Chapter 19 Bacteria and Viruses

Bacteria can survive in extreme temperatures. Some bacteria can even survive in this hot spring in Yellowstone National Park.

Inquiry Activity

Where are bacteria found?

Procedure

1. Label 2 sterile agar plates "control" and "exposed."
2. Tape closed the cover of the control plate. Remove the cover of the exposed plate. Leave both plates on the table for 5 minutes. Do not touch or breathe on the agar.
3. After 5 minutes, tape closed the lid of the exposed plate. Store both plates upside down in a warm place.
4. After 2 days, record the number of bacterial colonies on each plate. **CAUTION:** *Do not open the plates. Give them to your teacher for proper disposal.*

Think About It

1. **Observing** Which plate had more bacterial colonies? Explain your answer.
2. **Drawing Conclusions** Where did the bacteria on your plates come from? Explain your answer.

19–1 Prokaryotes

Imagine living all your life as the only family on your street. Then, one morning, you open the front door and discover houses all around you. You see neighbors tending their gardens and children walking to school. Where did all the people come from? What if the answer turned out to be that they had always been there—you just hadn't seen them? In fact, they had lived on your street for years and years before your house was even built. How would your view of the world change? What would it be like to go, almost overnight, from thinking that you were the only folks on the block to just one family in a crowded community? A bit of a shock?

Humans once had just such a shock. Suddenly, the street was very crowded! Thanks to Robert Hooke and Anton van Leeuwenhoek, the invention of the microscope opened our eyes to the world around us.

Microscopic life covers nearly every square centimeter of Earth. There are microorganisms of many different sizes and shapes, even in a drop of pond water. The smallest and most common microorganisms are **prokaryotes**—single-celled organisms that lack a nucleus.

Prokaryotes typically range in size from 1 to 5 micrometers, making them much smaller than most eukaryotic cells, which generally range from 10 to 100 micrometers in diameter. There are exceptions to this, of course. One example is *Epulopiscium fisheloni,* a gigantic prokaryote, shown in **Figure 19–1,** that is about 500 micrometers long.

Guide for Reading

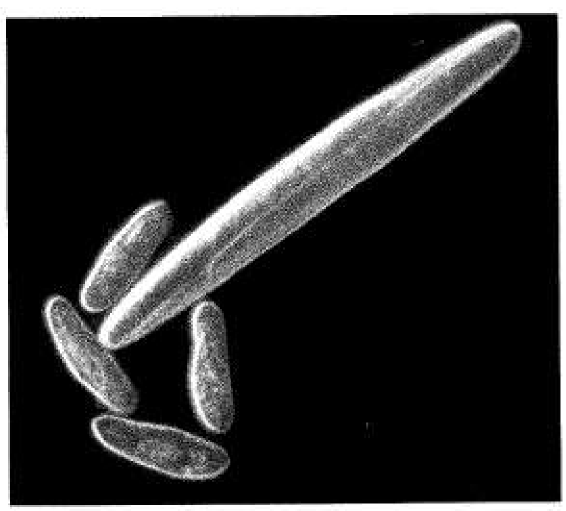
Key Concepts
- How do the two groups of prokaryotes differ?
- What factors are used to identify prokaryotes?

Vocabulary
prokaryote
bacillus
coccus
spirillum
flagellum
photoautotroph
chemoautotroph
photoheterotroph
binary fission
conjugation
endospore

Reading Strategy: Finding Main Ideas Before you read this section, write down the major headings of the section. Then, as you read the section, list the important information under each heading.

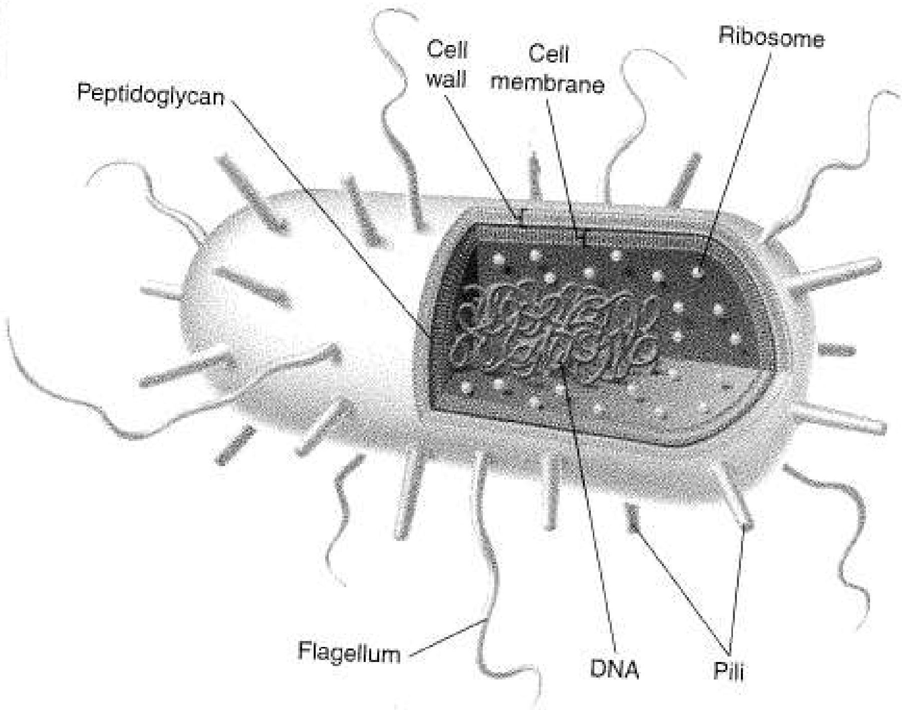
Classifying Prokaryotes

For many years, most prokaryotes were simply called "bacteria" and placed in a single kingdom—Monera. The word *bacteria* is so familiar that we will continue to use it as a common term to describe prokaryotes. More recently, however, biologists have begun to appreciate that prokaryotes can be divided into two very different groups: the eubacteria (yoo-bak-TEER-ee-uh) and the archaebacteria (ahr-kee-bak-TEER-ee-uh). Each group is now considered to be a separate kingdom. Some biologists think that the split between these two groups is so ancient and so fundamental that they should be called domains, a level of classification even higher than kingdom.



(magnification: 100×)

▶ **Figure 19–1** The large cell in this photograph is *Epulopiscium fisheloni,* one of the largest prokaryotes. Notice its size in relation to the neighboring cells, which are eukaryotic paramecia.



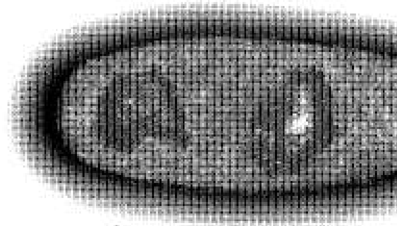


Figure 19–2 A bacterium such as *E. coli* has the basic structure typical of most prokaryotes: cell wall, cell membrane, and cytoplasm. The flagella are used by some prokaryotes for movement. The pili are involved in cell-to-cell contact. **The cell walls of eubacteria contain peptidoglycan, a type of carbohydrate that is not found in archaebacteria.**

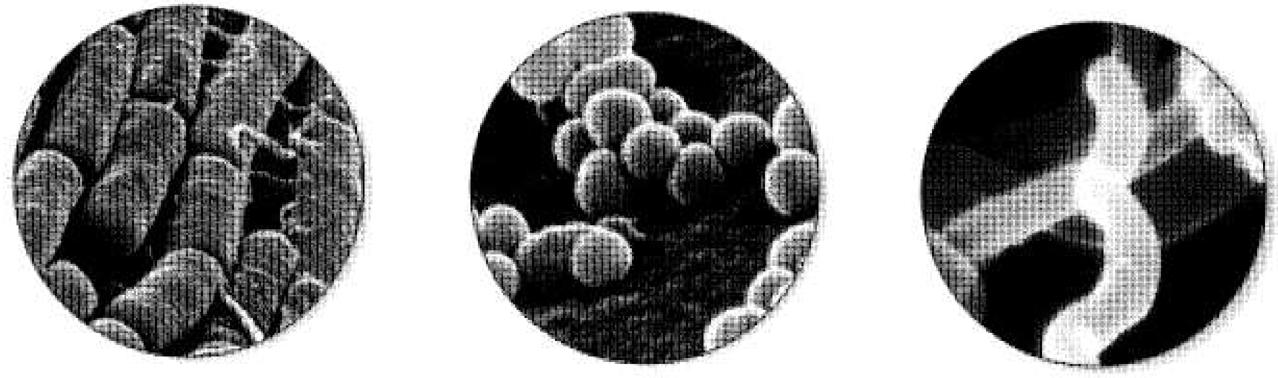
Eubacteria The larger of the two kingdoms of prokaryotes is the eubacteria. Eubacteria include a wide range of organisms with different lifestyles. The variety is so great, in fact, that biologists do not agree on exactly how many phyla to divide the kingdom into. Eubacteria live almost everywhere. Some live in the soil, whereas others infect large organisms and cause disease. **Figure 19–2** shows a diagram of *E. coli,* a typical eubacterium that lives in human intestines.

Like other prokaryotes, eubacteria are usually surrounded by a cell wall that protects the cell from injury and determines its shape. The cell walls of eubacteria contain peptidoglycan, a carbohydrate. Within the cell wall is a cell membrane that surrounds the cytoplasm. Some eubacteria have a second, outer, membrane.

Archaebacteria Under a microscope, archaebacteria look very similar to eubacteria. They are equally small, lack nuclei, and have cell walls. **Archaebacteria lack peptidoglycan, a carbohydrate found in the cell walls of eubacteria, and their membrane lipids are quite different. Also, the DNA sequences of key archaebacterial genes are more like those of eukaryotes than those of eubacteria.** Based on this and other data, scientists reason that archaebacteria may be the ancestors of eukaryotes.

Many archaebacteria live in extremely harsh environments. One group of archaebacteria is the methanogens, prokaryotes that produce methane gas. Methanogens live in oxygen-free environments, such as thick mud and the digestive tracts of animals. Other archaebacteria live in extremely salty environments, such as Utah's Great Salt Lake, or in hot springs where temperatures approach the boiling point of water.

✓CHECKPOINT *Where do many archaebacteria live?*



Bacilli
(magnification: 7000×)

Cocci
(magnification: 137,000×)

Spirilla
(magnification: about 100,000×)

Figure 19–3 **Prokaryotes can be identified by their shapes.** Prokaryotes usually have one of three basic shapes: rods (bacilli), spheres (cocci), or spirals (spirilla).

Identifying Prokaryotes

Because prokaryotes are so small, it may seem difficult to identify their characteristics. **Prokaryotes are identified by their shapes, the chemical natures of their cell walls, the ways they move, and the ways they obtain energy.**

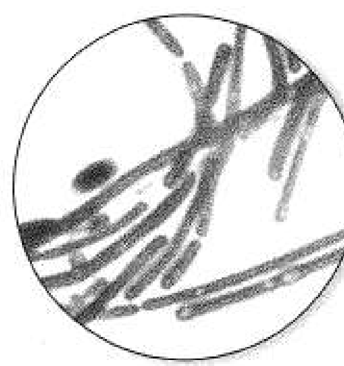
Shapes Look at the different shapes of prokaryotes shown in **Figure 19–3.** Rod-shaped prokaryotes are called **bacilli** (buh-SIL-eye; singular: bacillus). Spherical prokaryotes are called **cocci** (KAHK-sy; singular: coccus). Spiral and corkscrew-shaped prokaryotes are called **spirilla** (spy-RIL-uh; singular: spirillum).

Prokaryotes can arrange themselves in a number of different ways. Some cocci, including the disease-causing bacteria *Streptococcus* and *Pneumococcus,* form long chains. Others, such as *Staphylococcus,* form large clumps or clusters.

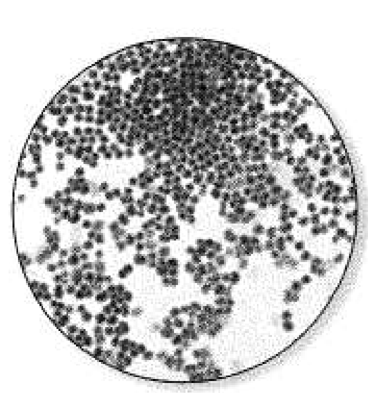
Cell Walls Two different types of cell walls are found in eubacteria. A method called Gram staining is used to tell them apart. The Gram stain consists of two dyes—one violet (the primary stain) and the other red (the counterstain). Bacterial cells with a cell wall containing mainly peptidoglycan absorb only the violet dye, so they appear purple under the microscope, as shown in **Figure 19–4.** These bacteria are called Gram-positive. Other bacteria have a second, outer, layer of lipid and carbohydrate molecules. This extra layer absorbs only the red stain. These bacteria, which appear pink, are said to be Gram-negative.

Movement You can also identify prokaryotes by studying how they move. Some are propelled by **flagella** (singular: flagellum). Flagella are whiplike structures used for movement. Other prokaryotes lash, snake, or spiral forward. Still others glide slowly along a layer of slimelike material they secrete. Many prokaryotes do not move at all.

Figure 19–4 **Prokaryotes can be identified by the chemical natures of their cell walls.** When treated with Gram stain, Gram-positive bacteria appear purple. Gram-negative bacteria appear pink.



Gram-Positive Bacteria
(magnification: about 3000×)



Gram-Negative Bacteria
(magnification: 150×)

Obtaining Energy

Prokaryotes have diverse adaptations that allow them to live in nearly every environment imaginable. No characteristic of prokaryotes illustrates their diversity better than the ways in which they obtain energy.

Autotrophs Several groups of prokaryotes carry out photosynthesis in a manner similar to green plants, and are called **photoautotrophs** (foh-toh-AW-tuh-trohfs). As you might expect, these organisms are found where light is plentiful, near the surfaces of lakes, streams, and oceans. One group, the cyanobacteria (sy-uh-noh-bak-TEER-ee-uh), contains a bluish pigment and chlorophyll *a,* the key pigment in photosynthesis. Cyanobacteria are found throughout the world—in fresh and salt water and on land. A few species survive in extremely hot water, such as in hot springs. Others survive in the Arctic, where they can even grow on snow. In fact, cyanobacteria are often the very first species to recolonize the site of a natural disaster, such as a volcanic eruption.

Other prokaryotes, called **chemoautotrophs** (keem-oh-AW-tuh-trohfs), obtain energy directly from inorganic molecules. Chemoautotrophs get energy from chemical reactions involving ammonia, hydrogen sulfide, nitrites, sulfur, or iron. Some chemoautotrophs live deep in the darkness of the ocean. They obtain energy from hydrogen sulfide gas that flows from hydrothermal vents on the ocean floor, such as the one shown in **Figure 19–5.**

Heterotrophs Most prokaryotes are heterotrophs like us, obtaining energy by taking in organic molecules and then breaking them down. In many situations, this means that prokaryotes compete directly with us for food. If food is not handled carefully, bacteria like *Staphylococcus aureus* may get to the dinner table before you do! Once there, these bacteria may not only "eat" some of the food ahead of time, but may also release chemicals that cause food poisoning.

A small but very interesting group of prokaryotes combines the autotrophic and heterotrophic styles of life. These organisms are photosynthetic—they capture sunlight for energy. But they also need organic compounds for nutrition. These bacteria are called **photoheterotrophs** (foh-toh-HET-ur-oh-trohfs), and there is nothing quite like them in the rest of the living world.

✓CHECKPOINT *What are photoheterotrophs?*

◀ **Figure 19–5** Ocean vents, such as this one, are often home to a rich fauna of organisms, including tube worms and other exotic organisms. **Applying Concepts** *Would photoautotrophs survive in this environment? Why or why not?*

Careers in Biology

Epidemiologist

Job Description: work for a university, health department, research or health organization, or medical corporation to identify and track diseases and develop programs that prevent or control the spread of disease

Education: Masters or Doctoral degree in epidemiology, including course work in statistics, demography, research design, and public health

Skills: good communication skills, strong computer skills, knowledge of health and medical conditions

Highlights: You get to ask lots of questions and travel. You can work on infectious diseases such as tuberculosis. Some epidemiologists work on specific issues such as tobacco addiction.

Elizabeth Lawton currently works on the infectious disease tuberculosis. She loves her job. "Because public health works at the population level, I get to help many people at one time," she says.

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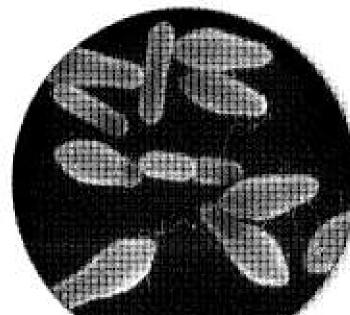
Releasing Energy

Like all organisms, bacteria need a constant supply of energy. This energy is released by the processes of cellular respiration, which requires oxygen, and fermentation, which does not. Organisms that require a constant supply of oxygen in order to live are called obligate aerobes. We, and many species of bacteria, are obligate aerobes. Some bacteria, however, do not require oxygen and, in fact, may be poisoned by it! These bacteria are called obligate anaerobes because they must live in the absence of oxygen. *Clostridium botulinum*—shown in **Figure 19–6**—is an obligate anaerobe found in soil. Because of its ability to grow without oxygen, it can grow in canned food that has not been properly sterilized. The bacteria produce a potentially deadly form of food poisoning known as botulism. Gases produced by the bacteria can cause affected cans of food to bulge.

A third group of bacteria can survive with or without oxygen and are known as facultative anaerobes. Facultative anaerobes do not require oxygen, but neither are they poisoned by its presence. Their ability to switch between cellular respiration and fermentation means that facultative anaerobes are able to grow just about anywhere. These bacteria are found in freshwater lakes and ponds, at the bottom of the ocean, and at the tops of the highest mountains. They are also found in the most thoroughly disinfected hospital rooms, and even in our own digestive systems.



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▲ **Figure 19–6** Botulism, a kind of food poisoning, is caused by the bacterium *Clostridium botulinum.* This type of bacterium is often found in foods that have not been properly sterilized. **Applying Concepts** *How can you avoid botulism?*

▼ **Figure 19–7** Most prokaryotes reproduce by binary fission (top), producing two identical "daughter" cells. Some prokaryotes take part in conjugation (bottom). Parts of genetic information are transferred from one cell to another by way of a hollow bridge. **Comparing and Contrasting** *Compare the process of conjugation to binary fission.*

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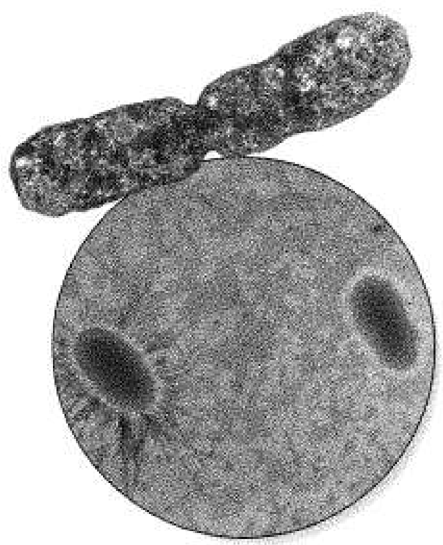

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Growth and Reproduction

When conditions are favorable, prokaryotes can grow and divide at astonishing rates. Some divide as often as every 20 minutes! If unlimited space and food were available to a single prokaryote and if all of its offspring divided every 20 minutes, in just 48 hours (2 days) they would reach a mass approximately 4000 times the mass of Earth! Fortunately, this does not happen. In nature, growth is held in check by the availability of food and the production of waste products.

How do prokaryotes reproduce? When a prokaryote has grown so that it has nearly doubled in size, it replicates its DNA and divides in half, producing two identical "daughter" cells. This type of reproduction is known as **binary fission.** Because binary fission does not involve the exchange or recombination of genetic information, it is an asexual form of reproduction.

Although most prokaryotes reproduce through binary fission, others can transfer genetic material from one cell to another. This exchange of genetic information is called conjugation. During **conjugation,** a hollow bridge forms between two cells, as shown in **Figure 19–7,** and genes move from one cell to the other. This transfer of genetic information increases the genetic diversity in populations of bacteria.

When growth conditions become unfavorable, many bacteria form structures called spores. One type of spore, called an **endospore,** is formed when a bacterium produces a thick internal wall that encloses its DNA and a portion of its cytoplasm. The endospore can remain dormant for months or even centuries, until more favorable growth conditions arise. The ability to form spores makes it possible for some bacteria to survive harsh conditions—such as extreme heat, dryness, or lack of nutrients—that might otherwise kill them.

19–1 Section Assessment

1. **Key Concept** Compare and contrast the two kingdoms of prokaryotes.
2. **Key Concept** What three factors can be used to identify prokaryotes?
3. What are some of the different ways that prokaryotes obtain energy?
4. Describe how prokaryotes reproduce and exchange genetic material.
5. **Critical Thinking Inferring** Why might an infection by Gram-negative bacteria be more difficult to treat than a Gram-positive bacterial infection?

iTEXT Assessment Use iText to review the important concepts in Section 19–1.

ALTERNATIVE ASSESSMENT

Making a Venn Diagram Create a Venn diagram that illustrates the similarities and differences between eubacteria and archaebacteria.

19–2 Bacteria in Nature

You probably remember the principal actors in the last film you saw. You might even recall some of the supporting actors. Have you ever thought that there would be no film at all without the hundreds of workers who are never seen on screen? Bacteria are just like those unseen workers. **Bacteria are vital to maintaining the living world. Some are producers that capture energy by photosynthesis. Others help to break down the nutrients in dead matter and the atmosphere, allowing other organisms to use the nutrients.**

Decomposers

Every living thing depends on a supply of raw materials. If these materials were lost forever when an organism died, life could not continue. Before long, plants would drain the soil of minerals and die, and the animals that depend on plants for food would starve. As decomposers, bacteria help the ecosystem recycle nutrients. When a tree dies and falls to the forest floor, armies of bacteria attack and digest the dead tissue. The bacteria break down dead matter into simpler substances, which are released into the soil and taken up by the roots of plants. Bacteria, as well as some eukaryotic organisms, such as insects and fungi, play important roles in this process.

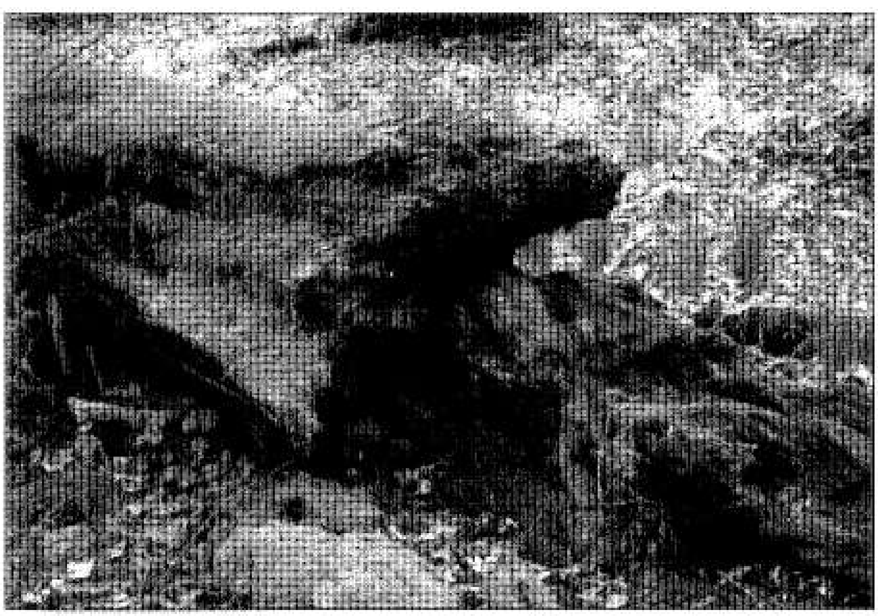
As recyclers, bacteria also perform critical steps in sewage treatment. Sewage contains human waste, discarded food, organic garbage, and even chemical waste. Bacteria break down complex compounds in the sewage into simpler ones. This process produces purified water, nitrogen and carbon dioxide gases, and leftover products that can be used as fertilizers.

Guide for Reading

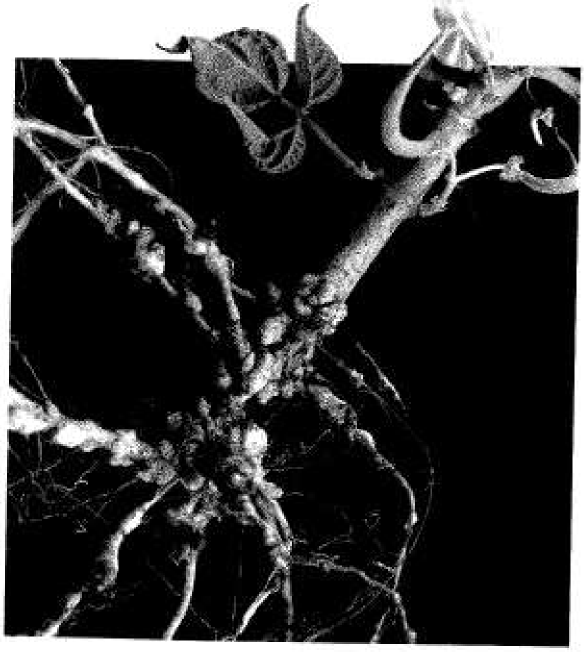
Key Concepts
- What ecological roles do bacteria play in the environment?
- How do bacteria cause disease?

