain (a) blue (b) pink (c) red (d) purple.
10. Eutrophication is the result of (a) antibiotics (b) pathogens (c) bacterial conjugation (d) population explosions.
11. Bacterial DNA is (a) a closed loop (b) encased in a capsule (c) linear (d) found in the nucleus.
12. The glycocalyx helps bacteria (a) survive unfavorable environmental conditions (b) stick to surfaces (c) metabolize gaseous nitrogen (d) ingest food.
13. During nitrogen fixation, gaseous nitrogen is converted to (a) carbon (b) ammonia (c) nitrate (d) methane.
14. An organism that must have oxygen to survive is (a) an obligate aerobe (b) a facultative anaerobe (c) a facultative aerobe (d) an obligate anaerobe.
15. Genetic recombination in bacteria can occur during the process of (a) conjugation (b) heterocyst formation (c) binary fission (d) endospore production.

Short Answer

16. Which bacteria move about by rotation?
17. List one distinguishing characteristic of each of the three main groups of archaebacteria.
18. Why are cyanobacteria no longer classified as algae?
19. Describe the capsule of a bacterium and its function.
20. Explain how saprophytic bacteria contribute to the recycling of nutrients in the environment.
21. How do chemoautotrophs harvest energy from their environment?
22. Describe one way bacteria can exchange genetic information.
23. Identify the metabolic process that bacteria use to make food products such as pickles and sauerkraut.
24. List some diseases caused by bacteria, and list the organs they affect.
25. Label the parts of the bacterium below.



CRITICAL THINKING

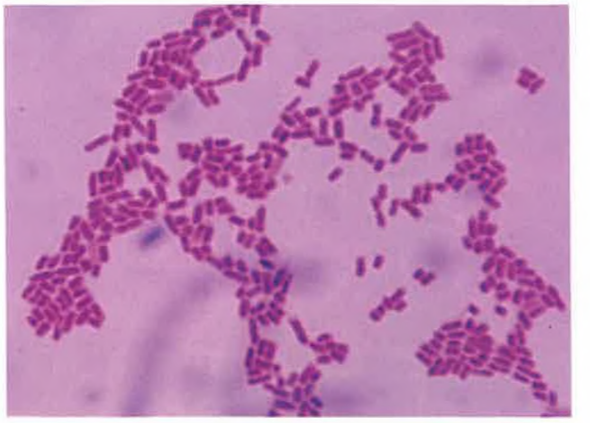
1. Scientists have only recently discovered fossilized bacteria. Explain why this discovery may have taken so long.
2. *Clostridium tetani,* the bacterium that causes tetanus, is an obligate anaerobe. From this information, would you infer that a deep puncture wound or a surface cut would be more likely to become infected by tetanus bacteria? Explain the reason for your inference.
3. Penicillin works by interfering with the ability of bacteria to polymerize the peptidoglycan cell wall. Given this fact, explain why Gram-positive bacteria are more susceptible to the effects of penicillin than are Gram-negative bacteria.

4. Some of the bacteria that are normally found in the human intestinal tract are beneficial. For example, *E. coli* produces vitamin K. However, *E. coli* can also cause diarrhea under exceptional circumstances, and it can cause serious infections if it invades other parts of the body. Other bacteria found in the digestive tract do not produce substances the body can use, but they do not produce substances that are harmful either. What positive role might they play?
5. Thermal-vent communities, which are extremely hot regions of ocean in areas where the Earth's crust is open, have some of the densest and most productive populations known to exist. What might explain this?
6. Over the last 20 years, the number of antibiotic-resistant bacterial pathogens has steadily increased. This is thought to be a result of antibiotic abuse by patients and doctors. Doctors tend to overprescribe antibiotics for patients who demand a quick fix for their illness. Just recently, the World Health Organization has established a global computer database so that doctors can report outbreaks of antibiotic resistance. What are the potential benefits of this database?
7. The antibiotic-sensitivity report (above right) lists several antibiotics that a bacterium from a patient is susceptible to. Based on these data, what do you infer is the Gram reaction of the pathogen? A "−" sign indicates that the bacterium is not sensitive to the antibiotic, and a "+" sign means that it is sensitive to the antibiotic. A "+++" sign means that it is very sensitive to the antibiotic.

Antibiotic-Sensitivity Report

Antibiotic	Sensitivity
Penicillin	−
Cephalosporin	−
Streptomycin	+++
Tetracycline	++
Bacitracin	−
Rifampin	−
Ampicillin	+++

8. Examine the photograph below of bacteria that have been treated with a Gram stain. Would you hypothesize that these bacteria produce endotoxins? Explain your answer.



EXTENSION

1. Read "The Cholera Lesson" in *Discover,* February 1999, on page 71. According to microbiologist Rita Colwell, where does the cholera-causing organism *Vibrio cholerae* live between outbreaks? Describe the methods she is designing to predict and prevent widespread disease.
2. Research and write a report on the use of bacteria in either the processing of foods or the treatment of sewage.
3. Visit or telephone your local public-health department, and ask for information on bacterial diseases that have been reported in your area in recent weeks. Report your findings to the class.

Culturing Bacteria

OBJECTIVES

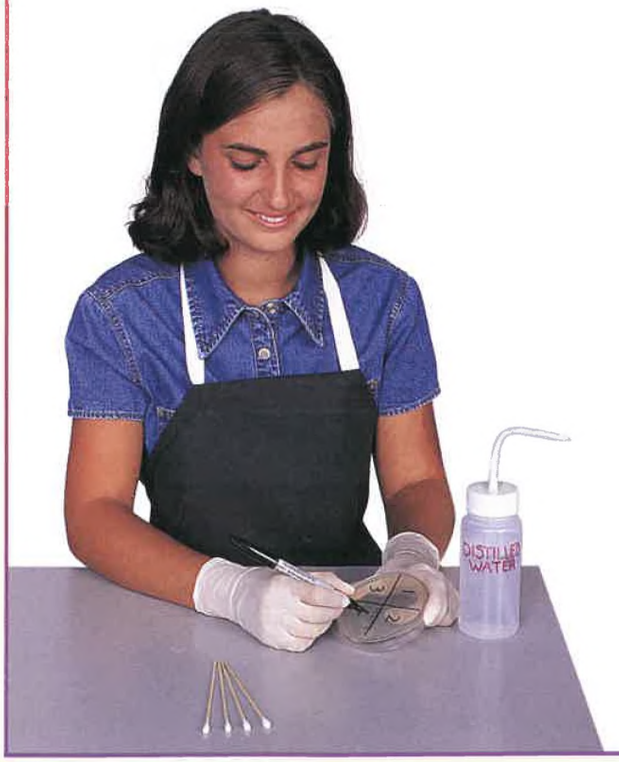
- Test common surfaces for the presence of bacteria.
- Learn a simple procedure for culturing bacteria.

PROCESS SKILLS

- observing
- hypothesizing
- experimenting
- collecting data
- analyzing data

MATERIALS

- Petri dish with nutrient agar
- glass-marking pen
- 4 sterile cotton swabs
- distilled water
- tape
- protective gloves



Background

1. Culturing bacteria involves growing microorganisms in a nutrient medium that is favorable for growth.
2. What are favorable conditions for the growth of most bacteria?
3. List some places in your school where bacteria are likely growing.
4. If bacteria reproduce once an hour and you start with one bacterium, how many bacteria do you have after 24 hours?

PART A Setting Up the Experiment

1. Discuss with your laboratory partner(s) places in school that would be likely to contain bacteria or that have conditions under which bacteria grow best. Make a list of three places where you will test for the presence of bacteria. Do not choose places outside your laboratory without your teacher's permission.
2. Obtain a Petri dish with nutrient agar from your teacher. Divide your Petri dish into four equal quadrants by writing on the outer bottom surface of the dish with the marking pen. Label the quadrants 1, 2, 3, and 4, as shown in the photograph at left. Also label the bottom of the dish with your group name or number. Do not mark on the top of the Petri dish because it will rotate with respect to the agar.
3. Use quadrant 1 as a control. Take a sterile cotton swab, and moisten it with distilled water. Be careful not to touch the cotton swab to any other surfaces, including your fingers. Remove the cover to the Petri dish, and rub the cotton swab across the nutrient agar in quadrant 1. Be careful to not tear the surface of the agar. Replace the cover immediately.
4. Take another sterile cotton swab, and moisten it with distilled water. Swipe the moistened swab across a surface that you have decided to test for the presence of bacteria. Be careful not to touch the cotton swab to any other surface. Touching the swab to other surfaces could contaminate the swab with bacteria other than that from your selected surface.

5. Remove the cover to the Petri dish, and rub the cotton swab across the nutrient agar in quadrant 2. This process transfers bacteria from the surface you have sampled to the nutrient agar in the Petri dish. Replace the cover immediately.
6. Repeat steps 4–6 for quadrants 3 and 4, using a clean cotton swab each time. Be sure to note in your lab report the areas that you swipe for each quadrant.
7. After you have swiped a sample in each quadrant of the Petri dish, seal the Petri dish with tape.
   CAUTION **Do not open the Petri dish again. Treat the contents of the Petri dish as you would any other pathogens.**
8. Place the Petri dish in a warm place with the cover side down for 24 hours.
9. Dispose of the cotton swabs according to your teacher's directions.
10. Clean up your lab materials and wash your hands before leaving the lab.

PART B Collecting Data

11. In your lab report, create a data table similar to the model shown below. Allow plenty of space to record your observations for each quadrant swabbed.
12. Check the Petri dish daily for bacterial growth until you no longer find new bacterial colonies (about seven days). Check your Petri dish and record your observations in your data table. What is happening that enables you to see bacteria? What does each colony represent?
13. Discard your Petri dish as directed by your teacher.

Analysis and Conclusions

1. On which surfaces did you find the most bacteria? the fewest bacteria? Did your results conform to your expectations? Explain.
2. Compare the colonies of bacteria that grew in each quadrant. What can you tell about the bacteria from the kind of colonies they produced?
3. What are some possible sources of error in the procedure you followed?
4. Combine the data obtained by the entire class. Which surfaces yielded the most bacteria?
5. Which of the surfaces that you sampled would you prefer to use as a food-preparation area? Explain your choice.
6. Would the amount of surface area that you sampled with your swab affect the number of colonies that grew on your dish? Explain your answer.
7. Can you tell by looking at the colonies on the dish if they would cause disease? Why or why not?
8. What test described in this chapter could you use to partially identify your bacteria? What characteristics of the bacteria could you learn from this test?

Further Inquiry

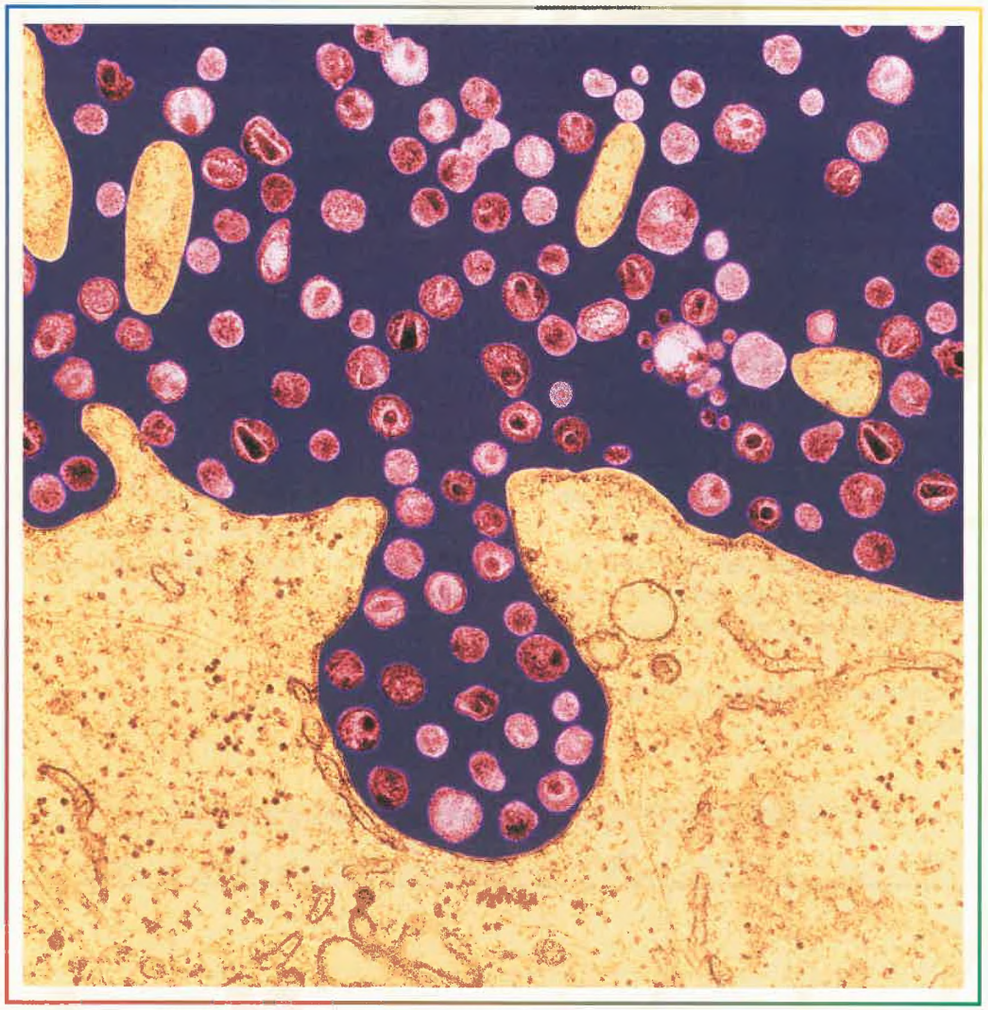
Design an experiment to test the effects of one variable, such as temperature or the presence of anitbacterial soap, on the growth of bacteria. What would you use as a control in your experiment?

PRESENCE OF BACTERIA ON COMMON SURFACES

Surface swabbed	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7

CHAPTER 25

VIRUSES



The human immunodeficiency virus (HIV), shown here stained pink, is the cause of acquired immune deficiency syndrome (AIDS). (TEM 29,640×)

FOCUS CONCEPT: ***Interdependence of Organisms***

As you read, note how the structure and replication cycle of viruses distinguish them from living organisms.

SECTION 25-1

STRUCTURE

*A **virus** is a nonliving particle composed of a nucleic acid and a protein coat. Although viruses are not living organisms, they are of interest to biologists because they cause many diseases in living organisms. Viruses are also quite useful in genetic research because they can change how a cell functions. The study of viruses is called **virology** (vie-RAH-luh-jee).*

OBJECTIVES

- Describe the structure and classification of viruses.
- Describe the achievement of Wendell Stanley in the development of virology.
- Identify the range of sizes and shapes among viruses.
- List the characteristics used to group viruses.
- Compare and contrast viroids and prions with viruses.

ADVENT OF VIROLOGY

By the late 1800s, scientists knew that some factor smaller than bacteria could transmit disease. But they lacked the technology to see these structures and to study them in depth. Scientists gained more awareness of the nature of viruses in 1935, when Wendell Stanley (1904–1971) crystallized the tobacco mosaic virus, an agent responsible for the mosaic mottling and withering of tobacco leaves. His work suggested that viruses might be chemicals rather than tiny cells. Until Stanley's crystallization of a virus, viruses were thought to be primitive cells that were perhaps ancestors of bacteria. Table 25-1 compares viruses with cells.

Virology now provides clues to the biochemistry of living organisms, including mutation, the combination of genetic material from different sources, and other essential processes of genetics. Also, pharmaceutical companies use viruses to develop new antiviral medications, and researchers continue to investigate the mechanisms of viral replication.

TABLE 25-1 *A Comparison of Viruses and Cells*

Characteristics of life	Virus	Cell
Growth	no	yes
Homeostasis	no	yes
Metabolism	no	yes
Mutation	yes	yes
Nucleic acid	DNA or RNA	DNA
Reproduction	only within host cell	independently by cell division
Structure	nucleic acid core, protein covering, and, in some cases, an envelope	cytoplasm, cell membrane, cytoskeleton, and, in the eukaryotic cell, organelles

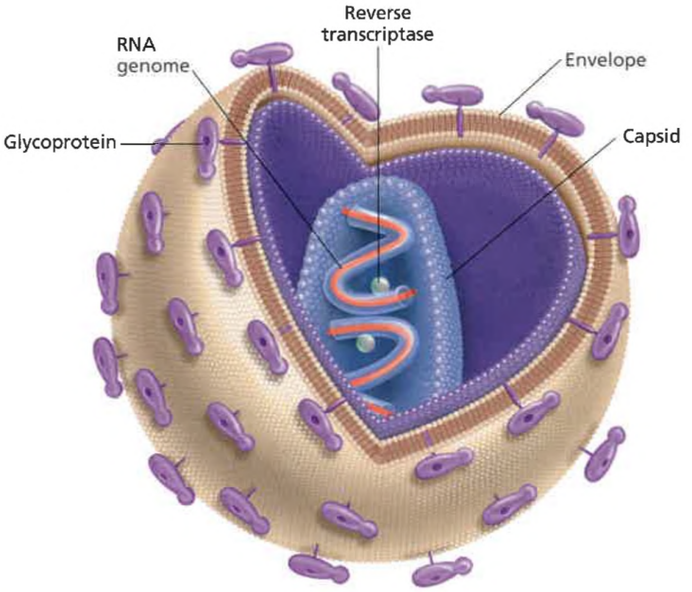


FIGURE 25-1
This view of the human immunodeficiency virus (HIV) displays some of the virus's structural features.

Word Roots and Origins

virus

from the Greek *ios*, meaning "poison"

Quick Lab

Calculating Nanometers

Materials meterstick with millimeter marks, paper, scissors, tape, pencil

Procedure Cut the paper into strips, and tape the strips together to form one strip that is 2 m long. On the paper, mark and label lines at 1 m, 20 cm, 2 cm, and 2 mm.

Analysis

1. Write an equation beside the 1 m line to show that 1 m contains 1 billion nanometers.
2. Write an equation at the end of the paper strip that shows the relationship between the length of the paper in meters and the length of the paper in nanometers.
3. How many nanometers are in 1 cm? How many nanometers are in 2 cm? in 20 cm? Write equations beside the 2 cm and the 20 cm marks to show the relationship of centimeters to nanometers.
4. How many millimeters are in 1 m? How many nanometers are in 1 mm? How many nanometers are in 2 mm? Write an equation by the 2 mm mark to show its relationship to nanometers.

CHARACTERISTICS OF VIRUSES

Viruses are among the smallest biological particles capable of causing disease in living organisms. Viruses range in size from the extremely small poliovirus, which is 20 nm in diameter, to the large smallpox virus, which is about 250 nm in diameter—about the same size as the smallest bacterium. One nanometer is equal to 0.001 µm (0.00000004 in.).

Viruses are constructed of compounds usually associated with cells, but they are not considered living organisms. They have some, but not all, of the characteristics of life listed in Chapter 1. They have no nucleus, cytoplasm, organelles, or cell membrane, and they are not capable of carrying out cellular functions. Moreover, viruses are able to replicate only by infecting cells and using the organelles and enzymes within cells.

Viral Structure

All viruses have two essential features—a nucleic acid and a protein coat surrounding it. Viral nucleic acid may be either DNA or RNA, but not both. The shape of the nucleic acid may be helical, a closed loop, or a long strand, depending on the virus. The protein coat surrounding the nucleic acid is called a **capsid** (KAP-sid).

Some viruses have a membrane-like structure outside the capsid called an **envelope.** The envelope, which is made mostly of lipids, is taken from a host cell membrane during replication. The envelope allows new viruses to infect host cells during the first stage of viral replication. Enveloped viruses include influenza, chickenpox, herpes simplex, and **HIV** (human immunodeficiency virus). Refer to the model of HIV in Figure 25-1 to identify each of the viral structures.

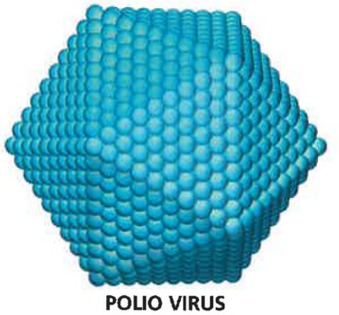
On the surface of the envelope are projections made of glycoprotein. These **glycoprotein** (GLIE-koh-PROH-teen) projections are protein-containing sugar chains that the virus uses to attach to a host cell.

Viral Shape

A virus's shape may be determined by its capsid or its nucleic acid. Figure 25-2 shows two examples of virus shapes. Some viruses have the shape of an **icosahedron** (ie-KOH-suh-HEE-druhn), which is a geometric shape with 20 triangular faces. The viral capsid forms this shape. Icosahedral viruses include those that cause herpes simplex, chickenpox, and polio.

Other viruses are shaped like a **helix** (HEE-liks). A helix resembles a coiled spring. The viral nucleic acid is responsible for this shape. The rabies, measles, and tobacco mosaic viruses are helical viruses.

TOBACCO MOSAIC VIRUS
(helical)



POLIO VIRUS
(icosahedral)

FIGURE 25-2
Viruses occur in different shapes. Helical and icosahedral are two examples of virus shapes.

GROUPING VIRUSES

The grouping of viruses is based on the presence of a capsid structure and an envelope. Viruses are also grouped according to whether they contain RNA or DNA and whether the nucleic acid is single-stranded or double-stranded. Therefore, viruses are grouped based on their shape and structure. Some common viral groups are presented in Table 25-2.

Virus Types

DNA and RNA viruses differ in the way they use the host cell's machinery to produce new viruses. For example, upon entering the host cell, a DNA virus may act in one of two ways: the virus may directly produce RNA that then makes more viral proteins or it may join with the host cell's DNA to direct the synthesis of new viruses.

TABLE 25-2 *Some Common Viruses of Humans*

Viral group	Nucleic acid	Shape and structure	Examples of diseases they cause
Papovaviruses	DNA	icosahedral, non-enveloped	warts, cancer
Adenoviruses	DNA	icosahedral, non-enveloped	respiratory and intestinal infections
Herpesviruses	DNA	icosahedral, enveloped	herpes simplex, chickenpox, shingles, infectious mononucleosis
Poxviruses	DNA	complex brick-shaped, enveloped	smallpox, cowpox
Picornaviruses	RNA	icosahedral, non-enveloped	poliomyelitis, hepatitis, cancer
Myxoviruses	RNA	helical, enveloped	influenza A, B, and C
Rhabdoviruses	RNA	helical, enveloped	rabies
Retroviruses	RNA	icosahedral, enveloped	AIDS, cancer

FIGURE 25-3
Viroids, which cause certain plant diseases, are infective RNA strands without capsids.

RNA viruses replicate differently from DNA viruses. Upon entering the host cell, viral RNA is released into the host cell's cytoplasm. There, it uses the host cell's ribosomes to produce new viral proteins.

Some RNA viruses, known as **retroviruses** (RE-troh-VIE-ruhs-uhz), contain an enzyme called reverse transcriptase in addition to RNA. **Reverse transcriptase** (tran-SKRIP-tays) uses RNA as a template to make DNA. The viral DNA is integrated into the host genome. The DNA then makes an RNA transcript of itself. This RNA is then translated into proteins that become part of new viruses. Reverse transcriptase is so named because it reverses the normal process of transcription, in which DNA serves as a template for producing RNA.

Viroids and Prions

Even simpler than viruses are the disease-causing agents called viroids and prions. **Viroids** (VIE-roidz) are the smallest known particles that are able to replicate. A viroid consists of a short, single strand of RNA and has no capsid, as shown in Figure 25-3. These simple RNA molecules are able to disrupt plant cell metabolism and damage entire crops. Economically important plants that have been affected by viroids include potatoes, cucumbers, avocados, and oranges.

Prions (PREE-ahnz) are abnormal forms of proteins that clump together inside a cell. This clumping activity eventually kills the cell, perhaps by blocking the cell's molecular traffic. Found on the surface of mammalian cells and in the brain of hosts, prions are composed of about 250 amino acids and have no associated nucleic acid.

Prions have been linked to certain diseases of the brain in humans and animals, such as scrapie. Scrapie is a disease in sheep that is characterized by slow degeneration of the nervous system. As the nervous system decays, the animals develop tremors and scrape their bodies against fence posts and tree trunks.

Bovine spongioform encephalopathy (BSE), or "mad cow disease," is a fatal brain disease of cattle that may be linked to prions. The prion that is thought to cause mad cow disease may be similar to one implicated in a human brain disease called Creutzfeld-Jakob (KROITZ-felt-YAK-ohb) disease (CJD).

SECTION 25-1 REVIEW

1. What are the two essential components of a virus?
2. What was the accomplishment of Wendell Stanley?
3. Explain how viruses are grouped.
4. What role do nucleic acids play in the grouping of viruses?
5. How do viroids and prions compare with viruses?
6. **CRITICAL THINKING** Are viruses considered to be living organisms? Justify your answer by referring to the characteristics of life presented in Chapter 1.

SECTION 25-2

VIRAL REPLICATION

Because viruses are not cells, they can replicate only by invading a host cell and using the enzymes and organelles of the host cell to make more viruses. Because they depend on host cells for replication, viruses are called ***obligate intracellular parasites.*** *Outside the host cell, a virus is a lifeless particle with no control over its movements. It is spread by the wind, in water, in food, or via blood or other body secretions.*

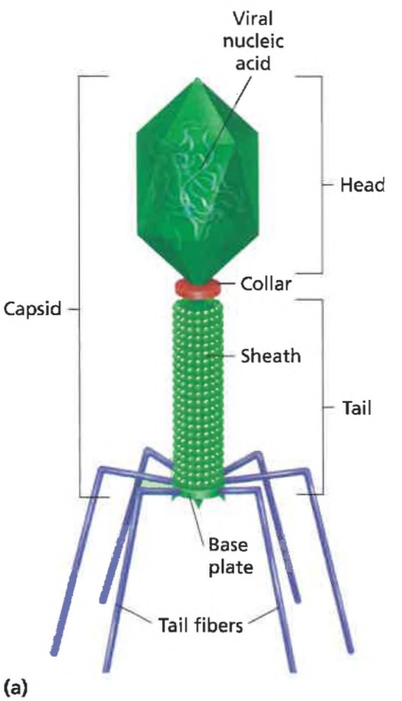
OBJECTIVES

- Describe a bacteriophage.
- Summarize the five phases of the lytic cycle.
- Compare the lytic and lysogenic cycles of viral replication.
- Differentiate between a prophage and a provirus.
- Summarize how viruses may have evolved.

THE BACTERIOPHAGE

In the 1950s, scientists gained a better understanding of viral replication through their work with **bacteriophages** (bak-TEER-ee-uh-fay-juz), which are viruses that infect bacteria. Bacteriophage replication cycles have been found to be similar to those of the viruses that cause colds, measles, and acquired immune deficiency syndrome. The most commonly studied bacteriophages, T phages, are known to infect a bacterium found in the human digestive tract, *Escherichia coli.*

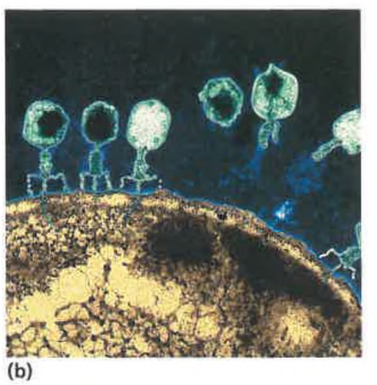
Examine the structure of the bacteriophage particle in Figure 25-4. Bacteriophages are composed of an icosahedral head that contains a nucleic acid. Beneath the head is a contractile tail that includes a collar and a sheath. The contractile tail helps inject the nucleic acid into the host cell. The tail rests on a base plate from which tail fibers emerge. These fibers assist the virus in attaching to a host cell. As you read about the replication cycles of bacteriophages, notice how the structure of the bacteriophage suits its function.