Vocabulary
nitrogen fixation
pathogen
antibiotic
sterilization

Reading Strategy: Using Prior Knowledge
Before you read this section, make a list of five things for which bacteria are known. Then, compare your list to the text as you read.



◀ Figure 19–8 Bacteria help to break down the nutrients in this tree, allowing other organisms to use the nutrients.



▲ **Figure 19–9** The knoblike structures on the roots of this soybean plant are called nodules. Within these nodules are the rod-shaped, nitrogen-fixing bacteria *Rhizobium.*

Nitrogen Fixers

Plants and animals depend on bacteria for nitrogen. Plants need nitrogen to make amino acids, which are the building blocks of proteins. Because animals eat plants, plant proteins supply nitrogen for animals. Although Earth's atmosphere is made up of approximately 80 percent nitrogen gas (N_2), plants cannot use that nitrogen directly. Nitrogen must first be "fixed" chemically to ammonia (NH_3) or other nitrogen compounds. Expensive synthetic fertilizers contain these nitrogen compounds, but bacteria produce them naturally. The process of converting nitrogen into a form plants can use is known as **nitrogen fixation.** Certain bacteria are the only organisms that can fix nitrogen in this way.

Many plants have symbiotic relationships with nitrogen-fixing bacteria. For example, soybeans and other legumes host the bacterium *Rhizobium. Rhizobium* grows in nodules, or knobs, that form on the roots of the soybean plant, as shown in **Figure 19–9**. The soybean plant provides a source of nutrients for *Rhizobium,* which converts nitrogen in the air into ammonia, which helps the plant. All plants benefit from nitrogen-fixing bacteria, but soybeans are a step ahead. Soybeans have their own fertilizer factories in their roots!

CHECKPOINT *What is nitrogen fixation?*

Biology and History

Eliminating Disease

Early discoveries with vaccination allowed new branches of science and medicine to develop. These new fields, such as bacteriology and immunology, would help in the crusade against diseases caused by bacteria and viruses.

1800

1820

Missouri Compromise temporarily maintains the balance of free and slave states in the United States.

1849

John Snow
Snow proves for the first time that cholera is spread by contaminated drinking water. Cholera is a bacterial infection of the intestines that causes diarrhea.

1856

William Budd
Budd shows that typhoid fever is a contagious disease. Typhoid is a bacterial infection that causes a high fever.

1881

Louis Pasteur
Pasteur develops the first effective vaccine against an infectious bacterial disease, anthrax. Anthrax is one of the oldest recorded diseases of animals.

1900

Bacteria and Disease

Have you ever heard a teacher say that when a few people misbehave, they ruin it for everybody? In a way, that saying could be applied to bacteria. Bacteria are everywhere in nature, but only a few cause disease. However, these **pathogens,** or disease-causing agents, seem to get all the attention, and they give the other bacteria a bad reputation.

Bacteria cause disease in one of two general ways. Some damage the tissues of the infected organism directly by breaking them down for food. Other bacteria release toxins (poisons) that harm the body.

Heterotrophic bacteria can make you sick by damaging cells and tissues. For example, the bacteria that cause tuberculosis break down lung tissue. In contrast, many cases of food poisoning are caused by bacterial toxins. When meat, poultry, and eggs are not cooked properly, these toxins can make you sick. The symptoms of food poisoning range from an upset stomach to serious illness. Bacterial toxins can also travel throughout the body. For example, the *Streptococcus* bacteria that cause strep throat can release toxins into the bloodstream. These toxins can cause a reddish rash over the body called scarlet fever.

Many bacterial diseases can be prevented by stimulating the body's immune system with vaccines. If a bacterial infection does occur, a number of drugs and natural compounds can be used to attack and destroy the invading bacteria. These drugs include antibiotics, such as penicillin and tetracycline.

Word Origins

Pathogen comes from the Greek words *pathos,* meaning "suffering," and *-genes,* meaning "born" or "produced." So a pathogen is something that produces suffering. **The Greek word *karkinos* means "cancer." What do you think a carcinogen is?**

Writing Activity

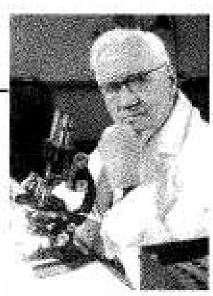
Use the Internet or a library to find out more about one of the people in this time line. Write a summary of the person's discovery as it might appear in a newspaper story of the time.

1904

Mary Mallon
Mallon is found to be the cause of an epidemic of typhoid fever in New York. She flees authorities, but before her death 51 cases of typhoid and 3 deaths will be attributed to her, giving her the nickname "Typhoid Mary."

1928

Alexander Fleming
Fleming discovers penicillin accidentally when an experiment with bacteria is contaminated by mold. He finds that penicillin is nontoxic but inhibits the growth of many types of disease-causing bacteria.



1980

Smallpox Eradicated
The World Health Organization certifies that smallpox has been eradicated. This was the first major disease to be completely eliminated.

1989

Fall of Berlin Wall; Cold War ends

1991

Cholera Epidemic
Over 390,000 cases of cholera are reported in 11 countries throughout South and Latin America. The disease appears on the continent after being absent from it for more than 70 years.

2000

Disease	Pathogen	Prevention
Tooth decay	*Streptococcus mutans*	Regular dental hygiene
Lyme disease	*Borrelia burgdorferi*	Protection from tick bites
Tetanus	*Clostridium tetani*	Current tetanus vaccination
Tuberculosis	*Mycobacterium tuberculosis*	Vaccination
Salmonella food poisoning	*Salmonella enteritidis*	Proper food-handling practices
Pneumonia	*Streptococcus pneumoniae*	Maintaining good health
Cholera	*Vibrio cholerae*	Clean water supplies

Common Diseases Caused by Bacteria

▲ **Figure 19–10** **Bacteria cause disease in one of two general ways. Some damage the tissues of an infected organism directly by breaking them down for food. Other bacteria release toxins that hurt the body.** Some of the diseases caused by pathogenic bacteria are listed in the above table.

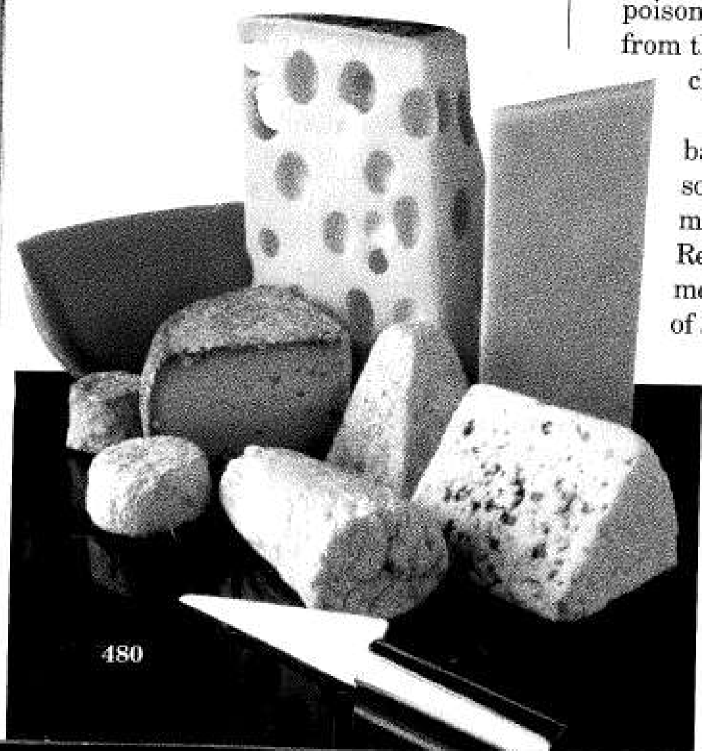
Antibiotics are compounds that block the growth and reproduction of bacteria. They can be used to cure many bacterial diseases. One of the major reasons for the dramatic increase in life expectancy during the past two centuries is an increased understanding of how to prevent and cure bacterial infections. **Figure 19–10** shows some common bacterial diseases, what pathogens cause them, and how they can be prevented.

Human Uses of Bacteria

Every day, you probably use food products that have been manufactured using bacteria. Bacteria are used in the production of a variety of foods, including cheese, yogurt, buttermilk, and sour cream. The cheeses shown in **Figure 19–11** are examples of such foods. Some bacteria are used to make pickles and sauerkraut, and some make vinegar from wine.

Bacteria are also used in industry. One type of bacterium can digest petroleum, making it very helpful in cleaning up small oil spills. Some bacteria remove waste products and poisons from water. Others can even help to mine minerals from the ground. Still others are used to synthesize drugs and chemicals through the techniques of genetic engineering.

Biotechnology companies have begun to realize that bacteria adapted to extreme environments may be a rich source of heat-stable enzymes. These enzymes can be used in medicine, food production, and industrial chemistry. Recently, a company signed a unique "bioprospecting" agreement with Yellowstone National Park, where more than half of all the hot springs and geysers on Earth are found.



◀ **Figure 19–11** Cheeses are only one kind of food made using bacteria. **Applying Concepts** *What other products are made with the help of bacteria?*

Controlling Bacteria

Most bacteria are harmless, and many are beneficial. However, the risks of bacterial infection are great enough to warrant efforts to control bacterial growth.

Sterilization destroys bacteria by subjecting them either to great heat or to chemical action. Most bacteria cannot survive high temperatures for a long time and can be killed in boiling water. An entire hospital, of course, cannot be dropped into boiling water. But a hospital can be sterilized, one room at a time, by using disinfectants. A disinfectant is a chemical solution that kills bacteria. Disinfectants are also used in the home to clean bathrooms, kitchens, and other rooms where bacteria may cause disease.

Bacteria can cause food to spoil. One method of stopping food from spoiling is refrigeration. Bacteria, like most organisms, usually grow more slowly at low temperatures. Food that is stored at a low temperature will keep longer because the bacteria will take much longer to multiply. In addition, many kinds of food can be sterilized by boiling, frying, or steaming. Each of these cooking techniques raises the temperature of the food to a point where the bacteria are killed.

If food is to be preserved for a long time, a method called canning is sometimes used. The food is heated to a high temperature. It then must be immediately placed into sterile glass jars or metal cans and sealed. Food that has been properly canned will last almost indefinitely. Finally, a number of chemical treatments will inhibit the growth of bacteria in food. These include treating food with everyday chemicals such as salt, vinegar, or sugar. Salted meat, pickled vegetables, and jam are examples of chemically preserved foods.

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19–2 Section Assessment

1. **Key Concept** What is the importance of bacteria in the environment?
2. **Key Concept** How do bacteria cause disease?
3. How are bacterial infections often treated?
4. Describe three methods of preventing bacterial growth in food.
5. **Critical Thinking Applying Concepts** You think you might have a bacterial infection. Would it be a good idea to ask for a vaccination against the bacteria? Why or why not?

iTEXT Assessment Use iText to review the important concepts in Section 19–2.

ALTERNATIVE ASSESSMENT

Creative Writing
In *War of the Worlds*, a book written by H. G. Wells, Earth is invaded by aliens. No weapons can kill the invaders, and civilization seems doomed. Earth is saved, however, when the invaders die from diseases they contract. Using a similar premise, write a story about people from Earth voyaging to another planet some time in the future.

19–3 Viruses

Guide for Reading

Key Concepts
- What is the structure of a virus?
- How do viruses cause infection?

Vocabulary
virus
capsid
bacteriophage
lytic infection
lysogenic infection
retrovirus
prion

Reading Strategy: Using Visuals As you read about viral replication in this section, trace each step in **Figures 19–14** and **19–15.** Then, list the steps, and write a few sentences to describe each step.

Imagine that you have been presented with a great challenge. Farmers in your region have begun to lose a valuable crop to a plant disease. The disease produces large pale spots on the leaves of plants similar to those shown in **Figure 19–12.** The diseased leaves look like mosaics of yellow and green. As the disease progresses, the leaves turn yellow, wither, and fall off, killing the plant.

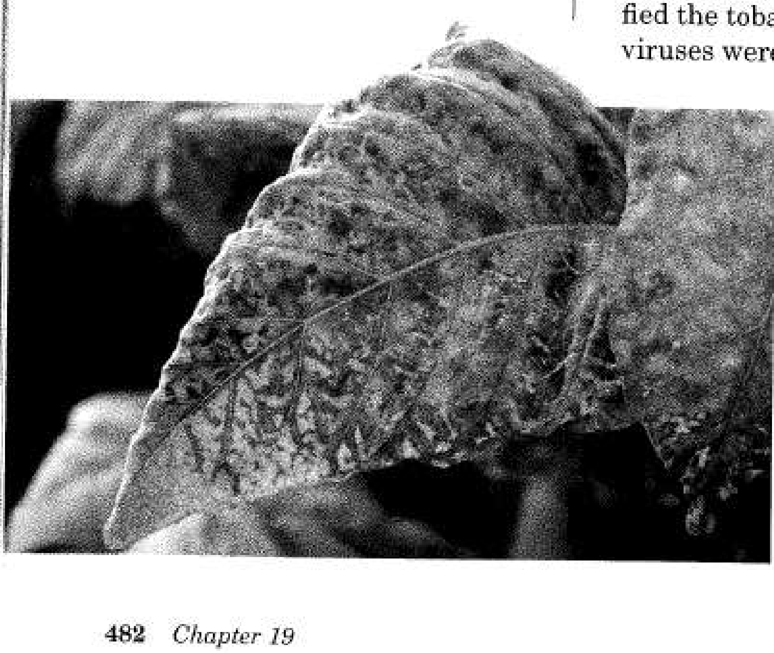
To determine what is causing the disease, you take leaves from a diseased plant and extract a juice. You place a few drops of the juice on the leaves of healthy plants. A few days later, the mosaic pattern is right where you put the drops. Could the source of disease be in the juice?

You use a microscope to look for a germ that might cause the disease, but none can be seen. Even when the tiniest of cells are filtered out of the juice, it still causes the disease. You infer that the juice must contain pathogens so small that they are not visible under the light microscope. Although you cannot see the disease-causing particles, you're sure they're there. You give them the name *virus,* from the Latin word for "poison."

If you think you could have come to all of these conclusions, congratulations! You're walking in the footsteps of a 28-year-old Russian biologist named Dmitri Ivanovski. In 1892, Ivanovski pinpointed the cause of tobacco mosaic disease to juice extracted from infected plants. In 1897, Dutch scientist Martinus Beijerinck determined that tiny particles in the juice caused the disease, and named these particles viruses.

What Is a Virus?

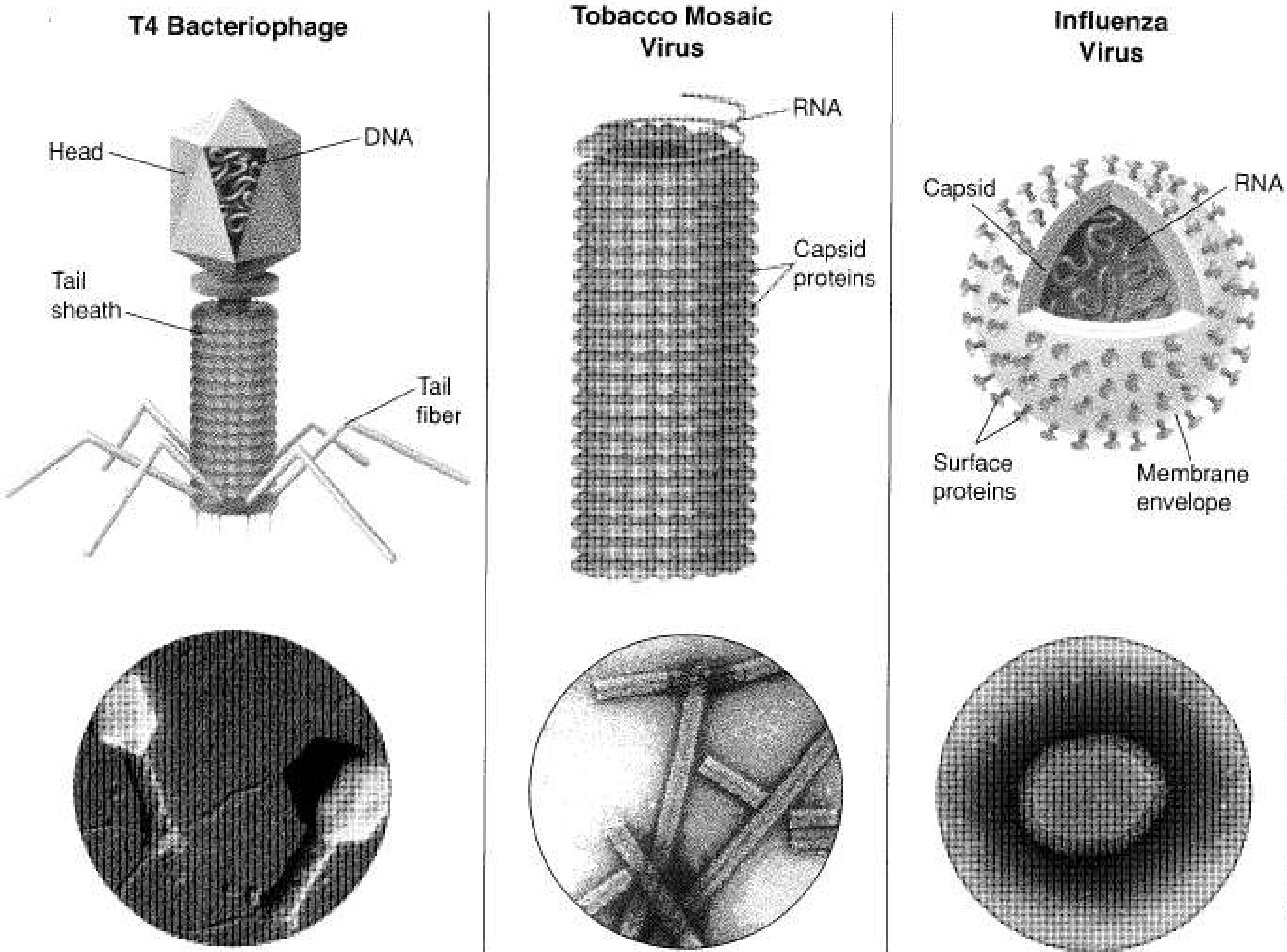
In 1935, when the American biochemist Wendell Stanley purified the tobacco mosaic virus into a crystal, it became clear that viruses were not living things. **Viruses** are particles of nucleic acid, protein, and in some cases lipids that can reproduce only by infecting living cells. Viruses differ widely in terms of size and structure. You can see examples of the diversity of viruses in **Figure 19–13.** All viruses, however, have one thing in common: They enter living cells and, once inside, use the machinery of the infected cell to produce more viruses.



◀ **Figure 19–12** Tobacco mosaic virus causes the leaves of tobacco plants to develop a pattern of spots called a mosaic.

FIGURE 19–13 VIRUS STRUCTURES

Viruses come in a variety of sizes and shapes. **A typical virus is composed of a core of either DNA or RNA, surrounded by a protein coat, or capsid.**



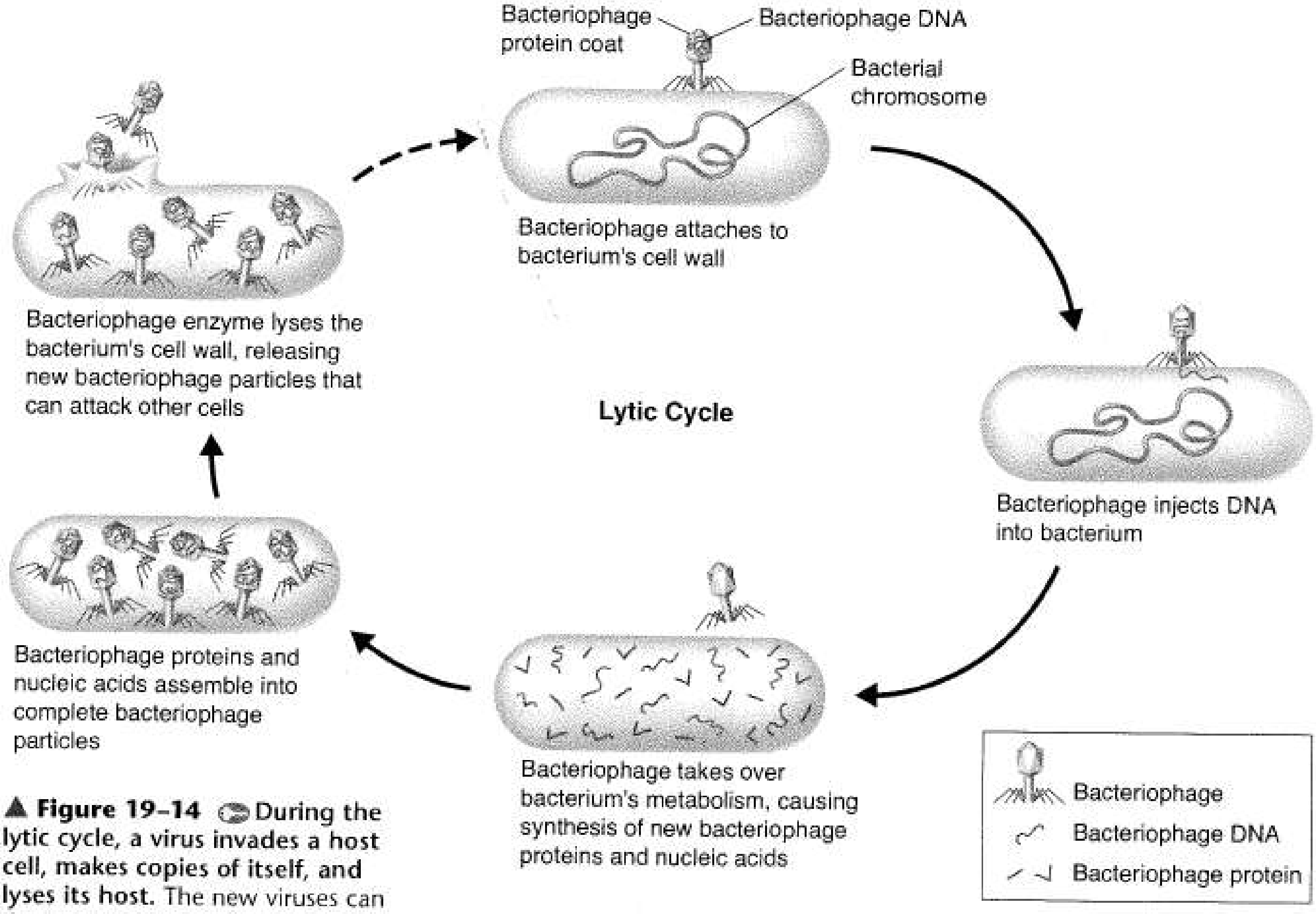
T4 Bacteriophage (magnification: 82,000×)

Tobacco Mosaic Virus (magnification: 200,000×)

Influenza Virus (magnification: 1,000,000×)

Most viruses are so small they can be seen only with the aid of a powerful electron microscope. **A typical virus is composed of a core of either DNA or RNA surrounded by a protein coat.** The simplest viruses contain only a few genes, while the most complex may have more than a hundred genes.

A virus's outer protein coat is called its **capsid.** The capsid includes proteins that enable a virus to enter a host cell. The capsid proteins of a typical virus bind to the surface of a cell and "trick" the cell into allowing it inside. Once inside, the viral genes take over. The cell transcribes the viral genes, putting the genetic program of the virus into effect. Sometimes that genetic program may simply cause the cell to make copies of the virus, but often it destroys the host cell.



▲ **Figure 19–14 During the lytic cycle, a virus invades a host cell, makes copies of itself, and lyses its host.** The new viruses can then go on to invade new host cells.

Discovery Channel School: To find out more about the transmission of a virus, view the videotape "Influenza: Tracking a Virus."

Viral Infection

Because viruses must bind precisely to proteins on the cell surface and then use a host's genetic system, most viruses are highly specific to the cells they infect. Plant viruses do not infect animal cells; most animal viruses infect only certain species of animals; and bacterial viruses infect only certain types of bacteria. **Bacteriophages** (bak-TEER-ee-uh-fayj-uz) are viruses that infect bacteria. As examples of how viruses infect cells, we will look at two bacteriophages known as T4 and lambda.