(a)

FIGURE 25-4

(a) This diagram shows the structural complexity of a bacteriophage. (b) This transmission electron micrograph shows a cross section of an *E. coli* cell being attacked by several bacteriophages. Some of the bacteriophages can be seen developing within the cell's cytoplasm, and some can be seen outside the cell. (TEM 138,600×)


(b)

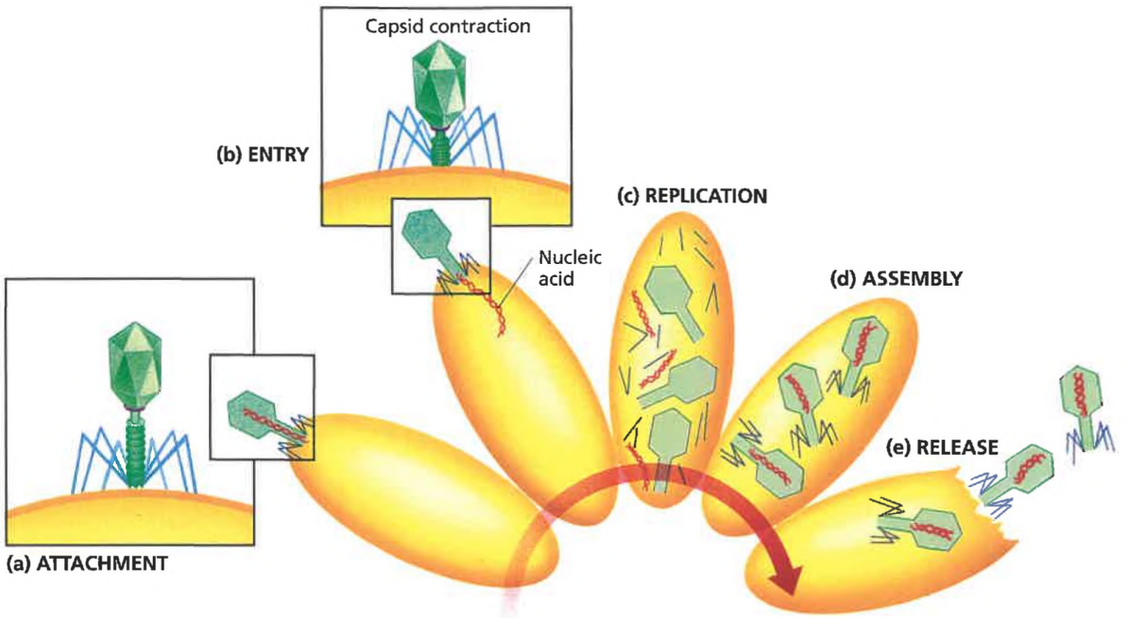


FIGURE 25-5

The lytic cycle of a virulent bacteriophage includes five steps: (a) attachment of the virus to a susceptible host cell, (b) entry of the viral DNA into the host cell, (c) replication of viral DNA, (d) assembly of new viruses, and (e) release of new viruses from a lysed host cell.

THE LYTIC CYCLE

During the **lytic cycle,** a virus invades a host cell, produces new viruses, destroys the host cell, and releases newly formed viruses. Viruses that undergo the lytic cycle are called **virulent** because they cause disease. The lytic cycle consists of five phases, as shown in Figure 25-5.

As Figure 25-5a shows, the bacteriophage first attaches to a susceptible bacterium by attaching its tail fibers to a receptor site. **Receptor sites** are specific sites that viruses recognize and attach to on the host cell's surface. If the bacteriophage does not find a receptor site, it cannot infect the cell. This specificity is true for many other viruses. For example, hepatitis virus infects only liver cells, and the glycoproteins on the surface of HIV and influenza enable them to attach only to specific types of cells.

Next the bacteriophage releases an enzyme that weakens a spot in the cell wall of the host, as shown in Figure 25-5b. Then the phage presses its sheath against the cell and injects its DNA into the host cell through the weak spot in the cell wall. The bacteriophage leaves its capsid outside the host cell.

As Figure 25-5c shows, the virus then takes control of the host's protein-synthesizing mechanisms, transcribing mRNA from the viral DNA. The resulting bacteriophage mRNA is translated by ribosomes and enzymes in the host cell into viral proteins and enzymes that form bacteriophage capsids. The viral DNA in the host bacteria is also replicated during this phase.

The replicated viral genes are enclosed in the newly created virus capsids, as shown in Figure 25-5d. The assembly of new virus particles usually occurs in the cytoplasm, but it also may take place in a eukaryotic host cell's nucleus.

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During the last phase of the lytic cycle, one of the enzymes that is produced by the bacteriophage genome causes the host cell to disintegrate, releasing the new bacteriophages. Cell disintegration, which is shown in Figure 25-5e, is called **lysis** (LIE-sis). In enveloped viruses, the newly formed viruses move to the cell surface and force their way through the cell membrane. As a result, the virus leaves the cell with a piece of the host cell membrane attached to the capsid. This "borrowed" cell membrane fragment becomes the viral envelope.

Word Roots and Origins

lysis

from the Greek *lysis*, meaning "loosening" or "dissolving"

THE LYSOGENIC CYCLE

Some viruses can infect a cell without causing its immediate destruction. Viruses that stay in their host cell for an extended period of time—days, months, or years—are in a **lysogenic** (lie-soh-JEN-ik) **cycle.** A virus that replicates through the lysogenic cycle and does not kill the host cell immediately is called a **temperate** virus. Examples of a DNA and an RNA virus replicating through the lysogenic cycle are discussed below.

Lysogeny in Bacteriophages

Temperate bacteriophages enter bacteria in the same way that a virulent bacteriophage does, as shown in Figures 25-6a and 25-6b. The tail fibers of the temperate bacteriophage attach to a specific receptor site on the bacterial cell wall. Then the bacteriophage injects its DNA into the host cell. Instead of immediately creating new RNA and viral proteins, however, the bacteriophage DNA integrates itself into the host cell's DNA, as shown in Figure 25-6c. The bacteriophage DNA molecule that integrates itself into a specific

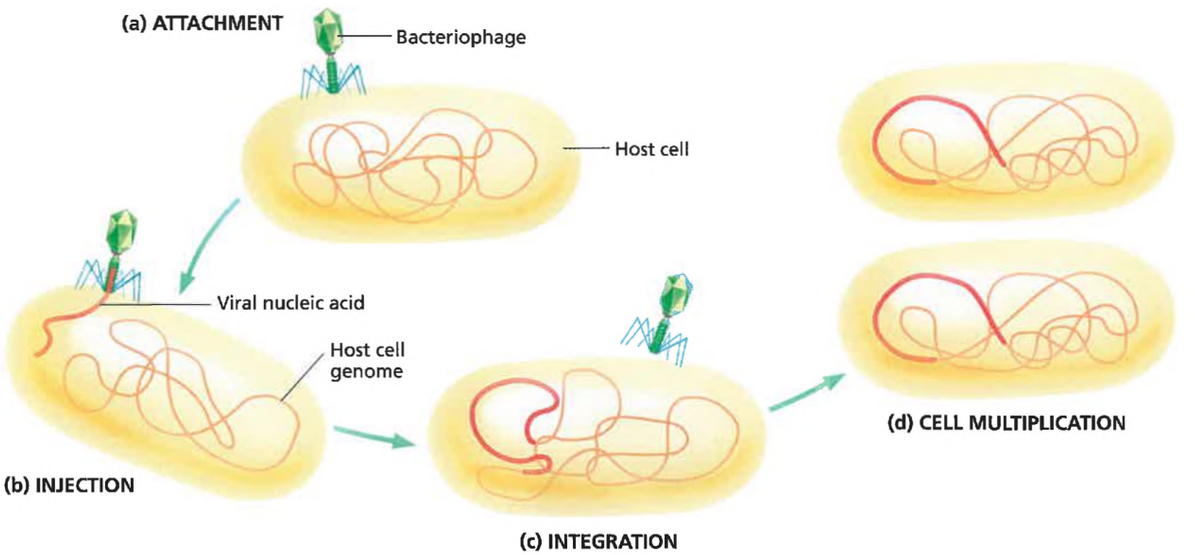


FIGURE 25-6

The lysogenic cycle of a temperate bacteriophage involves (a) the attachment of the virus to the host cell, (b) injection of viral DNA, (c) integration of the viral DNA into the host genome, and (d) multiplication of the host cell with the viral DNA.

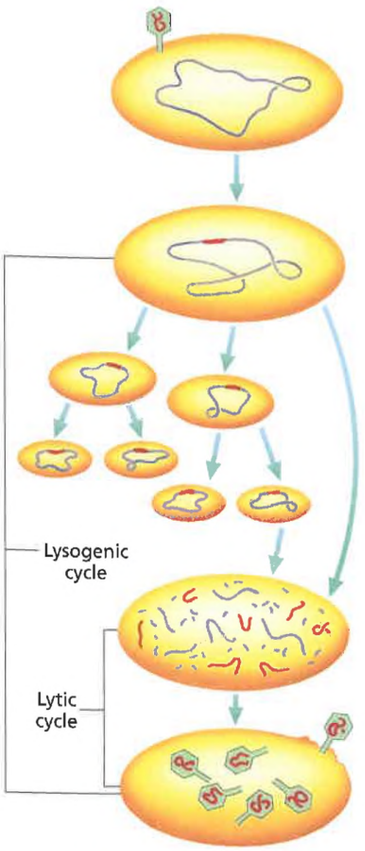


FIGURE 25-7
In the lysogenic cycle, a bacteriophage enters a cell and remains inactive in the host's genome until an external stimulus causes the virus to enter the lytic cycle.

site of the host cell's genome is called a **prophage** (PROH-fahj). The prophage replicates whenever the host bacterium reproduces, as shown in Figure 25-6d. As the host DNA replicates, so does the viral DNA, and each bacterial offspring is infected with a prophage. During the lysogenic cycle, the prophage does not harm the host cell. However, radiation or certain chemicals can cause a prophage to become virulent. Figure 25-7 shows that when the prophage becomes virulent, it enters the lytic cycle, proceeding with replication and destroying the host cell.

Lysogeny in HIV

The normal lysogenic cycle usually involves DNA viruses, but it can also involve RNA viruses, such as HIV, the virus that causes AIDS. When HIV infects a susceptible white blood cell, it attaches to receptor sites on the host cell's surface and enters the cell by fusing with the cell membrane. Next, viral RNA and reverse transcriptase are released into the cell's cytoplasm. Reverse transcriptase then transcribes the viral RNA into DNA. Recall from Section 25-1 that reverse transcriptase uses RNA as a template to make DNA.

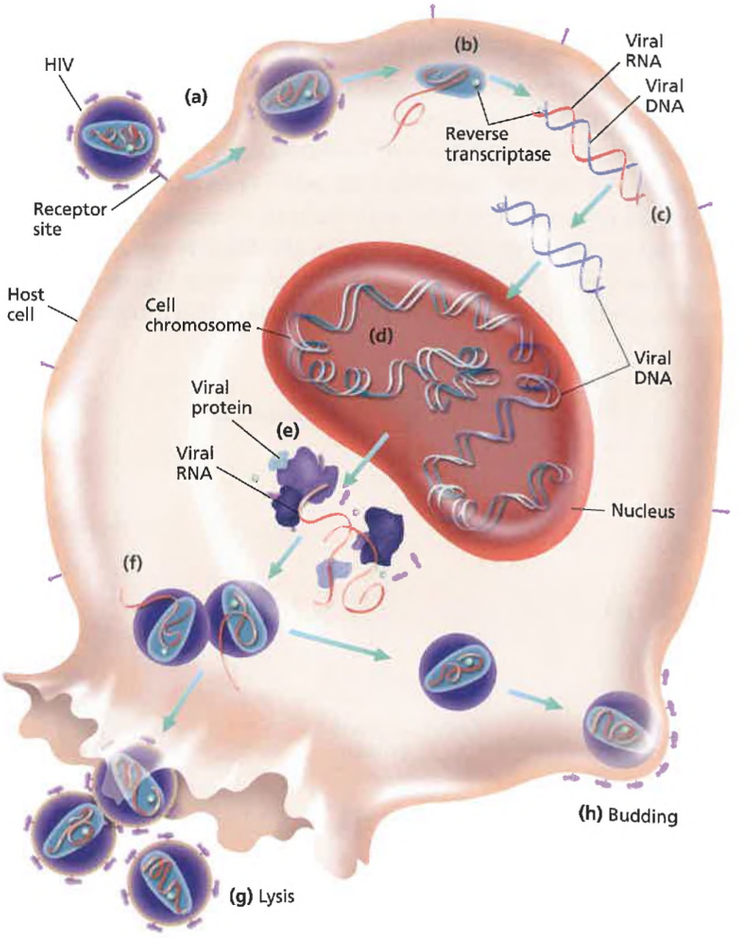


FIGURE 25-8
This figure traces the steps of HIV replication in a host cell. (a) HIV attaches to the receptor site. (b) The viral RNA is released from the capsid, and (c) reverse transcription takes place. (d) The viral DNA is integrated into the host genome. (e) Viral RNA and viral proteins are produced, and (f) viral assembly takes place. The assembled viral particles leave the cell through lysis (g) or budding (h).

As shown in Figure 25-8, the viral DNA molecule produced by reverse transcriptase inserts itself into the host cell's genome for an unspecified period of time. This viral DNA molecule is called a **provirus** (proh-VIE-rus). The lysogenic cycle ends when the provirus is transcribed into RNA and translated into viral proteins. These proteins are used in the assembly of new HIV particles containing capsids and enzymes. The new HIV particles are released after they lyse the cell or bud from the cell after taking a part of the cell's membrane for their viral envelope.

EVOLUTION

Because viruses depend on cells to replicate, most scientists reason that viruses evolved from early cells. The first viruses were probably naked pieces of nucleic acid that were able to travel from one cell to another, perhaps through damaged cell membranes. Over time, genes that allowed viruses to invade healthy cells evolved.

For example, when influenza viruses invade the human body, the immune system will destroy most of the viruses. However, a few of the viruses will escape destruction, enter cells, and begin producing thousands of copies of themselves within a few days.

How were a few viruses able to avoid destruction and begin replicating? These viruses are usually the result of mutations in the viral nucleic acid. Just as mutations in bacterial cells enable bacteria to become resistant to antibiotics, mutations in viruses can enable viruses to evade the immune system. Viruses that mutate quickly, such as the influenza virus and HIV, make it difficult for the immune system to immediately recognize and destroy them. The immune system will respond to the new strain of viruses eventually, but not until many new viruses are formed. Thus, it is difficult to develop vaccines that prevent these viral infections over long periods of time. To avoid this problem, the flu vaccine targets a different strain of influenza virus each year.

SECTION 25-2 REVIEW

1. Discuss the activities of a virus during the lytic cycle.
2. Compare and contrast the lytic and lysogenic cycles.
3. Describe the structure of a bacteriophage.
4. Explain the difference between a prophage and a provirus.
5. Discuss how the earliest viruses may have originated.
6. **CRITICAL THINKING** During the lytic cycle, the assembly of new viral particles can sometimes take place in the host cell's nucleus. This assembly in the host cell's nucleus does not occur with bacteriophage particles. Why?

SECTION

25-3

OBJECTIVES

- Name four viral diseases that result in serious illness in humans.
- Compare the two types of viral vaccines, and discuss other forms of viral-disease prevention.
- Discuss the relationship between viruses and cancer.
- Outline the onset of a virus outbreak.

VIRUSES AND HUMAN DISEASE

Viral diseases are among the most widespread illnesses in humans. These illnesses range from mild fevers to some forms of cancer and include several other severe and fatal diseases. Transmission of these illnesses varies; some are transmitted by human contact, while others are transmitted through water or an insect bite.

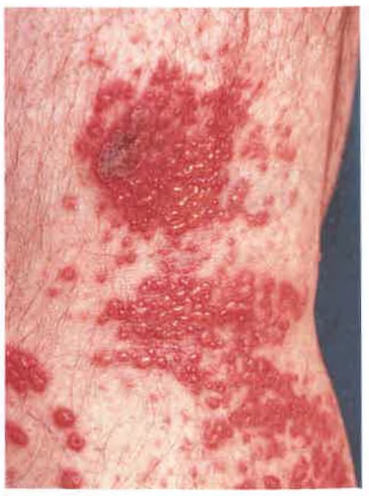
INFECTIOUS DISEASES

Many significant viral diseases are caused by viruses that use humans as their natural hosts. Some of the most common human viral diseases include the common cold, chickenpox, measles, mumps, polio, rabies, and hepatitis. Viral infections can affect various organs of the human body, including the brain, liver, heart, lungs, and the skin.

Rabies is transmitted from the bite of an infected animal, which carries the virus in its saliva. When a person is infected, the virus travels from the wound to the central nervous system. Symptoms of rabies include fever, headache, throat spasms, paralysis, and coma. Rabies is so lethal that few people have survived its effects.

Chickenpox is a highly contagious viral disease. The virus multiplies in the lungs and uses the network of blood vessels to reach the skin. Symptoms include fever and a skin rash. Transmission occurs from direct contact with the skin rash, which is the source of infectious virus particles, and through the air. Fortunately, the disease is usually mild, and recovery is usually followed by a lifelong resistance to reinfection. However, if all of the chickenpox virus is not destroyed, it can persist in the nerve cells as a provirus and cause a disease called shingles later during adulthood. Shingles results in a more severe case of chickenpox; the fever is higher, the immune system weakens, and pneumonia can occur. Like chickenpox, shingles is also defined by a skin rash. However, this painful rash is limited to an area of skin serviced by a particular neural pathway. For instance, the rash has been known to occur on only one side of the chest. The shingles rash can shed chickenpox viruses and infect susceptible children and adults. Note the characteristic skin rash of shingles in Figure 25-9.

FIGURE 25-9
The shingles rash, shown below, usually affects only one part of the body.



PREVENTION AND TREATMENT

The control of viral diseases is accomplished in two ways: vaccination to prevent disease and administration of **antiviral drugs**—drugs that interfere with viral nucleic acid synthesis—to infected patients. Unfortunately, there are few antiviral drugs compared with drugs used to treat bacterial, fungal, and parasitic infections. The most successful approach to controlling viral diseases has been prevention through vaccination. The Centers for Disease Control and Prevention in Atlanta, Georgia, is committed to the control and prevention of disease through research, as shown in Figure 25-10, and education.

Types of Virus Vaccines

As you will recall from Chapter 13, a vaccine is a preparation of pathogens or other materials that stimulates the body's immune system to provide protection against that pathogen. Some vaccines consist of inactivated or attenuated viruses. **Inactivated** viruses do not replicate in a host system. **Attenuated** viruses are viruses that have been genetically altered so that they are incapable of causing disease under normal circumstances. In general, vaccines made from attenuated viruses are preferred over those made from inactivated viruses because protection is greater and lasts longer. Additional doses of some vaccines, called booster shots, can extend a person's protection against some viruses.

By the 1960s, vaccines for measles, mumps, and rubella had been developed. The hepatitis B vaccine became available in the 1980s, and the chickenpox and hepatitis A vaccines were developed in the 1990s. Scientists continue to work on the development of an AIDS vaccine, but the genetic diversity and mutability of the virus create a problem for vaccine development. Educating people about HIV transmission is currently the best approach to slowing the spread of AIDS.

Smallpox Eradication Program

Smallpox once killed 40 percent of the people it infected, leaving the other 60 percent scarred and often blind. Smallpox is a DNA virus that is transmitted by nasal droplets emitted during sneezing and coughing. Symptoms include fever, headache, backache, and the development of a skin rash. This virus is hardy enough to be spread through infected blankets and clothing. Figure 25-11 shows a person infected with smallpox.

Vaccination played an important role in the eradication of smallpox. The World Health Organization began the smallpox eradication program in 1967. It ended in 1980, with the official declaration that smallpox had been eradicated. The program included vaccination and the quarantine of infected people. The last naturally acquired smallpox case occurred in Somalia in 1977.

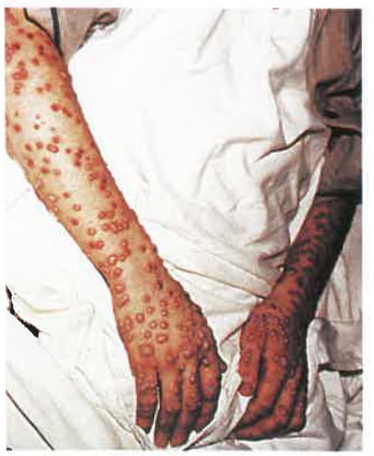
FIGURE 25-10
This technician is working in a level-4 laboratory at the Centers for Disease Control and Prevention (CDC). Workers in a level-4 laboratory use the highest level of security procedures to protect themselves from the world's deadliest viruses, such as Lassa fever virus, Ebola virus, and smallpox virus.

Word Roots and Origins

vaccine

from the Latin *vaccinus,* which means "pertaining to cows"

FIGURE 25-11
Smallpox is characterized by lesions covering the face, shoulders, chest, and in a later stage, arms and legs.



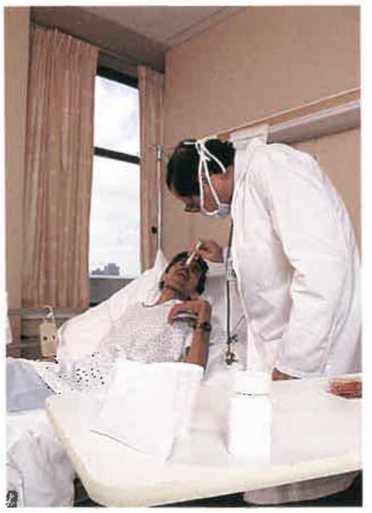


FIGURE 25-12
This physician is administering two different antiviral drugs—DDI (didexoyinosine) and AZT (azidothymidine)—to this AIDS patient. Because of HIV's ability to rapidly adapt to antiviral drugs, it is often necessary to administer more than one drug at a time in order to reduce the amount of virus in a patient.

Other Antiviral Approaches

One important part of viral disease prevention is the control of animals that spread viral disease. Yellow fever was completely eradicated in the United States through mosquito-control programs. Annual rabies vaccinations keep pets free of infection and protect humans too. Wildlife officials in the western part of the United States set out meat that contains an oral rabies vaccine to control the spread of rabies in coyotes and wolves.

Treatment of virally infected patients includes the use of antiviral agents. **Acyclovir** (ay-SIE-kloh-VEER) is used against herpes simplex and chickenpox, and **azidothymidine** (ay-ZIED-oh-THIE-mi-deen) **(AZT)** inhibits the reverse transcriptase of retroviruses, such as HIV. These drugs interfere with the synthesis of viral nucleic acids. Another class of drugs, called **protease inhibitors,** interferes with the synthesis of viral capsids during viral replication. Combinations of protease inhibitors and AZT have been shown to be helpful in slowing the progression from HIV infection (lysogenic phase) to AIDS (lytic phase). Figure 25-12 shows an AIDS patient undergoing treatment.

Antibiotics are not effective in the treatment of viral diseases. Antibiotics are used specifically to attack bacterial cells' metabolic machinery. Because viruses use only the host cell's machinery, antibiotics are of no use in destroying viruses.

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EMERGING VIRUSES

As medical researchers work to find cures for existing viral diseases, newly discovered viruses are emerging in different parts of the world. Emerging viruses are viruses that exist in isolated habitats, but infect humans when these habitats are developed. For example, Figure 25-13 shows a tropical forest in the Democratic Republic of Congo (formerly Zaire), where the emerging Ebola virus has been known to exist. When these forests are cleared, humans may be exposed to virus-infected animals. If these viruses can infect humans, they may spread with deadly consequences.

FIGURE 25-13
The remote tropical forests of the Democratic Republic of Congo (formerly Zaire) are the hiding places of the deadly Ebola virus.

Literature & Life

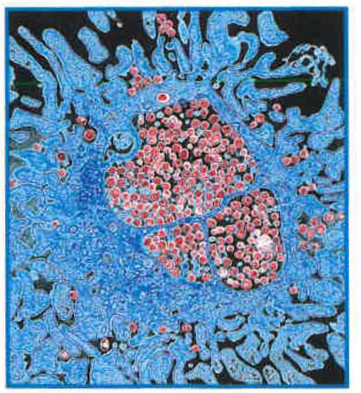
The AIDS Virus

The following is the introduction to Robert C. Gallo's article "The AIDS Virus," from the January 1987 issue of *Scientific American.*

It is a modern plague: the first great pandemic of the second half of the 20th century. The flat, clinical-sounding name given to the disease by epidemiologists—acquired immune deficiency syndrome—has been shortened to the chilling acronym AIDS. First described in 1981, AIDS is probably the result of a new infection of human beings that began in central Africa, perhaps as recently as the 1950's. From there it probably spread to the Caribbean and then to the U.S. and Europe. By now as many as two million people in the U.S. may be infected. In the endemic areas of Africa and the Caribbean the situation is much worse. Indeed, in some areas it may be too late to prevent a disturbingly high number of people from dying.

In sharp contrast to the bleak epidemiological picture of AIDS, the accumulation of knowledge about its cause has been remarkably quick. Only three years after the disease was described its cause was conclusively shown to be the third human retrovirus: human *T*-lymphotropic virus III (HTLV-III), which is also called human immunodeficiency virus (HIV). Like other retroviruses, HTLV-III has RNA as its genetic material. When the virus enters its host cell, a viral enzyme called reverse transcriptase exploits the viral RNA as a template to assemble a corresponding molecule of DNA. The DNA travels to the cell nucleus and inserts itself among the host's chromosomes, where it provides the basis for viral replication.

In the case of HTLV-III the host cell is often a *T4* lymphocyte, a white blood cell that has a central role in regulating the immune system. Once it is inside a *T4* cell, the



virus may remain latent until the lymphocyte is immunologically stimulated by a secondary infection. Then the virus bursts into action, reproducing itself so furiously that the new virus particles escaping from the cell riddle the cellular membrane with holes and the lymphocyte dies. The resulting depletion of *T4* cells—the hallmark of AIDS—leaves the patient vulnerable to "opportunistic" infections by agents that would not harm a healthy person.

How HTLV-III manages to replicate in a single burst after lying low, sometimes for years, is one of the most fundamental questions confronting AIDS researchers. Another important question is the full spectrum of diseases with which the virus is associated. Although most of the attention given to the virus has gone to AIDS, HTLV-III is also associated with brain disease and several types of cancer. In spite of such lingering questions, more is known about the AIDS virus than is known about any other retrovirus. The rapidity of that scientific advance was made possible partly by the discovery in 1978 of the first human retrovirus, HTLV-I, which causes leukemia. In its turn the new knowledge is making possible the measures that are desperately needed to treat AIDS and prevent its spread.

Reading for Meaning

What does Gallo mean by "opportunistic" infections? Use Gallo's description and the context of the article to figure it out.

Read Further

Gallo's article tells what was known about the AIDS virus in 1987. What new information might be included in a follow-up article about the AIDS virus today?

TABLE 25-3 *Viruses Linked to Human Cancers*

Type of virus	Mode of transmission	Type of cancer
Human T lymphotropic	mother-to-child transmission, body fluids, sexual contact	leukemia
Hepatitis B	body fluids, sexual contact, mother-to-child transmission	liver cancer
Epstein-Barr	physical contact	Burkitt's lymphoma
Human papillomavirus	sexual contact	cervical cancer

Examples of emerging viruses include hantavirus, which caused an outbreak of pneumonia in the southwestern United States in 1993; Machupo virus, which exists in South America; HIV, which originated in Africa; Ebola virus, which is found in Africa; and Lassa fever virus, which exists in West Africa. There are four known strains of the Ebola virus, all of which probably evolved from a common ancestor. One of these strains sickens only monkeys, but the other three strains are deadly to humans. Ebola's sudden emergence within the population of the Democratic Republic of Congo has left medical researchers puzzled over the identity of the animal host that carried the original Ebola virus strain.

VIRUSES AND CANCER

Recall that cancer is a condition that results from the uncontrolled reproduction of cells, which invade surrounding tissue. Scientists believe that cancers may be traced to genes within normal cells. When these genes are mutated by an outside agent, such as cigarette smoke, asbestos, sunlight, chemicals, or radiation, they may stimulate the cells to multiply uncontrollably. Cancer genes may also be triggered by certain lysogenic viruses. Some viruses associated with cancer are summarized in Table 25-3.

SECTION 25-3 REVIEW

1. List two diseases that are the result of a viral attack on the human nervous system.
2. Discuss the differences between attenuated and inactivated viruses.
3. Why are antibiotics not effective in the treatment of viral diseases?
4. Explain how human actions have contributed to the increase of emerging viral diseases.
5. Which replication cycle are viruses found in when they stimulate the activation of cancer genes?
6. **CRITICAL THINKING** Consider how emerging viruses develop. Would you consider emerging viruses to be new viruses? Why or why not?

CHAPTER 25 REVIEW

SUMMARY/VOCABULARY

25-1

- Viruses are biological particles composed of nucleic acid and a protein coat. Enveloped viruses also have a membrane enclosing them.
- Viruses are not usually considered living organisms because they lack most of the characteristics of living things.
- Wendell Stanley was the first scientist to report the crystallization of tobacco mosaic virus in 1935. This suggested that viruses might be chemicals rather than primitive cells.
- Viruses range in size from about 20 nm to about 250 nm in diameter.
- Many viruses have the shape of an icosahedron, which is a geometric figure containing 20 triangular faces. Other viruses take the shape of a helix, which resembles a coiled spring.
- Some viruses include a membrane-like envelope, with glycoprotein projections extending from the envelope.
- Viruses are grouped into families based on their nucleic acid type, their capsid structure, and the presence or absence of an envelope.
- Viruses probably originated from fragments of host-cell nucleic acid material.
- Viroids are viruslike particles composed of RNA only. Prions are pathogenic particles composed of protein only.

Vocabulary

capsid (488)
envelope (488)
glycoprotein (489)
helix (489)
HIV (488)
icosahedron (489)
prion (490)
retrovirus (490)
reverse transcriptase (490)
viroid (490)
virology (487)
virus (487)

25-2

- Bacteriophages are viruses that infect bacteria. Their discovery has increased scientists' understanding of virus replication.
- Replication by viruses occurs by either the lytic cycle or the lysogenic cycle.
- During the lytic cycle, the viral genome is released into the host cell, and replication of the virus follows immediately. Cellular components are used to make new viruses. A viral enzyme then causes host cell lysis and death.
- HIV infects specific white blood cells and remains in them as proviruses. As the immune system begins to fail, opportunistic infections occur; this condition is called AIDS.
- In the lysogenic cycle, the nucleic acid of the virus becomes part of the host cell's chromosome and remains with the cell in this form for many generations. HIV follows this pattern.

Vocabulary

bacteriophage (491)
lysis (493)
lysogenic cycle (493)
lytic cycle (492)
obligate intracellular parasite (491)
prophage (494)
provirus (495)
receptor site (492)
temperate (493)
virulent (492)

25-3

- Vaccination and antiviral drug therapy are two major approaches to controlling and preventing the spread of viral diseases.
- Emerging viruses do not usually infect humans, but they can when environmental conditions favor their contact with and infection of human populations.
- Several viruses are implicated in the development of cancers such as leukemia, Burkitt's lymphoma, and liver cancer.

Vocabulary

acyclovir (498)
antiviral drug (497)
attenuated (497)
azidothymidine (AZT) (498)
inactivated (497)
protease inhibitor (498)

REVIEW

Vocabulary

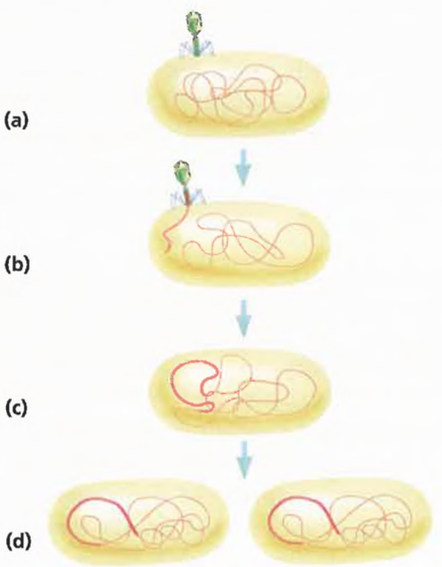
1. In a dictionary, look up the words *obligate, intracellular,* and *parasite,* and relate virus activity to the meaning of these words.
2. Viral infection is usually very specific. Identify the structure of the cell surface that permits only specific viruses to infect it.
3. Distinguish a virus from a provirus.
4. Use what you know about the meaning of the word *lysis* to explain the meanings of *lytic* and *lysogenic* cycles. If necessary, use your dictionary to help you.
5. Explain the meaning of the term *reverse transcriptase.*

Multiple Choice

6. A virus is a biologically active particle composed of (a) enzymes and fats (b) mitochondria and lysosomes (c) protein and nucleic acid (d) carbohydrates and ATP.
7. Which of the following was a key event in the development of virology? (a) the discovery of ribosomes (b) the discovery of nutrient agar (c) the crystallization of a virus (d) the discovery of protein structure
8. The term *icosahedron* refers to the structure of the viral (a) nucleic acid (b) capsid (c) lipid layer (d) receptor site.
9. Certain viruses have reverse transcriptase, an enzyme that (a) synthesizes RNA using DNA as a template (b) unites viral DNA with host DNA (c) synthesizes DNA using RNA as a template (d) assists the release of viruses from the host cell.
10. An essential aspect of viral replication is the (a) release of the viral nucleic acid in the cytoplasm of the host cell (b) entry of the viral envelope to the cytoplasm of the host cell (c) union of the viral envelope with the nuclear membrane of the cell (d) release of the viral capsid into the host cell nucleus.
11. Viroids differ from viruses in their (a) larger size (b) absence of a capsid (c) absence of nucleic acids (d) ability to cause disease in plants.
12. The head region of a bacteriophage is used to (a) attach the phage to the bacterial wall (b) enclose the nucleic acid (c) transmit the nucleic acid to the bacterium (d) take over the genetic machinery of the cell.
13. Lysis refers to the disintegration of (a) the bacteriophage capsid on entering the cell (b) the DNA of the host cell (c) a bacteriophage enzyme (d) the host cell.
14. Temperate viruses are those that (a) take over the genetic machinery of the host cell (b) are composed solely of protein (c) attach themselves to the ribosomes of the host cell (d) integrate their viral genes into the DNA of the host cell.
15. One virus that participates in the lysogenic cycle is (a) the measles virus (b) the rabies virus (c) HIV (d) the polio virus.

Short Answer

16. Explain the activity of reverse transcriptase.
17. Describe the structure of HIV.
18. DNA and RNA viruses differ in the way that they utilize the host cell's machinery to produce new viruses. Explain these differences.
19. Name the animal diseases that result from prion activity.
20. Identify the lettered steps in the figure below and identify the cycle.

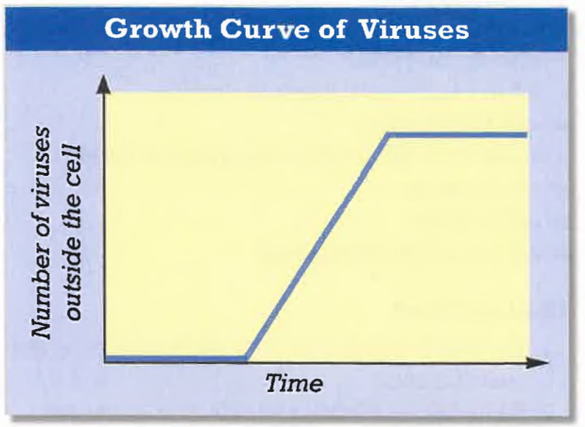


_____ CYCLE

21. What are some of the useful attributes of viruses?
22. Distinguish between a virulent virus and a temperate virus.
23. What causes a temperate bacteriophage to become virulent?
24. Explain the methods humans use to control viral diseases.
25. What agents can trigger cells to multiply uncontrollably?

CRITICAL THINKING

1. Some people suggest that the drug AZT (azidothymidine) can help patients infected with HIV. This drug blocks the enzyme reverse transcriptase. Explain how AZT might help HIV-infected patients.
2. People who have had a hepatitis B viral infection have a greater chance of developing liver cancer later in life, especially if they are exposed to aflatoxin. Aflatoxin is a mold toxin found in some foods, such as contaminated peanuts. What does this relationship suggest to you about the role of the hepatitis virus in causing cancer?
3. Lambda is a bacteriophage that attacks *E. coli* and may enter a lysogenic cycle. Once it enters the lysogenic cycle, the phage inhibits the entry of more phages. What is the evolutionary advantage to the phage of "immunizing" its host against further lambda infections?
4. Shingles is a disease caused by the same herpes virus that causes chickenpox. How do you account for the fact that shingles often appears years after the initial chickenpox attack?
5. Based on your knowledge of HIV structure and replication, describe one way to interrupt the replication of HIV.
6. Based on your understanding of virus replication, how might scientists cultivate or artificially reproduce viruses in the laboratory?
7. Look at the graph below. Discuss how the sharp jump in the number of viruses outside the cell corresponds to the phases of the lytic cycle.



EXTENSION

1. Read "What New Things Are Going to Kill Me?" in *Time,* November 8, 1999, on page 86. Explain why Richard Preston thinks that new microbes are the ticking time bomb in the new century.
2. Call your local hospital or family doctor, and ask how viral diseases are diagnosed. If possible, visit the clinical laboratory of a hospital to see how the tests are done.
3. Research and write a report on a preventable viral disease, such as polio or smallpox. In your report, discuss the process scientists followed in identifying the cause of the disease, isolating the virus, formulating a vaccine, and testing the vaccine.
4. Read "Down but Not Out" in *New Scientist,* February 5, 2000, on page 20. The World Health Organization plans to eradicate polio by 2005 and stop vaccinating people. Explain why some polio experts believe that stopping vaccinations is unwise, even though the disease has been eradicated.

CHAPTER 25 INVESTIGATION

Tobacco Mosaic Virus

OBJECTIVES

- Study the effect of cigarette tobacco on leaves of tobacco plants.

PROCESS SKILLS

- observing
- comparing and contrasting
- experimenting

MATERIALS

- lab apron
- protective gloves
- safety goggles
- 2 tobacco or tomato plants
- glass-marking pencil
- tobacco from several brands of cigarettes
- mortar and pestle
- 10 mL 0.1 M dibasic potassium phosphate solution
- 100 mL beaker
- cotton swabs
- 400 grit carborundum powder

Background

1. The tobacco mosaic virus, TMV, infects tobacco as well as other plants.
2. Plants that are infected with TMV have lesions and yellow patches on their leaves.
3. In what form do viruses exist outside host cells?

4. The tobacco mosaic virus is an RNA virus with rod-shaped capsids and proteins arranged in a spiral.
5. Plants damaged by wind, low temperatures, injury, or insects are more susceptible to plant viruses than healthy plants are.
6. Plant viruses are transmitted by insects, gardening tools, inheritance from the parent, and sexual reproduction.
7. Most viral diseases in plants have no known cures, but scientists are breeding various genetic forms of plants that are resistant to certain viruses.
8. Describe how viruses spread among organisms.
9. In this investigation, you will test whether tobacco from cigarettes can infect tobacco plants with TMV.

PART A Setting Up the Experiment

1. Put on a lab apron, gloves, and goggles before beginning this investigation.
2. Obtain two tobacco plants that have not been infected with TMV. Label one of the plants "control plant." Label the other plant "experimental plant."
3. CAUTION **Use poisonous chemicals with extreme caution. Keep your hands away from your face when handling plants or chemical mixtures.** Place pinches of tobacco from different brands of cigarettes into a mortar. Add 5 mL of dibasic potassium phosphate solution, and grind the mixture with a pestle as shown in the figure at left.
4. Pour the mixture into a labeled beaker. This mixture can be used to test whether cigarette tobacco can infect plants with TMV.
5. Wash your hands and all laboratory equipment used in this step with soap and water to avoid the accidental spread of the virus.
6. Moisten a sterile cotton swab with the mixture, and sprinkle a small amount of carborundum powder onto the moistened swab. Apply the mixture to two leaves on the "experimental" plant by swabbing the surface of the leaves several times. Why do you think swabbing the leaves with carborundum powder might facilitate infection?

7. Moisten a clean swab with dibasic potassium phosphate solution, and sprinkle a small amount of carborundum powder onto the moistened swab. This swab should *not* come into contact with the mixture of cigarette tobacco. Swab over the surface of two leaves on the control plant several times.
8. Do not allow the control plants to touch the experimental plants. Keep both plants away from other plants that may be in your investigation area, such as houseplants or garden plants. Wash your hands after handling each plant to avoid the accidental spread of TMV.
9. Treat both plants in precisely the same manner. The only difference between the two plants should be the experimental factor—exposure to cigarette tobacco. Both plants should receive the same amount of light and water.
10.  Clean up your materials according to your teacher's instructions and wash your hands before leaving the lab.

PART B Collecting Data

11. In your lab report, create a data table similar to the model shown below. Allow plenty of space to record your observations of each plant.
12. Check the control and experimental plants each day for one week. Record your observations of each plant in your lab report. Wash your hands after handling each plant to prevent contaminating your results.

Analysis and Conclusions

1. What differences, if any, did you detect in the two plants after one week?
2. Did the plants exposed to cigarette tobacco become infected with the tobacco mosaic virus?
3. Why do you think it was necessary to use tobacco from different brands of cigarettes?
4. What are some of the possible sources of error in the experiment?
5. Greenhouse operators generally do not allow smoking in their greenhouses. Aside from health and safety issues, how might your results support this practice?

Further Inquiry

The tobacco mosaic virus is capable of infecting different species of plants. Design an experiment to determine which of several types of plants are susceptible to the virus.

OBSERVATIONS OF TOBACCO PLANTS

Day	Control plants	Experimental plants
1		
2		
3		
4		
5		
6		
7		

CHAPTER 26

PROTOZOA

Stentor *displays two of the characteristics of protozoa, unicellularity and lack of tissue differentiation.*

FOCUS CONCEPT: ***Structure and Function***

As you read this chapter, note the wide variations in the shape, size, structure, and adaptations of protozoa as well as the features they have in common.

SECTION 26-1

OVERVIEW OF PROTOZOA

The kingdom Protista contains a diverse collection of eukaryotic organisms—protozoa, algae, slime molds, and water molds. Collectively, these organisms are called ***protists.*** *Protists are sometimes described as animal-like, plantlike, and funguslike. However, all protists are eukaryotic and lack tissue differentiation.*

OBJECTIVES

- Describe the characteristics of protozoa.
- Explain the role some protozoa play in aquatic ecosystems.
- Discuss a classification scheme used to identify protozoa.
- Name an adaptation that enables some protozoa to survive harsh environmental conditions.
- Briefly explain the evolution of protozoa.

CHARACTERISTICS

Protozoa are single-celled microscopic organisms that are noted for their ability to move independently. Biologists have identified about 65,000 species of protozoa, almost half of which are extinct species identified from fossils. Protozoa live in many different environments; they can drift in the ocean, creep across vegetation in freshwater rivers and ponds, crawl in deep soil, and even reproduce in the bodies of other organisms. The protozoan shown in Figure 26-1 lives in the gut of termites.

Most protozoans are heterotrophic, obtaining their nutrients by ingesting small molecules or cells. These particles are usually broken down in **food vacuoles,** membrane-bound chambers that contain digestive enzymes.

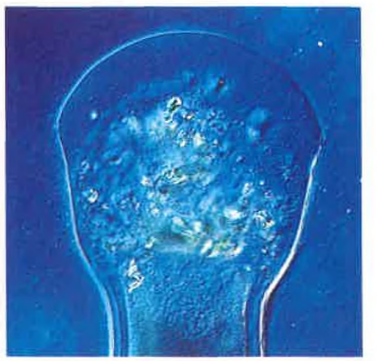
Many species of protozoa are free-living, while others are parasitic. Free-living protozoa live in any habitat where water is available at some time during the year. Many species make up **zooplankton,** a population of organisms that constitutes one of the primary sources of energy in aquatic ecosystems. Other free-living protozoa live in the soil. Parasitic protozoa usually have complex life cycles that take place in the cells, tissues, and bloodstream of their hosts. Several species cause a variety of serious human diseases, including malaria, amebic dysentery, and giardiasis.

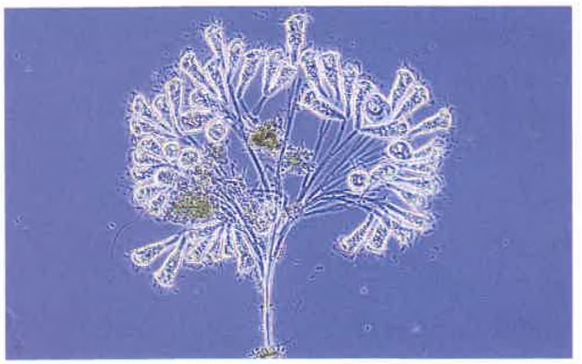
Reproduction

All protozoa are capable of asexual reproduction, usually by binary fission. During binary fission, a protozoan divides into two essentially identical individuals. Some species reproduce by **multiple fission,** a form of cell division that results in a number of identical individuals.

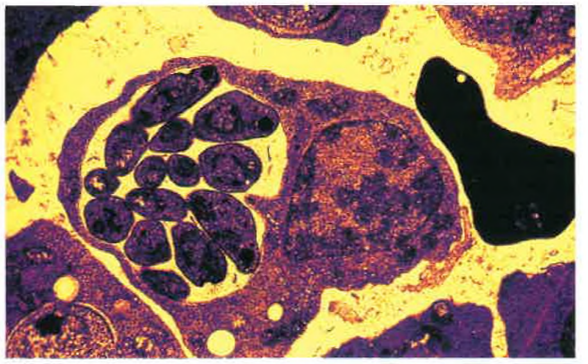
While all protozoa can reproduce asexually, a few species also reproduce sexually, through **conjugation.** During conjugation in protozoa, individuals from opposite mating strains pair and exchange genetic material. Conjugation in protozoa is a more complex process than conjugation in bacteria.

FIGURE 26-1
The phylum Zoomastigina includes *Trichonympha,* a protozoan that inhabits the gut of termites and helps the termite digest the cellulose in its diet.

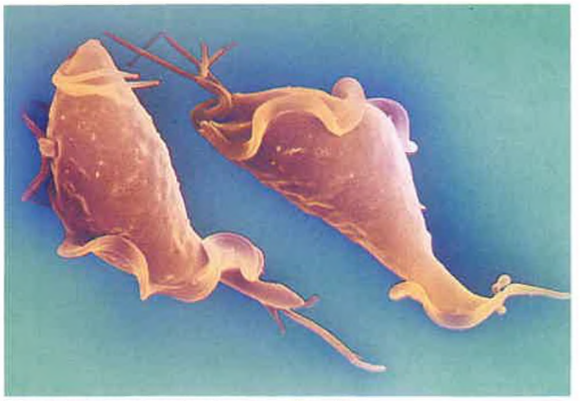




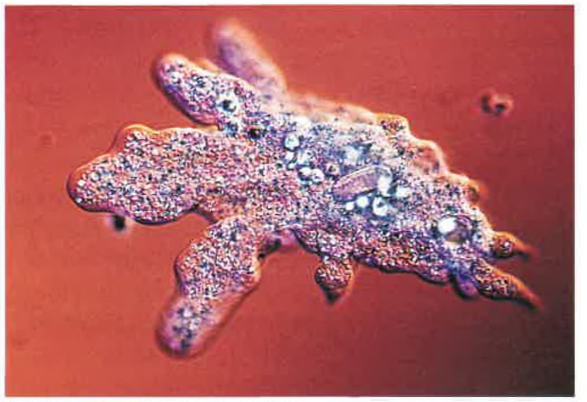
(a) *Zoothamnium,* a ciliate



(b) *Plasmodium,* a sporozoan



(c) *Trichomonas vaginalis,* a zooflagellate



(d) *Amoeba proteus,* a sarcodine

FIGURE 26-2
These organisms are representatives of the four phyla of protozoa.

Classification

Protozoa are members of the kingdom Protista, along with algae, slime molds, and water molds. Research into the evolutionary relationships among these organisms is constantly yielding new information and altering protistan classification. For this reason, biologists are always reevaluating the classification scheme. Protozoa are sometimes classified into four phyla: Sarcodina (SAHR-kuh-DIEN-uh), Ciliophora (sil-ee-AHF-uhr-uh), Zoomastigina (ZOH-uh-mas-tuh-JIEN-uh), and Sporozoa (spor-uh-ZOH-uh). A representative of each group is shown in Figure 26-2. The characteristics of these four phyla, along with representative genera, are summarized in Table 26-1.

Adaptations

Many species of protozoa have physiological mechanisms for monitoring conditions in their environment. For example, many free-living species have a localized region of pigment called an **eyespot.** Eyespots detect changes in the quantity and quality of light. Certain protozoan species also sense physical and chemical changes or obstacles in their environment. For instance, some protozoa will back up and bypass a noxious chemical.

Most protozoa are separated from their environment only by their delicate external cell membrane. These fragile organisms can survive in environments where extreme conditions often exist.

TABLE 26-1 A Summary of Protozoa

Phylum	Common name	Locomotion	Nutrition type	Representative genera
Sarcodina	sarcodines	pseudopodia	heterotrophic; some parasitic	*Amoeba* *Radiolaria* *Naegleria*
Ciliophora	ciliates	cilia	heterotrophic; some parasitic	*Paramecium* *Tetrahymena* *Balantidium*
Zoomastigina	zooflagellates	flagella	heterotrophic; some parasitic	*Trypanosoma* *Leishmania* *Giardia* *Trichonympha*
Sporozoa	sporozoans	(none in adult)	heterotrophic; some parasitic	*Plasmodium* *Toxoplasma*

Their hardiness is in part due to their ability to form cysts. A **cyst** is a dormant form characterized by a hardened external covering in which metabolic activity has ceased. Many species of protozoa form cysts in response to changes in the environment, such as nutrient deficiency, drought, decreased oxygen concentration, or pH or temperature changes. Cyst formation is extremely important to many protozoa that must survive such conditions between hosts. When favorable environmental conditions return, a protozoan emerges from the cyst and resumes metabolic activities.

Evolution

As you learned in Chapter 14, the first prokaryotes evolved more than 3.5 billion years ago. These organisms were the only life-forms on Earth for almost 2 billion years. About 1.5 billion years ago, the first eukaryotic organisms evolved. Protozoa are the descendants of these early eukaryotes. The first eukaryotes probably evolved through endosymbiosis, a process in which one prokaryote lives inside another and gradually both host and guest become dependent on one another.

Word Roots and Origins

cyst

from the Greek *kystis,* meaning "sac"

SECTION 26-1 REVIEW

1. What kind of organisms are found in the kingdom Protista? What characteristics do they share?
2. What are protozoa? How do they reproduce? What kinds of environments do they inhabit?
3. What role do some protozoa play in aquatic environments?
4. What is a cyst? Under what conditions might certain protozoa form cysts?
5. Why are protozoa considered some of the oldest existing life-forms?
6. **CRITICAL THINKING** On what basis can protozoa be classified? Does this classification scheme reflect evolutionary relationships among protozoa?

GREAT DISCOVERIES

The Origin of Eukaryotic Cells

HISTORICAL PERSPECTIVE

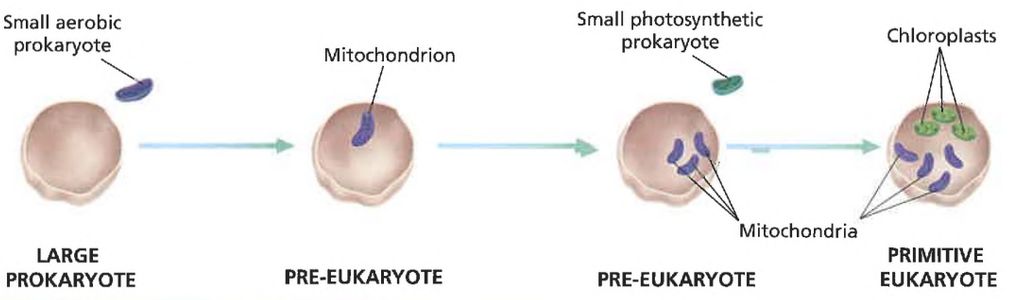
In the late nineteenth and early twentieth centuries, French, Russian, and American scientists speculated that mitochondria contained hereditary information similar to that found in the nucleus. They hypothesized that mitochondria evolved as a result of a symbiotic relationship between different types of bacteria. Attempts to culture mitochondria were unsuccessful, and given the popular view of bacteria as agents of disease, scientists generally disregarded the hypothesis that mitochondria evolved from symbiotic bacteria.

A "Dead" Hypothesis Reappears

In the 1950s, as an undergraduate at the University of Chicago, Lynn Margulis became interested in genetics and inheritance through her readings of the works of noted scientists. Although she had started college when she was only 15 years old, Margulis was not intimidated by the complexity of genetics. As a graduate student in genetics at the Universities of Wisconsin and California, she began to question well-established ideas about heredity and evolution. While at the University of Wisconsin, Margulis became aware of patterns of inheritance in components of the cytoplasm in plants and algae that did not seem to result from genes in the nucleus. After discussing her observations with her advisor, cell biologist Hans Ris, she concluded that the cytoplasm contains genes that function separately from those in the nucleus.

Using an electron microscope, Margulis and Ris were able to study chloroplasts and mitochondria in detail. They observed that both of these organelles have properties in common with modern bacteria. Both chloroplasts and mitochondria contain ribosomes and circular DNA, and they reproduce by binary fission.

These observations, along with the papers of biologists who had earlier suggested that hereditary information could be found in the cytoplasm, led Margulis to infer that the genes in chloroplasts and mitochondria may have had a different evolutionary origin than the genes in the nucleus. Margulis developed a hypothesis referred to as serial endosymbiosis. In this hypothesis, she proposed that eukaryotes evolved from symbiotic relationships established between anaerobic bacteria and intracellular aerobic bacteria.



The Evolution of Mitochondria and Chloroplasts

To explain the selective pressure for endosymbiosis, Margulis hypothesized that there was an "oxygen holocaust" on Earth about two billion years ago. The amount of oxygen in the atmosphere increased sharply, probably as a result of bacterial photosynthesis. The rise in oxygen levels killed most bacteria—but not all bacteria. Some small, oxygen-utilizing bacteria invaded larger, anaerobic or nonoxygen-utilizing bacteria. Although many of the anaerobic bacteria were unable to adapt to their new "guests" and died, a few survived and became a living food source for the invaders. In effect, the larger bacteria became hosts to parasitic aerobic bacteria. In turn, the invading, aerobic bacteria supplied some of the energy derived from their aerobic respiration to the host cell. Margulis proposed that these aerobic invaders may have been the evolutionary forerunners of modern mitochondria.

Margulis further hypothesized that chloroplasts evolved from an ancient invasion—this time by small, photosynthetic bacteria similar to modern blue-green bacteria. Thus, in addition to energy-producing components (the primitive mitochondria), the large host cells now had components that could produce food using simple molecules and the energy from sunlight. These increasingly complex host cells were primitive eukaryotes, the ancestors of modern algae and plants. What began as a parasitic relationship evolved to the mutual benefit of both host and parasite, resulting in the emergence of eukaryotic cells.

An Unpopular Idea

Margulis's article presenting her hypothesis was rejected by 15 journals before it was published in 1966 in the *Journal of Theoretical Biology.* In 1970, when she published an expanded account of her hypothesis in a book called *Origin of Eukaryotic Cells,* most biologists still rejected her ideas because of the absence of fossil evidence to support it.

In defending her hypothesis, Margulis cited experiments performed by Kwang Jeon, of the University of Tennessee. Jeon had infected a species of amoeba with a bacterial parasite. By culturing those amoebas that survived the infection, Jeon eventually produced a line of amoebas that were actually dependent on the bacteria for survival. Essentially, symbiosis and the selection that followed produced a new kind of amoeba in five years. Other studies in the late 1960s supported Margulis's endosymbiosis hypothesis.

By 1981, when Margulis published a revised version of her book, titled *Symbiosis in Cell Evolution,* her hypothesis was supported by a wealth of evidence and had become widely accepted. Since then, many more reports of endosymbiotic relationships have been published.

In one recent study, scientists at the University of Pennsylvania found evidence of endosymbiosis between protozoa and green algae. DNA from a previously unknown organelle in protozoa was identified as being similar to DNA found in algae plastids.

A Fast-Changing Science

In her preface to the 1992 edition of *Symbiosis in Cell Evolution,* Margulis refers to significant changes in biology. She calls the difference between prokaryotes and eukaryotes the most fundamental division in the organization of the living world. This certainly is a big change from the time when biologists considered the division of plants and animals to be the most basic division. As Margulis and others continue to explore microorganisms, there will undoubtedly be other changes in our understanding of the evolution of life.

Kwang Jeon provided experimental evidence that supported Margulis's hypothesis of evolution through endosymbiosis.

SECTION

26-2

OBJECTIVES

- Explain how sarcodines have contributed to Earth's geological features.
- Describe a type of sexual reproduction that occurs in ciliates.
- Identify four human diseases caused by zooflagellates.
- Discuss the life cycle of *Plasmodium.*

PROTOZOAN DIVERSITY

The broad diversity of protozoa is evident in the four major phyla identified by biologists. The phyla are distinguished by their form of locomotion, and each group contains a number of parasites that cause serious human diseases. The complexity of protozoa sets them apart from the relatively simple structures of bacteria and viruses.

PHYLUM SARCODINA

Biologists have classified 40,000 species of protozoa in the phylum Sarcodina (SAHR-kuh-DIE-nuh). Sarcodines include hundreds of species of amoebas, which inhabit fresh water, salt water, and soil. One of the most unusual sarcodines is *Pelomyxa carolinensis,* shown in Figure 26-3. These protozoa are found living on mud, rocks, and other surfaces in shallow, slow-moving streams and ponds.