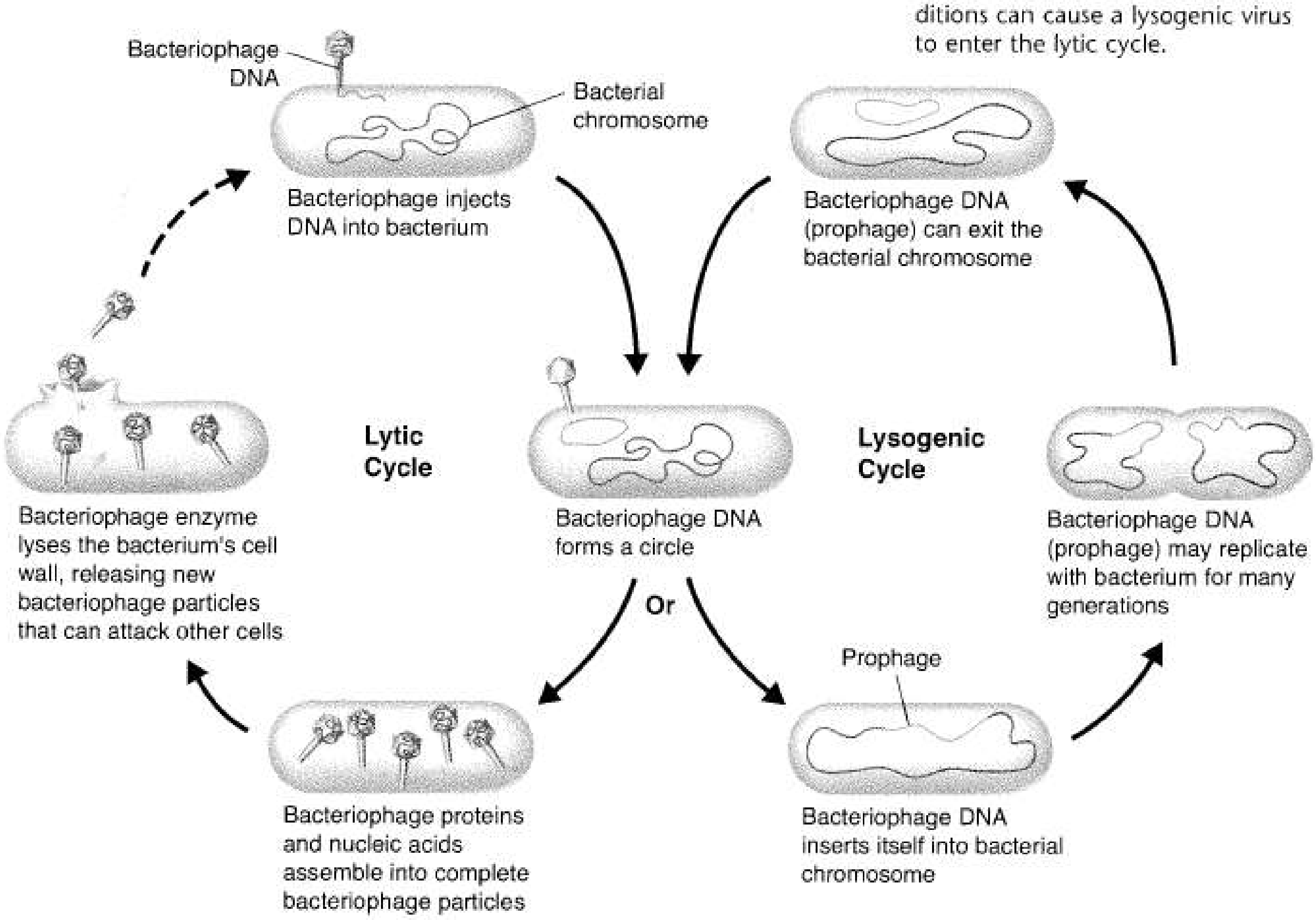
✓CHECKPOINT *What is a bacteriophage?*

Lytic Infection **Figure 19–14** shows the lytic cycle of bacteriophage T4. **In a lytic infection, a virus enters a cell, makes copies of itself, and causes the cell to burst.** Bacteriophage T4 has a DNA core inside an intricate capsid that is activated by contact with a host cell. T4 then injects its DNA directly into the cell. In most cases, the host cell cannot tell the difference between its own DNA and the DNA of the virus. Consequently, the cell begins to make messenger RNA from the genes of the virus. This viral mRNA acts like a molecular wrecking crew, shutting down and taking over the infected host cell. Some viral genes turn off the synthesis of molecules that are important to the infected cell.

The virus uses the materials of the host cell to make thousands of copies of itself. Before long, the infected cell lyses, or bursts, and releases hundreds of virus particles that may go on to infect other cells. Because the host cell is lysed and destroyed, this process is called a **lytic infection.**

In its own way, a lytic virus is similar to a desperado in the Old West. First, the outlaw eliminates the town's existing authority (host cell DNA). Then, the desperado demands to be outfitted with new weapons, horses, and riding equipment by terrorizing the local people (using the host cell to make proteins). Finally, the desperado forms a gang that leaves the town to attack new communities (the host cell bursts, releasing hundreds of virus particles).

Lysogenic Infection Other viruses cause a **lysogenic infection,** in which a host cell makes copies of the virus indefinitely. The bacteriophage lambda causes lysogenic infections, as shown in **Figure 19–15.** **In a lysogenic infection, a virus embeds its DNA into the DNA of the host cell and is replicated along with the host cell's DNA.** Unlike lytic viruses, lysogenic viruses do not lyse the host cell right away. Instead, a lysogenic virus will insert its DNA into the DNA of the host cell. The viral DNA that is embedded in the host's DNA is called a prophage.



▼ **Figure 19–15** **In a lysogenic infection, the viral DNA enters a host cell and inserts itself into the host's DNA.** Certain conditions can cause a lysogenic virus to enter the lytic cycle.

Quick Lab

How do viruses differ in structure?

Materials craft materials, metric ruler, scissors, tape

Procedure

1. Make models of two of the viruses shown in **Figure 19–13** on page 483.
2. Label the parts of each of your virus models.
3. Measure and record the length of each of your virus models in centimeters. Convert the length of each model into nanometers:
   1 cm = 10 million nm.
4. Calculate the length of each virus you modeled. Divide the length of each model by the length of the actual virus to determine how many times larger each model is than the virus it represents.

Analyze and Conclude

1. **Using Models** What parts of your models are found in all viruses?
2. **Drawing Conclusions** What parts do one or both of your models include that are found in only some viruses?
3. **Calculating** How many times larger are your models than the viruses they represent?

Viral DNA may not stay in the prophage form indefinitely. Eventually, any one of a number of factors will activate the DNA of the prophage, which will then remove itself from the host cell DNA and direct the synthesis of new virus particles. There are many differences between bacteriophages and the viruses that infect eukaryotic cells. Most viruses, however, show patterns of infection similar to either the lytic or lysogenic cycles of bacteriophages.

Viruses and Disease

Viruses cause human diseases such as polio, measles, AIDS, mumps, influenza, yellow fever, rabies, and the common cold. In most viral infections, viruses attack and destroy certain cells in the body, causing the symptoms of the disease.

The best way to protect against most viral diseases lies in prevention, often by the use of vaccines. A vaccine is a preparation of weakened or killed virus or viral proteins. When injected into the body, a vaccine stimulates the immune system, sometimes producing permanent immunity to the disease.

Most vaccines provide protection only if they are used before an infection begins. Once a viral disease has been contracted, it may be too late to control the infection. However, sometimes the symptoms of the infection can be treated.

Viruses and Cancer Certain viruses called oncogenic viruses cause cancer in animals. Oncogenic viruses generally carry genes that disrupt the normal controls over cell growth and division. By studying such viruses, scientists have identified many of the genes that regulate cell growth in eukaryotes.

To find out more about how scientists study disease, view the videotape "Hantavirus: A Tale of Mice and People."

Retroviruses Some viruses that contain RNA as their genetic information are called **retroviruses.** When retroviruses infect a cell, they produce a DNA copy of their RNA. This DNA, much like a prophage, is inserted into the DNA of the host cell. Retroviruses get their name from the fact that their genetic information is copied backward—that is, from RNA to DNA instead of from DNA to RNA. Retroviruses are responsible for some types of cancer in animals, including humans. HIV, the virus that causes AIDS, is a retrovirus.

Prions In 1972, American scientist Stanley Prusiner became interested in scrapie, an infectious disease in sheep for which the exact cause was unknown. Although he first suspected a virus, experiments suggested that the disease might actually be caused by tiny particles found in the brain. Unlike viruses, these particles contained no DNA or RNA, only protein. Prusiner called these particles **prions,** short for "protein infectious particles." There is strong evidence that mad cow disease and a similar disease in humans may also be caused by prions.

▲ **Figure 19–16** Prions may cause several infectious diseases, including mad cow disease. This cow was killed by mad cow disease. **Comparing and Contrasting** How are prions similar to viruses? How are they different?

Are Viruses Alive?

Viruses share the genetic code with living things and affect living things. But most biologists do not consider viruses to be alive because viruses do not have all the characteristics of life, which you learned about in Chapter 1. For example, viruses are not cells and are not able to reproduce independently. However, when viruses do infect living cells, they can make copies of themselves, regulate gene expression, and even evolve.

Although viruses are smaller and simpler than the smallest cells, they could not have been much like the first living things. It seems more likely that viruses developed after living cells. In fact, the first viruses may have evolved from the genetic material of living cells. Viruses have continued to evolve, along with the cells they infect, over billions of years.

19–3 Section Assessment

1. **Key Concept** What are the parts of a virus?
2. **Key Concept** Compare and contrast two ways that viruses cause infection.
3. What is the difference between a bacteriophage and a prophage?
4. What is a retrovirus?
5. **Critical Thinking Making Judgments** Do you think viruses should be considered a form of life? Describe the reasons for your opinion.

iTEXT **Assessment** Use iText to review the important concepts in Section 19–3.

Take It to the NET

Research a virus that is currently in the news. Then, prepare a FAQ (Frequently Asked Questions) sheet about the virus. Use the links provided in the Biology area at the Prentice Hall Web site for help in completing this activity: **www.phschool.com**

Identifying Limits to the Growth of Bacteria

Bacteria can be found nearly everywhere on Earth and are able to reproduce with amazing speed. So, why isn't Earth covered by huge numbers of bacteria? What prevents them from growing and reproducing in nature as quickly as they can in the laboratory? In this investigation, you will determine whether an environmental factor such as temperature can control the growth and reproduction of bacteria.

Problem

Does temperature limit the growth and reproduction of bacteria?

Materials

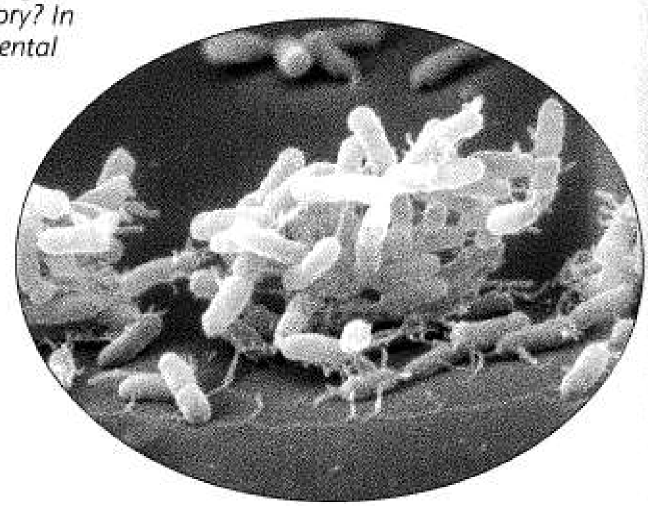
- 3 sterile agar plates
- hand lens
- bacterial culture
- sterile cotton swabs
- glass-marking pencil
- transparent tape
- thermometer

Skills

Analyzing Data, Drawing Conclusions

Procedure

1. **Predicting** Predict whether temperature will affect the growth rate of bacterial colonies. Record your prediction.
2. Use the hand lens to examine the sterile agar plates. They should appear clean, with no bacterial growth. Return any plates to your teacher that appear to be contaminated by bacteria or mold. **CAUTION:** *Wash your hands with warm water and soap before and after handling the agar plates.*
3. Use a glass-marking pencil to label the agar plates "3°C," "room temperature," and "37°C." Also, mark your name on each plate.
4. Put on your plastic gloves. Dip a sterile swab in the bacterial culture and wipe it back and forth in a zigzag pattern over the entire surface of the agar on one plate. Cover the plate and seal it with transparent tape. **CAUTION:** *Do not open the plates once they have been exposed to the air.*
5. Repeat step 4 with each plate, using a new sterile swab for each plate.
6. On a separate sheet of paper, make a copy of the data table shown. Use a thermometer to measure the room temperature. Record this temperature in the blank row of your copy of the data table.

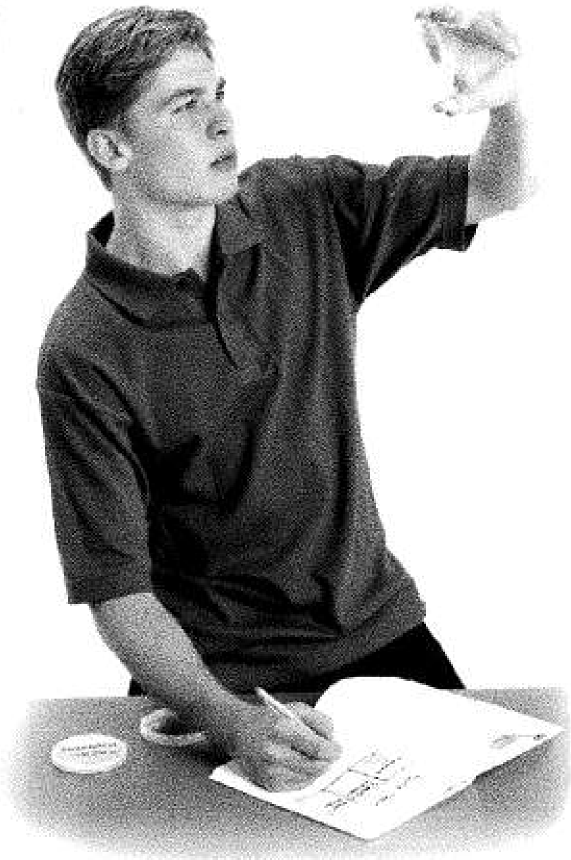


Salmonella enteritidis **bacteria**
(magnification: 17,000×)

7. Place the plate labeled "3°C" in a refrigerator. Leave the plate labeled "room temperature" at room temperature in a place designated by your teacher. Place the plate labeled "37°C" in an incubator. Be sure to store each plate upside down.
8. After 24 hours, examine each plate with a hand lens. Bacterial colonies look like small white or colored dots on the surface of the agar. In your copy of the data table, record the number of bacterial colonies on each agar plate. Return each of the plates to its location described in step 7.

Data Table

Temperature	Number of Colonies	
	24 hours	48 hours
3°C		
37°C		



9. After a second period of 24 hours, record in your data table the number of bacterial colonies on each agar plate. After you have completed your data table, place all your agar plates in the container designated by your teacher for safe disposal.
10. Make a graph of the results in your data table. Plot time on the *x*-axis and number of bacterial colonies on the *y*-axis. Use a different symbol to represent data from each day. After you have plotted all your data on your graph, draw a straight line or smooth curve as close as possible to all the points that represent observations after 24 hours. Draw a second curve or line through the points that represent observations after 48 hours.

Analyze and Conclude

1. **Analyzing Data** According to the graph of your data, at what temperature were the most bacterial colonies visible after 24 hours? At what temperature were the fewest bacterial colonies visible after 24 hours?
2. **Analyzing Data** Did the same plate have the most bacteria after 48 hours? The fewest?
3. **Analyzing Data** Describe the effect of temperature on the growth of bacteria in this experiment. How do you think the results might differ if you included higher temperatures in your experiment?
4. **Evaluating** Did the results of your experiment confirm your prediction?
5. **Inferring** What other factors besides temperature would you expect to affect the rate at which bacteria grow and reproduce?
6. **Drawing Conclusions** How can the results of your experiment help explain why the world is not covered by a thick layer of bacteria?

Go Further

Formulating Hypotheses Temperature is not the only environmental factor that affects the growth of bacteria. Propose a hypothesis about the effects of another variable on the growth of bacteria. Describe an experiment that could test your hypothesis.

Chapter 19 Study Guide

19–1 Prokaryotes

Key Concepts

- Archaebacteria lack peptidoglycan, a carbohydrate found in the cell walls of eubacteria, and their membrane lipids are quite different. Also, the DNA sequences of key archaebacterial genes are more like those of eukaryotes than eubacteria.
- Prokaryotes are identified by their shapes, the chemical natures of their cell walls, the ways they move, and the ways they obtain energy.

Vocabulary

prokaryote, p. 471
bacillus, p. 473
coccus, p. 473
spirillum, p. 473
flagellum, p. 473
photoautotroph, p. 474
chemoautotroph, p. 474
photoheterotroph, p. 474
binary fission, p. 476
conjugation, p. 476
endospore, p. 476

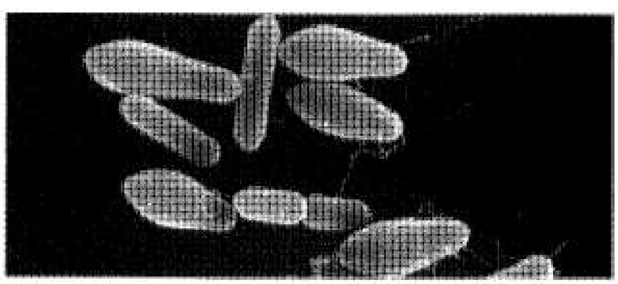
19–2 Bacteria in Nature

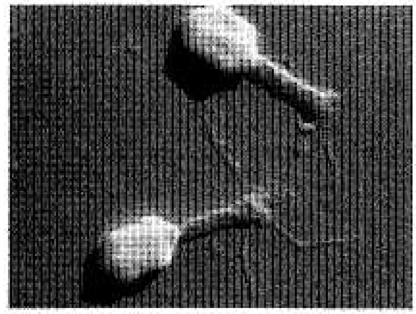
Key Concepts

- Bacteria are vital to maintaining the living world. Some are producers that capture energy by photosynthesis. Others help to break down the nutrients in dead matter and the atmosphere, allowing other organisms to use the nutrients.
- Bacteria cause disease in one of two general ways. Some damage the tissues of the infected organism directly by breaking them down for food. Other bacteria release toxins (poisons) that harm the body.

Vocabulary

nitrogen fixation, p. 478
pathogen, p. 479
antibiotic, p. 480
sterilization, p. 481





19–3 Viruses

Key Concepts

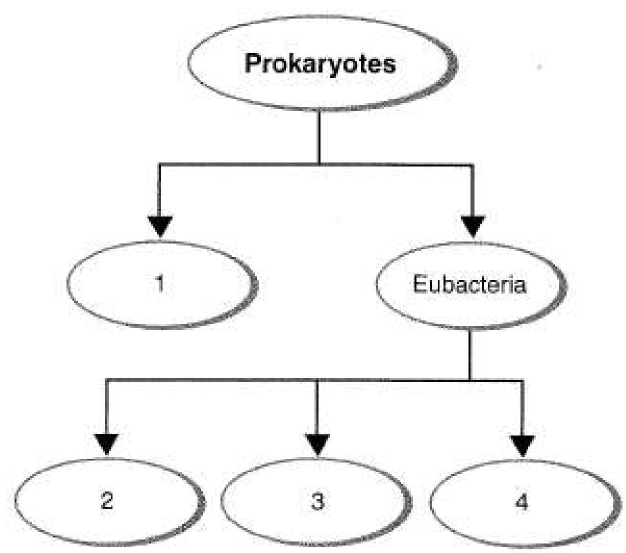
- A typical virus is composed of a core of either DNA or RNA surrounded by a protein coat.
- In a lytic infection, a virus enters a cell, makes copies of itself, and causes the cell to burst.
- In a lysogenic infection, a virus embeds its genome into the DNA of the host cell and is replicated along with the host cell's DNA.

Vocabulary

virus, p. 482
capsid, p. 483
bacteriophage, p. 484
lytic infection, p. 485
lysogenic infection, p. 485
retrovirus, p. 487
prion, p. 487

Thinking Visually

Complete this concept map, which shows the relationships among the groups of prokaryotes.



Preparing for the Living Environment Exam

Chapter 19

Part A

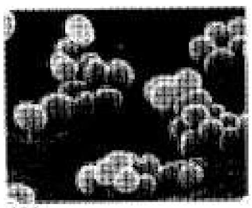
Multiple Choice

For each statement or question, select the number of the word or expression that, of those given, best completes the statement or answers the question.

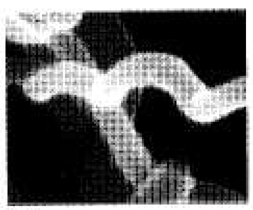
1 Prokaryotes are unlike all other organisms in that their cells
(1) lack nuclei (3) have cell walls
(2) have organelles (4) lack nucleic acids

2 Which photograph shows bacillus bacteria?


(1)


(3)


(2)


(4)

3 Which group includes the bacteria that contain chlorophyll *a*?
(1) archaebacteria (3) chemoautotrophs
(2) cyanobacteria (4) pathogens

4 Bacteria reproduce asexually by
(1) binary fission (3) conjugation
(2) spores (4) external fertilization

5 The process of converting nitrogen into a form plants can use is known as nitrogen
(1) conjugation (3) decomposition
(2) transfer (4) fixation

6 Which term best decribes disease-causing bacteria?
(1) cocci (3) pathogens
(2) bacilli (4) archaebacteria

7 The outer protein coat of a virus is a
(1) core of DNA (3) capsid
(2) core of RNA (4) membrane envelope

8 Which illness is caused by a virus?
(1) Lyme disease (3) tetanus
(2) measles (4) food poisoning

9 Which characteristic is *not* used to identify specific prokaryotes?
(1) cell size (3) cell movement
(2) cell shape (4) cell energy source

10 One group of viruses that contain RNA as their genetic information is
(1) oncogenic (3) capsids
(2) retroviruses (4) prophages

11 Which method is *not* used to protect food against microorganisms?
(1) salting (3) vaccination
(2) freezing (4) sterilization

12 Archaebacteria that live in oxygen-free environments include
(1) protists (3) retroviruses
(2) methanogens (4) bacteriophages

13 Which process is used for the exchange of genetic information between two bacterial cells?
(1) lytic cycle (3) binary fission
(2) conjugation (4) immunization

14 Spherical prokaryotes are called
(1) cocci (3) spirilla
(2) eubacteria (4) archaebacteria

15 The process of asexual reproduction in prokaryotes is called
(1) conjugation (3) lytic cycle
(2) immunization (4) binary fission

For question 16, complete the analogy by selecting the correct number. In analogies, A : B :: C : means "A is to B as C is to _?_."

16 Cell : cell membrane :: virus :
(1) cell wall (3) bacteriophage
(2) capsid (4) DNA core

Test-Taking Tip For questions containing the word *not*, begin by jotting down items that do fit the characteristic in question. Then, compare your notes with the answer choices and eliminate those that correspond to your list. Finally, check to see that your answer is correct by confirming that it does not fit the characteristic in question.

Preparing for the Living Environment Exam

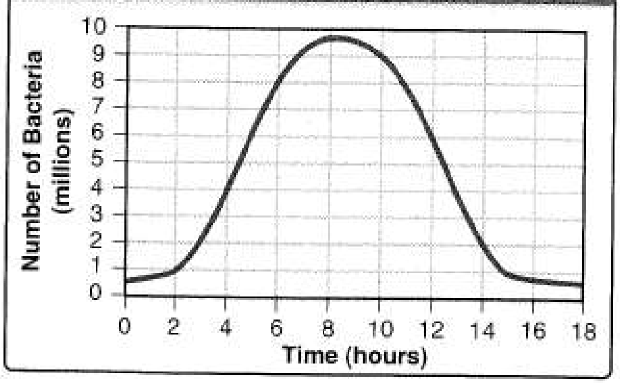
Parts B and C

Multiple Choice and Extended Response

For those questions that ask you to select a response, choose the one that best completes the statement or answers the question. For all others follow the directions given.

Base your answers to questions 17 and 18 on the graph below and on your knowledge of biology.

Bacterial Growth at 37°C



17 At which point in the graph does the number of living bacteria increase at the greatest rate?
(1) between hours 2 and 4
(2) between hours 4 and 6
(3) between hours 6 and 8
(4) between hours 10 and 14

18 Which is the most likely reason for the decrease in population shown?
(1) The temperature of the bacteria culture was too high after 8 hours
(2) The bacteria ceased mating after 8 hours
(3) More nutrients were added to the culture at regular intervals
(4) Waste products from the bacteria accumulated in the nutrient solution

19 State two distinguishing characteristics of prokaryotes.

20 Describe the three main cell shapes of prokaryotes.

21 How do scientists use stains to distinguish between Gram-positive and Gram-negative bacteria?

22 Describe two methods by which prokaryotes move.

23 State one way in which photoautotrophs are similar to chemoautotrophs and one way in which they are different.

24 State one way in which photoheterotrophs are similar to ordinary heterotrophs and one way in which they are different.