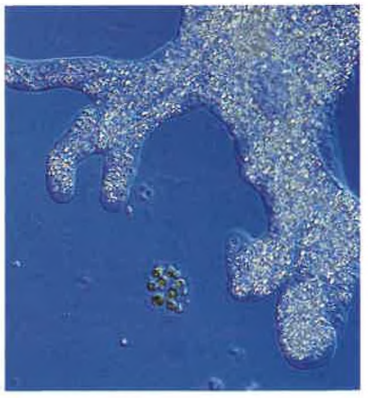
Most sarcodines have flexible cell membranes and are constantly thrusting out **pseudopodia** (SOO-duh-POH-dee-uh). Pseudopodia are large, rounded cytoplasmic extensions that function in movement. A pseudopodium forms when the **endoplasm,** the inner portion of the cytoplasm, pushes the **ectoplasm,** the outer layer, forward to create a blunt, armlike extension. Simultaneously, other pseudopodia retract, and the cytoplasm flows in the direction of the new pseudopodium. This form of movement, referred to as **ameboid movement,** is illustrated in Figure 26-4. Ameboid movement is a form of **cytoplasmic streaming,** the internal flowing of a cell's cytoplasm.

Sarcodines also use pseudopodia for feeding. Sarcodines live on other protists, which they engulf by phagocytosis. When a sarcodine feeds, it surrounds the food with its pseudopodia. A portion of the cell membrane then pinches together and surrounds the food in a food vacuole, in a process called endocytosis. Enzymes from the cytoplasm then enter the vacuole and digest the food. Undigested food leaves the cell in a reverse process called exocytosis.

Most freshwater sarcodines have an internal structure that is similar to that of the amoeba shown in Figure 26-4. Notice the **contractile vacuole,** an organelle that expels fluid from the cell. Freshwater organisms are usually hypertonic relative to their environment, so water diffuses into them. To maintain homeostasis, many freshwater protozoa have contractile vacuoles that rid the cell of excess water.

FIGURE 26-3

Sarcodines, such as this *Pelomyxa,* are characterized by cytoplasmic extensions called pseudopodia. By thrusting pseudopodia outward, a sarcodine can move across a surface or capture prey. (240×)



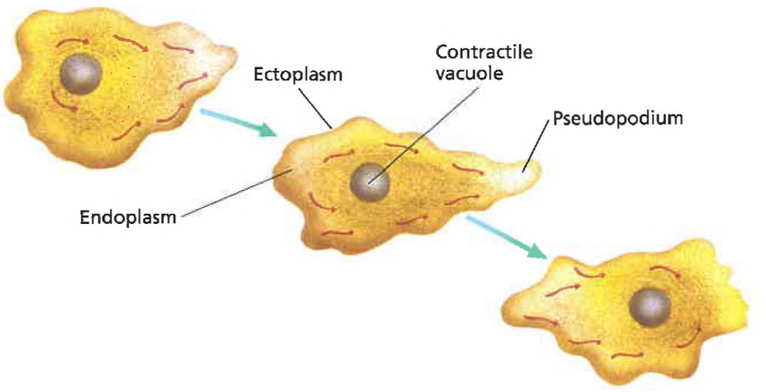


FIGURE 26-4
Ameboid movement is powered by cytoplasmic streaming (indicated here with arrows). As the cytoplasm surges forward to form a new tubelike pseudopodium, other pseudopodia retract.

Ecological Role

Many sarcodines are "naked," that is, their cell membranes are exposed directly to the environment. Some have their delicate cell membranes covered with a protective **test,** or shell. For example, **foraminifera** (FOHR-a-MIN-i-fohr-uh) are an ancient group of shelled sarcodines found primarily in oceans. Their tests, shown in Figure 26-5, have many chambers and are made of calcium carbonate. Slender pseudopodia extend through tiny openings in the test. The group of sarcodines called **radiolarians** (RAY-dee-OH-LER-ee-uhnz) is among the oldest known. Most radiolarians live in shallow, open water. Their tests contain silicon dioxide and usually have a radial arrangement of spines that extend through the shell. One example of their intricate tests is shown in Figure 26-6.

Foraminifera and radiolarians have existed since Precambrian times (more than 600 million years ago) and have left excellent fossil records. For millions of years, the tests of dead foraminifera have been sinking to the bottom of the ocean, where they have built up a calcium-rich layer of sediment. These sedimentary layers can be seen as limestone and chalk deposits that formed in the sea and later emerged as dry land. The chalk deposits in many areas of England, including the White Cliffs of Dover, were formed in this way. The Great Pyramids of Egypt were built with stones quarried from limestone beds that are made of a type of large foraminiferan that flourished during the early Tertiary period (between 7 and 70 million years ago). The tests of dead radiolarians have contributed to the formation of a type of rock called chert.

FIGURE 26-5
Foraminifera once inhabited these hard shells called tests.

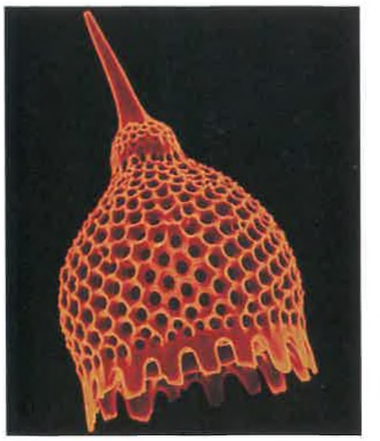


FIGURE 26-6
The phylum Sarcodina includes radiolarians, such as the one shown above, which are also covered by protective tests.

Human Diseases

Although most amoebas are free-living, some species live in the intestines of humans or other animals. One such amoeba, *Entamoeba histolytica,* can cause serious illness in humans. This amoeba enters the body via contaminated food and water. It lives in the large intestine, where it secretes enzymes that attack the intestinal lining and cause deep ulcers. If this occurs, a sometimes fatal disease called **amebic dysentery** may result. Affected individuals feel intense pain, and complications arise when the amoebas are carried by the blood to the liver and other organs.

FIGURE 26-7
Like all ciliates, paramecia such as *Paramecium* above move by using short, hairlike projections called cilia.

internetconnect
SCILINKS NSTA
TOPIC: Ciliophora
GO TO: www.scilinks.org
KEYWORD: HM514

PHYLUM CILIOPHORA

The 8,000 species that make up the phylum Ciliophora (SIL-EE-AWF-uh-ruh) swim by means of cilia, which are short, hairlike cytoplasmic projections that line the cell membrane. Members of the genus *Paramecium* are among the most thoroughly studied ciliates. Like all paramecia, *Paramecium,* shown in Figure 26-7, is abundant in ponds and slow-moving streams that contain plants and decaying organic matter. As you can see, a paramecium has cilia arranged in rows across its cell membrane. The cilia beat in synchronized strokes that pass in waves across the cell, causing the protozoan to rotate on its axis. Paramecia and other ciliates feed on bacteria, algae, and other small organisms that are found in all types of marine and freshwater habitats.

Internal Structure

Ciliates have the most elaborate organelles of any protozoa. Figure 26-8 illustrates the basic structure of a paramecium. A clear, elastic layer of protein, called a **pellicle,** surrounds the cell membrane. The pellicle has a funnel-like depression called an **oral groove,** which is lined with cilia. These beating cilia create water currents that sweep food down the groove to the **mouth pore.** The mouth pore opens into a **gullet,** which forms food vacuoles that circulate throughout the cytoplasm. Organic molecules in the vacuole are digested and absorbed. Molecules that are not digested move to the **anal pore,** where they are expelled.

Ciliates are multinucleate; that is, they have at least one macronucleus and one micronucleus. The large **macronucleus** contains

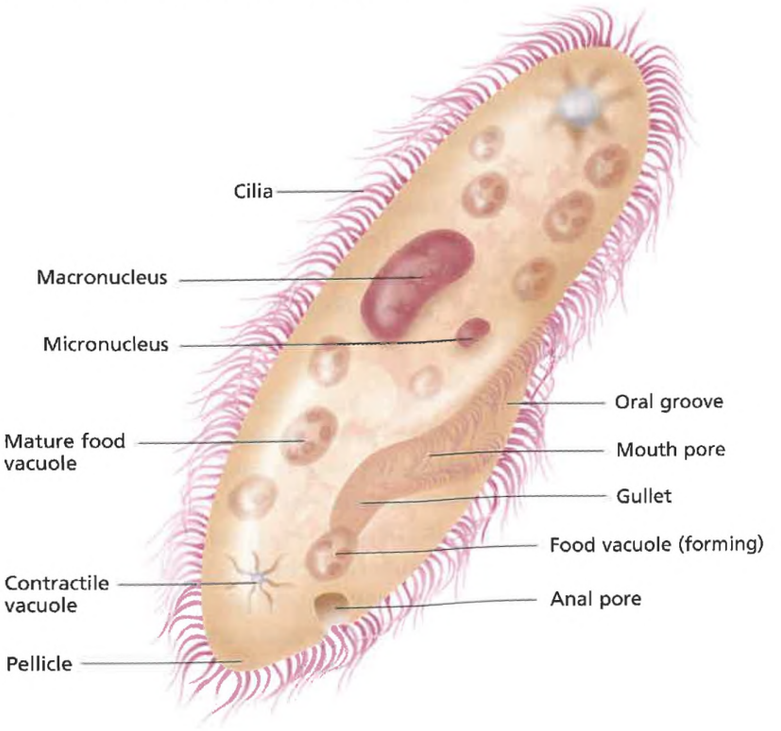
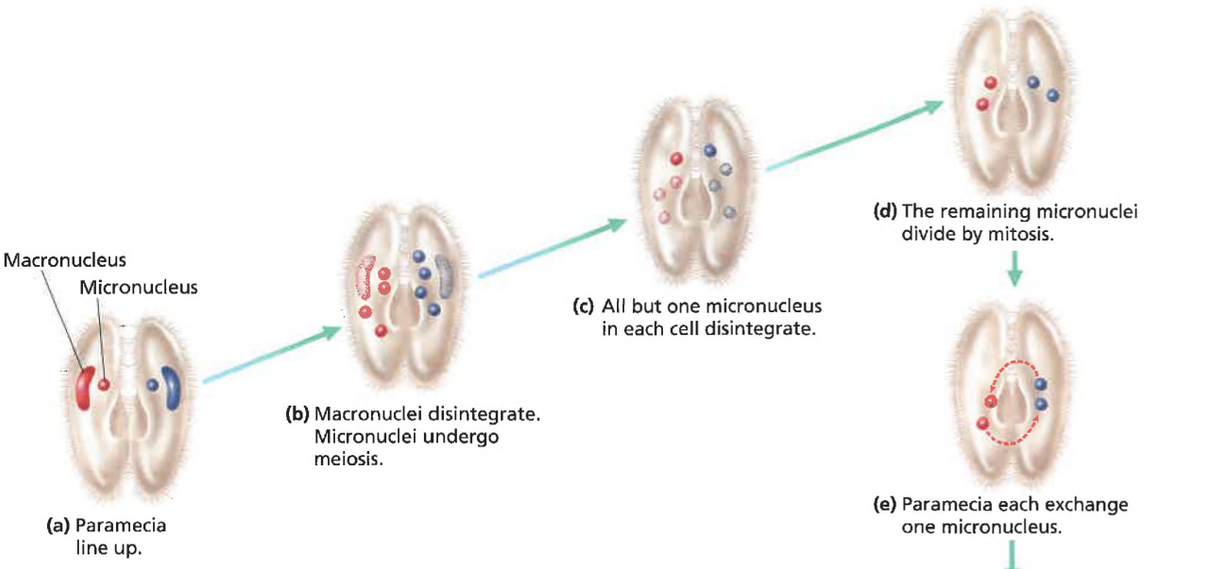


FIGURE 26-8
Paramecia have two types of nuclei: a large macronucleus and one or more small micronuclei. Paramecia have an oral groove, mouth pore, and gullet, into which food particles are drawn by currents produced by the beating cilia. They also have an anal pore, through which undigested waste is expelled from food vacuoles.



multiple copies of DNA and is responsible for metabolic and developmental functions. The macronucleus is also necessary for asexual reproduction. The smaller **micronucleus** participates in the exchange of genetic material between individuals during conjugation.

Reproduction

Asexual reproduction in ciliates occurs by binary fission. In this process, only the micronucleus divides by mitosis. The macronucleus, which has up to 500 times more DNA than the micronucleus, simply elongates and splits in half. One of the two halves goes to each new cell.

Sexual reproduction occurs in many ciliates by the process of conjugation. Conjugation in paramecia is illustrated in Figure 26-9. Conjugation begins when two organisms from opposite mating strains line up and join together. The macronucleus in each paramecium disintegrates. Each diploid micronucleus then undergoes meiosis, producing four haploid micronuclei. In each paramecium, all but one micronucleus disintegrate. The remaining micronucleus divides by mitosis, producing two identical haploid micronuclei. The two paramecia then exchange one micronucleus. The two micronuclei in each paramecium then fuse to form one diploid micronucleus. The two paramecia separate, and a macronucleus forms in each paramecium from products of mitotic divisions of the micronucleus. Although genetic material is exchanged during conjugation, no new cells are produced.

Following conjugation, each paramecium divides, producing a total of four genetically identical paramecia. Because genetic material is exchanged between the two original paramecia, the four offspring paramecia are genetically different from either original paramecium.

FIGURE 26-9

Paramecium reproduces by conjugation, a form of sexual reproduction in which genetic material is exchanged by two mating organisms.

FIGURE 26-10

These zooflagellates are called *Giardia lamblia*. The protozoa pictured in this scanning electron micrograph are shown in their natural habitat—the human intestine.

PHYLUM ZOOMASTIGINA

The 2,500 species that make up the phylum Zoomastigina (ZOO-uh-MAST-uh-JIE-nuh) are characterized by the presence of one or more flagella, long hairlike structures that are made up of microtubules and are used for moving. The rapid whipping motion of the flagella pushes or pulls the protozoan through water. Many zooflagellates are free-living species that move through lakes and ponds, where they feed on small organisms. Some of the most primitive protozoa are found in this phylum. *Giardia lamblia* is shown in Figure 26-10.

internetconnect

SCILINKS NSTA

TOPIC: Zoomastigina
GO TO: www.scilinks.org
KEYWORD: HM516

Human Disease

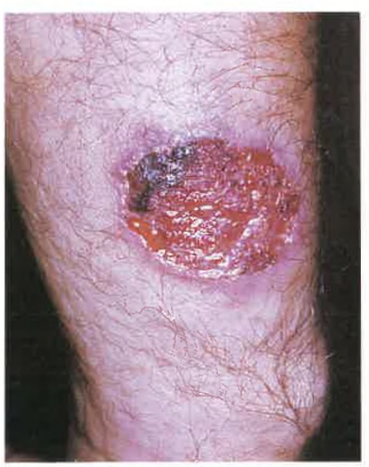
Some of the most important protozoan parasites are zooflagellates. Many of them belong to the genus *Trypanosoma.* They live in the blood of fish, amphibians, reptiles, birds, and mammals and are carried from host to host by bloodsucking insects, such as flies. Some species are nonpathogenic, but others produce severe diseases in humans and animals. For example, two species of *Trypanosoma* can cause African **trypanosomiasis** (TRIP-uh-NOH-soh-MIE-uh-sis), or sleeping sickness. Trypanosomiasis is transmitted by the tsetse fly, which lives only in Africa. The disease is characterized by increasing fever, lethargy, mental deterioration, and coma. Another species, called *Trypanosoma cruzi,* causes **Chagas' disease.** Chagas' disease is transmitted by an insect called the "kissing bug." Patients with Chagas' disease suffer from fever and severe heart damage.

A zooflagellate called *Leishmania donovani* is transmitted by sand flies. It causes leishmaniasis, a blood disease that afflicts millions of people in Africa, Asia, and Latin America. The disease is characterized by disfiguring skin sores, and it can be fatal. A leishmanial sore is shown in Figure 26-11.

Giardia lamblia causes **giardiasis** (JEE-ahr-DIE-uh-sis), an illness characterized by severe diarrhea and intestinal cramps. Several kinds of animals carry the parasite and contaminate water with their feces. Hikers and others who are likely to drink contaminated water are susceptible to giardiasis, and thousands of cases occur annually in the United States. The disease is usually not fatal, and drugs hasten recovery.

FIGURE 26-11

This person has leishmaniasis, which is caused by several species of *Leishmania. Leishmania* infects the skin, and some species infect major internal organs.



PHYLUM SPOROZOA

All 6,000 species in the phylum Sporozoa (SPOHR-uh-ZOH-uh) have adult forms with no means of locomotion. Most species are parasitic and have complex life cycles in which they develop a spore, an infective form protected by a resistant coat.

Sporozoans are carried in the blood and other tissues of their hosts, where they absorb nutrients and destroy host cell tissues. The sporozoan shown in Figure 26-12 is *Toxoplasma gondii,* a parasite found in birds, rodents, and domestic cats. In humans, it can cause **toxoplasmosis** (TAHKS-oh-plaz-MOH-sis), a disease that causes few or no symptoms in adults with healthy immune systems but that can be dangerous to a developing fetus or newborn. Some adults can become seriously ill with flu-like symptoms. One species of sporozoan closely related to *Toxoplasma* causes coccidiosis, a deadly disease that affects birds and young cattle.

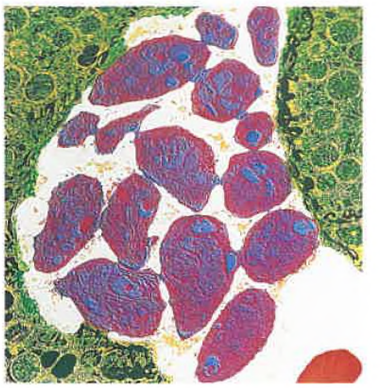


FIGURE 26-12
The sporozoan *Toxoplasma gondii* is pictured above in a section of human liver.

Plasmodium

The best-known sporozoan is *Plasmodium,* the protozoan that causes malaria. **Malaria** is a very serious disease characterized by severe chills, fever, sweating, fatigue, and great thirst. Victims die of anemia, kidney failure, or brain damage. The genus *Plasmodium* has caused more human deaths than any other genus in history. According to the World Health Organization, malaria afflicts 500 million people annually, killing as many as 2.7 million.

Four species of *Plasmodium* infect humans, and all have life cycles that involve the female *Anopheles* mosquito. When an infected mosquito bites a person, *Plasmodium* **sporozoites** enter the bloodstream and travel to liver cells, where they divide repeatedly. New spores called **merozoites** emerge and infect red blood cells, where they reproduce asexually. At regular intervals, the merozoites burst out of the red blood cells and release toxins into the blood. The destruction of red blood cells and the release of toxin in the blood cause the fever, anemia, and other symptoms of malaria. The merozoites infect other red blood cells and again reproduce asexually. This asexual reproduction can happen many times over a long period of time. Merozoites of some species remain in the liver and do not come out for months or years. Thus, an infected person could take antimalarial drugs and cure the infection in the blood, only to become ill again when the merozoites leave the liver cells. There are, however, antimalarial drugs that prevent the reoccurrence of malaria by killing the liver-stage parasites.

Some of the merozoites in the blood develop into specialized cells called **gametocytes.** When a female *Anopheles* bites the infected person, it ingests these gametocytes. In the mosquito's digestive system, the sperm and eggs combine to form a zygote. The nucleus of the zygote divides repeatedly to form more sporozoites. When the zygote bursts, the sporozoites migrate to the

Eco Connection

Protozoan Biocontrol

Scientists from the United States Department of Agriculture are conducting field studies with the protozoan *Edhazardia aedis* to test its effectiveness as a control agent of disease-carrying mosquitoes. The chemical DDT was used previously, but it was banned in the 1970s after it was discovered to be harmful to bird populations. *E. aedis,* which was discovered in Argentina, infects mosquito larvae in the water and kills them. Scientists think that this protozoan will prevent disease while causing no environmental damage.

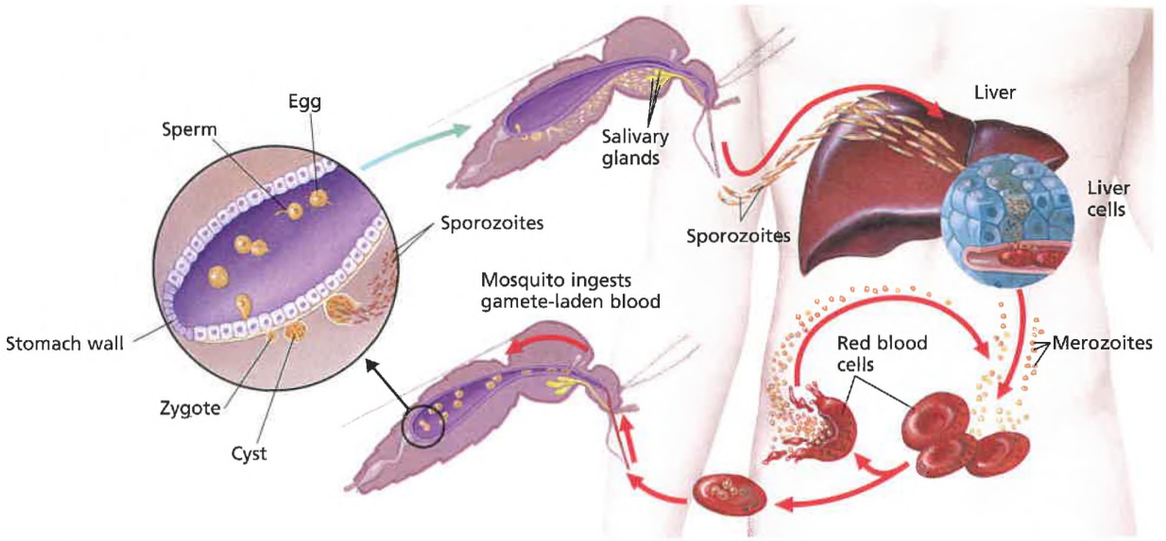


FIGURE 26-13

Malaria is caused by a sporozoan of the genus *Plasmodium*. *Plasmodium* is transmitted from host to host by female *Anopheles* mosquitoes. The host experiences attacks of chills and fever each time infected red blood cells burst and release the parasites that have multiplied within them. Some parasites develop into spores, which are picked up by uninfected *Anopheles* mosquitoes that bite the host.

body cavity and salivary glands of the mosquito. When the insect bites another person, the life cycle begins again. One effective way to reduce human deaths from malaria is to control mosquito populations. Without the mosquito hosts, the *Plasmodium* protozoans cannot complete their life cycle. The malaria life cycle is illustrated in Figure 26-13.

Malaria is usually cured with a drug derived from the cinchona tree, which is native to the Americas. This drug, quinine, has been used to treat malaria for over 500 years. As you learned in Chapter 24, bacteria can evolve resistance to antibiotics; similarly, sporozoans can evolve resistance to antimalarial drugs. Resistance to antimalarial drugs is a significant worldwide problem. Many more people will die from malaria despite the availability of drugs. Pharmaceutical companies have developed new drugs related to quinine, such as chloroquine and primaquine, but *Plasmodium* has evolved resistance to these newer quinine-related drugs. Although experimental malaria vaccines have not been successful, molecular techniques may offer new hope that a successful vaccine will be developed.

SECTION 26-2 REVIEW

1. **What are pseudopodia? What function do they serve in sarcodines?**
2. **How have sarcodines built geological features of the environment?**
3. **What is conjugation? How is this process advantageous for ciliates, such as *Paramecium*?**
4. **What kinds of disease can zooflagellates cause in humans?**
5. **Describe the life cycle of *Plasmodium*, the sporozoan that causes malaria. What features typical of sporozoans does this life cycle exhibit?**
6. **CRITICAL THINKING How might health workers attempt to control diseases caused by protozoa?**

CHAPTER 26 REVIEW

SUMMARY/VOCABULARY

26-1

- Protozoa are unicellular eukaryotic organisms classified in the kingdom Protista. They are found in moist habitats, and they include free-living and parasitic forms. Most species of protozoa are heterotrophic organisms that obtain nutrients by the process of phagocytosis.
- Many scientists believe that protozoa evolved from prokaryotes about 1.5 billion years ago.
- Many species of protozoa have adaptations for responding to changes in the environment. Such adaptations include eyespots and cyst formation.
- Protozoa are placed into four groups, according to the type of locomotion they display. The sarcodines move by means of pseudopodia, the ciliates move by means of cilia, the zooflagellates move by means of flagella, and the sporozoans are unable to move in the adult form.

Vocabulary

conjugation (507)
cyst (509)
eyespot (508)
food vacuole (507)
multiple fission (507)
protist (507)
protozoa (507)
zooplankton (507)

26-2

- The phylum Sarcodina consists of protozoa that move by means of pseudopodia. Sarcodines include amoebas, foraminifera, and radiolarians.
- Sarcodines move by means of cytoplasmic streaming. In this process, the endoplasm pushes the ectoplasm outward to form a pseudopodium. Pseudopodia are also used for phagocytosis.
- Most sarcodines are free-living, but the sarcodine *Entamoeba histolytica* is parasitic and causes the human disease amebic dysentery.
- The phylum Ciliophora consists of protozoa that move by means of cilia. Ciliates include the well-studied *Paramecium.* Paramecia have a complex array of organelles, including a macronucleus, a micronucleus, an oral groove, and an anal pore.
- Ciliates reproduce by binary fission as well as by sexual reproduction. Ciliates exchange genetic material by a process called conjugation.
- The phylum Zoomastigina consists of protozoa that move by means of flagella. Zooflagellates include *Trypanosoma,* a species that causes African sleeping sickness.
- Other important human diseases caused by zooflagellates are Chagas' disease, leishmaniasis, and giardiasis.
- The phylum Sporozoa is made up of protozoa that have complex life cycles in which they develop a spore. Virtually all species of sporozoans are parasites in humans and other animals.
- The sporozoan *Plasmodium* causes the disease malaria. Plasmodium has a complex life cycle. The *Anopheles* mosquito transmits the parasite, which causes extensive damage to the red blood cells in a victim.

Vocabulary

amebic dysentery (513)
ameboid movement (512)
anal pore (514)
Chagas' disease (516)
contractile vacuole (512)
cytoplasmic streaming (512)
ectoplasm (512)
endoplasm (512)
foraminiferan (513)
gametocyte (517)
giardiasis (516)
gullet (514)
macronucleus (514)
malaria (517)
merozoite (517)
micronucleus (515)
mouth pore (514)
oral groove (514)
pellicle (514)
pseudopodium (512)
radiolarian (513)
sporozoite (517)
test (513)
toxoplasmosis (517)
trypanosomiasis (516)

REVIEW

Vocabulary

1. Compare the following terms: protozoa, protozoan, and protist.
2. Research the meaning of the word *pseudopodium.* Why is this an appropriate term for the structure it defines?
3. Distinguish between the two regions of cytoplasm known as ectoplasm and endoplasm.
4. Research the meaning of the word *zooplankton.* Explain the relationship between the word's meaning and its roots.
5. Define the words *ciliate, zooflagellate,* and *sporozoan.*

Multiple Choice

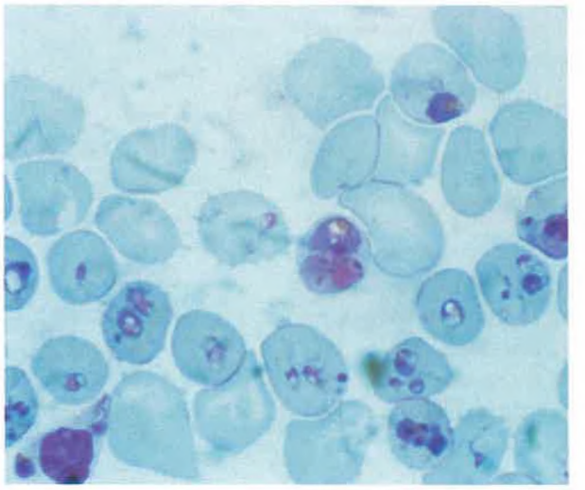
6. Most scientists believe that protists evolved from (a) free-living worms (b) trypanosomes (c) prokaryotes (d) euglenoids.
7. Protozoan habitats are characterized by the presence of (a) algae (b) moisture (c) blood (d) soil.
8. Some protozoa monitor light quality with (a) pseudopodia (b) eyespots (c) cilia (d) contractile vacuoles.
9. Pseudopodia are extensions of a sarcodine's (a) pellicle (b) cytoplasm (c) cilia (d) test.
10. A pellicle is a characteristic of the (a) zooflagellates (b) sarcodines (c) ciliates (d) sporozoans.
11. Ciliates, such as *Paramecium,* have (a) hard outer tests (b) parasitic life cycles that involve *Anopheles* mosquitoes (c) a complex array of organelles (d) silicon dioxide in their cell membranes.
12. Flagella are characteristic of members of the phylum (a) Zoomastigina (b) Sarcodina (c) Sporozoa (d) Ciliophora.
13. African sleeping sickness is transmitted by (a) tsetse flies (b) *Anopheles* mosquitoes (c) kissing bugs (d) muskrats.
14. Members of the phylum Sporozoa do not cause (a) toxoplasmosis (b) malaria (c) giardiasis (d) coccidiosis.
15. Malaria is transmitted by (a) tsetse flies (b) *Anopheles* mosquitoes (c) kissing bugs (d) *Trypanosoma cruzi.*

Short Answer

16. Describe the process of ameboid movement and how it helps with the amoeba's nutrition.
17. What adaptive significance does the contractile vacuole have in the freshwater sarcodine?
18. Describe a potentially fatal human disease caused by an amoeba.
19. Explain the process of conjugation in *Paramecium.* How does it differ from the process of conjugation in bacteria?
20. How does a ciliate, such as *Paramecium,* capture and digest food?
21. Why are ciliates considered the most complex group of protozoa?
22. Explain how parasitic zooflagellates infect their hosts. Give two examples.
23. What characteristic of sporozoans distinguishes them from the three other protozoan groups?
24. Draw a simplified life cycle of *Plasmodium,* showing the protozoan activity in both the mosquito and the human hosts.
25. Identify the protozoa that once inhabited the shells shown in the figure below. How have they contributed to the geological formation of Earth?