25 State one way to distinguish between an obligate aerobe and an obligate anaerobe.

26 Facultative anaerobes can survive with or without oxygen. How is this advantageous to them?

27 What is the role of certain bacteria in changing atmospheric nitrogen into a form usable by plants?

28 State the one thing that all viruses have in common concerning their interactions with living cells.

29 State one way the capsid protein is important to the functioning of a virus.

30 Describe the sequence of events that occurs during the lytic cycle of a T4 bacteriophage.

Base your answers to questions 31 and 32 on the information below and on your knowledge of biology.

An experiment was conducted to determine the effectiveness of different antibiotics against a certain strain of bacteria. Four disks, each soaked in a different antibiotic, were placed in a petri dish where the bacteria were growing. The results are summarized below.

Effects of Antibiotics

Antibiotic	Observation After One Week
A	No growth for 6 mm from disk edge
B	Growth all around disk edge
C	Growth all around disk edge
D	No growth for 2 mm from disk edge

31 State which antibiotics were the least effective at retarding the growth of the bacteria. Support your answer with data from the experiment.

32 State which antibiotic might be most effective for an infection caused by this strain of bacteria. Support your answer with data from the experiment.

33 Describe what happens to a bacterial cell when the bacteriophage DNA exits from the bacterial chromosome.

34 What is the most commonly used method to protect humans against most viral diseases?

35 Explain how other organisms would be affected if bacteria lost the ability to function in the recycling of nitrogen compounds.

36 Bacteria can be grown in the laboratory in a prepared medium. Can all viruses be grown on cultures of bacteria? Support your answer.

37 Explain why foods such as uncooked rice and raisins do not spoil.

38 Bacteria that live on teeth produce an acid that causes decay. Explain why people who do not brush regularly have more cavities than those who do.

39 A scientist finds a new organism but is unsure which kingdom it belongs to. The organism is unicellular, has a cell wall containing peptidoglycan, has a circular DNA molecule, and has ribosomes, but it lacks a nucleus. Based on these characteristics, which kingdom does it belong to?

40 Bacteria and viruses are often considered together because they have some things in common. Yet, they also differ in many significant ways. Compare the features and impact of both bacteria and viruses on humans and the environment. In your answer, be sure to
- compare the overall structure of a bacterial cell with the structure of a virus
- compare the genetic material of bacteria with the genetic material of viruses
- state one specific way each can be harmful to humans
- state one specific way each has been used by humans in a positive way
- state one specific way each has an impact on the environment

41 Explain how the outcome of binary fission differs from that of both endospore formation and conjugation.

42 Describe the design of an experiment to test the hypothesis that contact of an agar plate with a finger results in more bacterial growth than the exposure of the plate to classroom air.

Base your answers to questions 43 and 44 on the information below and on your knowledge of biology.

The data table shows the results of an experiment conducted with one species of bacterium. The bacteria were grown for 24 hours in five dishes with nutrient media at several different pH levels, all at a temperature of 37°C.

pH of the Nutrient Medium	Number of Bacterial Colonies on the Nutrient Medium
5	10
6	50
7	60
8	70
9	5

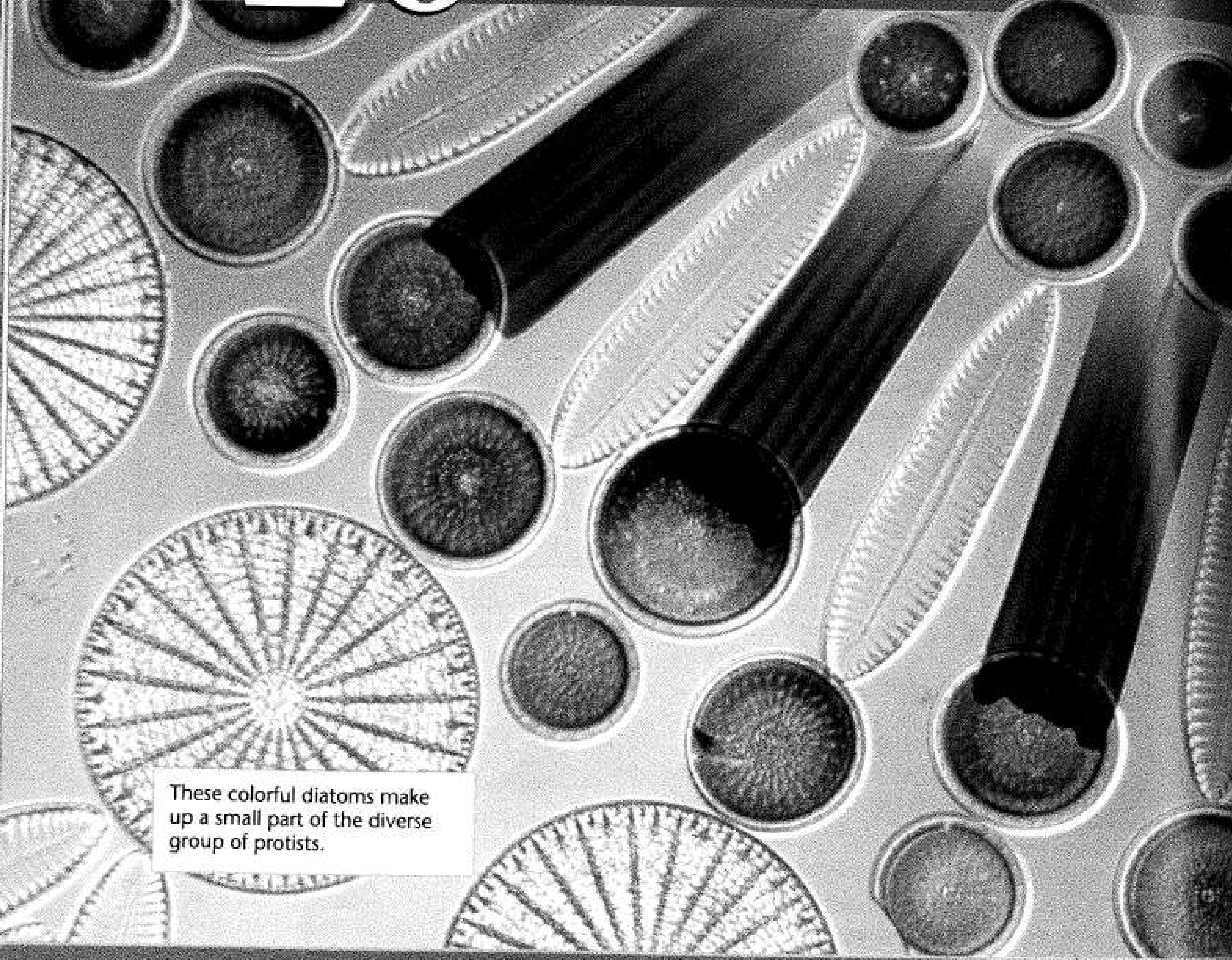
43 The most appropriate title for this data table is
(1) The Effect of pH of Bacteria on Nutrient Media at 37°C
(2) The Effect of pH on Bacterial Population Growth
(3) The Effect of Bacterial Population Growth on pH
(4) The Effect of Bacteria at 37°C for 24 Hours

44 State an appropriate conclusion that could be drawn from the data reported in the table.

Take It to the NET

Can bacteria become ill? Visit the Prentice Hall Web site at **www.phschool.com** to learn more about bacteriophages, viruses that infect bacteria. Then, answer the following questions:
- How can you determine whether bacteriophages are present in bacteria?
- Can bacteriophages be used to cure humans of diseases caused by pathogenic bacteria?
- Why are bacteriophages considered to be important tools in bacteriological research?

Chapter 20 Protists



These colorful diatoms make up a small part of the diverse group of protists.

Inquiry Activity

What are protists?

Procedure

1. Place a drop of water containing a variety of microorganisms on a microscope slide. Add a drop of methyl cellulose and a coverslip. Observe the slide under the microscope at low and high magnifications.
2. Record your observations. Draw and label each type of organism.
3. Draw a chart listing each type of organism that you observed and its characteristics.

Think About It

1. **Classifying** Are any of these organisms bacteria, animals, or plants? Explain your answer.
2. **Forming Operational Definitions** The organisms you observed are members of a group called protists. Write a definition of *protist*.

20–1 The Kingdom Protista

On a dark, quiet night you sit at the stern of a tiny sailboat as it glides through the calm waters of a coastal inlet. Suddenly, the boat's wake sparkles with its own light. As the stern cuts through the water, glimmering points of light leave a ghostly trail into the darkness. What's responsible for this eerie display? You've just had a close encounter with one group of some of the most remarkable organisms in the world—the protists.

What Is a Protist?

The kingdom Protista is a diverse group that may include more than 200,000 species. Biologists have argued for years over the best way to classify protists, and the issue may never be settled. In fact, protists are defined less by what they are and more by what they are not: A **protist** is any organism that is not a plant, an animal, a fungus, or a prokaryote. **Protists are eukaryotes that are not members of the kingdoms Plantae, Animalia, or Fungi.** Recall that a eukaryote has a nucleus and other membrane-bound organelles. Although most protists are unicellular, quite a few are not, as you can see in **Figure 20–1.** A few protists actually consist of hundreds or even thousands of cells but are still considered protists because they are so similar to others that are truly unicellular.

Evolution of Protists

Protists are members of a kingdom whose formal name, *Protista,* comes from Greek words meaning "the very first." The name is appropriate. The first eukaryotic organisms on Earth, which appeared nearly 1.5 billion years ago, were protists.

Guide for Reading

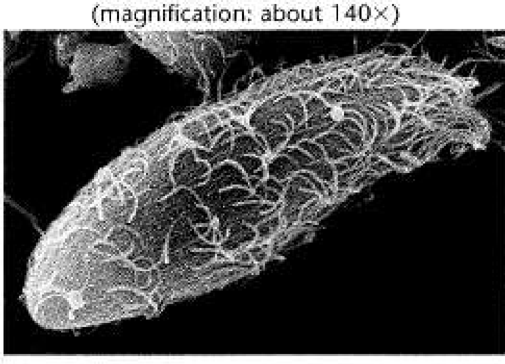
Key Concept
- What are protists?

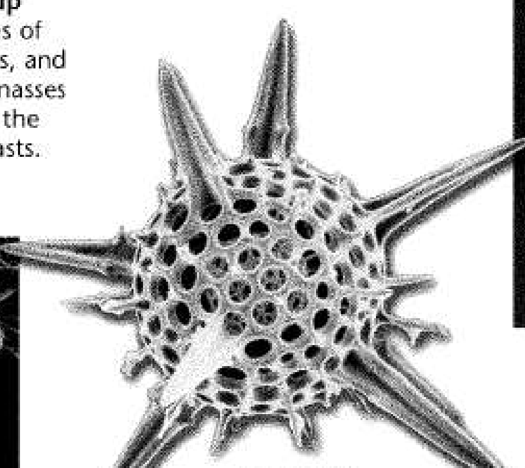
Vocabulary
protist

Reading Strategy: Summarizing As you read, find the main ideas for each blue heading. Write down a few key words from each main idea. Then, use the key words in your summary. Reread and revise your summary, keeping only the most important ideas.

Figure 20–1 **Protists are a diverse group of mainly single-celled eukaryotes.** Examples of protists include freshwater ciliates, radiolarians, and *Spirogyra. Spirogyra* may form slimy floating masses in fresh water. The organism's name refers to the helical arrangement of its ribbonlike chloroplasts.

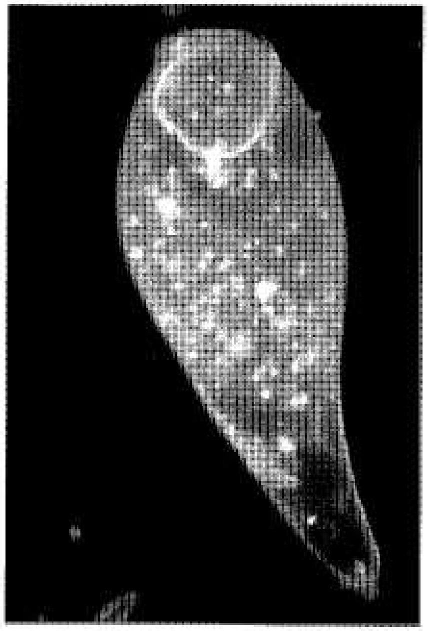
Euplotes (a freshwater ciliate)
(magnification: about 140×)





Radiolarian
(magnification: 3400×)

Spirogyra
(magnification: 400×)



(magnification: 350×)

▲ **Figure 20–2** According to one hypothesis, some organelles in eukaryotic cells were once symbiotic prokaryotes that lived inside other cells. For example, the mitochondria found in this *Stentor* may be descended from early prokaryotes. **Formulating Hypotheses** ***What other organelle may originally have been symbiotic cells?***

Where did the first protists come from? American biologist Lynn Margulis has hypothesized that the first eukaryotic cells may have evolved from a symbiosis of several cells. Mitochondria and chloroplasts found in eukaryotic cells may be descended from aerobic and photosynthetic prokaryotes that began to live inside larger cells. **Figure 20–2** shows a typical protist.

Classification of Protists

Protists are so diverse that many biologists have suggested that they should be broken up into several kingdoms. This idea is supported by recent studies of protist DNA indicating that different groups of protists evolved independently from archaebacteria. Unfortunately, at present, biologists simply don't agree on how best to classify the protists. Therefore, in this textbook, we will take the traditional approach of considering the protists as a single kingdom.

One way to classify protists is according to the way they obtain nutrition. Thus, many protists that are heterotrophs are called animallike protists. Those that produce their own food by photosynthesis are called plantlike protists. Finally, those that obtain their food by external digestion—either as decomposers or parasites—are called funguslike protists. This is the way in which we will organize our investigation of the protists.

It is important to understand, however, that these categories are an artificial way to organize a very diverse group of organisms. Categories based on the way protists obtain food do not reflect the evolutionary history of these organisms. For example, all animallike protists did not necessarily share a relatively recent ancestor. The protistan family tree is likely to be redrawn many times as the genes of the many species of protists are analyzed and compared using the powerful tools of molecular biology.

20–1 Section Assessment

1. **Key Concept** What is a protist?
2. Describe Margulis's theory about the evolution of protists.
3. Are most protists unicellular or multicellular?
4. What are the three methods that protists use to obtain food?
5. **Critical Thinking Using Analogies** In what way is the kingdom Protista similar to a group of people who do not belong to a political party?

iTEXT Assessment Use iText to review the important concepts in Section 20–1.

ALTERNATIVE ASSESSMENT

Creative Writing
Write and illustrate a brief newspaper story explaining the hypothesis that eukaryotic cells evolved from a symbiosis of several prokaryotes with larger cells.

20–2 Animallike Protists: Protozoans

At one time, animallike protists were called protozoa, which means "first animals," and were classified separately from more plantlike protists. Like animals, these organisms are heterotrophs. The four phyla of animallike protists are distinguished from one another by their means of movement. As you will read, zooflagellates swim with flagella, sarcodines move by extensions of their cytoplasm, ciliates move by means of cilia, and sporozoans do not move on their own at all.

Zooflagellates

Many protists easily move through their aquatic environments propelled by flagella. Flagella are long, whiplike projections that allow a cell to move. **Animallike protists that swim using flagella are classified in the phylum Zoomastigina and are often referred to as zooflagellates.** Most zooflagellates (zoh-oh-FLAJ-uh-lits) have either one or two flagella, although a few species have many flagella. Two representative zooflagellates are shown in **Figure 20–3**.

Zooflagellates are generally able to absorb food through their cell membranes. Many live in lakes and streams, where they absorb nutrients from decaying organic material. Others live within the bodies of other organisms, taking advantage of the food that the larger organism provides.

Most zooflagellates reproduce asexually by means of binary fission, including mitotic cell division. Binary fission results in two cells that are genetically identical. Some zooflagellates, however, have a sexual life cycle as well. During sexual reproduction, gamete cells are produced by meiosis. When gametes from two organisms fuse, an organism with a new combination of genetic information is formed.

Guide for Reading

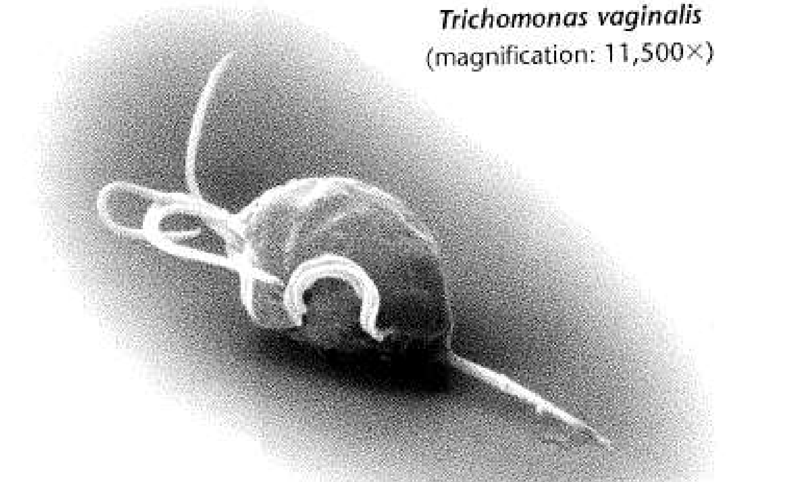
Key Concepts
- What are the distinguishing features of the major phyla of animallike protists?
- How do animallike protists harm other living things?

Vocabulary
- pseudopod
- amoeboid movement
- food vacuole • cilium
- trichocyst • macronucleus
- micronucleus • gullet
- anal pore • contractile vacuole
- conjugation

Reading Strategy: Building Vocabulary
Before you read, preview new vocabulary by skimming the section and making a list of the boldfaced terms. Leave space to make notes as you read.

Figure 20–3 Zooflagellates are animallike protists that swim using flagella.

Leishmania donovani
(magnification: 4800×)



Trichomonas vaginalis
(magnification: 11,500×)

Word Origins

Pseudopod comes from the Greek words *pseudes*, meaning "false" and *-pous*, meaning "foot." So *pseudopod* means "false foot." The suffix *-onym* comes from the Greek word *onoma*, meaning "name." **What do you think the word *pseudonym* means?**

Sarcodines

Members of the phylum Sarcodina, or sarcodines, move by means of temporary projections of cytoplasm known as **pseudopods** (SOO-doh-pahdz). **Sarcodines are animallike protists that use pseudopods for feeding and movement.** The best-known sarcodines are the amoebas, shown in **Figure 20–4.** Amoebas are flexible, active cells with thick pseudopods that extend out of the central mass of the cell. The cytoplasm of the cell streams into the pseudopod, and the rest of the cell follows. This type of locomotion is known as **amoeboid movement.**

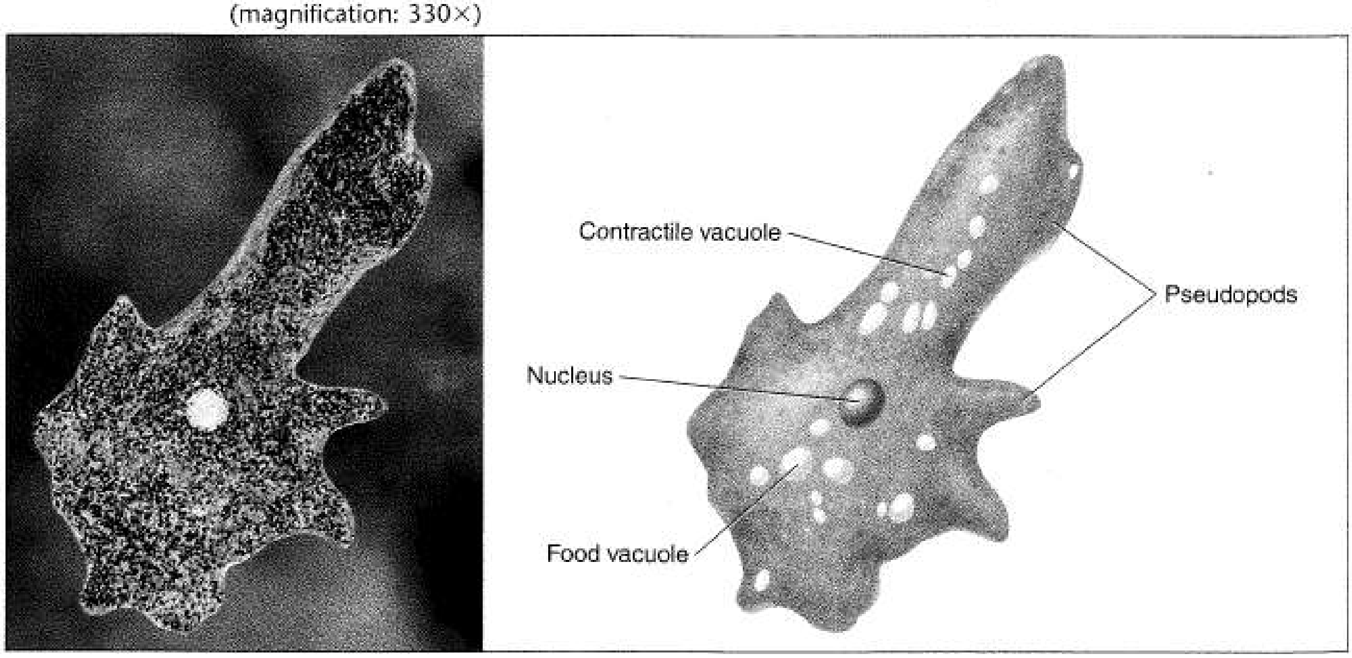
Amoebas can capture and digest particles of food and even other cells. They do this by surrounding their meal, then taking it inside themselves to form a food vacuole. A **food vacuole** is a small cavity in the cytoplasm that temporarily stores food. Once inside the cell, the material is digested rapidly and the nutrients are passed along to the rest of the cell. Amoebas reproduce by means of binary fission.

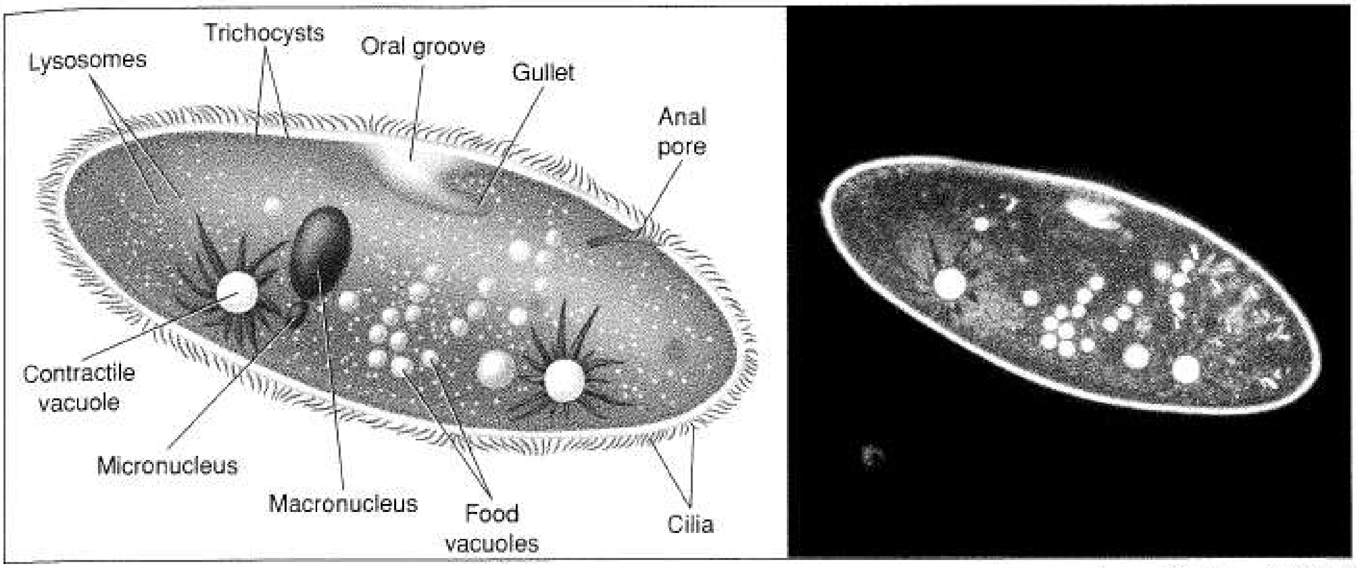
Foraminiferans, another member of Sarcodina, are abundant in the warmer regions of the oceans. Foraminiferans secrete shells of calcium carbonate ($CaCO_3$). As they die, the calcium carbonate from their shells accumulates on the bottom of the ocean. In some regions, thick deposits of foraminiferan shells have formed on the ocean floor. The white chalk cliffs of Dover, England, are huge deposits of foraminiferan skeletons that were raised above sea level by geological processes.