CRITICAL THINKING

1. Many scientists suggest that paramecia are more complex than amoebas. What adaptations in paramecia would justify this claim?
2. Many protozoa feed by means of pseudopodia. What stimulus might cause these cytoplasmic extensions to form?
3. The process of conjugation is complex. It requires an expenditure of energy and other resources. Relate the high biological cost of conjugation to the adaptive advantage of exchanging genetic material.
4. Scientists are trying to develop a vaccine against malaria, but because malaria has several life stages, scientists must decide which life stage to develop a vaccine against. Some scientists are trying to develop a vaccine against gametocytes as a way of controlling malaria. If they are successful in developing this vaccine, how will it help people living in areas where malaria regularly occurs? Explain your answer.
5. Many parasitic protozoa, such as *Entamoeba histolytica,* are able to form cysts whenever they pass out of a host. Why is cyst formation an advantage to a parasitic protozoan?
6. Some protozoan parasites are very difficult to grow in test tubes because they lose the ability to produce certain key enzymes or growth factors when outside their host. How is this host-parasite relationship similar to that described in the hypothesis of endosymbiosis? How is it different?
7. Study the micrograph below showing the sporozoan *Plasmodium*. What evolutionary advantage does *Plasmodium* gain by forming gametocytes?



EXTENSION

1. Read "Intruder in the Heart" in *Discover,* December 1998, on page 38. Why is Chagas' disease so difficult to diagnose? Describe how humans become infected with Chagas' disease. What is the main reason heart transplantation is seldom an effective treatment for Chagas' disease?
2. Write a report on the types of protozoa found in zooplankton in the ocean. In your report, include information about the species of fish that depend on these protozoa as a food source.
3. Collect water from at least three sources—ponds, lakes, taps, or ditches—and examine the samples under a microscope. Count the different kinds of protozoa in each sample, and draw sketches of all the types you see.
4. Read "New Combination Vaccine May Fight Malaria" in *Science News,* February 20, 1999, on page 117. How many people die of malaria each year? Describe how the new vaccine works against malaria.

CHAPTER 26 INVESTIGATION

Observing *Paramecium*

OBJECTIVES

- Observe protozoa under a compound light microscope.
- Compare *Paramecium* with *Euglena.*
- Test the effects of different solutions on the movement of a paramecium's contractile vacuoles.

PROCESS SKILLS

- observing
- comparing and contrasting
- collecting data
- analyzing data

MATERIALS

- safety goggles
- medicine droppers
- *Paramecium* culture
- *Euglena* culture
- microscope slides
- methyl cellulose
- coverslips
- compound light microscope
- stopwatch or clock with second hand
- distilled water
- paper towels
- salt water

Background

1. List some of the general characteristics of the kingdom Protista.
2. Distinguish between protists and protozoa.
3. Distinguish members of the phylum Ciliophora from other phyla of protozoa.
4. What foods do ciliates eat? How do they take in and digest food?
5. What function does the contractile vacuole serve in the *Paramecium*?

PART A Comparing *Paramecium* with *Euglena*

1. CAUTION **Put on safety goggles. If you get methyl cellulose in your eyes, immediately flush it out at the eyewash station while calling to your teacher. Slides break easily. Use caution when handling them.** Using a medicine dropper, place one drop of methyl cellulose on a microscope slide.
2. Place one drop of *Paramecium* culture on the methyl cellulose to slow the paramecia down, and cover them with a coverslip.
3. Use the low-power setting of your microscope to locate the paramecia and observe their movement. Then change to the high-power setting.
4. Examine one paramecium under the high-power setting of your microscope. Check for the structural details of the paramecium by changing the fine adjustment and altering the light conditions. If the organism moves out of view, move the slide to keep up with it. If you are unsuccessful, return to low power to scan a larger field, and begin again.
5. Make a sketch of a paramecium in your lab report. Label the cilia, oral groove, mouth pore, and gullet in your sketch. Note the color of the food vacuoles.
6. Remove the coverslip. Add one drop of *Euglena* culture to the slide. Cover and examine under high power. *Euglena* is a protist that you will study in Chapter 27. Its green color is due to chloroplasts.
7. As you view these two protists, note the relative sizes of the two kinds of organisms. Compare their means of locomotion.
8. Observe the food vacuoles in the paramecia. Did they change color after you added the *Euglena* culture to the slide?

PART B Observing the Contractile Vacuoles of *Paramecium*

9. In your lab report, prepare a data table similar to the one shown below.
10. Find a paramecium that is easy to observe, and identify its contractile vacuoles—the two roundish forms at each end of the organism. Count how many times the contractile vacuoles fill and empty in one minute. Record your data in your data table in the row labeled "Culture medium."
11. Repeat step 10, observing two different paramecia.
12. Use a clean medicine dropper to put some distilled water at one edge of the coverslip. Draw the distilled water to the other side of the slide by placing a paper towel at the opposite edge of the coverslip.
13. Count how many times the contractile vacuoles fill and empty in one minute when the paramecium is in distilled water. Record the number of pulses per minute in your data table in the row labeled "Distilled water." Repeat the process using two different paramecia.
14. Using a clean medicine dropper, put some salt water at one edge of the coverslip. Draw the salt water to the other side of the slide by placing a paper towel at the opposite edge of the coverslip as you did in step 12. Then count the number of times the contractile vacuoles fill and empty in one minute in the saltwater environment. Record the number of pulses per minute in your data table in the row labeled "Salt water." Repeat the process using two different paramecia.
15. Average the number of pulses per minute by adding the counts you obtained for each environment and dividing by 3. Record the average pulses per minute in the last column of your data table.
16.  Clean up your lab materials and wash your hands before leaving the lab.

Analysis and Conclusions

1. Based on your observations in Part A, is *Paramecium* autotrophic or heterotrophic? Explain your answer.
2. Explain any changes in the color of the food vacuoles in Part A.
3. What effect did the distilled water have on the paramecium's contractile vacuoles in Part B?
4. What effect did the salt water have on the paramecium's contractile vacuoles?
5. Did you use a control in Part B? Explain your answer.
6. Return to the data table you completed in Part B. Using the terms *isotonic, hypotonic,* and *hypertonic,* describe the three different environments you observed the paramecium in.
7. Explain how the external environment affected the number of pulses of the contractile vacuoles. (Hint: Compare the effects of a hypotonic solution with those of a hypertonic solution.)
8. Explain how contractile vacuoles are important to the survival of paramecia living in freshwater environments.
9. *Paramecium* is among the protists called protozoa, which means "first animals." In what way is this description accurate or misleading?

Further Inquiry

Design an experiment to test the responses of protozoa to a range of temperatures or a range of pH.

CONTRACTILE VACUOLE PULSES

Environment	Number of pulses per minute			Average pulses per minute
	paramecium 1	paramecium 2	paramecium 3	
Culture medium				
Distilled water				
Salt water				

CHAPTER 27

ALGAE AND FUNGUSLIKE PROTISTS

Algae, such as these kelp, Macrocystis pyrifera, *off the coast of California, are giants among protists. They grow in massive groves that support large numbers of aquatic organisms.*

FOCUS CONCEPT: ***Structure and Function***

As you read this chapter, note that algae and funguslike protists are extremely diverse groups of organisms that vary in structure, reproduction, and biochemistry.

SECTION 27-1

OVERVIEW OF ALGAE

Algae are plantlike organisms that belong to the kingdom Protista. Although most species of algae are unicellular, some, such as the Macrocystis pyrifera *shown on the opposite page, are large, multicellular organisms. Algae differ from protozoa, which are also classified in the kingdom Protista, in that they manufacture their food through the process of photosynthesis. This section explores the basic characteristics of algae.*

OBJECTIVES

- Compare algae with other protists.
- Explain how algae differ from plants.
- Describe the various body structures of algae.
- Identify the characteristics used to classify algae into seven phyla.
- Summarize the events of asexual and sexual reproduction in representative genera of algae.

CHARACTERISTICS

Algae are a diverse group of protists. They range in size from microscopic single-celled organisms to large seaweeds that may be hundreds of feet long. Unlike protozoa, which are heterotrophic, **algae** are autotrophic protists—they have chloroplasts and produce their own carbohydrates by photosynthesis. In the past, some classification systems placed algae in the plant kingdom. However, algae lack tissue differentiation and thus have no true roots, stems, or leaves. The reproductive structures of algae also differ from those of plants; they form gametes in single-celled **gametangia** (GAM-uh-TAN-jee-uh), or gamete chambers. Plants, by contrast, form gametes in multicellular gametangia. For these reasons, algae are classified as protists.

Despite their diversity, different kinds of algae have several features in common. For example, most algae are aquatic and have flagella at some point in their life cycle. In addition, algal cells often contain **pyrenoids** (pie-REE-NOYDZ), organelles that synthesize and store starch.

STRUCTURE

The body portion of an alga is called a **thallus** (THAL-uhs). The thallus of an alga is usually haploid. A variety of thallus formats characterize algae. In some species, the thallus consists of a single cell. In other species, it is made up of many cells in varying arrangements. Four types of algae are recognized, based on the following body structures: unicellular, colonial, filamentous, and multicellular.

Unicellular algae have a structure that consists of a single cell. Most unicellular algae are aquatic organisms that compose the **phytoplankton,** a population of photosynthetic organisms that

Word Roots and Origins

algae

from the Latin *alga,* meaning "seaweed"

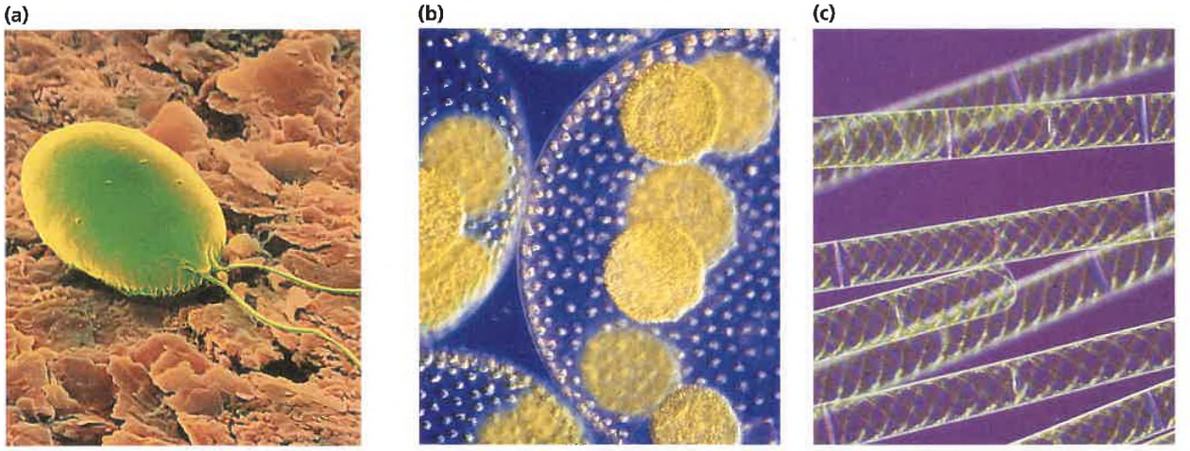


FIGURE 27-1

Algae are characterized by a variety of body structures. (a) *Chlamydomonas* is a flagellated unicellular organism (2,905×). (b) An example of a colonial green alga is *Volvox* (400×). (c) *Spirogyra* is a green alga with a filamentous body form (291×). (d) Some multicellular algae are sheetlike; *Ulva* has a thin, leaflike form.

forms the foundation of aquatic food chains. Through photosynthesis, phytoplankton produces almost half the world's carbohydrates, thereby providing important nutrients for numerous aquatic organisms. Such unicellular algae are also among the major producers of oxygen in the atmosphere. The *Chlamydomonas* in Figure 27-1a is an example of a unicellular alga.

Colonial algae, such as *Volvox,* shown in Figure 27-1b, have a structure that consists of groups of cells acting in a coordinated manner. Some of these cells become specialized. This division of labor allows colonial algae to move, feed, and reproduce efficiently.

Filamentous algae, such as *Spirogyra,* shown in Figure 27-1c, have a slender, rod-shaped thallus composed of rows of cells joined end to end. Other species of filamentous algae have specialized structures that anchor the thallus to the ocean bottom. This adaptation secures the alga in one place as it grows toward the sunlight at the water's surface.

Multicellular algae often have a large, complex thallus. For instance, *Ulva,* shown in Figure 27-1d, has a leaflike thallus that may be several centimeters wide but only two cells thick. The giant kelp, *Macrocystis,* is among the largest of the multicellular algae. It has rubbery leaflike portions, stemlike regions, and enlarged air bladders.

CLASSIFICATION

Algae are classified into seven phyla, based on their color, type of chlorophyll, form of food-storage substance, and cell wall composition. All known phyla contain the light-absorbing photosynthetic pigment chlorophyll *a.* However, different types of algae also contain other forms of chlorophylls—such as chlorophylls *b, c,* or *d*—that absorb slightly different wavelengths of light. Some phyla also have accessory pigments that give them their characteristic color. The seven phyla of algae are summarized in Table 27-1.

TABLE 27-1 Seven Phyla of Algae

Phylum	Thallus format	Photosynthetic pigments	Form of food storage	Cell wall composition
Chlorophyta (green algae, 7,000 species)	unicellular, colonial, filamentous, and multicellular	chlorophylls *a* and *b*, carotenoids	starch	polysaccharides, primarily cellulose
Phaeophyta (brown algae, 1,500 species)	multicellular	chlorophylls *a* and *c*, carotenoids, fucoxanthin	laminarin (an oily carbohydrate)	cellulose with alginic acid
Rhodophyta (red algae, 4,000 species)	multicellular	chlorophyll *a*, phycobilins, carotenoids	starch	cellulose or pectin, many with calcium carbonate
Bacillariophyta (diatoms, 11,500 species)	mostly unicellular; some colonial	chlorophylls *a* and *c*, carotenoids, xanthophyll	leucosin (an oily carbohydrate)	pectin, many with silicon dioxide
Dinoflagellata (dinoflagellates, 1,100 species)	unicellular	chlorophylls *a* and *c*, carotenoids	starch	cellulose
Chrysophyta (golden algae, 850 species)	mostly unicellular; some colonial	chlorophylls *a* and *c*, xanthophyll, carotenoids	laminarin (an oily carbohydrate)	cellulose
Euglenophyta (euglenoids, 1,000 species)	unicellular	chlorophylls *a* and *b*, carotenoids, xanthophyll	paramylon (a starch)	no cell wall, protein-rich pellicle

REPRODUCTION

Many species of algae reproduce both asexually and sexually. Sexual reproduction in algae is often triggered by environmental stress. Some species reproduce only asexually.

Both asexual and sexual reproduction have been studied extensively in the unicellular green alga *Chlamydomonas*. As a mature organism, *Chlamydomonas* exists as a flagellated haploid cell. During asexual reproduction, the alga first absorbs its flagellum. Then the haploid cell divides mitotically up to three times, and from two to eight haploid flagellated cells called **zoospores** (ZOH-oh-SPOHRZ) develop within the parent cell. These motile asexual reproductive cells break out of the parent cell, disperse, and eventually grow to full size.

Sexual reproduction in *Chlamydomonas* also begins by haploid cells dividing mitotically to produce either "plus" or "minus" gametes. (The *plus* and *minus* terminology describes gametes that look similar but differ in chemical composition.) A plus gamete and a minus gamete come into contact with one another and shed their cell walls. They fuse and form a diploid zygote, which develops a thick protective wall. A zygote in such a resting state is called a **zygospore** (ZIE-go-SPOHR). A zygospore can withstand unfavorable environmental conditions. When favorable conditions exist, the thick wall opens and

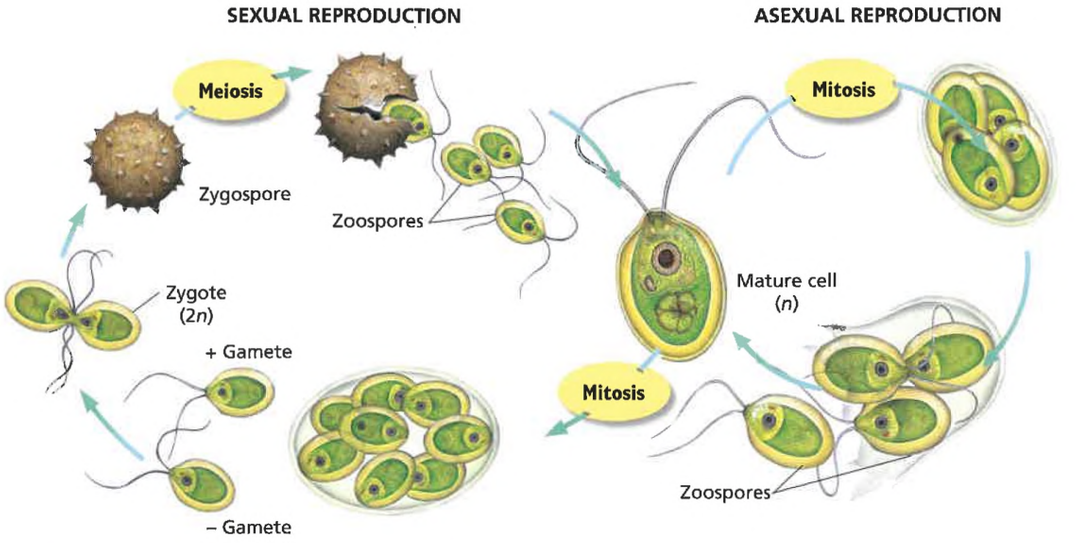


FIGURE 27-2

The unicellular green alga *Chlamydomonas* reproduces asexually by mitosis. It also reproduces sexually when gametes of opposite mating types fuse.

the living zoospore emerges. It then undergoes meiosis, forming numerous haploid *Chlamydomonas* cells that grow into mature organisms. The life cycle of *Chlamydomonas* is illustrated in Figure 27-2.

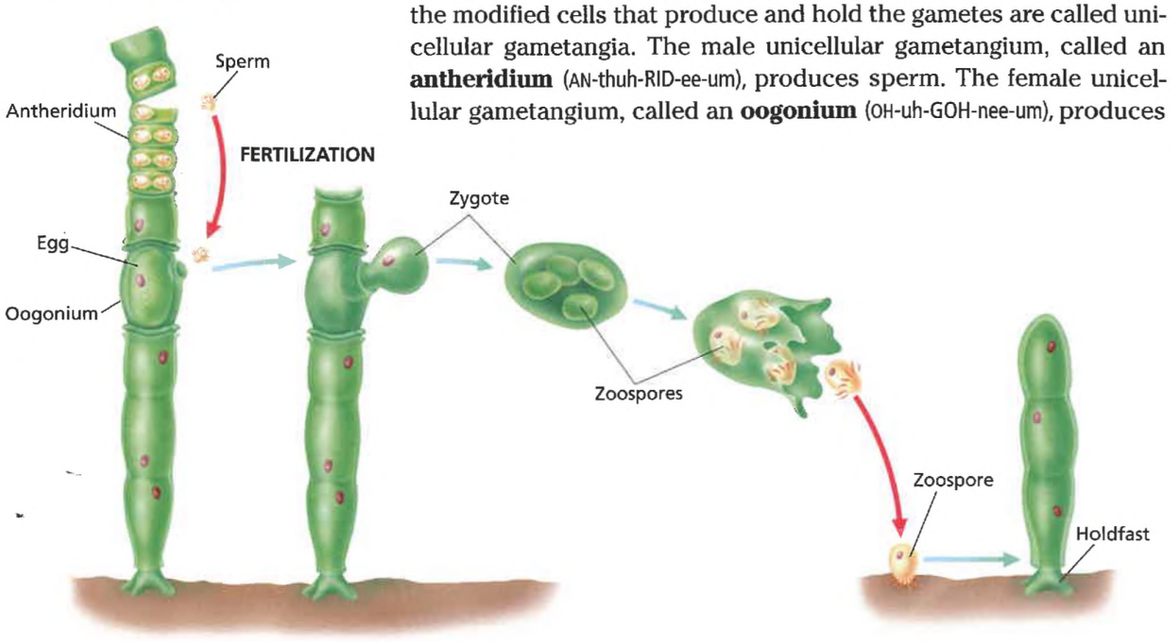
Reproduction in Multicellular Algae

Reproduction of multicellular algae varies widely among the phyla. Reproduction in red and brown algae is particularly complex, with that of the red algae often involving three states in a sexual life cycle. Examination of the following algal life cycles illustrates some of the reproductive variation in algae.

Oedogonium is a filamentous green alga. As shown in Figure 27-3, *Oedogonium* has cells specialized for producing gametes. Recall that the modified cells that produce and hold the gametes are called unicellular gametangia. The male unicellular gametangium, called an **antheridium** (AN-thuh-RID-ee-um), produces sperm. The female unicellular gametangium, called an **oogonium** (OH-uh-GOH-nee-um), produces

FIGURE 27-3

Oedogonium reproduces sexually by producing male and female gametes. The sperm, released into the surrounding water, swim to the egg.



an egg. The antheridium releases flagellated sperm into the surrounding water, where they swim to an oogonium and enter through small pores. After fertilization, the resulting zygote is released from the oogonium and forms a thick-walled, resting spore. The diploid spore then undergoes meiosis, forming four haploid zoospores that are released into the water. Each zoospore settles and divides. One of the new cells becomes a rootlike **holdfast,** and the other divides and forms a new filament.

The filamentous green alga *Spirogyra* reproduces sexually by a process called conjugation. During conjugation, two filaments align side by side. The walls of adjacent cells then dissolve and a conjugation tube forms between the cells. One cell contains a plus gamete. Its contents move through the conjugation tube, enter the adjacent cell, and fuse with the minus gamete. After fertilization, the resulting zygote develops a thick wall, falls from the parent filament, and becomes a resting spore. It later produces a new *Spirogyra* filament.

The leaflike alga *Ulva* has a sexual reproductive cycle that is characterized by a pattern called **alternation of generations.** As illustrated in Figure 27-4, a life cycle that exhibits alternation of generations has two distinct multicellular phases—a haploid, gamete-producing phase called a **gametophyte** (guh-MEE-tuh-FIET) and a diploid, spore-producing phase called a **sporophyte** (SPOHR-uh-FIET). The adult sporophyte has reproductive cells called **sporangia** (spoh-RAN-jee-uh), which produce haploid zoospores by meiosis. The zoospores divide mitotically and form motile spores, which settle on rocks and grow into multicellular, haploid gametophytes. Note that the gametophyte looks exactly like the sporophyte. The gametophyte produces gametangia and then produces plus and minus gametes that unite and form zygotes. As shown in Figure 27-4, the diploid zygote completes the cycle by dividing mitotically into a new diploid sporophyte.

The phenomenon of alternation of generations in green algae is important because it also occurs in more-complex land plants. However, in plants the gametophyte and sporophyte generations do not resemble each other as they do in *Ulva.* Also, the male and female gametes (sperm and egg) in plants are developed in multicellular reproductive structures, rather than in the unicellular gametangia seen in *Ulva.*

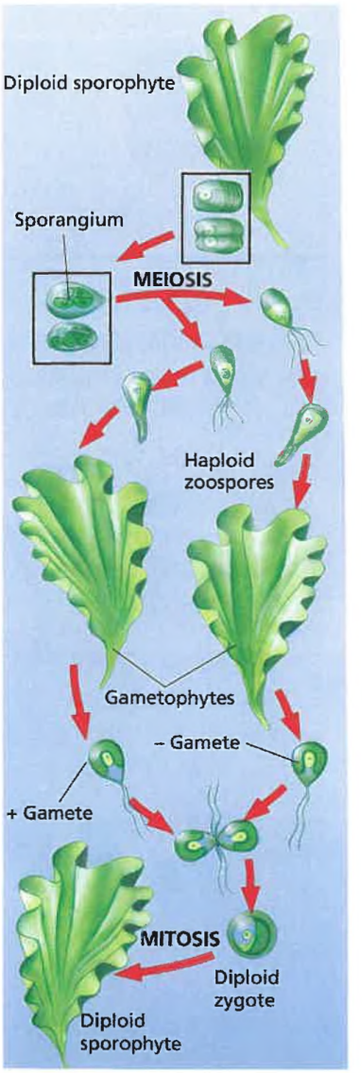


FIGURE 27-4
The multicellular green alga *Ulva* has a life cycle characterized by alternation of generations. Its haploid and diploid forms are equal in appearance and duration.

SECTION 27-1 REVIEW

1. In what ways do algae differ from protozoa?
2. How are algae similar to plants? How are they different?
3. How is body structure used to group algae?
4. What characteristics are used to classify algae into seven phyla?
5. Describe the general process of reproduction in the unicellular alga *Chlamydomonas.*
6. **CRITICAL THINKING** What adaptive advantage do you think different types of chlorophylls confer on algae?

SECTION

27-2

OBJECTIVES

- Explain why the phylum Chlorophyta is considered the most diverse phylum of algae.
- Describe the characteristics of the members of the phyla Phaeophyta and Rhodophyta.
- Describe the essential characteristics of diatoms, and explain their industrial importance.
- List the important structural characteristics associated with dinoflagellates.
- Discuss why *Euglena* is considered both a protozoan and an alga.

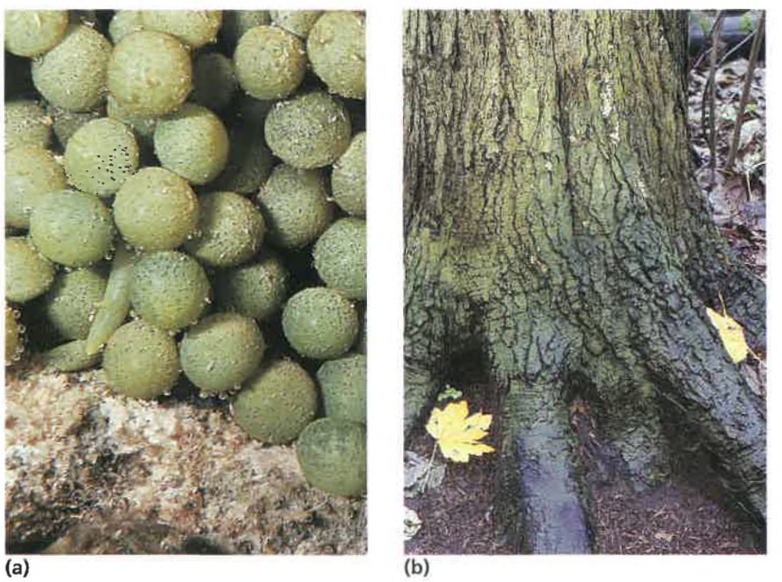
ALGAL DIVERSITY

The seven phyla of algae are a showcase of diversity. Microscopic forms, such as diatoms, dinoflagellates, and euglenoids, differ enough to be placed in separate phyla. Pigmentation distinguishes the green algae, red algae, brown algae, and golden algae, which are also placed in separate phyla.