The sarcodines also include a group of organisms known as the heliozoans. The name *Heliozoan* means "sun animal." Heliozoans produce shells of silica (SiO_2). Thin spikes of cytoplasm, supported by microtubules, project from the shells, making heliozoans look like the sun's rays.

▼ **Figure 20–4 Sarcodines use pseudopods for feeding and movement.** *Amoeba proteus*, a common sarcodine, moves by first extending a pseudopod away from its body. The organism's cytoplasm then streams into the pseudopod. This shifting of the mass of the cell away from where it originated is a slow but effective way to move from place to place. Amoebas also use pseudopods to surround and ingest prey.

(magnification: 330×)





(magnification: 2500×)

▲ **Figure 20–5** **Ciliates use hairlike projections called cilia for feeding and movement.** Ciliates, including this paramecium, are covered with short hairlike cilia that propel them through the water. Cilia also line the organism's gullet and move its food—usually bacteria—to the organism's interior. There, the food particles are engulfed, forming food vacuoles. The contractile vacuoles collect and remove excess water.

Ciliates

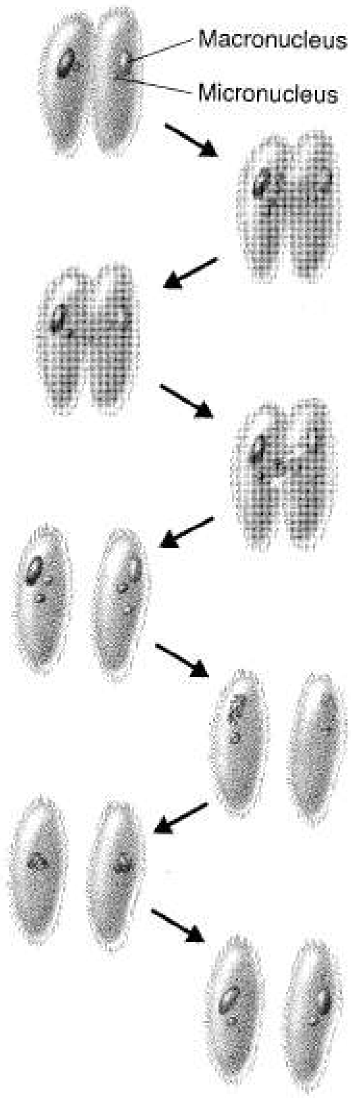
The phylum Ciliophora is named for **cilia** (singular: cilium), short hairlike projections similar to flagella. **Members of the phylum Ciliophora, known as ciliates, use cilia for feeding and movement.** The internal structure of cilia and flagella are identical. The beating of cilia, like the pull of hundreds of oars in an ancient ship, propels a cell rapidly through water.

Ciliates are found in both fresh and salt water. In fact, a lake or stream near your home might contain many different ciliates. Most ciliates are free living, which means that they do not exist as parasites or symbionts.

✓CHECKPOINT *What are cilia, and how do ciliates use them?*

Internal Anatomy Some of the best known ciliates belong to the genus *Paramecium*. A paramecium can be as long as 350 micrometers. Its cilia, which are organized into evenly spaced rows and bundles, beat in a regular, efficient pattern. The cell membrane of a paramecium is highly structured and has trichocysts just below its surface. **Trichocysts** (TRY-koh-sists) are very small, bottle-shaped structures used for defense. When a paramecium is confronted by danger, such as a predator, the trichocysts release stiff projections that protect the cell.

A paramecium's internal anatomy is shown in **Figure 20–5.** Like most ciliates, a paramecium possesses two types of nuclei: a macronucleus and one or more smaller micronuclei. Why does a ciliate need two types of nuclei? The **macronucleus** is a "working library" of genetic information—a site for keeping multiple copies of most of the genes that the cell needs in its day-to-day existence. The **micronucleus,** by contrast, contains a "reserve copy" of all of the cell's genes.



▲ **Figure 20–6** During conjugation, two paramecia attach themselves to each other and exchange genetic information. Conjugation increases genetic diversity. **Interpreting Graphics** *What structures do paramecia exchange during conjugation?*

Many ciliates obtain food by using cilia to sweep food particles into the **gullet,** an indentation in one side of the organism. The particles are trapped in the gullet and forced into food vacuoles that form at its base. The food vacuoles pinch off into the cytoplasm and eventually fuse with lysosomes, which contain digestive enzymes. The material in the food vacuoles is digested, and the organism obtains nourishment. Waste materials are emptied into the environment when the food vacuole fuses with a region of the cell membrane called the **anal pore.**

In fresh water, water may move into the paramecium by osmosis. This excess water is collected in vacuoles. These vacuoles empty into canals that are arranged in a star-shaped pattern around contractile vacuoles. **Contractile vacuoles** are cavities in the cytoplasm that are specialized to collect water. When a contractile vacuole is full, it contracts abruptly, pumping water out of the organism.

Conjugation Under most conditions, ciliates reproduce asexually by mitosis and binary fission. When placed under stress, however, paramecia may engage in a process known as **conjugation** that allows them to exchange genetic material with other individuals. The process of conjugation is shown in **Figure 20–6.**

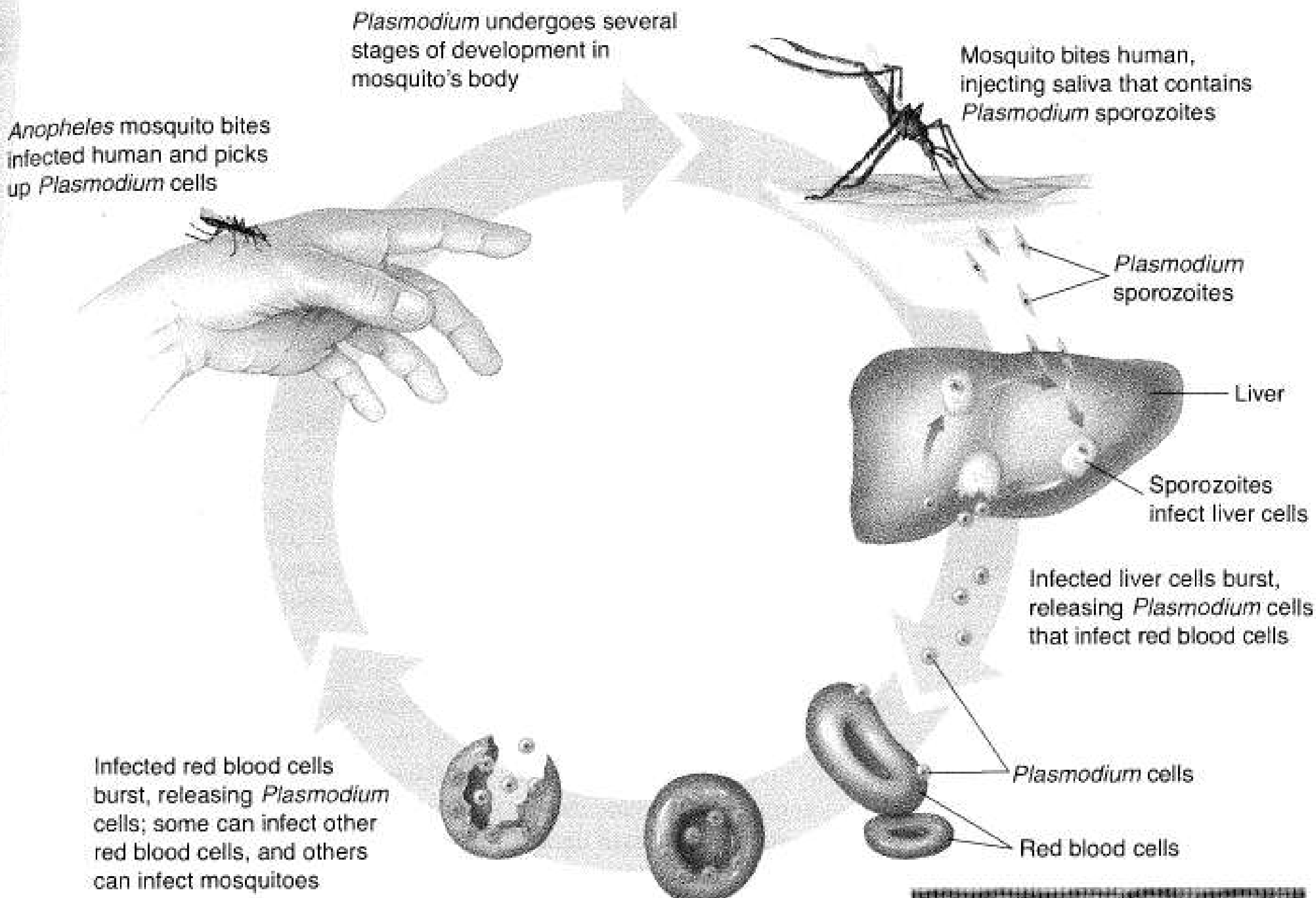
As conjugation begins, two paramecia attach themselves to each other. After meiosis of their diploid micronuclei, each organism is left with four haploid micronuclei. Three of these micronuclei disintegrate. The remaining micronucleus in each organism divides, forming a pair of identical micronuclei. The two organisms then exchange one micronucleus from their pair. The macronuclei disintegrate, and new macronuclei form from micronuclei. The two paramecia that participated in conjugation are both genetically changed from their former state. By the end of the process, they are genetically identical to each other.

Strictly speaking, conjugation is not reproduction because no new individuals are formed. It is, however, a sexual process because new combinations of genetic information are produced. Within a large population, the process of conjugation helps to create and maintain genetic diversity.

Sporozoans

While many animallike protists are free living, some are parasites of animals. **Members of the phylum Sporozoa do not move on their own and are parasitic.** Sporozoans are parasites of a wide variety of organisms, including worms, fish, birds, and humans. Many sporozoans have complex life cycles that involve more than one host. Sporozoans reproduce by means of sporozoites. Under the right conditions, a sporozoite can attach itself to a host cell, penetrate it, and then live within it as a parasite.

✓CHECKPOINT *How do sporozoans reproduce?*



Animallike Protists and Disease

Animallike protists are found throughout the world. They are some of the most common organisms in the oceans. They are also abundant in fresh water, on land, and in the bodies of larger organisms. Unfortunately for humans and for other organisms, many protists are disease-causing parasites. **Some animallike protists cause serious diseases, including malaria and African sleeping sickness.**

Malaria Malaria is one of the world's most serious infectious diseases. Between 300 and 500 million people suffer from malaria, and as many as 2 million people die from it every year. The sporozoan *Plasmodium,* which causes malaria, is carried by the female *Anopheles* mosquito.

The cycle of malarial infection is illustrated in **Figure 20–7.** When an infected mosquito bites a human, its saliva, which contains sporozoites of the parasite, enters the bloodstream. Once inside the body, *Plasmodium* infects liver cells and then red blood cells. *Plasmodium* multiplies rapidly within the infected cells. When red blood cells burst, they dump large amounts of toxins, or poisons, into the bloodstream. The toxins produce the chills and fever that are symptoms of malaria.

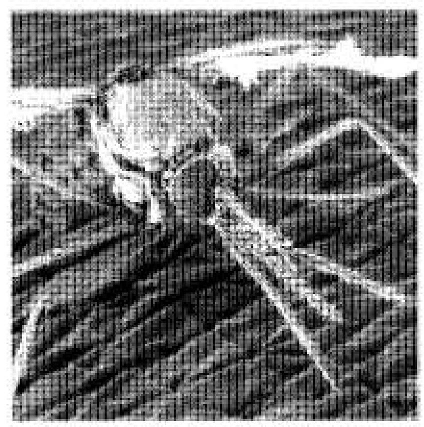
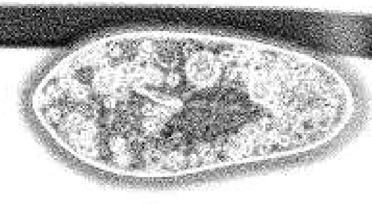


Figure 20–7 **Animallike protists can cause serious diseases, including malaria.** The bite of an *Anopheles* mosquito can transmit *Plasmodium* sporozoites. Once in the human body, *Plasmodium* infects liver cells and red blood cells and multiplies.

Quick Lab



How does a paramecium eat?

Materials paramecium culture, 2 dropper pipettes, microscope, microscope slide, coverslip, *Chlorella* culture, toothpick, carmine dye

Procedure

1. Use separate dropper pipettes to place a drop of paramecium culture and a drop of *Chlorella* (green alga) culture next to each other on a microscope slide.
2. Use a toothpick to transfer a few granules of carmine dye to the drops on the slide. Add a coverslip so that the two drops mix.
3. Place the slide on the stage of a microscope. Use the low-power objective to locate several paramecia.
4. Use the high-power objective to observe the contents and behavior of the paramecia.

Analyze and Conclude

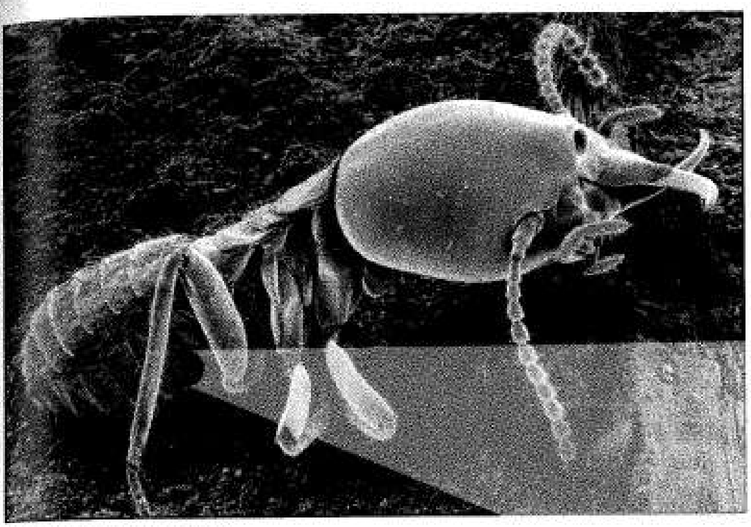
1. **Observing** Where did the *Chlorella* cells and carmine dye granules accumulate?
2. **Inferring** How do you think this happened to the *Chlorella* cells and carmine dye granules?
3. **Formulating Hypotheses** What process in the paramecia do you think resulted in this change?

Although drugs such as chloroquinine are effective against some forms of the disease, many strains of *Plasmodium* are resistant to these drugs. Medical scientists have developed a number of vaccines against malaria, but to date most are only partially effective. Therefore, for the immediate future, the best means of controlling malaria involve controlling the mosquitoes that carry it.

Other Protistan Diseases Zooflagellates of the genus *Trypanosoma* are responsible for African sleeping sickness. The trypanosomes that cause African sleeping sickness are spread by the bite of an insect known as the tsetse fly. Trypanosomes cause chills and rashes, and they can also infect nerve cells. Severe damage to the nervous system causes individuals to lose consciousness, lapsing into the deep and often fatal coma from which the disease gets its name. The control of the tsetse fly and the protist pathogens that it spreads is a major goal of health workers in Africa.

Amebic dysentery, which is characterized by severe diarrhea, is caused by an organism that looks like the harmless amoebas that you may find in a nearby pond. *Entamoeba*, a parasite spread by contaminated drinking water, can attack the wall of the intestine, causing extensive bleeding.

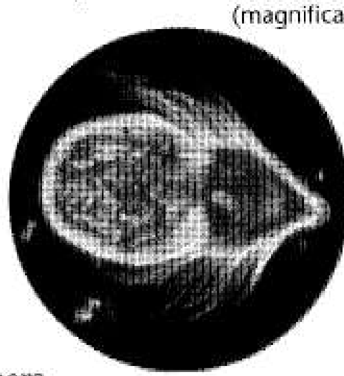
Amebic dysentery is most common in areas with poor sanitation, but even crystal-clear mountain streams may be contaminated with another flagellated pathogen, *Giardia*. *Giardia* produces tough microscopic cysts that can be killed only by boiling water thoroughly or by adding iodine to the water. Infection by *Giardia* can cause severe diarrhea and digestive system problems.



(magnification: 10×)

Figure 20–8 You can see particles of wood inside the body of *Trichonympha*, a wood-digesting protist (below). *Trichonympha* lives in the digestive systems of insects such as termites (left), allowing them to obtain nutrients from the wood they eat. **Predicting** ***What would happen if a termite's* Trichonympha *colony died?***

(magnification: about 250×)



Ecology of Animallike Protists

Many animallike protists play essential roles in the living world. Some live symbiotically within other organisms. Others recycle nutrients by breaking down dead organic matter. Many animallike protists live in seas and lakes, where they are eaten by tiny animals, which in turn serve as food for larger animals.

Some animallike protists are beneficial to other organisms. *Trichonympha*, shown in **Figure 20–8**, is a zooflagellate that lives within the digestive systems of termites. This protist makes it possible for the termites to eat wood. Termites do not have enzymes to break down the cellulose in wood. (Incidentally, neither do humans, so it does us little good to nibble on a piece of wood.) How, then, does a termite digest cellulose? In a sense, it doesn't. *Trichonympha* does.

Trichonympha and other organisms in the termites' gut manufacture cellulase. Cellulase is an enzyme that breaks the chemical bonds in cellulose and makes it possible for termites to digest wood. Thus, with the help of their protist partners, termites can munch away, busily digesting all the wood they can eat.

20–2 Section Assessment

1. **Key Concept** What are the four major phyla of animallike protists? How do members of each of these groups move?
2. **Key Concept** What animallike protists cause disease?
3. How does a macronucleus differ in function from a micronucleus?
4. Describe the role of animallike protists in the environment.
5. **Critical Thinking Comparing and Contrasting** Compare animallike protists that have flagella to those that have cilia.

iTEXT **Assessment** Use iText to review the important concepts in Section 20–2.

ALTERNATIVE ASSESSMENT

Creating a Pamphlet
Write and illustrate a public health pamphlet that features two types of waterborne protists that cause disease in humans. Your pamphlet should list symptoms associated with infection and present information on how to avoid waterborne diseases.

How Should Water Be Protected Against *Cryptosporidium*?

In April of 1993, more than 403,000 people in Milwaukee were infected, and 47 died, in an outbreak of severe intestinal diarrhea spread by public drinking water. The cause was a parasitic protist known as *Cryptosporidium* that attaches itself to the lining of the intestines. The epidemic was brought under control only by requiring the boiling of drinking water.

How did the water become contaminated with *Cryptosporidium*? No one knows for sure, but it's possible that runoff from an animal slaughterhouse had contaminated streams that flow into the city's water supply. Milwaukee's water was purified by filtration and chlorination and met the highest government standards. Unfortunately, *Cryptosporidium* is so small—only 4 to 7 µm in diameter—that it can pass through the high-volume filters used in public water purification systems. *Cryptosporidium* is also resistant to chlorine. What is the best way to protect the public against future outbreaks?

The Viewpoints

Purify at Point of Use

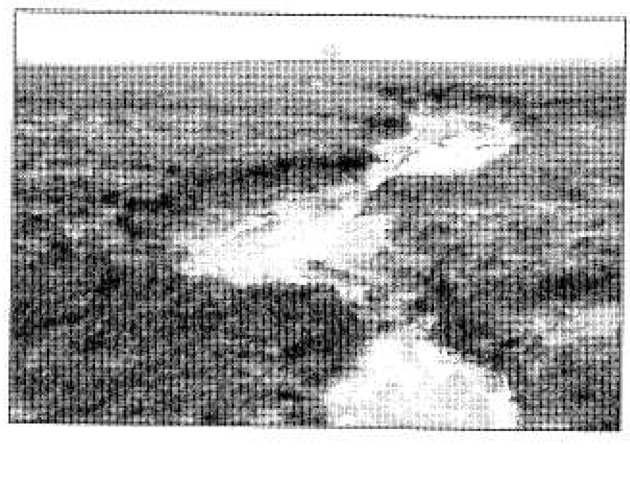
Because public water purification systems cannot control *Cryptosporidium*, public policy should focus on the individual. Consumers everywhere should be advised to purchase and install household filters. The best of these filters can remove 99.9 percent of particles larger than 1 µm, which should effectively eliminate *Cryptosporidium* from the drinking water of most users. In addition, people with weakened immune systems should be advised to boil all of their drinking water.

Purify and Protect the Supply

Point-of-use purification will never provide effective public protection against a Milwaukee-like outbreak. It is unrealistic to expect every houshold to install and maintain high-tech filtering systems. The best strategy is, therefore, to focus on the water supply itself. Water from streams that feed into public water supplies should be carefully tested for *Cryptosporidium* and vigorously protected against contaminant runoff. Even though absolute removal of all *Cryptosporidium* may not be possible, filters should be installed that reduce contamination to levels low enough to protect the public health.

You Decide

1. **Defining the Issue** What are the major public issues regarding water supply protection from the protist *Cryptosporidium*?
2. **Analyzing the Viewpoints** What are the options for the protection of drinking water? What are the benefits of each option? What are the costs? Who is affected by each option?
3. **Forming Your Opinion** Should public policy focus on the water supply or on point-of-use protection for individuals?
4. **Role-Playing** Suppose you were the head of the water supply board of a major American city that had a small amount of extra money in its annual budget. How would you advise the city council to allocate the money: to public education about *Cryptosporidium* or to research on better ways to lower the level of *Cryptosporidium* in the water supply?



20–3 Plantlike Protists: Unicellular Algae

Many protists contain the green pigment chlorophyll and carry out photosynthesis. Many of these organisms are highly motile, or able to move about. Despite this, the fact that they perform photosynthesis is so important that we group these protists in a separate category, the plantlike protists. Plantlike protists are commonly called "algae."

Some scientists place those algae that are more closely related to plants in the kingdom Plantae. In this textbook, we will consider all forms of algae, including those most closely related to plants, to be protists. There are seven major phyla of algae classified according to a variety of cellular characteristics. The first four phyla, which contain unicellular organisms, are discussed in this section. These four phyla are the euglenophytes, the dinoflagellates, the chrysophytes, and the diatoms. The last three phyla include many multicellular organisms and will be discussed in the next section.

Guide for Reading

Key Concepts
- What is the function of chlorophyll and accessory pigments in algae?
- What are the distinguishing features of the major phyla of unicellular algae?

Vocabulary
accessory pigment
eyespot
pellicle
phytoplankton

Reading Strategy: Summarizing As you read, make a list of the types of unicellular algae. Write a sentence about each type.

Chlorophyll and Accessory Pigments

One of the key characteristics used to classify algae is the type of photosynthetic pigments they contain. As you will remember, light is necessary for photosynthesis, and it is chlorophyll and the accessory pigments that trap the energy of sunlight.

Life in deep water poses a major difficulty for algae: a shortage of light. As sunlight passes through water, much of the light's energy is absorbed by the water. In particular, sea water absorbs large amounts of the red and violet wavelengths. Therefore, the light becomes dimmer and bluer as the depth of the water increases. Because chlorophyll *a* is most efficient at capturing red and violet light, the dim blue light that penetrates into deep water contains very little light energy that chlorophyll *a* can use.

In adapting to conditions of limited light, various groups of algae have evolved different forms of chlorophyll. Each form of chlorophyll—chlorophyll *a*, chlorophyll *b*, and chlorophyll *c*—absorbs different wavelengths of light. The result of this evolution is that algae can use more of the energy of sunlight than just the red and violet wavelengths.

▶ **Figure 20–9** **Chlorophyll and other pigments allow algae to collect and use energy from sunlight.** These green algae of the species *Acetabularia calyculus* live on the roots of mangrove trees in Florida.

Many algae also have compounds called **accessory pigments** that absorb light at different wavelengths than chlorophyll. Accessory pigments pass the energy they absorb to the algae's photosynthetic machinery. **Chlorophyll and accessory pigments allow algae to harvest and use the energy from sunlight.** Because accessory pigments reflect different wavelengths of light than chlorophyll, they give algae a wide range of colors.

Euglenophytes

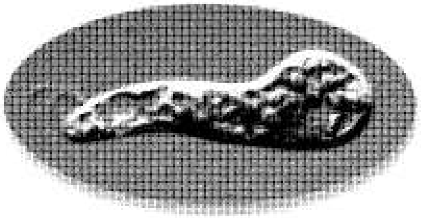
Members of the phylum Euglenophyta (yoo-glee-nuh-FYT-uh), or euglenophytes, are closely related to the animallike flagellates. **Euglenophytes are plantlike protists that have two flagella but no cell wall.** Although euglenophytes possess chloroplasts, in most other respects they are remarkably similar to zooflagellates.

The phylum takes its name from the genus *Euglena*. Euglenas are found in ponds and lakes throughout the world. A typical euglena, such as the one shown in **Figure 20–10,** is about 50 micrometers in length. Euglenas are excellent swimmers. Two flagella emerge from a gullet at one end of the cell, and the longer of these two flagella spins in a pattern that pulls the organism rapidly through the water. Near the gullet end of the cell is a cluster of reddish pigment known as the **eyespot,** which helps the organism find sunlight to power photosynthesis. If sunlight is not available, euglenas can also live as heterotrophs, absorbing the nutrients available in decayed organic material. Euglenas store carbohydrates in small storage bodies.