PHYLUM CHLOROPHYTA

The phylum Chlorophyta (KLOH-rah-FIED-uh) contains more than 7,000 identified species of organisms called green algae. Members of this phylum have an amazing number of forms and reproductive methods. Their body structures range from single cells and colonial forms to multicellular filaments and sheets. Most species, such as the *Caulerpa racemosa* shown in Figure 27-5a, are aquatic. However, some species, such as the *Protococcus* shown in Figure 27-5b, inhabit moist terrestrial environments, such as the soil, rock surfaces, and tree trunks. Some species live as symbiotic partners in the cells of invertebrates or as part of organisms called lichens.

Biologists reason that green algae gave rise to land plants. Evidence supporting this idea includes the fact that both groups of organisms have chloroplasts that contain chlorophylls *a* and *b*. Both also have many carotenoids and store their food as starch. In addition, both green algae and plants have cell walls made of cellulose.



(a) (b)

FIGURE 27-5
The bunch-of-grapes (a) is an example of a marine green algae. These Chlorophyta are found worldwide. Other Chlorophyta, such as the green *Protococcus* growing on this tree (b), are found in moist environments on land.

PHYLUM PHAEOPHYTA

The phylum Phaeophyta contains approximately 1,500 species of organisms called brown algae. Brown algae are mostly marine, and they include the plantlike organisms called seaweeds and kelps. They are most common along rocky coasts where ocean water is cool. A few species, such as *Sargassum,* are found far offshore, where they form dense floating mats.

The brown algae contain chlorophylls *a* and *c* and a large amount of pigment called **fucoxanthin** (FYOO-koh-ZAN-thin), which gives them their characteristic brown color. The food they produce is stored as **laminarin,** a carbohydrate with glucose units that are linked differently than those in starch.

All brown algae are multicellular, and most are large, often reaching lengths of more than 45 m (147 ft). Some of the largest algae known are classified in the phylum Phaeophyta. The large brown alga shown in Figure 27-6 is *Macrocystis,* a genus that thrives in intertidal zones. Individual alga can grow to a length of 100 m (328 ft). The thallus is anchored to the ocean bottom by a rootlike holdfast. The stemlike portion of the alga is called the **stipe.** And the leaflike region, modified to capture sunlight for photosynthesis, is called the **blade.** The cell walls of *Macrocystis* contain alginic acid, a source of a commercially important substance called **alginate.** Alginate is used in cosmetics and various drugs, as food, and as a stabilizer in most ice creams.

FIGURE 27-6
Macrocystis is an example of brown algae. Also known as giant kelp, this species is a member of the phylum Phaeophyta.

Word Roots and Origins

stipe

from the Latin *stipes,* meaning "log" or "trunk of a tree"

PHYLUM RHODOPHYTA

The phylum Rhodophyta contains 4,000 species of organisms called red algae. A few species of red algae live in fresh water or on land, but most are marine seaweeds. Red algae are usually smaller than brown algae and are found as deep as 200 m (657 ft). The red alga *Corallina* is shown in Figure 27-7.

Red algae contain chlorophyll *a* and pigments called **phycobilins.** Phycobilins play an important role in absorbing light for photosynthesis. These pigments can absorb the wavelengths of light that penetrate deep into the water. Thus, they may make it possible for red algae to live at depths where algae lacking these pigments cannot survive. Despite their common name, not all red algae are red. The depth at which they live in the ocean determines the amount of pigment they have. Because Rhodophyta live at varying depths, their color also varies.

Certain species of red algae have cell walls that are coated with a sticky substance called **carageenan** (KAR-uh-GEEN-uhn). Carageenan is a polysaccharide used in the production of cosmetics, gelatin capsules, and some types of cheese. **Agar,** which is used as a gel-forming base for culturing microbes, is also extracted from the cell walls of red algae.

FIGURE 27-7
Although not as large as the Phaeophyta, the Rhodophyta, such as this *Corallina,* are often referred to as seaweeds.

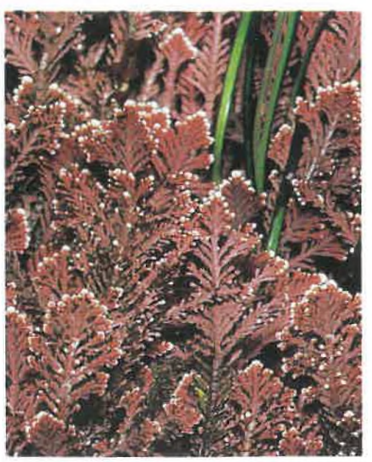


FIGURE 27-8

Diatoms, such as these, usually reproduce asexually. Sexual reproduction among diatoms is rare. (320×)

PHYLUM BACILLARIOPHYTA

The phylum Bacillariophyta contains 11,500 species of organisms called diatoms. **Diatoms** are abundant in both freshwater and marine environments. Their cell walls, commonly called shells, consist of two pieces that fit together like a box with a lid. Each half is called a **valve.** The shells contain silicon dioxide. Figure 27-8 shows two types of diatoms. **Centric diatoms** have circular or triangular shells and are most abundant in marine environments. **Pennate diatoms** have rectangular shells and are most abundant in freshwater ponds and lakes. Some pennate diatoms move by secreting threads that attach to the surface of the water. When these threads contract, they pull the diatom forward.

Diatoms are an abundant component of phytoplankton and are important producers in freshwater and marine food webs. They are an essential source of nutrients for microscopic heterotrophs. In addition, they release an abundance of oxygen.

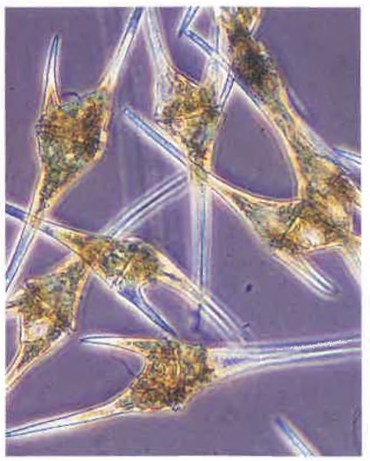
When diatoms die, their shells sink and accumulate in large numbers, forming a layer of material called **diatomaceous** (DIE-uh-tuh-MAY-shuhs) **earth.** Diatomaceous earth is slightly abrasive and is a major component of many commercial products, such as detergents, paint removers, fertilizers, insulators, and some types of toothpaste.

PHYLUM DINOFLAGELLATA

The phylum Dinoflagellata contains 1,100 species of organisms called dinoflagellates. Dinoflagellates are small, usually unicellular organisms. Most are photosynthetic, but a few species are colorless and heterotrophic. Along with diatoms, dinoflagellates are one of the major producers of organic matter in marine environments.

FIGURE 27-9

Dinoflagellates, such as these, often harbor endosymbiotic cyanobacteria. Dinoflagellates can also be endosymbionts in sponges, jellyfish, corals, and some types of protozoa. (450×)



Photosynthetic dinoflagellates usually have a yellowish green to brown color due to a large amount of pigments called carotenoids as well as other pigments and chlorophylls *a* and *c*. Most dinoflagellates have two flagella of unequal length, as shown in Figure 27-9. Each flagellum fits into one of two grooves that run perpendicular to each other. Movement of the flagella causes the dinoflagellate to spin like a top through the water. Dinoflagellates' cell walls are made of cellulose plates that look like armor when seen under a microscope.

Some species of dinoflagellates, such as *Noctiluca,* can produce **bioluminescence,** a display of sparkling light often seen in ocean water at night. Other species produce toxins and red pigments. When their populations explode, they turn the water brownish red, resulting in a phenomenon known as **red tide.** Red tides are fairly common in the Gulf of Mexico off the coast of Florida. When shellfish, including oysters, feed on the dinoflagellates, they also consume the toxins, which are dangerous to humans who eat the shellfish.

PHYLUM CHRYSOPHYTA

The phylum Chrysophyta contains about 850 species of organisms called golden algae. Most of the golden algae live in fresh water, but a few are found in marine environments. The cells form highly resistant cysts that enable them to survive beneath frozen surfaces of lakes in winter and dry lake beds during summer. Two flagella of unequal length are located at one end of each cell.

Most of the species placed in this phylum are some shade of yellow or brown due to the presence of large amounts of carotenoids. They also have chlorophylls *a* and *c*. Golden algae store much of their surplus energy as oil and are important in the formation of petroleum deposits.

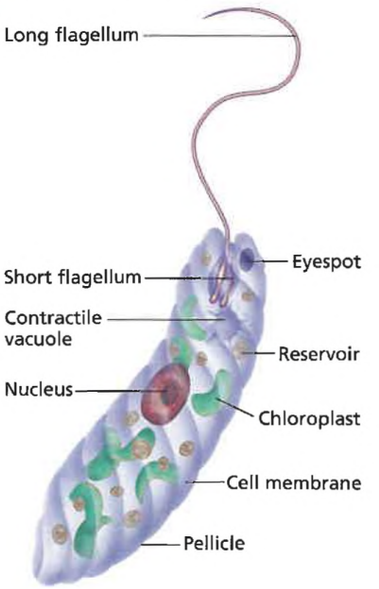
PHYLUM EUGLENOPHYTA

The phylum Euglenophyta contains approximately 1,000 species of flagellated unicellular algae called **euglenoids.** Euglenoids show both plantlike and animal-like characteristics. They are plantlike in that many have chlorophyll and are photosynthetic; they are animal-like in that they lack a cell wall and are highly motile. Euglenoids contain chlorophylls *a* and *b* and the pigments known as carotenoids. Most species live in fresh water, but a few are found in moist environments, such as in soil or in the digestive tracts of certain animals.

A familiar genus of euglenoids is *Euglena,* shown in Figure 27-10. *Euglena* is abundant in fresh water, especially water polluted by excess nutrients. This protist has an elastic, transparent pellicle made of protein just beneath its cell membrane. It also has a contractile vacuole to rid the cell of excess water. Because *Euglena* lacks a cell wall, it is fairly flexible and can change its shape as it swims about. Although usually photosynthetic, if *Euglena* is raised in a dark environment, it will not form chloroplasts and will become heterotrophic.

FIGURE 27-10

Euglena gracilis, shown below, is a familiar type of euglenoid. It is propelled by a long flagellum. An eyespot guides it toward light.



SECTION 27-2 REVIEW

1. Why are green algae considered a diverse group of algae?
2. Which phylum contains the largest multicellular forms of algae? In what way are these algae commercially important?
3. What characteristics enable red algae to exist in deep marine environments?
4. What is a diatom? What useful commercial products do the shells of these algae yield?
5. Which phylum is composed of unicellular organisms that usually have two flagella and a cell wall made of cellulose plates?
6. **CRITICAL THINKING** If a *Euglena* that is raised in the dark loses its chloroplasts, will it grow new ones if it is returned to the light?

SECTION

27-3

OBJECTIVES

- Describe the two forms that characterize the life cycle of the slime mold.
- Describe the environment in which slime molds live.
- Outline the basic life cycles of the two groups of slime molds.
- Point out the unique characteristics of water molds.

FUNGUSLIKE PROTISTS

The kingdom Protista contains a number of funguslike protists in addition to the algae. Among these are the slime molds and water molds. These organisms have unique life cycles that set them apart from the protozoa, algae, and fungi. However, like all of these groups, they are eukaryotic. They are multicellular or large multinucleate heterotrophic organisms with very little tissue specialization.

SLIME MOLDS

Slime molds are a curious group of organisms. They spend part of their lives in a mobile, amoeba-like feeding form, engulfing organic matter and bacteria much as protozoa do. However, they also produce funguslike reproductive structures, which is why they were once classified as fungi. Slime molds are typically found growing on damp soil, rotting logs, decaying leaves, or other decomposing organic matter in moist areas. These organisms appear as glistening, viscous masses of slime: some are white, but most are yellow or red.

Biologists recognize two groups of slime molds—the cellular slime molds (phylum Acrasiomycota) and the plasmodial slime molds (phylum Myxomycota). These groups are not closely related, but they share certain characteristics. For example, both types have life cycles with two phases: a mobile feeding stage and a stationary reproductive stage. During reproduction, slime molds produce a spore-bearing structure called a **fruiting body.**

Phylum Acrasiomycota

The phylum Acrasiomycota (ah-KRAYZH-ee-oh-mie-KOH-tuh) comprises about 65 species of cellular slime molds. **Cellular slime molds** live as individual haploid cells that move about like amoebas. Each cell moves as an independent organism, creeping over rotting logs and soil or swimming in fresh water, ingesting bacteria and other food.

When food or water becomes scarce, the cells release a chemical that attracts nearby cells and causes them to gather by the hundreds or thousands to form a dense structure called a pseudoplasmodium, as shown in Figure 27-11. A **pseudoplasmodium** is a coordinated colony of individual cells that resembles a slug, and it leaves a slimy trail as it crawls over decaying logs, leaves, and twigs. During this stage, the cells move as one unit, even though each cell retains its cell membrane and identity. Eventually, the

FIGURE 27-11

The well-known cellular slime mold *Dictyostelium discoideum* can be easily grown in the laboratory. Approximately 65 other species of cellular slime molds are known to exist. (80×)

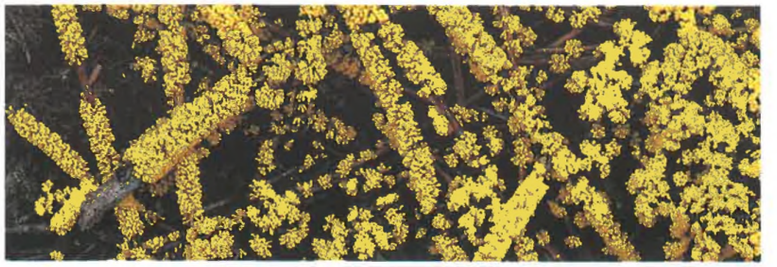


FIGURE 27-12
The plasmodial slime mold *Physarum* has a bright yellow plasmodium. This naked mass of cytoplasm feeds on bacteria and other microorganisms. The reproductive structures are stalked fruiting bodies.

pseudoplasmodium settles and forms a fruiting body in which haploid spores develop. When the fruiting body breaks open, the wind disperses the spores to new locations. Each spore may grow into an individual amoeboid cell, thus completing the life cycle.

Phylum Myxomycota

Approximately 450 species of **plasmodial slime molds** compose the phylum Myxomycota (MIKS-oh-mie-KOH-tuh). During the feeding stage of its life cycle, a plasmodial slime mold is a mass of cytoplasm called a **plasmodium,** and it may be as large as several square meters. Each plasmodium is **multinucleate,** meaning it contains thousands of nuclei. As the plasmodium moves along the forest floor, it engulfs decaying leaves and other debris by the process of phagocytosis.

When food or water is scarce, the plasmodium crawls to an exposed surface and begins to reproduce, as shown in Figure 27-12. It forms stalked fruiting bodies in which haploid spores form by meiosis. The spores are very resistant to adverse conditions. Under favorable conditions, they crack open and give rise to haploid reproductive cells. Two such cells fuse, and their nuclei combine to form a diploid nucleus. Repeated divisions by mitosis follow, but the cells do not undergo cytokinesis, so the result is the multinucleated cytoplasm characteristic of the plasmodium.

Quick Lab

Observing Slime Mold

Materials slime mold culture, oatmeal, vinegar, cotton swab, dissecting microscope

Procedure

1. Observe the movement of the slime mold. Identify the plasmodium, the nuclei, and the food vacuoles. Draw and label the structures you have observed.
2. Drop a small bit of oatmeal near an outside edge of the slime mold.
3. Dip the swab in vinegar and touch it to the slime mold.

Analysis How does a slime mold move? How does it react to oatmeal? To vinegar?

WATER MOLDS

A **water mold** is a funguslike organism composed of branching filaments of cells. Most water molds are aquatic and are commonly found in bodies of fresh water. However, some live in the soil, and some are parasites. For example, water molds are familiar as the white fuzz on diseased aquarium fish or on organic matter floating on water.

Phylum Oomycota

The phylum Oomycota includes a number of organisms that are pathogenic to plants. For example, the water mold *Phytophthora infestans* causes late blight in potatoes and was responsible for the Irish potato famine in the mid-1800s. **Blight** is a disease of plants characterized by quickly developing decay and discoloring of leaves, stems, and flowers. Late blight is demonstrated in Figure 27-13.

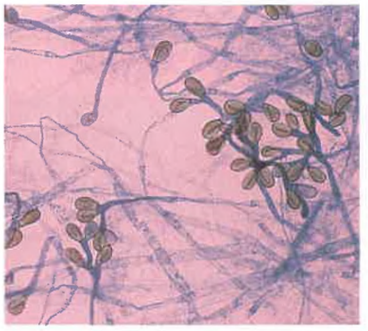
FIGURE 27-13
Potato blight is caused by the water mold *Phytophthora infestans.* Between 1845 and 1849, the late blight of potatoes devastated farms in Ireland, forcing the mass emigration of Irish people to countries such as Australia and the United States.

FIGURE 27-14

Downy mildew on grapes is caused by *Plasmopara viticola,* which grows on the leaves and fruit of grapes. This protist can cause significant economic harm if it is not carefully controlled.

FIGURE 27-15

Chytrids, such as this *Allomyces,* are considered by many scientists to be more like fungi than like protists, but the presence of motile cells has caused them to be classified as protists. Although most are aquatic, some live in moist soil. (70×)



Another example of a plant pathogenic oomycete is *Plasmopara viticola.* This organism infects grape plants, attacking the leaves and the fruit. *Plasmopara* infection causes the grape leaves to wilt and die. Young grape plants are also attacked and may also wilt and die from *Plasmopara* infection. *Plasmopara* may also infect vegetables and other fruits. Figure 27-14 shows a grape plant infected with *Plasmopara viticola.*

Water molds reproduce asexually and sexually. During asexual reproduction, they produce motile, flagellated reproductive zoospores. Zoospores germinate into threadlike cells, which accumulate to form a matlike mass. Some zoospores form a reproductive structure called a sporangium, in which new zoospores are produced.

During sexual reproduction, the cells of the water mold develop egg-containing and sperm-containing structures. Fertilization tubes grow between the two types of structures, enabling haploid sperm cells to fertilize haploid egg cells and form diploid zygotes. A zygote develops into a new mass of filaments, from which asexual sporangia as well as sexual oogonia and antheridia form.

Phylum Chytridiomycota

Biologists place approximately 750 protist species in the phylum Chytridiomycota (kie-TRID-ee-oh-mie-KOH-tuh). The **chytrids** (KIE-tridz) are primarily aquatic protists characterized by gametes and zoospores with a single, posterior flagellum. Most chytrids are unicellular. Some chytrids have long filamentous bodies that anchor the organism. Many chytrids are parasites on algae, plants, and insects, while others are saprophytes.

Until recently, biologists classified this phylum with the protists, but many biologists now think that chytrids should be classified as fungi. Chytrids and fungi have similar characteristics; they have similar methods for absorbing nutrients through the cell wall, cell walls that are made of the same type of material, and long filamentous bodies. Fungi also share similar types of enzymes and biochemical pathways with chytrids. Because of all of these similarities, biologists think that chytrids are a link between protists and fungi. An example of a chytrid is shown in Figure 27-15.

SECTION 27-3 REVIEW

1. What two phases are found in the life cycle of slime molds?
2. In which phyla are the slime molds classified?
3. What are the distinctive features of the pseudoplasmodium, and which organisms form this structure?
4. When do the plasmodial slime molds form their fruiting body?
5. What are the characteristic features of water molds?
6. **CRITICAL THINKING** What evolutionary advantage do pseudoplasmodia gain by producing fruiting bodies?

CHAPTER 27 REVIEW

SUMMARY/VOCABULARY

27-1

- The kingdom Protista includes algae, which are mostly aquatic organisms that contain chlorophyll. Algae include microscopic single cells and giant marine kelps.
- Algae produce large amounts of organic matter, which serves as nutrients for other organisms. Algae also add an enormous amount of oxygen to the atmosphere.
- The body portion of an alga is the thallus. It may consist of a single cell, a colony of cells, a filament, or a complex multicellular arrangement.
- Algae can be classified into seven phyla, based on color, type of chlorophyll, and form of food-storage substances.
- Algae reproduce asexually by mitosis and sexually by more-complex methods.
- In the leaflike alga *Ulva,* an alternation of generations takes place, with a gametophyte and sporophyte phase.

Vocabulary

algae (525)
alternation of generations (529)
antheridium (528)
colonial alga (526)
filamentous alga (526)
gametangium (525)
gametophyte (529)
holdfast (529)
multicellular alga (526)
oogonium (528)
phytoplankton (525)
pyrenoid (525)
sporangium (529)
sporophyte (529)
thallus (525)
unicellular alga (525)
zoospore (527)
zygospore (527)

27-2

- The phylum Chlorophyta consists of green algae. Green algae contain chlorophylls *a* and *b,* carotenoids, and cell walls made of cellulose.
- The phylum Phaeophyta is made up of brown algae. Brown algae contain chlorophylls *a* and *c* and carotenoids including fucoxanthin.
- The phylum Rhodophyta consists of red algae. Red algae contain chlorophyll *a* and phycobilins.
- The phylum Bacillariophyta is made up of diatoms. These unicellular algae have shells that contain silicon dioxide.
- The phylum Dinoflagellata includes the dinoflagellates. Dinoflagellates contain chlorophylls *a* and *c* and carotenoids. Most species have two flagella.
- The phylum Chrysophyta consists of the golden algae. Golden algae contain chlorophylls *a* and *c* and large amounts of carotenoids.
- The phylum Euglenophyta is made up of euglenoids, such as *Euglena.* Euglenoids show both plantlike and animal-like characteristics.

Vocabulary

agar (531)
alginate (531)
bioluminescence (532)
blade (531)
carageenan (531)
centric diatom (532)
diatom (532)
diatomaceous earth (532)
euglenoid (533)
fucoxanthin (531)
laminarin (531)
pennate diatom (532)
phycobilin (531)
red tide (532)
stipe (531)
valve (532)

27-3

- Slime molds are eukaryotes. Their life cycles include a creeping amoeba-like form and a reproductive spore-bearing form.
- Slime molds are classified into phylum Acrasiomycota and phylum Myxomycota.
- The phylum Oomycota contains funguslike organisms called water molds. Water molds are composed of branching filaments.

Vocabulary

blight (535)
cellular slime mold (534)
chytrid (536)
fruiting body (534)
multinucleate (535)
plasmodial slime mold (535)
plasmodium (535)
pseudoplasmodium (534)
water mold (535)

REVIEW

Vocabulary

In the following groups of terms, choose the term that does not belong, and explain why it does not belong.

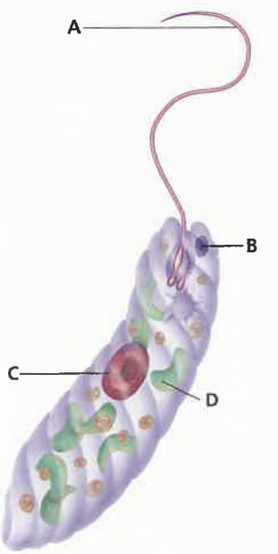
1. gametophyte, sporophyte, fruiting body
2. chlorophyll *a,* carotenoids, phytoplankton
3. plasmodium, blade, holdfast
4. water mold, cellular slime mold, kelp
5. diatomaceous earth, red tide, bioluminescence

Multiple Choice

6. The green alga *Chlamydomonas* reproduces asexually by forming (a) a zygote (b) a gametophyte (c) zoospores (d) an opposite mating type.
7. The green alga *Ulva* forms a sporophyte that has structures called (a) sporangia (b) antheridia (c) gametangia (d) carageenan.
8. The green alga *Oedogonium* produces a unicellular female gametangium called (a) an antheridium (b) a zygospore (c) a conjugation tube (d) an oogonium.
9. Red algae contain an accessory pigment called (a) phycobilin (b) fucoxanthin (c) carotene (d) xanthophyll.
10. The phenomenon know as red tide is caused by a population explosion of (a) diatoms (b) red algae (c) water molds (d) dinoflagellates.
11. Many types of algae have flagellated reproductive cells called (a) sporangia (b) zoospores (c) zygospores (d) sporophytes.
12. A pyrenoid is an organelle that (a) lends golden algae their yellow color (b) anchors seaweeds to the ocean floor (c) makes and stores starch (d) enables some types of algae to produce light.
13. Biologists believe that the most likely ancestors of land plants are members of the phylum (a) Chrysophyta (b) Euglenophyta (c) Phaeophyta (d) Chlorophyta.
14. The feeding stage of a plasmodial slime mold is called (a) an amoeba (b) a fruiting body (c) a plasmodium (d) a zygospore.
15. In addition to protozoa and algae, the kingdom Protista contains organisms called (a) euglenoids (b) slime molds (c) dinoflagellates (d) diatoms.

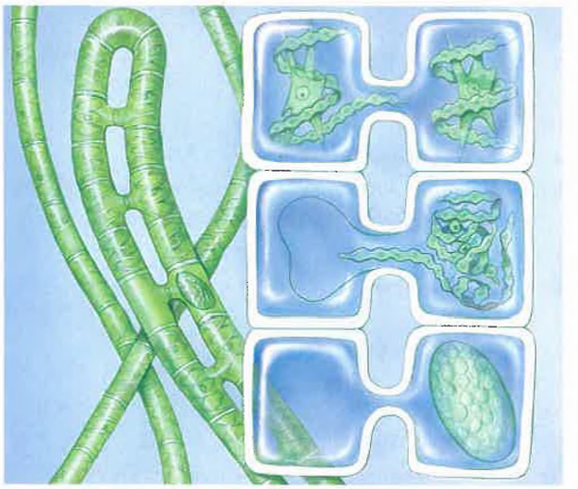
Short Answer

16. How are algae similar to protozoa? How are they different? What characteristics do algae share with plants? What characteristics differ?
17. List the characteristics used to classify algae into seven phyla.
18. Compare the types of food-storage molecules found in the seven types of algae. What is the most common food-storage molecule used by algae?
19. List the types of pigments found in the seven phyla of algae. What is the most common photosynthetic pigment found in algae?
20. What is a thallus? What kinds of thallus formats are found in algae?
21. Summarize three types of sexual reproduction that occur in algae. Does sexual reproduction in algal protists occur in only multicellular algae?
22. Why are euglenoids described as both plant-like and animal-like organisms? Explain how euglenoids can be both heterotrophic and autotrophic.
23. What is a fruiting body? At what point of their life cycle do slime molds form fruiting bodies?
24. Define the term *multinucleate.* What kind of protists are characterized by this form of cell structure?
25. Identify the structures in the figure below. What is the name of this organism?



CRITICAL THINKING

1. Several years ago, many botanists classified algae as plants. They also classified flagellated *Euglena* as photosynthetic protozoa. Algae are now classified as protists, and *Euglena* is now considered an alga. What do these changes tell you about the classification systems of living things?
2. In the Pacific Northwest of the United States, people believe it is unsafe to collect and eat shellfish during the months that lack an *r* in their name. Name these months, and give a possible scientific explanation for the belief. Keep in mind that shellfish obtain their food by filtering water.
3. The horsetail plant, *Equisetum,* has silicon dioxide in the outer cells of its stem. Diatoms also contain silicon dioxide in their shells. Explain whether the presence of this compound in both organisms indicates a close relationship. (Hint: Consider the types of evolution described in Chapter 15.)
4. Scientists often use a pigment called phycoerythrin to label parts of cells so that they can be seen with a special type of microscope that uses ultraviolet light. Phycoerythrin fluoresces under ultraviolet light. Because ultraviolet light is a higher frequency of light, it can penetrate deeper into water than can visible light. Based on this information and what you read in this chapter, which phylum of algae do you think produces phycoerythrin? Justify your answer.
5. Explain how the absence of a cell wall in *Euglena* makes the function of the contractile vacuole critical.
6. Examine the drawing of lateral conjugation in *Spirogyra* in which adjacent cells of the same filament have conjugated. Explain whether this type of conjugation offers more or less genetic recombination than does sclariform conjugation, in which conjugation is between the cells of two different filaments.



EXTENSION

1. Read "The Lurking Perils of *Pfiesteria*" in *Scientific American,* August 1999, on page 42. Prepare a report that discusses the role *Pfiesteria piscicida* has in fish kills in several major estuaries. Include in your report a description of the toxic and nontoxic forms *Pfiesteria* can assume. Describe the toxin's indirect effects on the survival of fish. Explain how *Pfiesteria* can be dangerous to people.
2. Visit your local grocery store or supermarket, and find at least three items that contain carageenan, a polysaccharide derived from red algae.
3. Gather samples of soil, dead leaves, old grass, and fresh leaves. Place each sample in a jar or test tube filled with clean water, and leave the samples near a light source. Examine the samples under a microscope once a week, and make drawings of the types of organisms you find. What do your observations reveal about the different habitats of algae?

CHAPTER 27 INVESTIGATION

Classifying Green Algae

OBJECTIVES

- Observe live specimens of green algae.
- Compare unicellular, colonial, thalloid, and filamentous green algae.
- Classify genera of colonial green algae.

PROCESS SKILLS

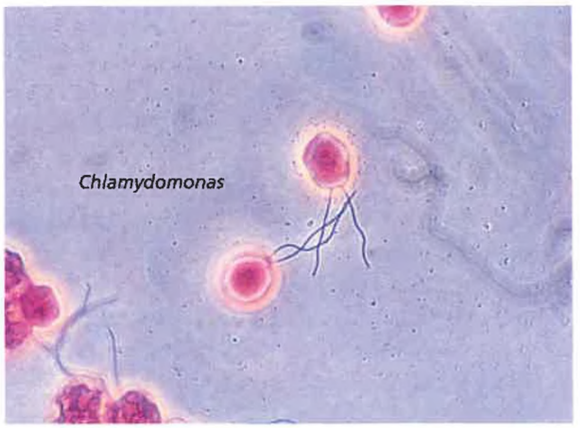
- observing
- comparing and contrasting
- classifying
- inferring

MATERIALS

- culture of *Chlamydomonas*
- colonial green algae culture *(Chlamydomonas, Eudorina, Gonium, Pandorina, Volvox,* and *Hydrodictyon)*
- culture of *Spirogyra*
- 3 depression slides
- 3 coverslips
- 3 medicine droppers
- compound light microscope

Background

1. Distinguish between the terms *protozoa* and *algae.*
2. Green algae are either unicellular, colonial, filamentous, or thalloid.
3. Explain why green plants are thought to have evolved from green algae.



4. List characteristics of green algae. Include ways that algae differ from plants.
5. How do green algae differ from other algae?

PART A Observing Unicellular Green Algae

1. Make a table similar to the one below in your lab report. Allow substantial space in your data table for labeled sketches of the different kinds of green algae you will view in this investigation. Use your data table to record your observations of each kind of green algae that you view.
2. CAUTION **Slides break easily. Use caution when handling them.** Prepare a wet mount of the *Chlamydomonas* culture by placing a drop of the culture on a microscope slide with a medicine dropper and placing a coverslip on top of the specimen.

OBSERVATIONS OF GREEN ALGAE

Genus	Sketch of organism	Type of green algae (unicellular, colonial, filamentous, or thalloid)

3. Examine the slide of *Chlamydomonas,* first under low power and then under high power.
4. In your lab report, make a sketch of *Chlamydomonas.* Label the cell wall, flagella, nucleus, and chloroplasts, if they are visible.

Volvox

PART B Observing and Identifying Colonial Green Algae

5. CAUTION **Slides break easily. Use caution when handling them.** Prepare a wet mount of the colonial green algae culture, using a clean medicine dropper, a clean microscope slide, and a clean coverslip.
6. Examine the slide of mixed colonial green algae under low power, switching to the high-power setting as needed for clarity. Your slide should resemble the photograph of *Volvox* above. How many different kinds of colonial green algae can you find?
7. In your data table, draw each type of colonial green algae you observe. How are these algae different in appearance from *Chlamydomonas*?
8. Use the dichotomous key, above right, to identify each type of colonial green algae. Choose an alga, and start at 1. Decide which choice describes the alga. If the alga is not identified, go to the next number and make the next decision. Continue until you identify the alga. Then label your drawing of the alga according to the identification you made.

PART C Observing Filamentous Green Algae

9. CAUTION **Slides break easily. Use caution when handling them.** Prepare a wet mount of the *Spirogyra* culture, using a clean medicine dropper, a clean microscope slide, and a clean coverslip.

DICHOTOMOUS KEY FOR COLONIAL GREEN ALGAE

1a	single cells	***Chlamydomonas***
1b	colony of cells	go to 2
2a	colony flattened or netlike	go to 3
2b	colony round	go to 4
3a	netlike colony	***Hydrodictyon***
3b	flattened colony	***Gonium***
4a	more than 100 cells in colony	***Volvox***
4b	fewer than 100 cells in colony	go to 5
5a	cells close together	***Pandorina***
5b	cells apart from each other	***Eudorina***

10. Examine *Spirogyra* under low power. Switch to the high-power setting if you need more magnification to see the specimen clearly. How does *Spirogyra* differ in appearance from the other kinds of algae you have observed in this investigation?
11. In your data table, make a sketch of *Spirogyra.* Label the filaments and the individual cells in your drawing. Also label the spiral-shaped chloroplasts if they are visible.
12. Clean up your lab materials and wash your hands before leaving the lab.

Analysis and Conclusions

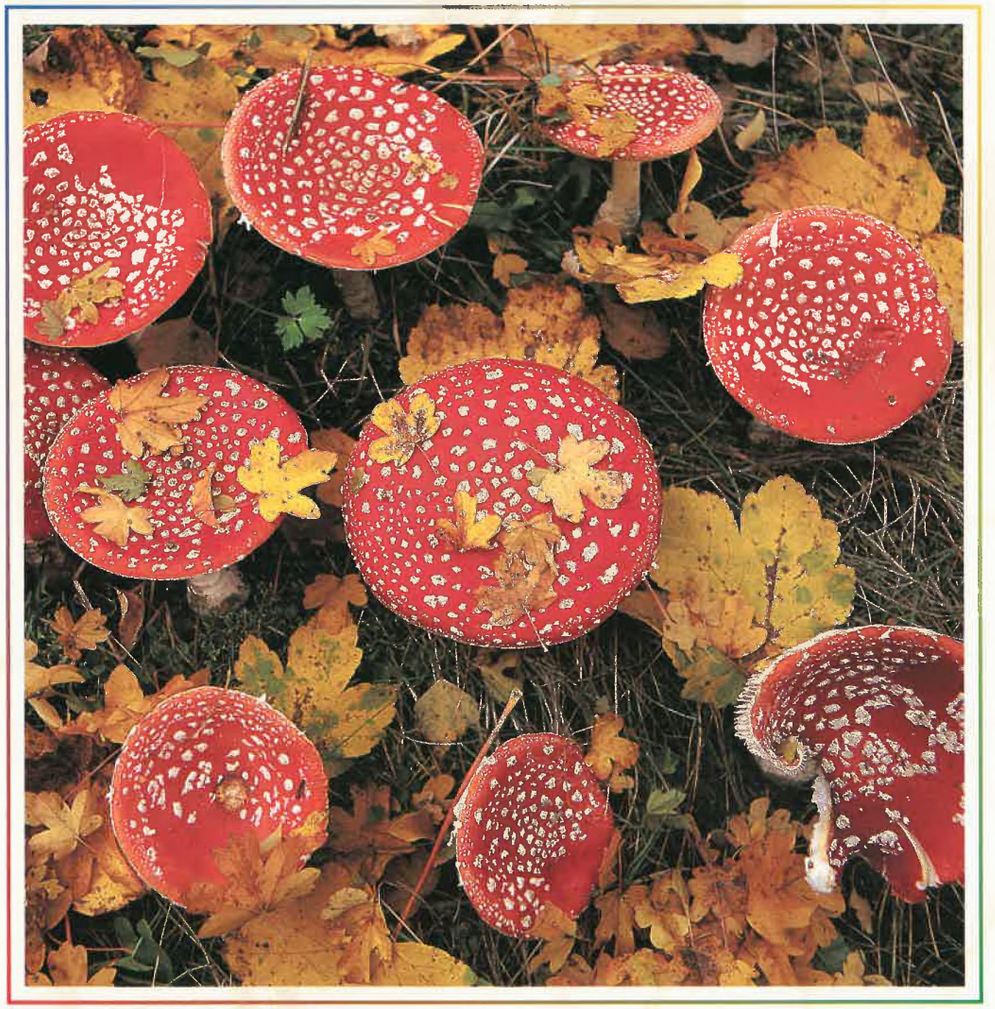
1. What characteristics did all of the algae you viewed have in common?
2. Describe examples of specialization in the different kinds of algae you viewed. In which types of algae do some cells depend on others?
3. What differences did you observe between small and large colonies of algae?
4. Which specializations in algae are characteristic of green plants?

Further Inquiry

How might you search for evidence of evolutionary relationships among algae and between algae and green plants?

CHAPTER 28

FUNGI



Fungi, such as these mushrooms, are important decomposers in nature.

FOCUS CONCEPT: ***Cell Structure and Function***

As you read, note how the distinctive traits of fungi, such as their structure and physiology, enable them to affect their environment and thus human health.

SECTION 28-1

OVERVIEW OF FUNGI

In the six-kingdom classification of organisms, fungi are in their own kingdom. They differ from other organisms in several ways, including in structure, in method of reproduction, and in methods of obtaining nutrients.

OBJECTIVES

- Describe the origin and evolution of fungi.
- Compare fungi with other eukaryotic organisms.
- Describe how fungi obtain nutrients.
- Distinguish between a hypha and a mycelium.

CHARACTERISTICS

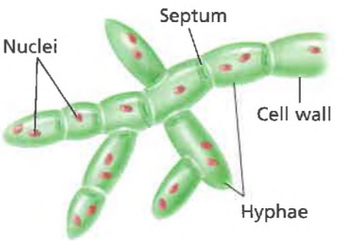
Fungi are eukaryotic, nonphotosynthetic organisms, and most are multicellular heterotrophs. Most fungi are microscopic molds or yeasts. **Molds,** such as the fungus that grows on bread and oranges, are tangled masses of filaments of cells. **Yeasts** are unicellular organisms whose colonies resemble those of bacteria. Yeasts are best known as the microorganisms that make bread rise.

Filaments of fungi are called **hyphae** (HIE-fee). The cell walls of hyphae contain **chitin** (KIE-tin), a complex polysaccharide not found in bacteria, protists, or other microorganisms but found in insects. The presence of chitin distinguishes cell walls of fungi from those of plants, which have cellulose but no chitin. Fungi range in size from the microscopic yeast to the largest organism in the world—the fungus *Armillaria,* which lives underground and occupies a space of up to eight hectares (861,000 ft^2). The study of fungi is called **mycology** (mie-KAHL-uh-jee).

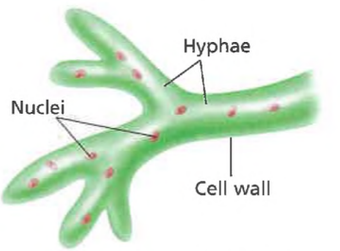
While animals and many microorganisms ingest their nutrients before digesting them, fungi secrete enzymes and then absorb the digested nutrients through their cell wall. Like animals, fungi store energy in the form of glycogen. Most fungi are saprophytic, that is, they live on organic compounds that they absorb from dead organisms in the environment. This characteristic makes fungi a very important recycler of organic material in nature.

Structure of Fungi

A mat of hyphae visible to the unaided eye is a **mycelium** (mie-SEE-lee-uhm). The hyphae of fungi that commonly grow on old bread and fruit form mycelia. In some species, the cells that make up hyphae are divided by cross sections called **septa** (SEP-tuh). Hyphae whose cells are divided by septa are called septate hyphae. The hyphae of species that do not have septa are called **coenocytic** (SEE-noh-SIT-ik). The general structures of septate and nonseptate hyphae are shown in Figure 28-1. Hyphae increase in length by cellular growth and division at the tip. As the hyphae grow, the size of the mycelium increases. When hyphae encounter organic matter, such



(a) SEPTATE HYPHAE



(b) COENOCYTIC HYPHAE

FIGURE 28-1
The hyphae of some fungi have separating walls called septa (a). The hyphae of other fungi do not have septa and are called coenocytic (b).

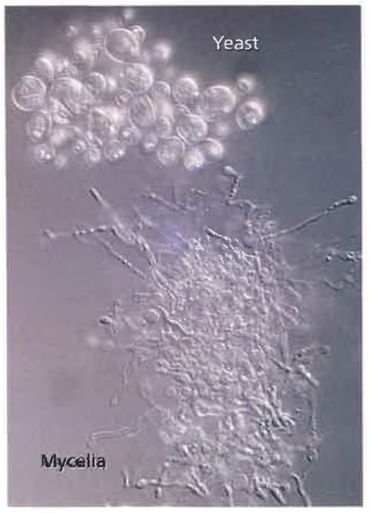


FIGURE 28-2

This light micrograph shows the dimorphic fungus *Paracoccidioides brasiliensis* as it changes from its unicellular yeast form to a mycelial form. Note how the hyphae grow out from the yeast.

as a tree trunk or dead animal, they secrete digestive enzymes and then absorb the digested nutrients.

Several species of fungi are able to change their form in response to changes in their environment. For example, *Histoplasma capsulatum,* which causes a severe disease in humans that can resemble tuberculosis, normally grows as a mycelium on the ground. However, when it invades a human, the increased temperature and available nutrients cause the fungus to grow unicellularly as a yeast. This ability to change, demonstrated in Figure 28-2, is called **dimorphism** (die-MOR-FIZ-uhm).

Asexual Reproduction

Most fungi reproduce both sexually and asexually. Asexually, fungi produce thousands of genetically identical haploid spores, usually on modified cells of the hyphae. When these spores are placed in favorable environmental conditions, they germinate and grow new hyphae, which will form a mycelium and can produce thousands of new asexual spores.

A variety of asexual spores are formed by different fungi. For example, **sporangiophores** (spoh-RAN-jee-oh-FOHRZ) are specialized hyphae that look like upright stalks. On top of a sporangiophore is an enclosing sac called a **sporangium** (spoh-RAN-jee-UHM). Inside each sporangium, spores called **sporangiospores** (spoh-RAN-jee-oh-SPOHRZ) are made. *Rhizopus,* the black mycelial fungus that is commonly found growing on bread, is an example of a sporangiospore-forming fungus.

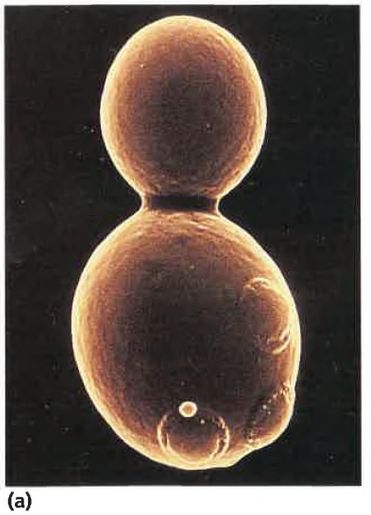
Other fungi form spores called **conidia** (koh-NID-ee-uh), which are formed without the protection of an enclosing sac. Conidia are formed on top of a stalklike structure called a **conidiophore** (koh-NID-ee-uh-FOHR). *Penicillium,* which produces penicillin and cheese, is a fungus that reproduces asexually by means of conidia.

Asexual reproduction may also occur by **fragmentation.** In this process, a septate hypha dries and shatters, releasing individual cells that act as spores. The fungus that causes athlete's foot reproduces this way.

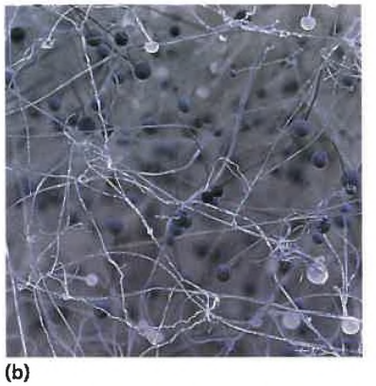
Yeast reproduce by a process called budding. **Budding** is an asexual process in which part of a yeast cell pinches itself off to produce a small offspring cell. Budding may be repeated many times. Three types of asexual reproduction are shown in Figure 28-3.

FIGURE 28-3

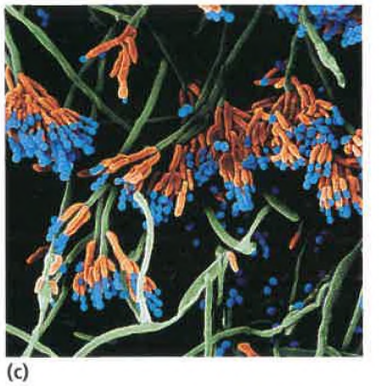
Fungi reproduce asexually in many different ways. Yeasts (a) pinch off a piece of their cell to produce new cells. The common bread mold *Rhizopus stolonifer* (b) produces a hyphal stalk to disperse its spores. *Penicillium* produces unprotected conidia (c).



(a)



(b)



(c)

TABLE 28-1 *The Three Phyla of Fungi*

Phylum and number of species	Structure	Asexual reproduction	Sexual reproduction (where identified)	Examples
Zygomycota 600 species	coenocytic hyphae	spores from sporangia	conjugation results in zygospores	*Mucor, Rhizopus, Penicillium* species
Basidiomycota 25,000 species	septate hyphae	rare	basidia produce basidiospores	*Puccinia, Ustilago* (mushrooms)
Ascomycota 60,000 species	septate or unicellular hyphae	conidia, budding	asci produce ascospores	bread yeast, morel

Sexual Reproduction

Many but not all species of fungi are also able to reproduce sexually. Fungi are neither male nor female. They occur in mating types that are sometimes called "minus" and "plus." When two different mating types of the same species encounter one another, the hyphae of one mating type fuse with the hyphae of the opposite mating type. These fused hyphae give rise to a specialized structure, which produces and scatters genetically diverse spores. Unlike most eukaryotes, most fungi are haploid throughout most of their life cycle.

The ability of some fungi to reproduce both sexually and asexually provides an adaptive advantage. When the environment is favorable, rapid asexual reproduction ensures an increased spread of the species. During environmental stress, sexual reproduction ensures genetic recombination, increasing the likelihood that offspring will be better adapted to the new environmental conditions.

Evolution

The first fungi were probably unicellular organisms that might have clung together after mitosis to form a long filament of cells. Biologists think fungi colonized dry land at about the same time that early plants did. They reason that fungi, like other eukaryotes, arose from prokaryotes, possibly by endosymbiosis. According to the fossil record, all modern phyla of fungi had evolved by about 300 million years ago. These phyla are listed in Table 28-1.

Eco Connection

Fungi in the Food Chain

The well-known northern spotted owl depends indirectly on a forest fungus for its survival. The owls prey on northern flying squirrels, and the squirrels depend on truffles for the bulk of their diet. Truffles are the sexual reproductive structure of some fungal species.

SECTION 28-1 REVIEW

1. How do fungi obtain nutrients?
2. Why does a fungus that reproduces both sexually and asexually have an evolutionary advantage over an organism that reproduces only asexually?
3. Describe dimorphism.
4. What characteristic makes fungi an important resource recycler?
5. Compare how fungi obtain nutrients with how protists obtain nutrients.
6. **CRITICAL THINKING** Based on fossil evidence, scientists think that fungi adapted to land dwelling at about the same time plants did. Explain why fungi might have adapted to land dwelling before plants did.

SECTION

28-2

OBJECTIVES

- List the characteristics that distinguish the three phyla of fungi.
- Identify the common sexual reproductive traits of the three phyla of fungi.
- Define *mycorrhiza* and *lichens*, and distinguish between them.
- Explain the importance of mycorrhizae and lichens to the environment.

CLASSIFICATION

The approximately 100,000 species of fungi are classified in three phyla. Traditionally, fungi have been classified according to their structure and form of sexual reproduction. While these are no longer the sole bases of classification, these characteristics are still useful in identifying fungi.

PHYLUM ZYGOMYCOTA

Most species in the phylum Zygomycota (ZIE-goh-MIE-koh-tuh) are terrestrial organisms found primarily in soil that is rich in organic matter. The hyphae of zygomycetes are coenocytic.

Rhizopus stolonifer, the common bread fungus, which is illustrated in Figure 28-4, is in phylum Zygomycota. The hyphae that anchor the mold to the surface of the bread and that penetrate the bread's surface are called **rhizoids** (RIE-zoydz). Digestive enzymes produced by rhizoids break down organic compounds to release nutrients in the bread. Other hyphae, called **stolons** (STOH-lahnz), grow across the surface of the bread.

Sexual reproduction in zygomycetes is called conjugation. Conjugation in fungi occurs when two compatible mating types meet and hyphae from each mating type line up next to each other. Short branches form on the hyphae of both strains and grow outward until they touch each other. A septum forms near the tip of each branch, and a cell called a gametangium develops. A **gametangium** (GAM-ee-TAN-jee-uhm) is a sexual reproductive structure that contains a nucleus of a mating type. The nucleus within each parent's gametangium divides several times. When the gametangia

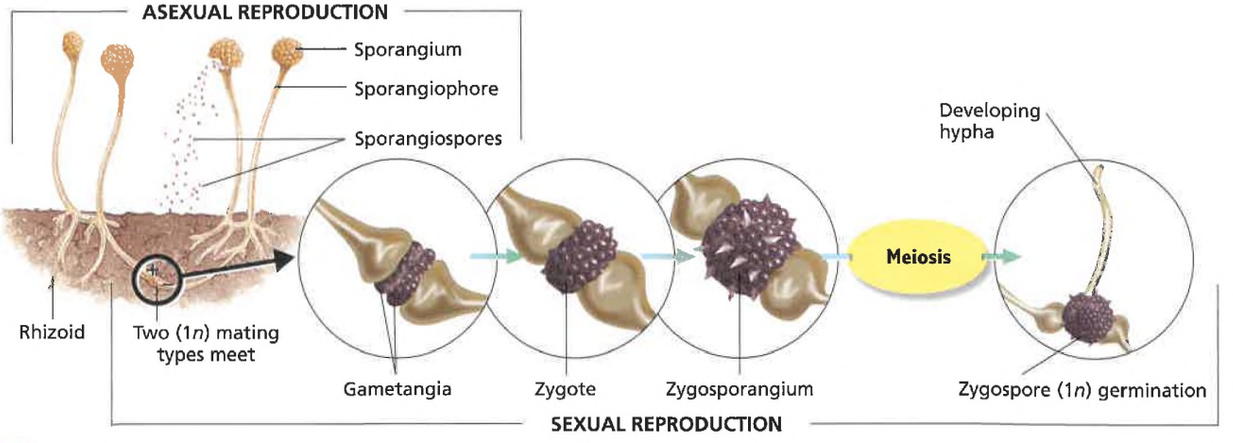


FIGURE 28-4

Zygomycetes can reproduce both sexually and asexually. Sexually, when two compatible mating types meet, they produce specialized cells called gametangia. After the gametangia fuse, the nuclei from both types fuse and eventually produce genetically diverse zygospores.

fuse, the nuclei mix and fuse in pairs, each pair containing a nucleus from each mating type. The fused gametangia, called a **zygosporangium** (ZIE-goh-spohr-AN-jee-uhm), forms a thick wall and becomes dormant. Germination depends on environmental conditions. A sporangiophore grows from the diploid zygosporangium and produces a sporangium, which ruptures and releases haploid spores.

Word Roots and Origins

rhizoid

from the Greek *rhiza,* meaning "root"

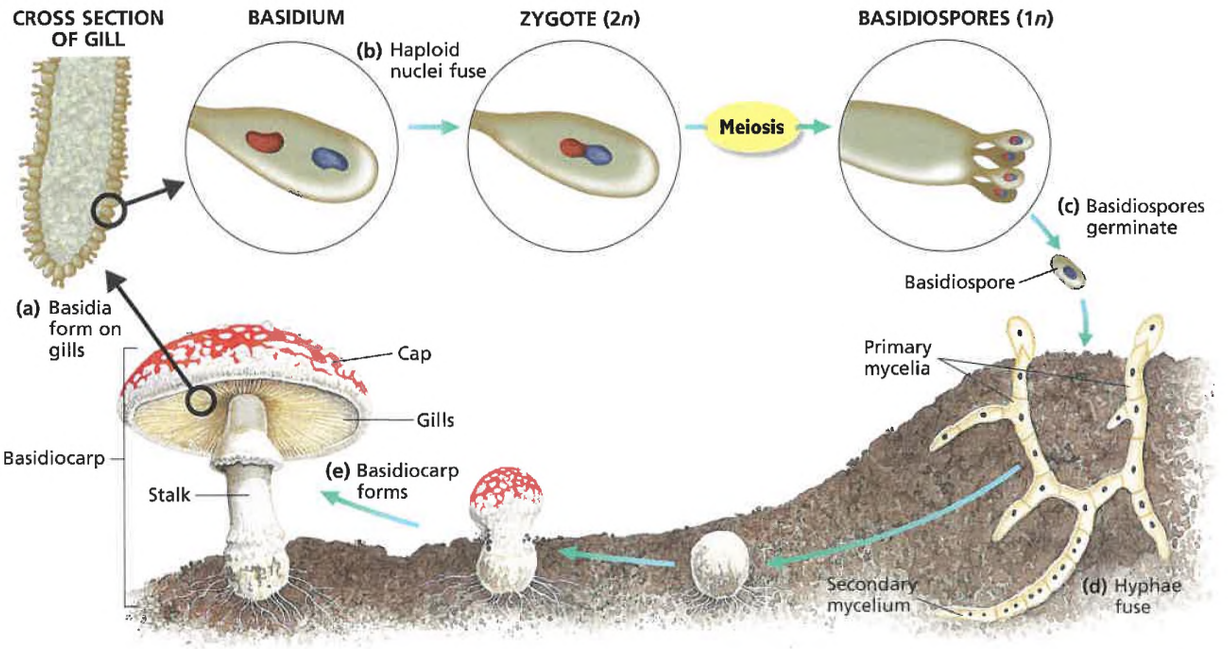
PHYLUM BASIDIOMYCOTA

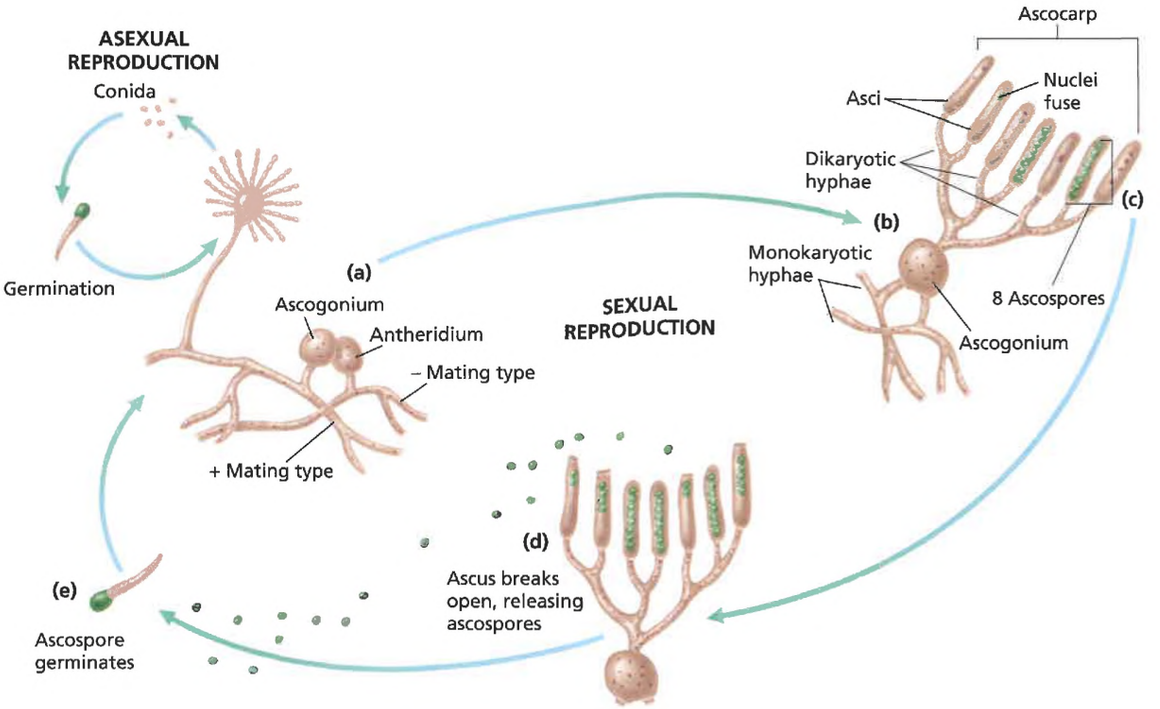
Basidiomycetes (bah-SID-ee-oh-MIE-seets) are often called club fungi because they produce small clublike reproductive structures called **basidia** (bah-SID-ee-uh) during sexual reproduction. Sexual reproduction in basidiomycetes is outlined in Figure 28-5.