Euglenas do not have cell walls, but they do have an intricate cell membrane called a **pellicle.** The pellicle is folded into a series of ribbonlike ridges, each ridge supported by microtubules. The pellicle is tough and flexible, allowing euglenas to squirm and crawl through mud when there is not enough water to allow them to swim. Euglenas reproduce asexually by means of binary fission.

CHECKPOINT *What are eyespots, and why are they important to euglenas?*

▼ **Figure 20–10 Euglenophytes are plantlike protists that have two flagella but no cell wall.** The green structures inside the euglena shown are chloroplasts, which allow the organism to carry on photosynthesis when light is available. Euglenas are covered by a ridged pellicle. A pigmented eyespot helps the organism find the light that powers photosynthesis, while movement is produced by the flagella that protrude from one end of the organism. Like paramecia, euglenas expel excess water through a contractile vacuole.



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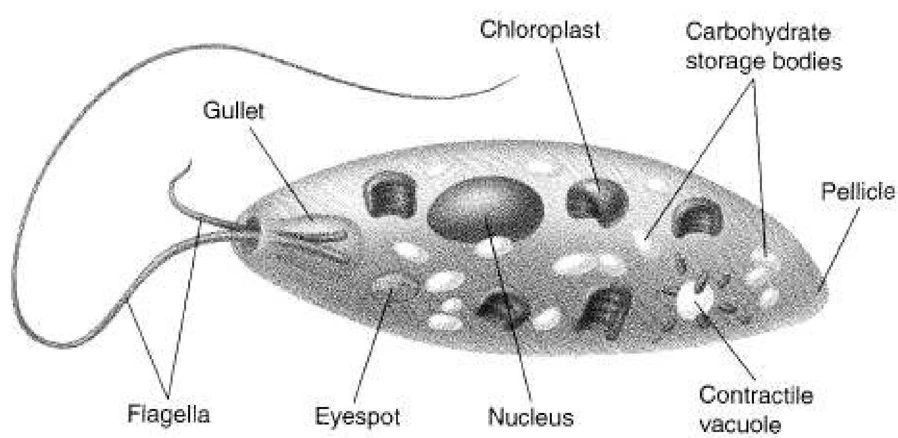
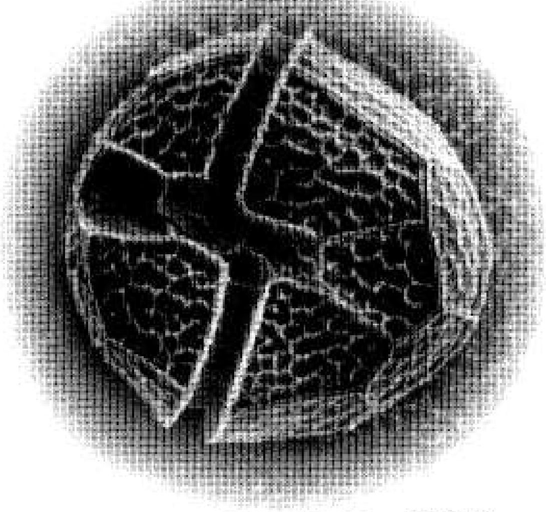


Dinoflagellates

Dinoflagellates are members of the phylum Pyrrophyta (pir-uh-FYT-uh). **About half of dinoflagellates are photosynthetic; the other half live as heterotrophs.** Dinoflagellates generally have two flagella, and these often wrap around the organism in grooves between two thick plates of cellulose that protect the cell, as shown in **Figure 20–11.** Most dinoflagellates reproduce asexually by binary fission.

Many dinoflagellate species are luminescent. When agitated by sudden movement in the water, many dinoflagellates give off light. Some areas of the ocean are so filled with dinoflagellates that the movement of an oar or the hull of a boat will cause the dark water to shimmer with a ghostly blue light. This luminescent property gives the phylum its name, *Pyrrophyta*, which means "fire plants."

Another interesting property of the dinoflagellates has to do with their genetic material. Like other organisms, dinoflagellates store genetic information in the form of DNA. In all other eukaryotic cells, however, that DNA is tightly bound with proteins known as histones. Dinoflagellates do not have histones; in fact, they are the only eukaryotes that do not. The reason for this difference, as well as an explanation of how the functions of histone proteins are carried out when none are present in dinoflagellates, remains a mystery.



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▲ **Figure 20–11** **Some dinoflagellates are photosynthetic, while others are heterotrophs.** The paired flagella of a dinoflagellate lie in grooves around its circumference, shown here in red. The flagella propel the organism, spinning, through the water.

Chrysophytes

The phylum Chrysophyta (kris-uh-FYT-uh) includes the yellow-green algae and the golden-brown algae. The chloroplasts of these organisms contain bright yellow pigments that give the phylum its name. *Chrysophyta* means "golden plants." **Members of the phylum Chrysophyta are a diverse group of plantlike protists that have gold-colored chloroplasts.**

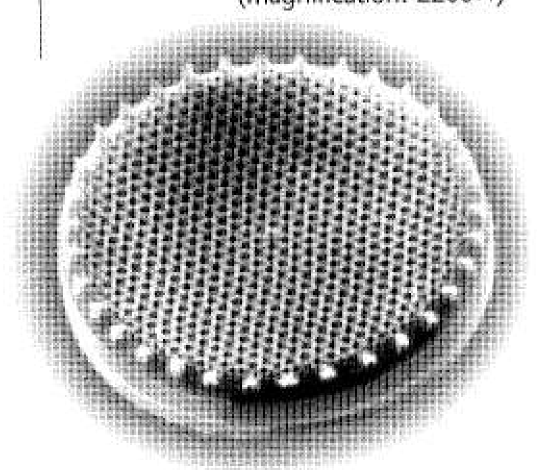
The cell walls of some chrysophytes contain the carbohydrate pectin rather than cellulose, while others contain both pectin and cellulose. Chrysophytes generally store food in the form of oil rather than starch. They reproduce both asexually and sexually. Most are solitary, but some form threadlike colonies.

Diatoms

Members of the phylum Bacillariophyta (bas-uh-lehr-ee-uh-FYT-uh), or diatoms, are among the most abundant organisms on Earth. They are also some of the most beautiful. **Diatoms produce thin, delicate cell walls rich in silicon (Si)—the main ingredient in glass.** These walls are shaped like the two sides of a petri dish or flat pillbox, with one side fitted snugly into the other. The cell walls have fine lines and patterns that almost seem to be etched, or carved, into their glasslike brilliance, as shown in **Figure 20–12.**

▼ **Figure 20–12** **Tiny jewellike diatoms such as this centric diatom have cell walls rich in silicon.**

(magnification: 2200×)

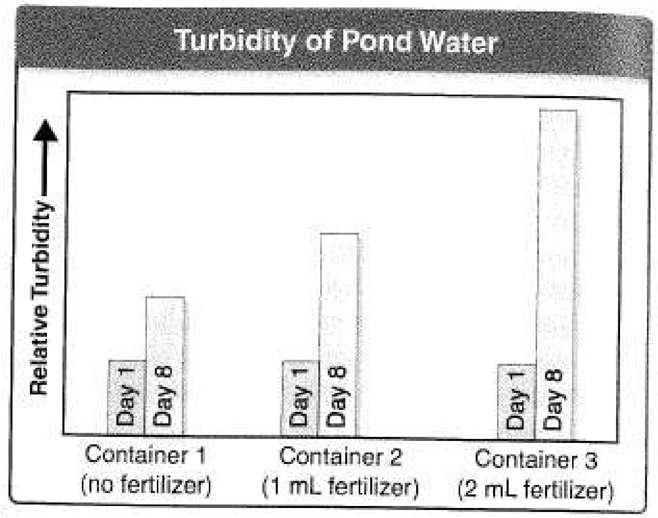


Analyzing Data

Fertilizers and Algae

The growth of algae in bodies of water is affected by the addition of plant fertilizers—a pollutant. A group of students collected three large, clear containers of pond water. They used a turbidity meter to measure the cloudiness of the water. The cloudiness, or turbidity, is a rough indicator of the amount of algae present.

The students did not add anything to the first container. To the second container, they added 1 mL of undiluted liquid plant fertilizer. To the third container, they added 2 mL of fertilizer. They then left the containers in a window for 1 week and measured the turbidity again on the eighth day. Their data are summarized in the table.



1. **Controlling Variables** What is the responding variable in the students' experiment?
2. **Designing Experiments** What is the role of the first container of water, to which no fertilizer was added?
3. **Using Tables and Graphs** In which container did the algae grow the most?
4. **Drawing Conclusions** What can you conclude about the effect of fertilizers on the growth of algae?

Ecology of Unicellular Algae

Plantlike protists are common in both fresh and salt water, and thus are an important part of freshwater and marine ecosystems. A few species of algae, however, can cause serious problems.

Plantlike protists play a major ecological role on Earth. Plantlike protists are important organisms whose position at the base of the food chain makes much of the diversity of aquatic life possible. They make up a considerable part of the **phytoplankton** (fy-toh-PLANK-tun), the population of small, photosynthetic organisms found near the surface of the ocean. About half of the photosynthesis that occurs on Earth is carried out by phytoplankton. Phytoplankton provide a direct source of nourishment for organisms as diverse as shrimp and whales. Even land animals such as humans obtain nourishment indirectly from the phytoplankton. When you eat a tuna fish sandwich, you are eating fish that fed on smaller fish that fed on still smaller animals that fed on plantlike protists.

Symbiotic Algae Unicellular algae form some spectacular symbiotic relationships with other organisms. For example, many types of coral contain intercellular dinoflagellates. These dinoflagellates allow the tiny coral animals to use the food products of photosynthesis. This food allows coral to grow in areas where nutrients are scarce. In turn, the dinoflagellates can feed on the waste products of the coral animals.

Other dinoflagellates make their homes within other organisms. In the giant clam *Tridacna gigas*, an organ called the mantle contains large numbers of symbiotic photosynthetic protists. These dinoflagellates are positioned so that they gather as much sunlight as possible, thereby increasing the nutrient benefit to the clam.

Algal Blooms Because many protists, including euglenophytes, absorb organic material directly and use it for food, they grow rapidly in regions where sewage is discharged. These protists play a vital role in recycling sewage and other waste materials. When the amount of waste is excessive, however, populations of euglenophytes and other algae may grow into enormous masses known as blooms. While not harmful in themselves, these algal blooms quickly deplete the water of nutrients, and the cells begin to die in great numbers. The decomposition of these dead algae can rob water of its oxygen, choking its resident fish and invertebrate life.

Great blooms of the dinoflagellates *Gonyaulax* and *Gymnodinium* have occurred in recent years on the east coast of the United States, although scientists are not sure of the reason. These blooms, such as the one shown in **Figure 20–13,** are known as "red tides." These species produce a potentially dangerous toxin. Filter-feeding shellfish such as clams can trap *Gonyaulax* and *Gymnodinium* for food and become filled with the toxin. Eating shellfish from water infected with red tide can cause serious illness, paralysis, and even death.

Figure 20–13 Blooms of the dinoflagellate *Gymnodinium* (inset) can produce red tides. *Gymnodinium* contains a toxin that becomes concentrated in the tissue of filter feeders such as clams and oysters. **Inferring** ***How can red tides be harmful to humans?***

20–3 Section Assessment

1. **Key Concept** What do chlorophyll and accessory pigments do in algae?
2. **Key Concept** What are the four phyla of unicellular plantlike protists?
3. What is the role of unicellular algae in the environment?
4. How do most unicellular algae get food? How does this differ from the way most animallike protists get food?
5. **Critical Thinking Problem Solving** Identify two ways to reduce the problem of algal blooms in fresh water.

iTEXT Assessment Use iText to review the important concepts in Section 20–3.

Take It to the NET

Read about a group of algae called choanoflagellates. Then, write a brief report on the structure and evolutionary significance of these protists. Use the links provided in the Biology area at the Prentice Hall Web site for help in completing this activity: **www.phschool.com**

20–4 Plantlike Protists: Red, Brown, and Green Algae

Guide for Reading

Key Concepts
- What are the distinguishing features of the major phyla of multicellular algae?
- How do multicellular algae reproduce?

Vocabulary
phycobilin
filament
alternation of generations
gametophyte
spore
sporophyte

Reading Strategy: Outlining Before you read, use the blue and green headings to make an outline about multicellular algae. As you read, add phrases or a sentence after each heading to provide key information.

Have you ever taken a walk along a rocky beach at low tide? As the water recedes, in many places it reveals a damp forest of green and brown "plants" clinging to the rocks. These seaweeds, as they are generally called, have the size, color, and appearance of plants, but technically they are not plants. They are actually algae. Unlike the algae you studied in the last section, however, most of these algae are multicellular, like plants. They also have reproductive cycles that are sometimes very similar to those of plants. Many of them have cell walls and photosynthetic pigments that are identical to those of plants. Many of these algae also possess highly specialized tissues.

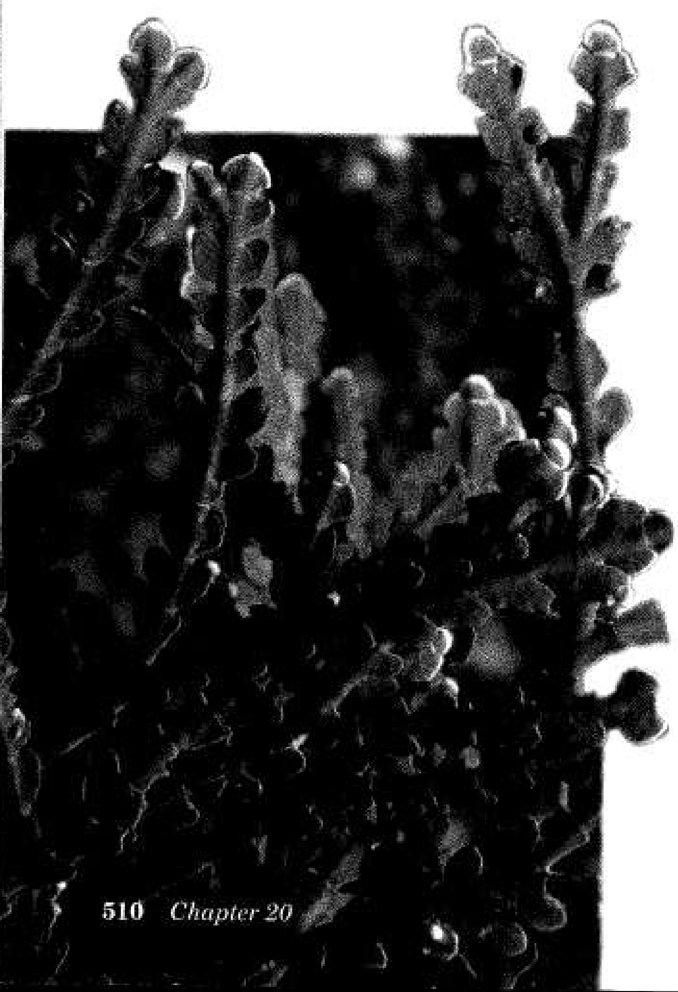
The three phyla of algae that are largely multicellular are commonly known as red algae, brown algae, and green algae. Although there are many differences among these phyla, the most important ones, for which the groups are named, involve their photosynthetic pigments.

Red Algae

Red algae are members of the phylum Rhodophyta (roh-duh-FYT-uh), meaning "red plants." **Red algae are able to live at great depths due to their efficiency in harvesting light energy. Red algae contain chlorophyll *a* and reddish accessory pigments called phycobilins. Phycobilins** (fy-koh-BIL-inz) are especially good at absorbing blue light, enabling red algae to live deeper in the ocean than many other photosynthetic algae. Many red algae are actually green, purple, or reddish black, depending upon the other pigments they contain. Red algae are an important group of marine algae that can be found in waters from the polar regions to the tropics. The highly efficient light-harvesting pigments in these algae enable them to grow anywhere from the ocean's surface to depths of up to 260 meters.

Most species of red algae are multicellular, and all species have complex life cycles. Red algae lack flagella and centrioles.

One common red alga is *Chondrus crispus*, or Irish moss. It grows in tide pools and on rocky coastlines. Other red algae, known as the coralline algae and shown in **Figure 20–14**, play an important role in the formation of coral reefs by helping to stabilize them.



◀ **Figure 20–14** **Red algae contain chlorophyll *a* and reddish pigments called phycobilins.** Coralline algae, a type of red alga, collect calcium carbonate in their cell walls, giving them a tough, stony texture.

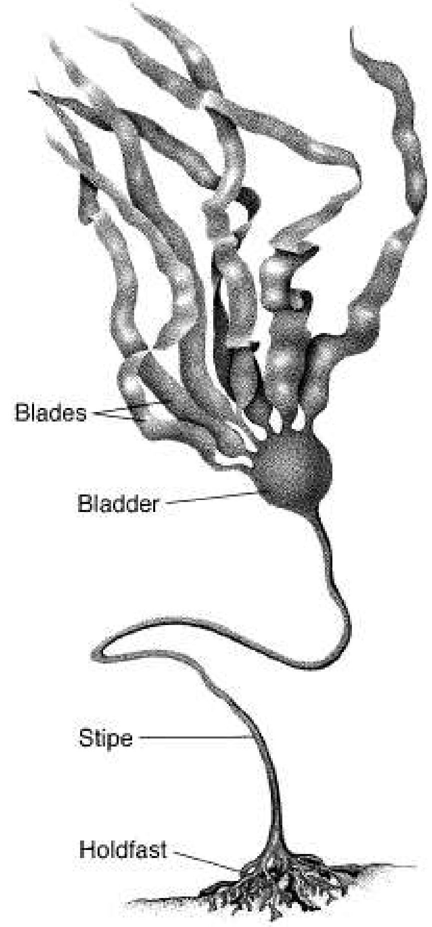
Brown Algae

Brown algae belong to the phylum Phaeophyta (fay-uh-FYT-uh), meaning "dusky plants." **Brown algae contain chlorophyll *a* and *c*, as well as a brown accessory pigment, fucoxanthin.** The combination of fucoxanthin (fyoo-koh-ZAN-thin) and chlorophyll *c* gives most of these algae a dark, yellow-brown color. Brown algae are the largest and most complex of the algae. All brown algae are multicellular and most are marine, commonly found in cool, shallow coastal waters of temperate or arctic areas.

The largest known alga is giant kelp, a brown alga that can grow to more than 60 meters in length. Another brown alga called *Sargassum* forms huge floating mats many kilometers long in an area of the Atlantic Ocean near Bermuda known as the Sargasso Sea. Bunches of *Sargassum* often drift on currents to beaches in the Caribbean and southern United States.

One of the most common brown alga is *Fucus*, or rockweed, found along the rocky coast of the eastern United States. Each *Fucus* plant has a holdfast, a structure that attaches the alga to the bottom. The body of the alga consists of flattened stemlike structures called stipes, leaflike structures called blades, and gas-filled swellings called bladders, which float and keep the algae upright in the water. **Figure 20–15** shows the structures of a brown alga.

CHECKPOINT *What does a holdfast do?*

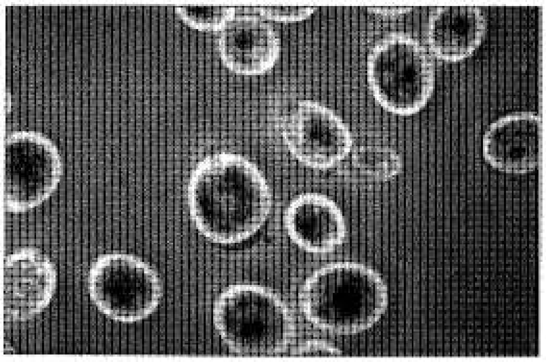


▲ **Figure 20–15** Brown algae contain chlorophyll *a* and *c*, plus fucoxanthin, a brown pigment.

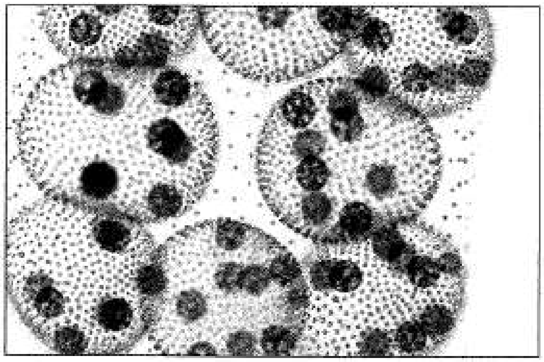
Green Algae

Green algae are members of the phylum Chlorophyta (klawr-uh-FYT-uh), which means "green plants" in Greek. **Green algae share many characteristics with plants, including their photosynthetic pigments and cell wall composition.** Green algae have cellulose in their cell walls, contain chlorophyll *a* and *b*, and store food in the form of starch, just like land plants. One stage in the life cycle of mosses—small land plants you will learn about in the next unit—looks remarkably like a tangled mass of green algae strands. All these characteristics lead scientists to hypothesize that the ancestors of modern land plants looked a lot like certain species of living green algae. Unfortunately, algae rarely form fossils, so there is no single specific fossil that scientists can call an ancestor of both living algae and mosses. However, scientists think that mosses and green algae shared such a common algaelike ancestor millions of years ago.

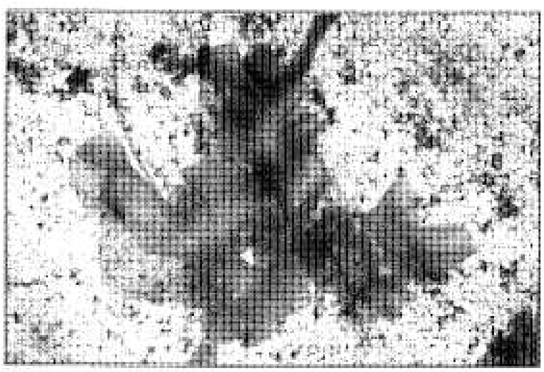
Green algae are found in fresh and salt water, and even in moist areas on land. Many species live most of their lives as single cells. Others form colonies, groups of similar cells that are joined together but show few specialized structures. A few green algae are multicellular and have well-developed specialized structures.



Chlamydomonas (magnification: 1000×)



Volvox (magnification: 450×)



Ulva

Figure 20–16 **Green algae have the same photosynthetic pigments and cell wall compositions as plants.** *Chlamydomonas* is a unicellular green alga that lives in ponds. Delicate spherical colonies of the green alga *Volvox* live in fresh water. New colonies can develop within existing colonies and are released when the older colony ruptures. *Ulva* is a multicellular green alga that lives along seacoasts.

Unicellular Green Algae *Chlamydomonas* (kluh-mid-uh-MOHN-uz), a typical single-celled green alga, grows in ponds, ditches, and wet soil. *Chlamydomonas* is a small egg-shaped cell with two flagella and a single large, cup-shaped chloroplast. Within the base of the chloroplast is a region that synthesizes and stores starch. *Chlamydomonas* lacks the large vacuoles found in the cells of land plants. Instead, it has two small contractile vacuoles. *Chlamydomonas* and two other green algae are shown in **Figure 20–16.**

Colonial Green Algae Several species of green algae live in multicellular colonies. The freshwater alga *Spirogyra* forms long threadlike colonies called **filaments,** in which the cells are stacked almost like soda cans placed end to end.

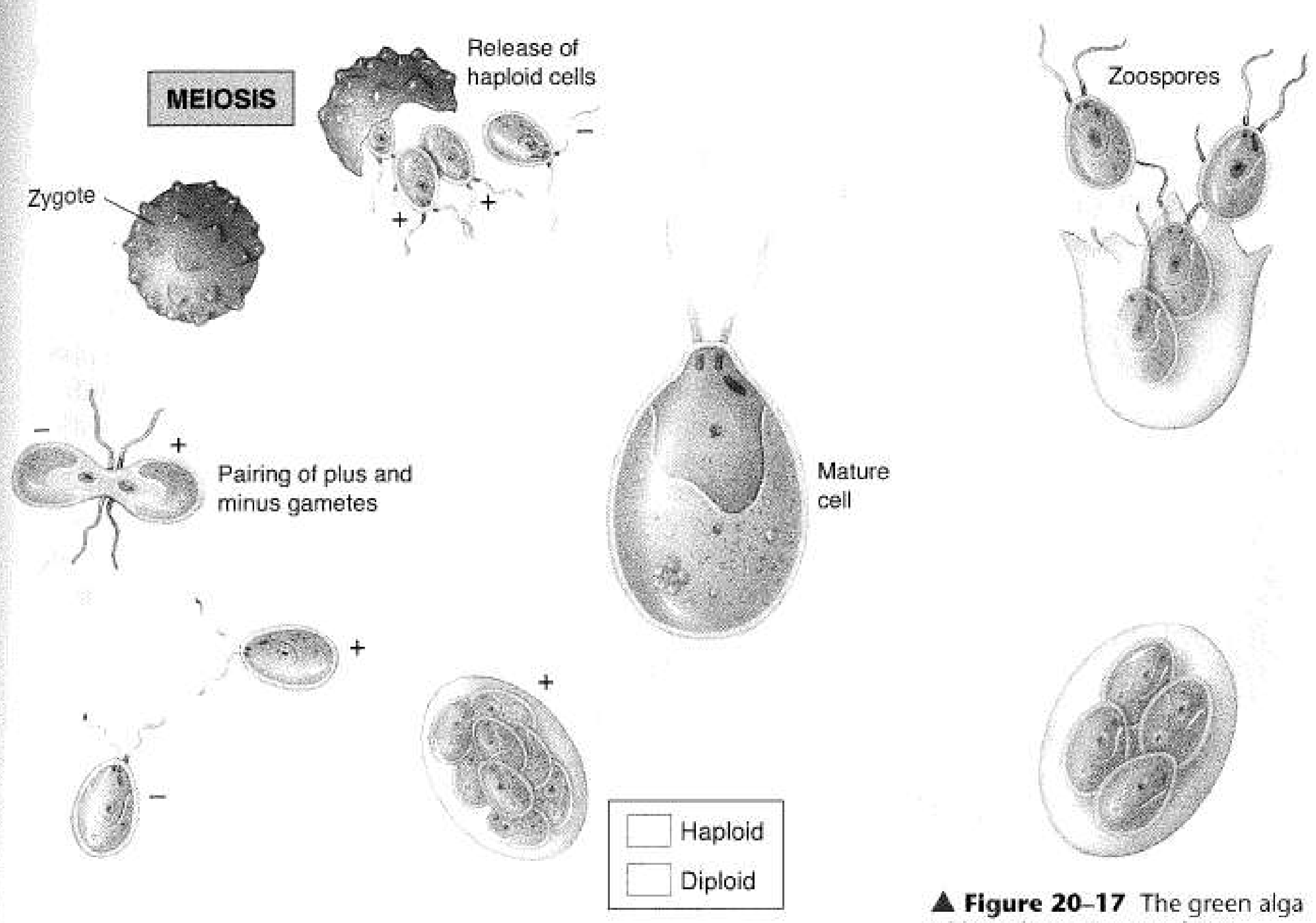
Volvox colonies are more elaborate, consisting of as few as 500 to as many as 50,000 cells arranged to form hollow spheres. The cells in a *Volvox* colony are connected to one another by strands of cytoplasm, enabling them to coordinate movement. When the colony moves, cells on one side of the colony "pull" with their flagella, and the cells on the other side of the colony have to "push." Although most cells in a *Volvox* colony are identical, a few gamete-producing cells are specialized for reproduction. Because it shows some cell specialization, *Volvox* straddles the fence between colonial and multicellular life.

Multicellular Green Algae *Ulva*, or "sea lettuce," is a bright-green marine alga that is commonly found along rocky seacoasts. *Ulva* is a true multicellular organism, containing several specialized cell types. Although the body of *Ulva* is only two cells thick, it is tough enough to survive the pounding of waves on the shores where it lives. A group of cells at its base forms holdfasts that attach *Ulva* to the rocks.

Reproduction in Green Algae

The life cycles of many algae include both a diploid and a haploid generation. Recall from Chapter 11 that diploid cells have two sets of chromosomes, whereas haploid cells have a single set. Many algae switch back and forth between haploid and diploid stages during their life cycles, in a process known as **alternation of generations.** Many species also shift back and forth between sexual and asexual forms of reproduction.

Reproduction in *Chlamydomonas* The single-celled *Chlamydomonas* spends most of its life in the haploid stage. As long as its living conditions are suitable, this haploid cell reproduces asexually, producing cells called zoospores by mitosis. As you learned in Chapter 10, reproduction by mitosis is asexual. The two haploid daughter cells produced by mitosis are genetically identical to the single haploid cell that entered mitosis.



▲ **Figure 20–17** The green alga *Chlamydomonas* reproduces asexually by producing zoospores and sexually by producing zygotes. **Interpreting Graphics** *Which form of reproduction includes a diploid organism that can survive adverse conditions?*

If conditions become unfavorable, *Chlamydomonas* can also reproduce sexually. The life cycle of *Chlamydomonas* is shown in **Figure 20–17.** The haploid cells continue to undergo mitosis, but instead of releasing zoospores, the cells release gametes. The gametes, which look identical, are of two opposite mating types, + (plus) and − (minus). During sexual reproduction, the gametes gather in large groups. Then + and − gametes form pairs that soon move away from the group. The paired gametes join flagella and spin around in the water. Both members of the pair then shed their cell walls and fuse, forming a diploid zygote.

The zygote sinks to the bottom of the pond and grows a thick protective wall. Within this protective wall, *Chlamydomonas* can survive freezing or drying conditions that would ordinarily kill it. When conditions once again become favorable, the zygote begins to grow. It divides by meiosis to produce four flagellated haploid cells. These haploid cells can swim away, mature, and reproduce asexually. Thus, during its life cycle, *Chlamydomonas* alternates between a haploid stage, in which it spends most of its life, and a brief diploid stage, represented by the zygote cell.

CHECKPOINT *What two types of gametes does* Chlamydomonas *produce?*

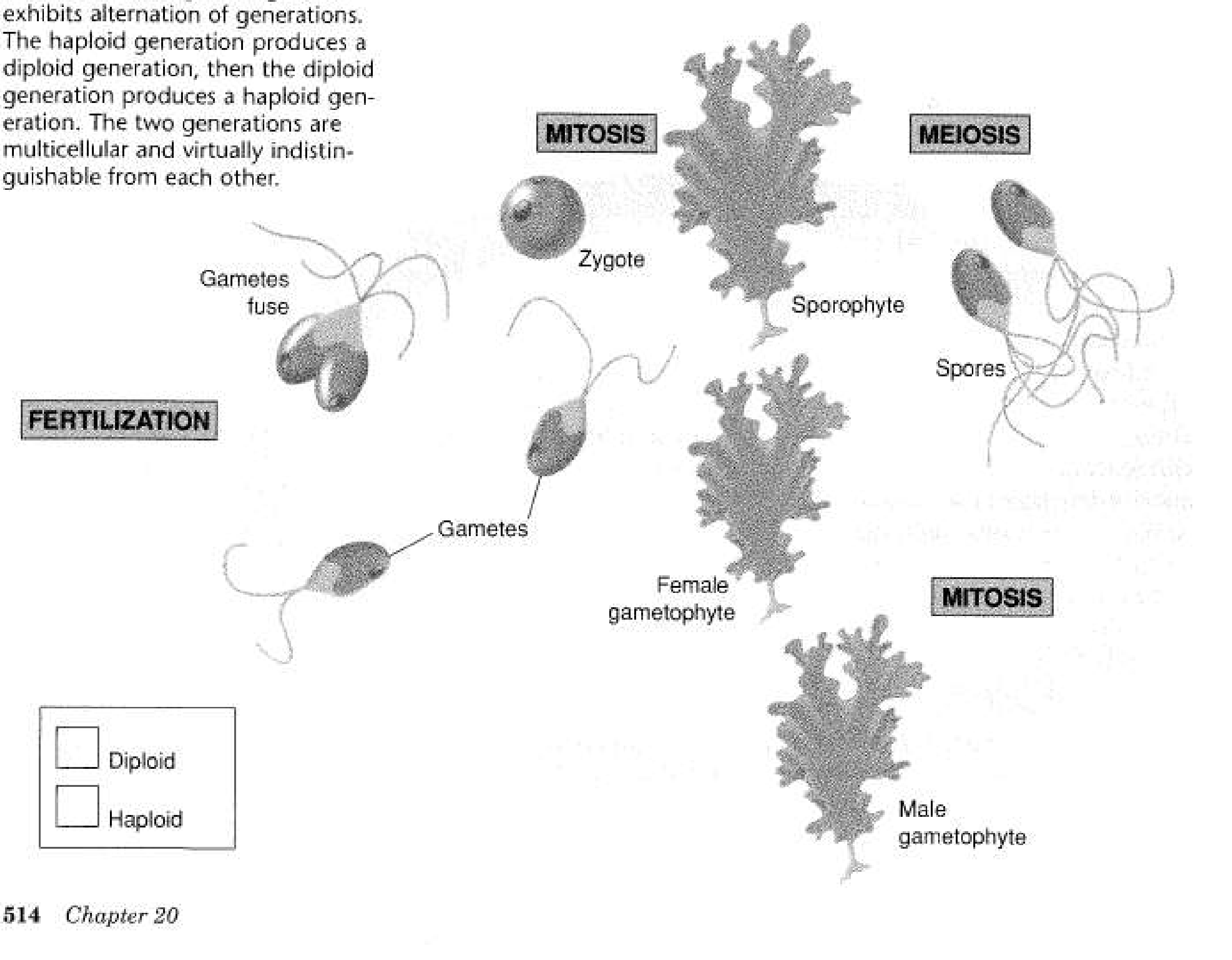
Reproduction in *Ulva* The life cycle of the green alga *Ulva* involves an alternation of generations in which both the diploid and haploid phases are large, multicellular organisms. In fact, the haploid and diploid phases of *Ulva* are so similar that only an expert can tell them apart!

The haploid phase of *Ulva* produces two forms of gametes—male and female. Because they produce gametes, the haploid forms of *Ulva* are known as **gametophytes** (guh-MEET-uh-fyts), or gamete-producing plants.

When male and female gametes fuse, they produce a diploid zygote cell, which then grows into a large, diploid multicellular *Ulva*. The diploid *Ulva* undergoes meiosis to produce haploid reproductive cells called **spores**. Each of these spores is able to grow into a new individual without fusing with another cell. Because the diploid *Ulva* produces spores, it is known as a **sporophyte** (SPOH-ruh-fyt), or spore-producing organism.

Take a close look at the life cycle of *Ulva* in **Figure 20–18**, because the alternation of generations it displays is a pattern you will see repeated over and over again in the plants. *Ulva*'s life cycle includes two separate phases that alternate in a regular pattern: sporophyte, then gametophyte, then sporophyte again. Complex life cycles involving alternation of generations are characteristic of the members of the plant kingdom. This is one of the reasons some biologists favor classifying multicellular algae such as *Ulva* as plants.

▼ Figure 20–18 The life cycles of most algae include both diploid and haploid generations. The multicellular green alga *Ulva* exhibits alternation of generations. The haploid generation produces a diploid generation, then the diploid generation produces a haploid generation. The two generations are multicellular and virtually indistinguishable from each other.



Human Uses of Algae

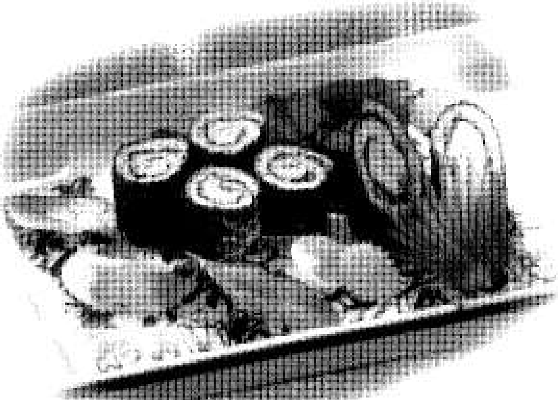
Algae are a major food source for life in the oceans. Algae have even been called the "grasses" of the seas, because they make up much of the base of the food chain upon which sea animals "graze." The enormous brown kelp forests off the coasts of North America are home to many animal species.

Algae produce much of Earth's oxygen through photosynthesis. Scientists calculate that about half of all the photosynthesis that occurs on Earth is performed by algae. This fact alone makes algae one of the most important groups of organisms on the entire planet.

Over the years, people have learned to use algae—and the chemicals produced by algae—in many different ways. Many species of algae are rich in vitamin C and iron. Chemicals in algae are used to treat stomach ulcers, high blood pressure, arthritis, and other health problems.

Have you ever eaten algae? Almost certainly, your answer should be yes. In Japan, the red alga *Porphyra* is grown on special marine farms. Dried *Porphyra*—called *nori* in Japanese—is dark green and paper-thin. Nori is used to wrap portions of rice, fish, and vegetables to make sushi, as shown in **Figure 20–19.** You say you've never had sushi? Well, you've probably eaten ice cream, salad dressing, pudding, or a candy bar. Other products from algae are used in pancake syrups and eggnog.

Industry has even more uses for algae. Chemicals from algae are used to make plastics, waxes, transistors, deodorants, paints, lubricants, and even artificial wood. Algae even have an important use in scientific laboratories. The compound agar, derived from certain seaweeds, thickens the nutrient mixtures scientists use to grow bacteria and other microorganisms.



▲ **Figure 20–19** People have found many different uses for algae. The red alga *Porphyra* is used as a wrapper in Japanese sushi rolls. Ice cream often contains algin, a thickener made from brown algae. **Predicting** ***How would your life be different without products made from algae?***

20–4 Section Assessment

1. **Key Concept** Describe the main features of the major phyla of multicellular algae.
2. **Key Concept** What is alternation of generations?
3. How are multicellular algae important at a global level?
4. Why can red algae live in deeper water than green algae?
5. **Critical Thinking Classifying** Do you think green algae should be classified as plants? Give reasons for your answer.

iTEXT Assessment Use iText to review the important concepts in Section 20–4.

ALTERNATIVE ASSESSMENT

Organizing Information Make a poster illustrating three types of multicellular algae. Your poster should have detailed drawings or photographs of each group. Each illustration must show the correct classification and have two written characteristics of each group.

20–5 Funguslike Protists

Guide for Reading

Key Concepts
- What are the similarities and differences between funguslike protists and fungi?
- What are the defining characteristics of the slime molds and water molds?

Vocabulary
cellular slime mold
acellular slime mold
plasmodium
hypha
zoosporangium
antheridium
oogonium

Reading Strategy: Predicting Before you read, preview the life cycles in **Figures 20–22** and **20–23.** Predict how these life cycles are similar and how they are different.

If you look closely at the debris-laden floor of a forest after several days of rain, you may see glistening patches of what looks like brightly colored mold. Funguslike protists grow in damp, nutrient-rich environments and absorb food through their cell membranes, much like fungi. In fact, these organisms have sometimes been classified as fungi, even though their cellular structure more closely resembles that of the protists. **Like fungi, the funguslike protists are heterotrophs that absorb nutrients from dead or decaying organic matter. But unlike most true fungi, funguslike protists have centrioles. They also lack the chitin cell walls of true fungi.** The funguslike protists include the cellular slime molds, the acellular slime molds, and the water molds.

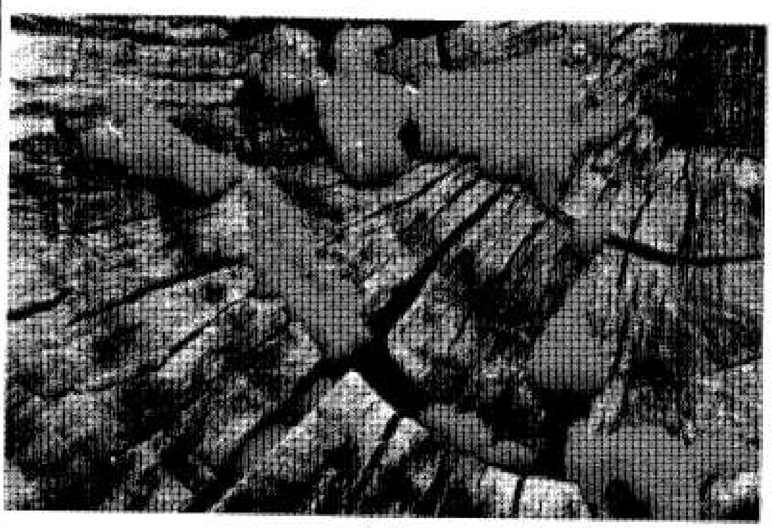
Slime Molds

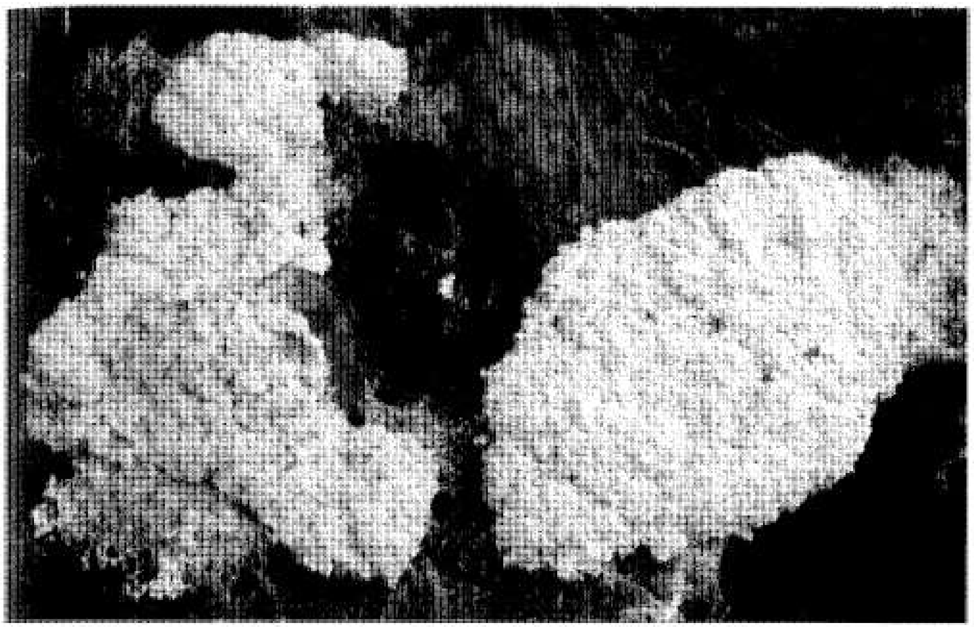
Slime molds are found in places that are damp and rich in organic matter, such as the floor of a forest or a backyard compost pile. **Slime molds are funguslike protists that play key roles in recycling organic material.** At one stage of their life cycle, slime molds look just like amoebas. At other stages, they form moldlike clumps that produce spores, almost like fungi.

Two broad groups of slime molds are recognized. The individual cells of **cellular slime molds** remain distinct—separated by cell membranes—during every phase of the mold's life cycle. Slime molds that pass through a stage in which their cells fuse to form large cells with many nuclei are called **acellular slime molds.**

Cellular Slime Molds Cellular slime molds belong to the phylum Acrasiomycota (ak-ruh-see-oh-my-KOH-tuh). They spend most of their lives as free-living cells that are not easily distinguishable from soil amoebas. In nutrient-rich soils, these amoeboid cells reproduce rapidly. When their food supply is exhausted, they send out chemical signals that attract other cells of the same species. Within a few days, thousands of cells aggregate into a large sluglike colony that begins to function like a single organism. The colony migrates for several centimeters, then stops and produces a fruiting body, a slender reproductive structure that produces spores. Eventually, the spores are scattered from the fruiting body. Each spore gives rise to a single amoeba-like cell that starts the cycle all over again, as shown in **Figure 20–22.**

▼ **Figure 20–20 Funguslike protists lack chlorophyll and absorb nutrients from dead organic matter.** Slime molds like this red raspberry slime mold are often found in the damp, shaded environments preferred by many fungi.



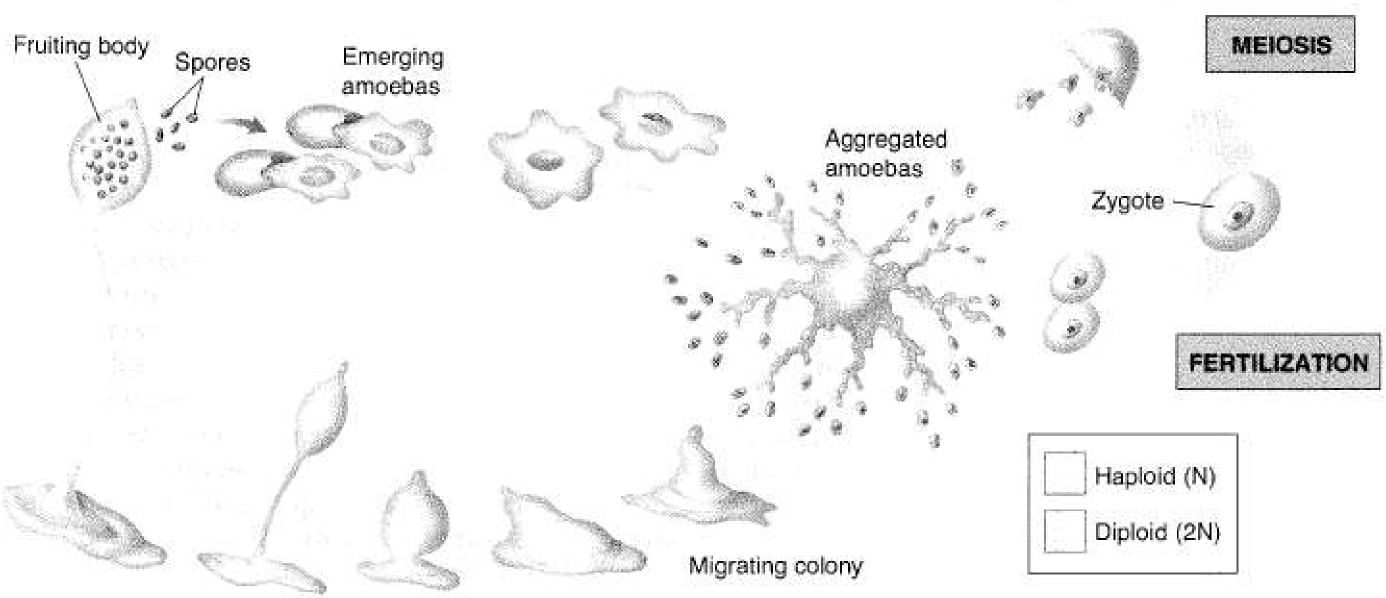


◀ **Figure 20–21** **Slime molds help recycle organic matter.** The two main groups of slime molds are cellular slime molds and acellular slime molds.

In many ways, these remarkable organisms challenge our understanding of what it means to be multicellular. During much of their life cycle, cellular slime molds are unicellular organisms that look and behave like animallike protists. When they aggregate, however, they act very much like multicellular organisms. Slime molds have been especially interesting to biologists who study how cells send signals and regulate development. They have kept biologists busy for decades, but their secrets are still not fully understood.

CHECKPOINT *Why is it difficult to classify cellular slime molds as unicellular or multicellular?*

▼ **Figure 20–22** Cellular slime molds reproduce asexually. **Interpreting Graphics** *Is most of the cellular slime mold life cycle haploid or diploid?*



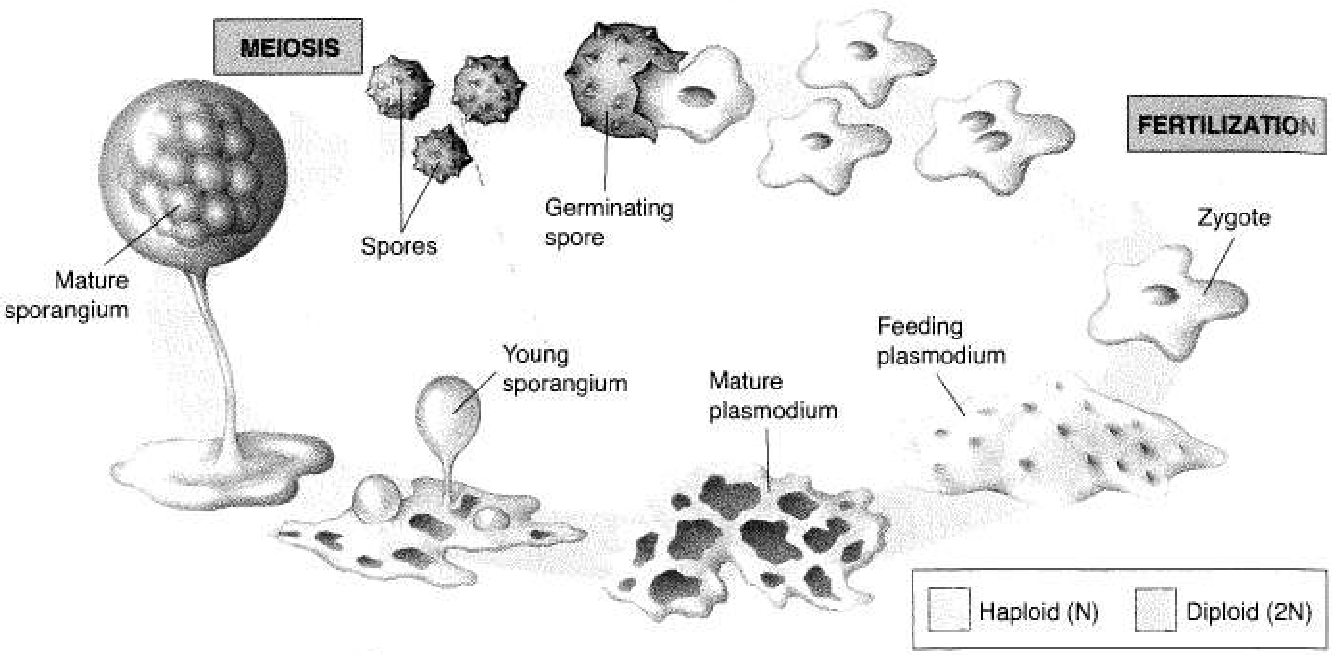


Figure 20–23 The plasmodium of an acellular slime mold is the collection of many amoeba-like organisms, but their separateness is not preserved. The plasmodium is a multinucleate structure contained in a single cell membrane. The plasmodium will eventually produce sporangia, which in turn will produce haploid spores. Upon pairing up and fusing, these result in new diploid amoeba-like cells. **Interpreting Graphics** ***What stage of the life cycle is shown in the photograph?***

Acellular Slime Molds Acellular slime molds belong to the phylum Myxomycota (myk-suh-my-KOH-tuh). Like cellular slime molds, acellular slime molds begin their life cycles as amoeba-like cells. However, when they aggregate, their cells fuse to produce structures with many nuclei.