The spore-bearing structure of basidiomycetes is an aboveground structure called the **basidiocarp** (bah-SID-ee-oh-KARP). Mushrooms are basidiocarps. The basidiocarp consists of a stem called a stalk and a flattened structure known as a cap. On the underside of the cap are rows of gills that radiate out from the center. Each gill is lined with thousands of dikaryotic basidia. Cells containing two nuclei are called **dikaryotic** (die-KAR-ee-OH-tik). In each basidium, two nuclei fuse to form a zygote ($2n$). The zygote undergoes meiosis to form four haploid nuclei. These develop into four **basidiospores** (bah-SID-ee-oh-SPOHRZ), which are then released into the air. Under favorable environmental conditions, basidiospores germinate to produce haploid mycelia that grow underground. When compatible mating types encounter one another, their hyphae fuse and form a basidiocarp, which emerges aboveground.

FIGURE 28-5

On the gills of the basidiocarp, thousands of dikaryotic basidia form (a). The haploid nuclei inside each basidium fuse to form a diploid nucleus (b). The diploid nucleus undergoes meiosis, producing basidiospores. The basidiocarp releases the basidiospores (c), which fall to the ground and germinate. Underground, the hyphae of compatible mating types fuse and form a mycelium (d). Secondary mycelia intertwine and grow to form a basidiocarp (e).





Compatible mating types form special structures (a) that fuse to form an ascogonium (b). From the ascogonium, dikaryotic hyphae grow and intertwine with monokaryotic hyphae to form an ascocarp. The tips of the dikaryotic hyphae form asci inside, and ascospores form (c). When the ascus ruptures (d), it releases the ascospores, which then germinate (e) to form new monokaryotic hyphae.

FIGURE 28-7

The ascocarp of this ascomycete, *Sarcoscypha coccinea,* is the sexual reproductive structure from which ascospores are released.

PHYLUM ASCOMYCOTA

Ascomycetes (ASK-oh-MIE-seets) are distinguished by the presence of saclike compartments where sexually produced spores form. Ascomycetes, also called sac fungi, live parasitically and in various habitats, including salt water, fresh water, and land.

Sexual reproduction in the ascomycetes begins when the hyphae of two compatible mating types form male and female haploid gametangia. The female gametangium is called an **ascogonium** (AS-koh-GOH-nee-uhm), and the male gametangium is called an **antheridium** (AN-thuhr-ID-ee-uhm), as shown in Figure 28-6. As the ascogonium and antheridium approach one another, a tube forms between them and the nuclei from the antheridium cross the tube and enter the ascogonium. Dikaryotic hyphae grow out of the ascogonium and intertwine with the monokaryotic hyphae of the original fungi (parents) to form a visible cuplike structure called the **ascocarp** (AS-koh-KAHRP). Cells that contain one nucleus are called **monokaryotic** (mah-noh-KAR-ee-OH-tik). An example of an ascocarp is shown in Figure 28-7.

Within the ascocarp, sacs called **asci** (AS-kee) develop at the tips of the dikaryotic hyphae. Within the asci, the haploid nuclei fuse. The zygotes undergo meiosis once and divide again by mitosis to form eight haploid nuclei. The eight nuclei form walls and become **ascospores** (AS-koh-SPOHRZ), which are released. When an ascospore germinates, a new haploid hypha emerges.

The traditional brewer's and baker's yeasts *(Saccharomyces cerevisiae)* are ascomycetes. *S. cerevisiae* makes bread rise and ferments grapes to make wine and grain to make beer.

Deuteromycota

Fungi that do not have a sexual stage are placed in a group called **fungi imperfecti,** or deuteromycota. Recent phylogenetic analyses have led some mycologists to place these fungi in the other three established phyla. Most species of fungi that were formerly classified as fungi imperfecti can now be classified in the phylum Ascomycota. However, some biologists disagree with this reclassification.

MYCORRHIZAE AND LICHENS

A **mycorrhiza** (MIE-koh-RIE-zah) is a symbiotic association between a fungus and plant roots, as shown in Figure 28-8. Over 90 percent of plants contain such fungi on their roots. The fungus absorbs and concentrates phosphate and other ions for delivery to the plant root and provides a secondary root system. In turn, the fungi receive sugars synthesized by the plant during photosynthesis. Many zygomycetes and basidiomycetes form mycorrhizae. These mycorrhizal relationships coevolved with plants.

Lichens (LIE-kenz) represent symbiotic relationships between a fungus and a photosynthetic partner (usually a cyanobacterium or green alga). Most fungi in lichens are ascomycetes. The photosynthesizer synthesizes sugars for the fungus, while the fungus provides moisture, shelter, and anchorage for the photosynthesizer. The fungus produces acids that decompose rocks making minerals available to the lichen. The chemical decomposition of rocks by lichens contributes to the production of soil.

Lichens are identified according to their distribution and structure. **Crustose** lichens grow as a layer on the surface of rocks and trees. **Fruticose** lichens are shrublike, and some grow up to 1.5 m (5 ft) in length. **Foliose** lichens live on flat surfaces, where they form matlike growths with tangled bodies. One example of a lichen is shown in Figure 28-9.

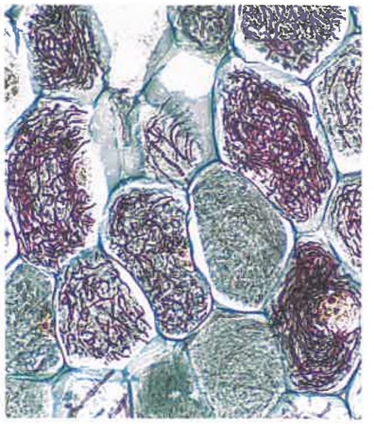


FIGURE 28-8
In this light micrograph, the stained hyphae of the mycorrhizae have infiltrated the plant root cells. (300×)

FIGURE 28-9
Lichens are grouped according to their type of body. For example, this red lichen is a crustose lichen that grows on rocks.

SECTION 28-2 REVIEW

1. Explain why some fungi are called club fungi, and identify their phylum.
2. Compare and contrast the basidiocarp with the ascocarp.
3. Explain why lichens are important to the environment.
4. Describe the Ascomycota life cycle.
5. Explain the benefits plants and fungi derive from a mycorrhizal relationship.
6. **CRITICAL THINKING** Morels are ascomycetes that resemble mushrooms. Even though they resemble Basidiomycota they are classified as Ascomycota. What evolutionary mechanism causes fungi of one phylum to resemble fungi of another phylum?

SECTION

28-3

OBJECTIVES

- Describe three ways that fungi cause disease in humans.
- Describe the types of food that fungi provide.
- Provide examples of fungi's industrial importance.

FUNGI AND HUMANS

Fungi are important to humans. Some fungi cause devastating human and plant diseases, while others serve as important food sources for humans. Fungi are also used to produce chemicals, fuels, and pharmaceutical compounds.

FUNGI AND HUMAN DISEASE

Fungi can sometimes attack the tissues of living plants and animals and cause disease. Fungal disease is a major concern for humans because fungi attack not only us but also our food sources, making fungi competitors with humans for nutrients.

Mold spores can cause mild to serious allergies in some people. Billions of mold spores can become airborne and may then be inhaled, triggering an allergic reaction. Sniffling, sneezing, and respiratory distress are symptoms of an allergic reaction. Fungi can also infect and poison humans. Table 28-2 lists some infectious human fungal diseases.

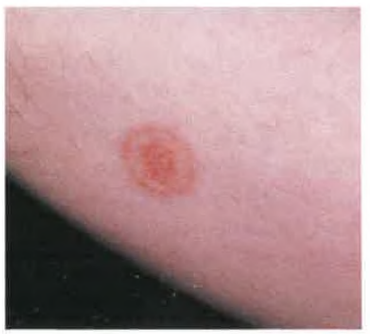
Fungal Skin Infections

Fungi may infect the skin, hair, nails, and tissues of the body. For example, fungi on the skin can cause athlete's foot or ringworm, as shown in Figure 28-10. Ringworm, so named because people once thought they saw living worms in the rings on the skin, can occur almost anywhere on the skin. Athlete's foot occurs on the foot and between the toes.

Another fungal pathogen is *Candida albicans.* This yeast is commonly found in the mouth, intestine, and, in women, in the vaginal tract. It exists in balance with other microorganisms, such as bacteria. However, when conditions change, such as when some antibiotics are used or when pregnancy or illness occurs, then *Candida albicans* can flourish.

FIGURE 28-10

Ringworm is a fungal infection of the skin. The dried skin that falls off a lesion is contaminated with fungal spores. These spores can infect other people and spread the infection.



Other Fungal Illnesses

Serious fungal diseases that involve the internal organs are often caused by dimorphic fungi such as *Histoplasma capsulatum, Paracoccidiodes brasiliensis, Coccidioides immitis,* and *Blastomyces dermatitidis.* If their spores are inhaled, they can cause severe respiratory illness and spread to many other organs, sometimes resulting in death. They grow as a mold on the ground, but when they infect a human, they become unicellular. *H. capsulatum,* which often

TABLE 28-2 *Summary of Human Fungal Diseases*

Disease	Symptoms	Fungus	Route of transmission
Athlete's foot	fluid-filled blisters, scaly skin, itching	*Trichophyton* species (Ascomycete) or *Epidermophyton* species	contact with skin lesions or contaminated floors
Ringworm	ring-shaped skin lesions	*Microsporum, Trichophyton* (Ascomycetes)	contact with skin lesions, contaminated floors, or contaminated objects
Vaginal yeast infection	burning sensation, itching, discharge	*Candida*	contact with fecal material, diabetes; antibiotic treatments increase susceptibility
Tinea cruris (jock itch)	intense itching, ring-shaped lesions	*Microsporum, Trichophyton* (Ascomycetes)	contact with skin lesions, contaminated floors, or contaminated objects
Histoplasmosis	fever, chills, headache, body aches, chest pains, nonproductive cough	*Histoplasma capsulatum* (Ascomycete)	inhalation of airborne conidia

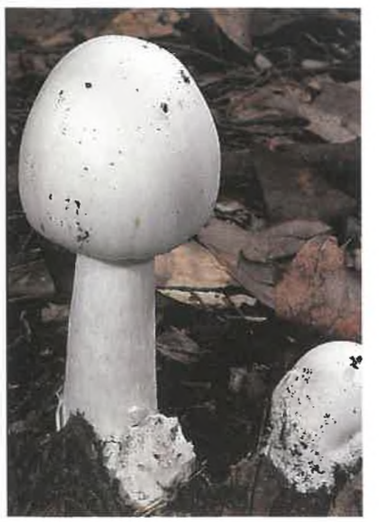
grows as a mold in the feces of birds, can become airborne when dried feces are disturbed and can then be inhaled.

Sometimes humans accidentally eat poisonous mushrooms. For example, *Amanita* species contain extremely dangerous toxins that can destroy a person's liver within one week. Figure 28-11 shows an example of an *Amanita* mushroom. The danger of *Amanita* mushrooms is reflected in their nicknames—"death angel" and "destroying angel."

Other fungal poisons include the **aflatoxins** (AF-luh-TAHKS-ins), poisons produced by some species of *Aspergillus.* Aflatoxins cause liver cancer. Fungi that make aflatoxin may be found as contaminants in peanuts and in grains such as corn and grain sorghum.

FIGURE 28-11

Poisonous mushrooms, such as this *Amanita virosa,* harm people when they are mistaken for edible mushrooms. Intense abdominal pain, vomiting, and diarrhea occur, followed by a short recovery period. Damage occurs in the liver, kidneys, and muscles. The symptoms persist for about six to eight days, and death occurs in about 50 to 90 percent of the cases.



FUNGI IN INDUSTRY

Fungi produce many products used in nonfood industries. For example, *Penicillium* species produce penicillin, and *Cephalosporium* species produce cephalosporin antibiotics. *Rhizopus* causes chemical transformations of specific chemicals to make cortisone and similar drugs. Cortisone is used to reduce joint swelling.

The yeast *Saccharomyces cerevisiae* is an important tool in genetic engineering. For example, the vaccine for hepatitis B was developed by inserting hepatitis B genes into yeast plasmids. The yeast uses the inserted viral genes to produce viral proteins that are used as vaccines. Yeast is also used to produce ethanol, a main ingredient in the automobile fuel gasohol.

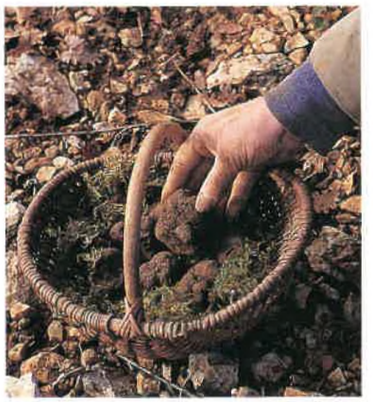


FIGURE 28-12

Morels and truffles are prized by gourmets for their delicate flavor. Truffles (top) grow in association with oak trees. Truffle hunters often use specially trained pigs or dogs to help find truffles. Morels (bottom) grow wild in the Americas and are usually found in the spring.

TABLE 28-3 Food Products and Fungi

Type of food	Fungus
Cheeses: blue, brie, Camembert, Gorgonzola, Limburger, Roquefort	*Penicillium* species
Beer, wine	*Saccharomyces carlsbergensis*, *Saccharomyces cerevisiae*
Soy products: miso (Japanese), soy sauce, tempeh (Indonesian), tofu (Japanese)	*Aspergillus oryzae*, *Rhizopus* species, *Mucor* species
Nutritional yeast	*Saccharomyces* species
Breads	*Saccharomyces cerevisiae*

Fungi and Food Industries

Many fungi are valuable food sources for humans. Yeast, such as *Saccharomyces*, is an important nutritional supplement because it contains vitamins, minerals, and other nutrients. Mushrooms are also an important food. *Agaricus* (white button), shiitake, and portabella mushrooms are often found in grocery stores in the United States. In other parts of the world, people prize the taste of other fungi, such as truffles and morels, which are pictured in Figure 28-12. Truffles and morels are ascocarps found near the roots of trees. Table 28-3 summarizes some of the uses of fungi in food.

Fungi not only can add value to food but also can take value away. Many fungi are important plant pathogens that attack grain or fruit. For example, wheat rust is a basidiomycete that attacks wheat grains. Other fungi can attack food crops such as corn, beans, onions, squashes, and tomatoes.

Fungi also produce several chemical compounds that are important to the food-processing industry, such as citric and gluconic acids. Citric acid is used in soft drinks and candies. Gluconic acid is fed to chickens to enhance the hardness of eggshells. *Ashbya gossypii* is a producer of vitamin B_2, an important nutritional supplement.

SECTION 28-3 REVIEW

1. **Explain how fungi cause disease in humans.**
2. **Which fungi cause athlete's foot and vaginal yeast infection?**
3. **List the types of foods that are derived from fungi.**
4. **Name three nonfood products produced by fungi.**
5. **Explain how fungi compete with humans for nutrients.**
6. **CRITICAL THINKING Why would upsetting the balance of microorganisms in the body, such as occurs during antibiotic treatments, cause a yeast infection?**

CHAPTER 28 REVIEW

SUMMARY/VOCABULARY

28-1

- Fungi are eukaryotic, nonphotosynthetic organisms that can be unicellular or multicellular.
- Fungi are among the most important decomposers of organic matter in the soil. Fungi secrete extracellular enzymes that digest material and absorb simple organic molecules from the environment.
- All modern phyla of fungi had evolved by 300 million years ago. Fungi probably evolved from the prokaryotes and then adapted to various terrestrial environments.
- Hyphae are tangled masses of fungal filaments. Some species have partitions called septa in their hyphae that separate the individual cells.
- Most fungi reproduce asexually and sexually.

Vocabulary

budding (544)
chitin (543)
coenocytic (543)
conidium (544)
conidiophore (544)
dimorphism (544)
fragmentation (544)
hypha (543)
mold (543)
mycology (543)
mycelium (543)
septa (543)
sporangiophore (544)
sporangiospore (544)
sporangium (544)
yeast (543)

28-2

- The phylum Zygomycota is coenocytic. Asexual sporangiospores form within sacs called sporangia. Sexual reproduction results in zygospores.
- The phylum Basidiomycota includes mushrooms. Mushrooms, or basidiocarps, are sexual reproductive structures. Basidiocarps produce basidia, which produce basidiospores.
- Most fungi are found in the phylum Ascomycota, also called the sac fungi. The intertwining of the hyphae produces a visible ascocarp, which resembles a cup. Mating produces ascospores.
- Yeast are unicellular Ascomycota. They reproduce asexually by budding. Yeast are used for brewing, baking, and genetic engineering.
- Mycorrhizae are symbiotic relationships between plant roots and fungi. Fungi provide nutrients to the plant and derive nutrients from the plant.
- Lichens represent symbiotic relationships between fungi and cyanobacteria, or green algae. Fungi dissolve nutrients from rock. Algae and cyanobacteria provide fungi with carbohydrates. Lichens are highly sensitive to environmental changes.

Vocabulary

antheridium (548)
ascocarp (548)
ascogonium (548)
ascospore (548)
ascus (548)
basidium (547)
basidiocarp (547)
basidiospore (547)
crustose (549)
dikaryotic (547)
foliose (549)
fruticose (549)
fungi imperfecti (549)
gametangium (546)
lichen (549)
monokaryotic (548)
mycorrhiza (549)
rhizoid (546)
stolon (546)
zygosporangium (547)

28-3

- *Candida albicans* is an opportunistic pathogen that causes disease in the oral, intestinal, and vaginal tissues of humans.
- Fungi cause diseases such as athlete's foot, ringworm, and jock itch, and these diseases are easily spread.
- Pathogenic fungi that cause serious disease include *Histoplasma capsulatum, Blastomyces dermatitidis,* and *Coccidioides immitis. H. capsulatum* is associated with bird droppings.
- Some fungi, such as portabella mushrooms and yeasts, are edible. *Amanita* mushrooms, among others, are poisonous.
- In industry, fungi produce antibiotics, fuels, and foods. Yeasts are also valuable genetic-engineering research tools.

Vocabulary

aflatoxin (551)

REVIEW

Vocabulary

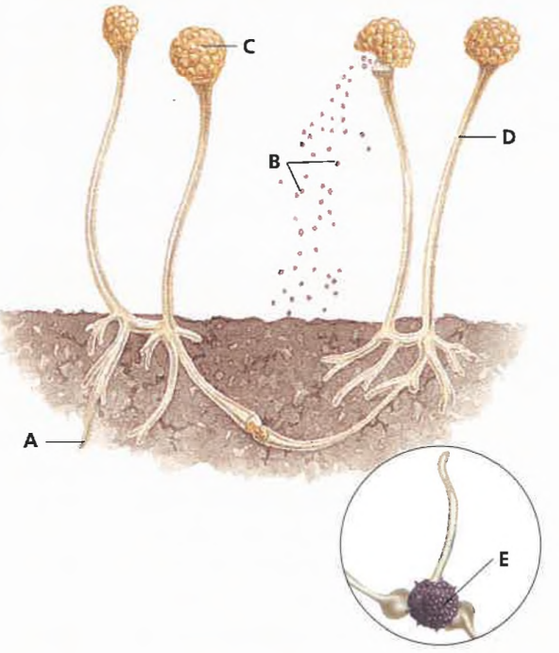
1. Distinguish between a mycorrhiza and a rhizoid.
2. Differentiate between a sporangiophore, a sprangiospore, and a sporangium.
3. Differentiate between an ascocarp, an ascogonium, an ascospore, and an ascus.
4. Distinguish between *monokaryotic* and *dikaryotic.*
5. Differentiate between basidia, a basidiocarp, and a basidiospore.

Multiple Choice

6. Hyphae of the phylum Zygomycota are considered (a) coenocytic (b) monokaryotic (c) nonnuclear (d) plasmodial.
7. The common edible mushroom found in your grocery store is classified in the phylum (a) Basidiomycota (b) Ascomycota (c) Oomycota (d) Zygomycota.
8. The female gametangium in sac fungi is called an (a) oogonium (b) ascogonium (c) antheridium (d) oospore.
9. Fungi that feed on decaying organic matter are said to be (a) saprophytic (b) parasitic (c) mutualistic (d) symbiotic.
10. The fungus *Rhizopus* usually can be found growing on (a) soil (b) fruit (c) bread (d) decaying logs.
11. The walls that separate cells in fungal hyphae are known as (a) rhizoids (b) gills (c) asci (d) septa.
12. Lichens represent symbiotic associations of fungi and (a) roots (b) roundworms (c) water molds (d) green algae.
13. The gills of a mushroom are the sites of spore-bearing structures known as (a) basidia (b) conidiophores (c) basidiocarps (d) ascocarps.
14. In a mycorrhiza, a fungus lives in a symbiotic relationship with a (a) virus (b) slime mold (c) plant (d) bacterium.
15. All of the following human diseases are caused by a species of fungus, except (a) ringworm (b) athlete's foot (c) histoplasmosis (d) influenza.

Short Answer

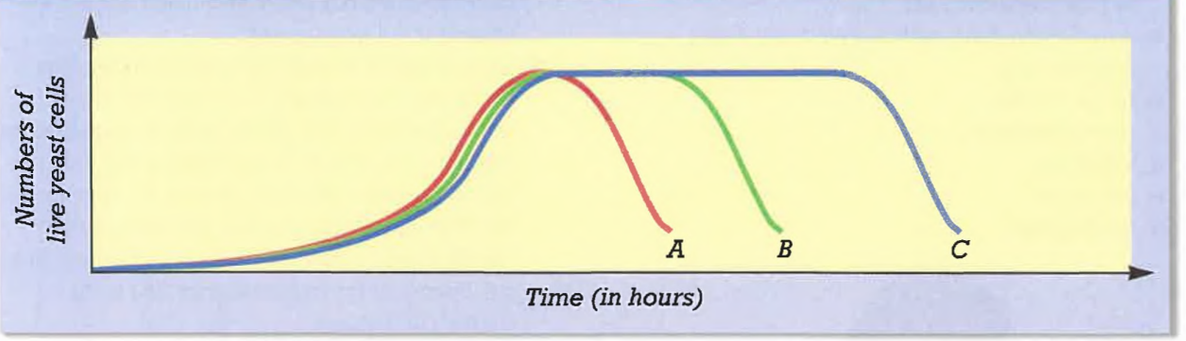
16. How do the sexual reproductive structures in the three phyla of fungi resemble one another? How do they differ?
17. Explain why biologists think fungi colonized dry land at the same time as plants did.
18. How does a coenocytic hypha differ from a septate hypha? Name two examples of fungi that are coenocytic and two more that are septate.
19. Explain how fungi contribute to nutrient cycling in the environment.
20. Describe mutualism, and give an example of such a relationship involving fungi.
21. Explain what a rust is and how it affects humans.
22. What similarities are there between a mycorrhiza and a lichen?
23. Describe three ways that fungi cause disease in humans and three ways that fungi are useful or beneficial to humans.
24. Describe how a fungus growing in feces can infect a person's lungs. Name an example of a fungus that can do this.
25. Identify the lettered structures in the figure below. What phylum does this organism represent?



CRITICAL THINKING

1. The cell walls of fungi and the exoskeletons of insects and crustaceans contain chitin. Tell whether this is of phylogenetic significance, and explain why.
2. Many fungi are fatally poisonous to mammals. What adaptive advantage do toxins give to a fungus?
3. Long before antibiotics were discovered, it was common practice to place a piece of moldy bread on wounds. Explain why this practice might have helped the wounds heal.
4. Fungi such as *Penicillium* engage in a kind of chemical warfare against other microorganisms by producing chemicals that diffuse outward and kill nearby organisms. Explain how producing antibiotics is an adaptive advantage for fungi.
5. Most fungi grow best at temperatures of about 15°C to 21°C. *Aspergillus fumigatus,* however, can grow well at 37°C. Knowing this, where would you expect *A. fumigatus* to grow?
6. *Drosophila,* the common fruit fly, ingests juices from ripe fruit and yeast. How might the fruit fly help speed the natural decay of fruit?
7. When transplanting a wild plant to garden soil, it is very important to include some of the soil from the original habitat. Give a possible explanation, based on the information from this chapter.
8. A winemaker experimenting with three different strains of yeast charts the number of viable yeast as the grapes ferment. The three strains were grown in separate containers, at the same temperature, and with the same type of grape. Why does strain C survive longer than strains A or B?

Growth of Three Strains of Yeast



EXTENSION

1. Read "Joyous Mushrooms" in *Natural History,* September 1999, on page 48. Describe the work of natural historian, amateur mycologist, and artist Mary Elizabeth Banning.
2. Use the library to research the ways that medical science has been influenced by the study of fungi. Investigate the discovery of penicillin and other drugs derived from fungi. Investigate the role played by fungi in various diseases.
3. Prepare a yeast culture by adding a pinch of baker's yeast to a mixture of nine parts water and one part molasses. Allow the culture to ferment, and examine it under a microscope. Make a drawing of several yeast cells, and identify any visible cell parts.
4. Read "The Lichen Connection" in *Popular Science,* July 1998, on page 22. Describe how lichens are valuable to earthquake researchers.

Observing Fungi on Food

OBJECTIVES

- Recognize fungal growth on food.
- Identify environmental conditions that favor the growth of fungi on food and those that inhibit it.

PROCESS SKILLS

- designing an experiment
- collecting data
- organizing data
- analyzing results

MATERIALS

- safety goggles
- lab apron
- disposable gloves
- 2 sterile Petri dishes with nutrient medium (such as potato dextrose agar)
- 2 sterile Petri dishes with nutrient medium and propionic acid
- fungal samples
- stereomicroscope
- toothpicks
- wax pencil
- masking tape

Background

1. How do multicellular fungi, such as molds, obtain nutrients?
2. How do multicellular fungi reproduce and grow?
3. What ecological role do fungi fulfill?
4. How might fungi growing on food harm someone who eats it?

PART A Experimental Setup

1. CAUTION **Put on safety goggles, a lab apron, and disposable gloves.** Obtain four sterile Petri dishes, two with nutrient medium and two with nutrient medium plus propionic acid. Label the dishes for the presence or absence of propionic acid.
2. Examine the fungal samples through a dissecting microscope. Select a dense growth of a fungus from which you will take samples.
3. Use a toothpick to scoop up a small sample of the fungus you have selected. In the two Petri dishes without propionic acid, gently touch the sample to the medium in four places. Raise the lids of the dishes as little as possible while doing this. Do the same for the two Petri dishes with propionic acid, using a clean toothpick and another small sample of the same fungus. Dispose of the toothpicks according to the teacher's instructions.
4. Place a piece of masking tape on opposite sides of each dish to hold the lid and bottom together. Label each Petri dish with your name.
5. Design an experiment to determine which of two opposite environmental conditions is better for fungal growth. Some possible combinations are warm/cold, light/dark, and moist/dry. Label one of the two environmental conditions you selected on a dish with propionic acid. Label the other environmental condition on the other two Petri dishes (one with propionic acid and one without). Then incubate all four dishes under the appropriate conditions.

FUNGAL GROWTH IN DIFFERENT ENVIRONMENTS

Dish	Environmental condition	Propionic acid?	Source of fungus	Growth
1				
2				
3				
4				

6. Create a data table similar to the model above to record your experimental observations for your lab report. For example, the table above is designed to record any growth that may occur under two different environmental conditions (warm/cold, sunlight/dark, moist/dry), source of the fungus, and if propionic acid is present. Design your data table to fit your own experiment. Remember to allow plenty of space to record your observations. Be sure to label your Petri dishes with the appropriate environmental conditions and with the date on which the experiment was begun.

PART B Comparing Amounts of Growth

7. After one week, examine each dish under the stereomicroscope without opening the dish.
8. Record your observations in your data table in your lab report.
9. Examine dishes belonging to other groups, especially those grown under different environmental conditions.
10. Add your observations of those dishes to your lab report.
11.  Clean up your materials and wash your hands before leaving the lab. Dispose of all materials according to instructions provided by your teacher.

Analysis and Conclusions

1. Besides the environmental conditions you chose, what additional factor was tested in your experiment?
2. What steps were taken in your experiment to avoid contamination of the plates?
3. How would contamination of the plates affect the results of your experiment? What are the possible sources of contamination of your experiment?
4. What does extensive fungal growth on a plate indicate? What does lack of fungal growth on a plate indicate?
5. What effect does propionic acid have on fungal growth? How do you know?
6. Why do you think propionic acid is added to foods?
7. Which environmental conditions favor fungal growth? Which inhibit it?
8. Compare the results for the different kinds of fungi grown. Did fungi from certain food sources grow more rapidly than others?
9. Based on your conclusions, under what conditions would you keep a nonsterile food product if you wanted to prevent it from becoming moldy?
10. Has this lab changed your attitude toward food storage? If so, how?

Further Inquiry

Design an experiment that determines the kinds of food that best support fungal growth and whether the presence of chemicals inhibits fungal growth.