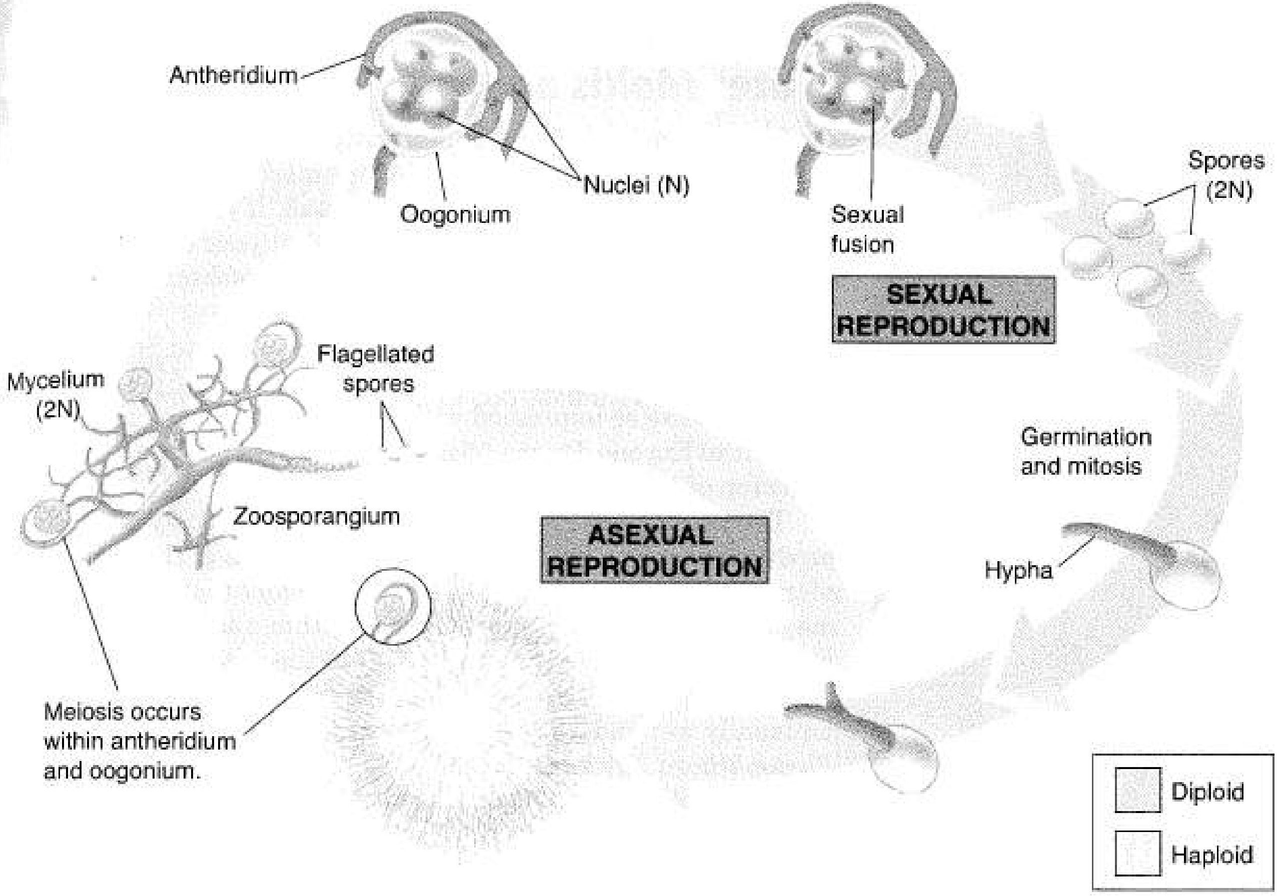
These structures are known as **plasmodia** (singular: plasmodium). The large plasmodium of an acellular slime mold, such as the one shown in **Figure 20–23,** is actually a single structure with many nuclei. A plasmodium may grow as large as several meters in diameter!

Eventually, small fruiting bodies, or sporangia, spring up from the plasmodium. The sporangia produce haploid spores by meiosis. These spores scatter to the ground where they germinate into flagellated cells. The flagellated cells then fuse to produce diploid zygotes that repeat the cycle.

Water Molds

If you have seen white fuzz growing on the surface of a dead fish in the water, you have seen a water mold in action. Water molds, or oomycetes, are members of the phylum Oomycota (oh-oh-my-KOH-tuh). **Oomycetes thrive on dead or decaying organic matter in water and are plant parasites on land.** Oomycetes are commonly known as water molds, but they are not true fungi. Water molds produce thin filaments known as **hyphae.** These hyphae do not have walls between their cells; as a result, water mold hyphae are multinucleate. In addition, water molds have cell walls made of cellulose and produce motile spores, two characteristics that fungi do not have.

Water molds have both sexual and asexual phases in their life cycle, as shown in **Figure 20–24.** In asexual reproduction, portions of the hyphae develop into **zoosporangia** (singular: zoosporangium), which are spore cases. Each zoosporangium



▲ **Figure 20–24** **Water molds live on decaying organic matter in water.** Water molds reproduce both asexually and sexually. During asexual reproduction, flagellated spores are produced by the diploid (2N) mycelium. These spores grow into new mycelia. During sexual reproduction, a male nucleus fuses with a female nucleus.

produces flagellated spores that swim away from the zoosporangium in search of food. When they find food, the spores develop into hyphae, which then grow into new organisms.

Sexual reproduction takes place in specialized structures that are formed by the hyphae. One structure, the **antheridium** (an-thur-ID-ee-um), produces male nuclei. The other structure, the **oogonium** (oh-oh-GOH-nee-um), produces female nuclei. Fertilization, or sexual fusion, occurs within the oogonium, and the spores that form develop into new organisms.

CHECKPOINT *Where does sexual reproduction in water molds take place?*

Ecology of Funguslike Protists

Slime molds and water molds are most important as recyclers of organic material. In plain language, that means that they help things rot. How important is that? A walk through woods or grassland will quickly show that the ground is not littered with the bodies of dead animals and plants. Why not? After these organisms die, their tissues are quickly broken down by slime molds, water molds, mushrooms, and other decomposers. The dark, rich topsoil that provides plants with nutrients is the product of all of this activity.

Some funguslike protists can harm living things. In addition to their beneficial function as decomposers, land-dwelling water molds cause a number of important plant diseases. These diseases include mildews and blights of grapes and tomatoes.

Water Molds and the Potato Famine

One water mold helped to permanently change the character of the United States. Roughly 40 million Americans can trace at least some part of their ancestry to Ireland. If you are one of those people, the chances are very good that your life and the lives of your ancestors were changed by the combination of a plant and a protist.

The plant was the potato. Potatoes are native to South America, where they were cultivated by the Incas. Spanish explorers were so impressed with this plant that they introduced it to Europe. By the 1840s, potatoes had become the major food crop of Ireland.

The protist was *Phytophthora infestans*, an oomycete that produces airborne spores that destroy all parts of the potato plant. Potatoes that are infected with *Phytophthora infestans* may appear normal at harvest time. Within a few weeks, however, the protist makes its way into the potato, reducing it to a spongy sac of spores and dust. The summer of 1845 was unusually wet and cool, ideal conditions for the growth of *Phytophthora infestans*. By the end of the growing season, the potato blight caused by this pathogen had destroyed as much as 60 percent of the Irish potato crop. The photographs in **Figure 20–25** show how *Phytophthora infestans* attacks potatoes. The art shows a woman digging for potatoes in a field.

Because the poorest farmers depended upon potatoes for their food, the effects were tragic. The loss of much of the crop in 1845 and an even greater loss in 1846 led to the starvation of more than a million people.

The Great Potato Famine, or the Great Hunger, as the event is also known, led to the immediate migration of about 1.5 million Irish people to the United States. There, they quickly changed the ethnic and political character of many American cities.

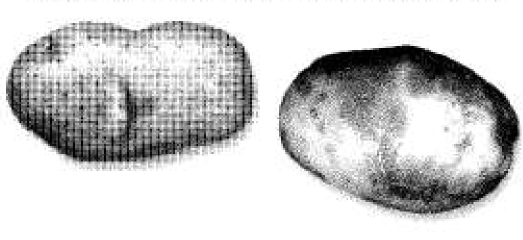


Figure 20–25 *Phytophthora infestans* is an oomycete that attacks potatoes (bottom right). In the summer of 1846, *Phytophthora infestans* destroyed nearly the entire potato crop of Ireland in days, leading to the Great Potato Famine. **Applying Concepts** ***How did the famine affect the United States?***

20–5 Section Assessment

1. **Key Concept** How are funguslike protists and fungi similar? How are they different?
2. **Key Concept** Compare acellular slime molds, cellular slime molds, and water molds.
3. What is the role of slime molds in the environment?
4. How can water molds affect other living things?
5. **Critical Thinking Comparing and Contrasting** How is the sluglike mass of cellular slime molds similar to the plasmodium of acellular slime molds? How do they differ?

iTEXT Assessment Use iText to review the important concepts in Section 20–5.

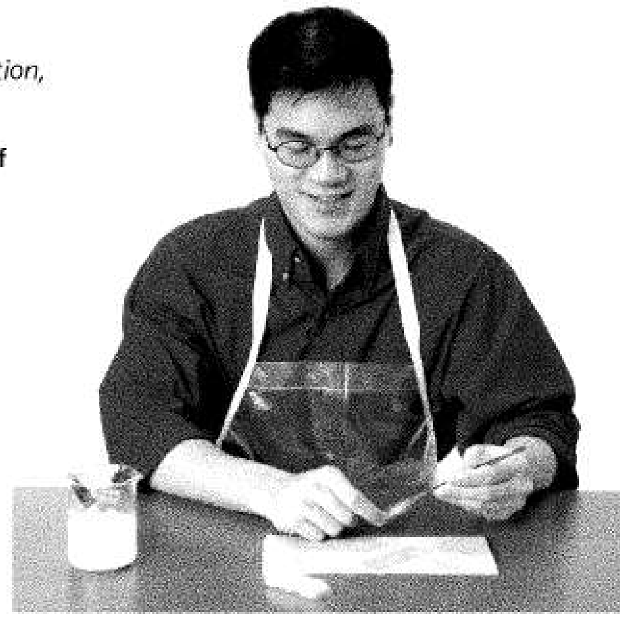
ALTERNATIVE ASSESSMENT

Constructing a Flowchart Draw two flowcharts—one showing the steps from unicellular existence through multicellular existence and reproduction in cellular slime molds and one showing those steps in acellular slime molds.

Design an Experiment

Investigating Contractile Vacuoles

Most freshwater protists have contractile vacuoles. These organelles regulate the concentration of water in the cytoplasm. In this investigation, you will observe how this structure works under various conditions.



Problem **How do the salt concentration and temperature of the environment affect the action of contractile vacuoles?**

Materials

- 3 *Paramecium caudatum* cultures at room temperature, 25°C (fresh water, 0.5% salt solution, 1.0% salt solution)
- *Paramecium caudatum* culture at 2°C in fresh water
- dropper pipette
- 4 microscope slides
- coverslips
- microscope
- cotton ball
- forceps
- clock with second hand

Skills Designing Experiments, Observing

Design Your Experiment

1. Use a dropper pipette to put one drop of *Paramecium caudatum* culture in fresh water at 25°C on a microscope slide.
2. Use forceps to pull apart a cotton ball and put a few threads in the drop of water. Cover the drop with a coverslip.
3. Use the low-power objective of the microscope to locate and focus on one paramecium. If necessary, increase the magnification to observe the alternating contractions of the two contractile vacuoles.
4. Record how long a contractile vacuole takes to contract and refill.
5. **Formulating Hypotheses** Record a hypothesis about how salt concentration and temperature will affect the rate at which the contractile vacuole contracts and expands.
6. **Designing Experiments** Design an experiment to test your hypothesis. Construct a data table to record your observations. With your teacher's approval, carry out your experiment.

Analyze and Conclude

1. **Observing** How did an increase in the concentration of salt in its environment affect the paramecium's contractile vacuoles?
2. **Inferring** What can you infer from this result about the rate at which water enters the paramecium in salt solutions? Explain your answer.
3. **Observing** How did temperature affect the contractile vacuoles?
4. **Drawing Conclusions** What can you conclude about the paramecium's use of energy from the effect of temperature on the contractile vacuoles?

Go Further

Designing Experiments Does temperature affect paramecia in other ways? Design an experiment to investigate the effects of temperature on movement or feeding. With your teacher's approval, carry out your experiment.

Chapter 20 Study Guide

20–1 The Kingdom Protista

Key Concept

- Protists are eukaryotes that are not members of the kingdoms Plantae, Animalia, or Fungi.

Vocabulary

protist, p. 495

20–2 Animallike Protists: Protozoans

Key Concepts

- Animallike protists that swim using flagella are classified in the phylum Zoomastigina and are often referred to as zooflagellates.
- Sarcodines are animallike protists that use pseudopods for feeding and movement.
- Members of the phylum Ciliophora, known as ciliates, use cilia for feeding and movement.
- Members of the phylum Sporozoa do not move on their own and are parasitic.
- Some animallike protists cause serious diseases, including malaria and African sleeping sickness.

Vocabulary

- pseudopod, p. 498
- amoeboid movement, p. 498
- food vacuole, p. 498 • cilium, p. 499
- trichocyst, p. 499 • macronucleus, p. 499
- micronucleus, p. 499 • gullet, p. 500
- anal pore, p. 500 • contractile vacuole, p. 500
- conjugation, p. 500

20–3 Plantlike Protists: Unicellular Algae

Key Concepts

- Chlorophyll and accessory pigments allow algae to harvest and use the energy from sunlight.
- Euglenophytes are plantlike protists that have two flagella but no cell wall.
- About half of dinoflagellates are photosynthetic; the other half live as heterotrophs.
- Members of the phylum Chrysophyta are a diverse group of plantlike protists that have gold-colored chloroplasts.
- Diatoms produce thin, delicate cell walls rich in silicon (Si)—the main ingredient in glass.

Vocabulary

- accessory pigment, p. 506 • eyespot, p. 506
- pellicle, p. 506 • phytoplankton, p. 508

20–4 Plantlike Protists: Red, Brown, and Green Algae

Key Concepts

- Red algae are able to live at great depths due to their efficiency in harvesting light energy. Red algae contain chlorophyll *a* and reddish accessory pigments called phycobilins.
- Brown algae contain chlorophyll *a* and *c*, as well as a brown accessory pigment, fucoxanthin.
- Green algae share many characteristics with plants, including their photosynthetic pigments and cell wall composition.
- The life cycles of most algae include both a diploid and a haploid generation.

Vocabulary

phycobilin, p. 510
filament, p. 512
alternation of generations, p. 512
gametophyte, p. 514
spore, p. 514
sporophyte, p. 514

20–5 Funguslike Protists

Key Concepts

- Funguslike protists lack chlorophyll and absorb nutrients from dead or decaying organic matter. But unlike most true fungi, funguslike protists have centrioles. They also lack the chitin cell walls of true fungi.
- Slime molds are funguslike protists that play key roles in recycling organic material.
- Oomycetes thrive on dead or decaying organic matter in water and are plant parasites on land.

Vocabulary

cellular slime mold, p. 516
acellular slime mold, p. 516
plasmodium, p. 518
hypha, p. 518
zoosporangium, p. 518
antheridium, p. 519
oogonium, p. 519

Thinking Visually

Make a table that compares the means of feeding and movement of the four main groups of protists.

Preparing for the Living Environment Exam

Chapter 20

Part A

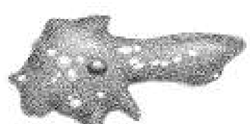
Multiple Choice

For each statement or question, select the number of the word or expression that, of those given, best completes the statement or answers the question.

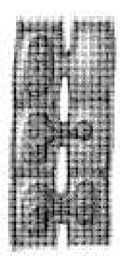
1 Which description applies to most protists?
(1) unicellular prokaryotes
(2) multicellular prokaryotes
(3) unicellular eukaryotes
(4) multicellular eukaryotes

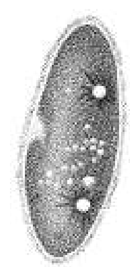
2 For defense, a paramecium uses small, bottle-shaped structures known as
(1) cilia (3) trichocysts
(2) pseudopodia (4) micronuclei

3 Which of the diagrams below shows the process of conjugation?


(1)


(3)


(2)


(4)

4 The population of small, photosynthetic organisms found near the ocean surface is called
(1) euglenophytes
(2) chrysophytes
(3) phytoplankton
(4) dinoflagellates

5 Which organisms are chiefly involved in the recycling of dead matter?
(1) fungi (3) carnivores
(2) algae (4) autotrophs

6 The thin filaments produced by water molds are known as
(1) oogonia (3) antheridia
(2) zoosporangia (4) hyphae

7 Slime molds are found primarily in
(1) oceans
(2) rotting wood or compost piles
(3) fast-moving streams
(4) deserts

8 Which structure in a unicellular organism corresponds in function with human lungs?
(1) vacuole (3) cell membrane
(2) nucleus (4) mitochondrion

9 Because the relative concentration of water in the pond in which a paramecium lives is greater than the concentration of water in its cytoplasm, water molecules constantly move from the pond into the organism. The best long-term solution to the problem of maintaining a stable internal environment is for the paramecium to
(1) change the water into carbon dioxide and excrete it
(2) store water molecules
(3) incorporate water molecules into its structure
(4) actively transport water molecules out of the cell

10 The cilia of paramecia are tiny hairlike structures that help paramecia to move from one location to another. Which of the following best describes the importance of cilia to paramecia?
(1) Cilia help in maintaining homeostasis.
(2) Cilia are useful in the process of diffusion.
(3) The ability to decompose other organisms is made possible by cilia action.
(4) Asexual reproduction is made possible directly through the activities of cilia.

11 All one-celled organisms are able to continue living because of their ability to
(1) produce food
(2) excrete wastes
(3) produce offspring
(4) produce hormones

Test-Taking Tip As you briefly scan the questions, mark those that may be pure guesswork on your part and save them for last. (Do not write in this book.) Use your time on those questions that you can reason through and for which you can eliminate answers.

Preparing for the Living Environment Exam

Parts B and C

Multiple Choice and Extended Response

For those questions that ask you to select a response, choose the one that best completes the statement or answers the question. For all others follow the directions given.

12 Explain how the terms *animallike, plantlike,* and *funguslike* are useful in classifying protists.

13 Describe the two methods euglenophytes can use to obtain energy.

14 Describe the process of alternation of generations. Explain its significance.

15 Explain the connection between water pollution and the occurrence of a red tide.

16 All freshwater protozoans have contractile vacuoles to get rid of excess water. Describe the process responsible for this excess water.

17 Explain the role of plantlike protists in aquatic food chains.

18 Your teacher asks you to observe and classify into the correct phylum the following protists:

Protist A: Organism has no cell wall, lacks chlorophyll, and moves using pseudopodia

Protist B: Organism has no cell wall, contains chlorophyll, and has two flagella

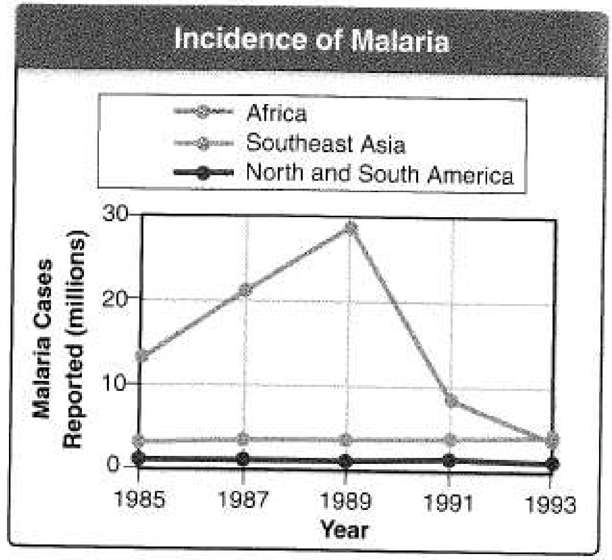
Protist C: Cells appear amoebalike and seem to fuse to produce structures with nuclei, lack chlorophyll, and have fruiting bodies that produce spores that geminate into flagellated cells

Copy and complete the below chart.

Protist	Traits	Phylum
A		
B		
C		

19 At one time, living things were classified as animals if they moved or ingested food and as plants if they did not move or ingest food. State two difficulties that would arise in trying to classify the protists according to these criteria.

Base your answers to questions 20 through 22 on the graph below and on your knowledge of biology.



20 Based on the data in the graph, the incidence of malaria is

(1) decreasing in Southeast Asia and increasing in South America

(2) increasing in Africa and decreasing in Southeast Asia

(3) decreasing in Africa and increasing in Southeast Asia

(4) increasing in Southeast Asia and in North and South America

21 It is estimated that there are at least ten actual cases of malaria for every one reported and shown in the graph. Based on this estimate, how many cases of malaria were there in Africa in 1991?

22 Note the rapid change in malaria cases in Africa after 1989. Many question that the number of actual cases of malaria changed so rapidly. Explain what other factors could have affected the number of cases reported.

Base your answers to questions 23 through 25 on the information and chart below and on your knowledge of biology.

A study was done to determine the effect of different salt concentrations on the number of contractions per minute of contractile vacuoles of paramecia.

Four beakers of water containing different salt concentrations and equal numbers of paramecia were prepared. All other environmental conditions were constant. The paramecia were then observed through a compound light microscope, and the contractions of the contractile vacuoles were counted. Whenever a contractile vacuole contracts, it is pumping water out of a paramecium. The results were recorded in the data table below.

Salt Concentration vs. Contractions

Beaker	Salt Concentration (mg/mL)	Contractions per Minute
A	0.000	5.5
B	0.001	4.0
C	0.010	2.5
D	0.100	1.5

23 Using the information in the data table, construct a line graph on your own sheet of graph paper. Be sure that you
- label and scale the two axes appropriately
- plot the data, surround each point with a small circle, and connect the points

24 According to the information in the data table, which statement is true?
(1) Beaker B has a lower salt concentration than Beaker A.
(2) Beaker C has a lower salt concentration than Beaker D.
(3) The paramecia in Beaker A respond the least to the water concentration in the beaker.
(4) The paramecia in Beaker D have nonfunctioning contractile vacuoles.

25 According to the data, as the salt concentration increases, the number of contractions per minute changes. What most likely accounts for this change?
(1) a decrease in water concentration outside the paramecium
(2) a decrease in salt concentration outside the paramecium
(3) an increased diffusion of salt out of the paramecium
(4) an increased percentage of water inside the paramecium

For questions 26 through 29, select the structure, chosen from the list below, that is most closely associated with the statement. Then, record the number on your paper. A choice may be used once, more than once, or not at all.

(1) Contractile vacuole
(2) Gullet
(3) Trichocyst
(4) Food vacuole
(5) Anal pore

26 Where food particles in a unicellular organism's body are digested

27 Indentation where food particles are trapped

28 Collects and gets rid of excess water

29 Site where waste is released into the environment

Base your answers to questions 30 through 32 on the information below and on your knowledge of biology.

Algae are the foundation of most aquatic food chains in both marine and freshwater ecosystems. Through the process of photosynthesis, algae are able to combine inorganic raw materials into energy-rich organic compounds.

30 Name the reactants and products of photosynthesis. (*Hint:* You may wish to refer back to Chapter 8 for help in answering this question.)

31 Name the organelle that serves as the site of photosynthesis in algal cells.

32 Where might algae get the raw materials they need to carry out photosynthesis?

Take It to the NET

Which protists live in a pond environment? Visit the Prentice Hall Web site at **www.phschool.com** to find out about the residents of a typical pond. Then, answer the following questions:
- What major groups of protists are found in ponds?
- How can you create an image of an algal protist using fluorescence? Which parts will be visible?
- What are mummy-shaped diatoms?
- What is the approximate width of an amoeba?