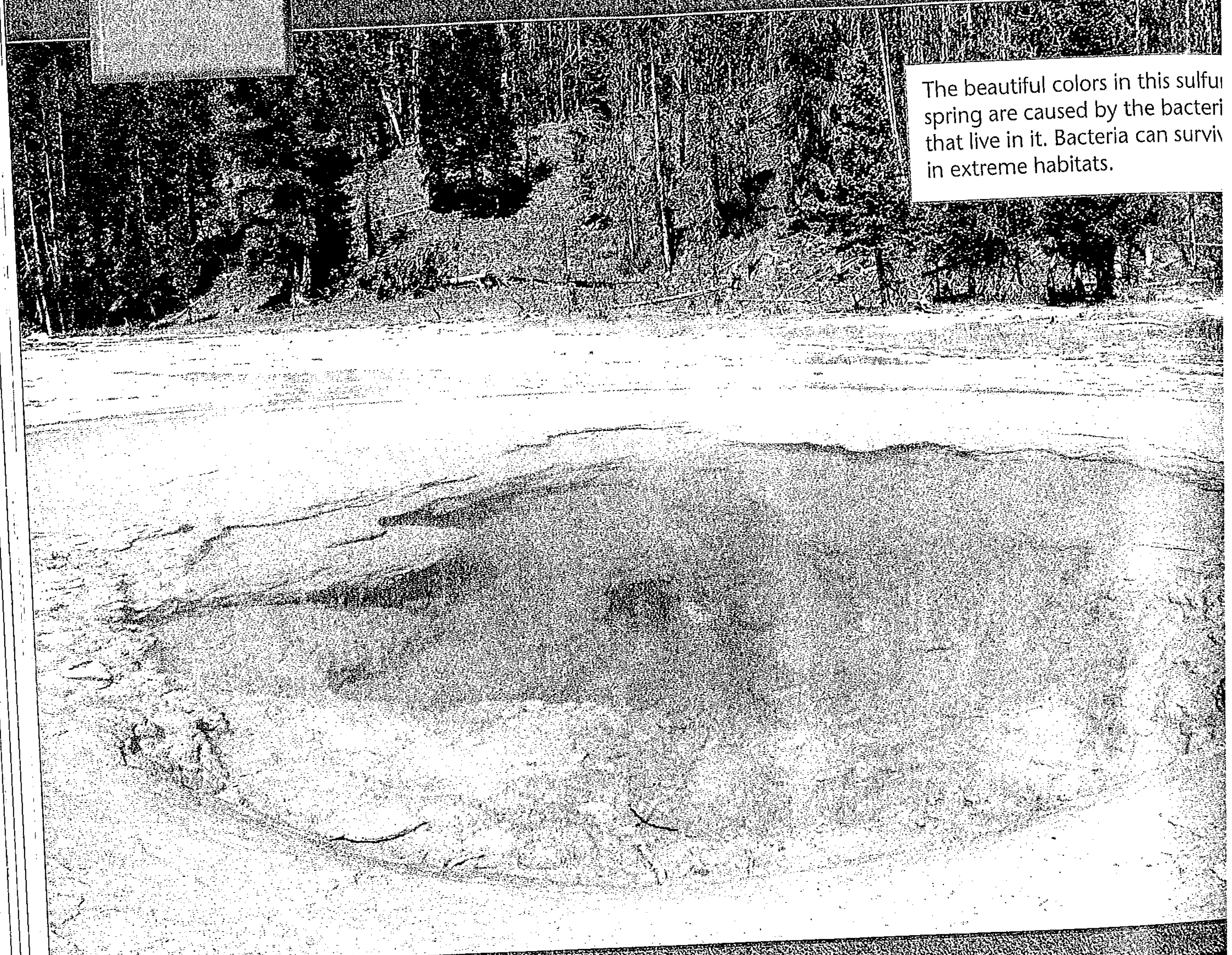
CHAPTER 19

Bacteria and Viruses



The beautiful colors in this sulfu spring are caused by the bacteri that live in it. Bacteria can surviv in extreme habitats.

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 ope the plates. Give them to your teacher for dispos*

Think About It

1. **Observing** Which plate had more colonies?
2. **Drawing Conclusions** Where did the bact your plates come from? Explain your answer.
3. **Asking Questions** Write three questions yo investigate using your observations and result

19–1 Bacteria

Imagine living all your life as a member of 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 and your family 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 hidden, living world around us.

Microscopic life covers nearly every square centimeter of Earth. There are microorganisms of many different sizes and shapes, even in a single drop of pond water. The smallest and most common microorganisms are **prokaryotes**—unicellular organisms that lack a nucleus. For many years, most prokaryotes were called "bacteria." The word *bacteria* is so familiar that we will use it as a common term to describe prokaryotes.

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

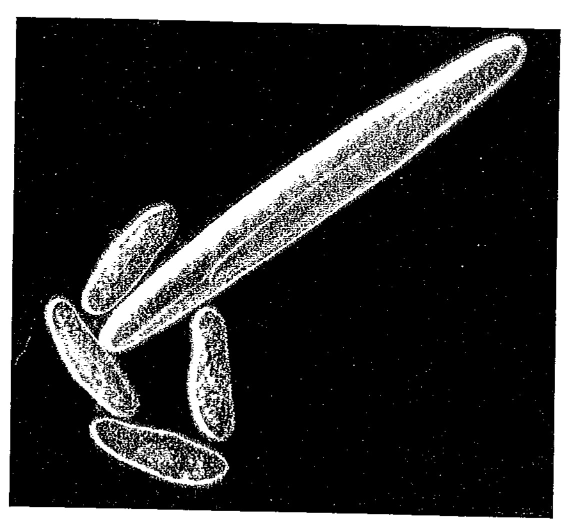
Key Concepts
- How do the two groups of prokaryotes differ?
- What factors are used to identify prokaryotes?
- What is the importance of bacteria?

Vocabulary
prokaryote • bacillus
coccus • spirillum
chemoheterotroph
photoheterotroph
photoautotroph
chemoautotroph
obligate aerobe
obligate anaerobe
facultative anaerobe
binary fission
conjugation • endospore
nitrogen fixation

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

Until fairly recently, all prokaryotes were placed in a single kingdom—Monera. 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.

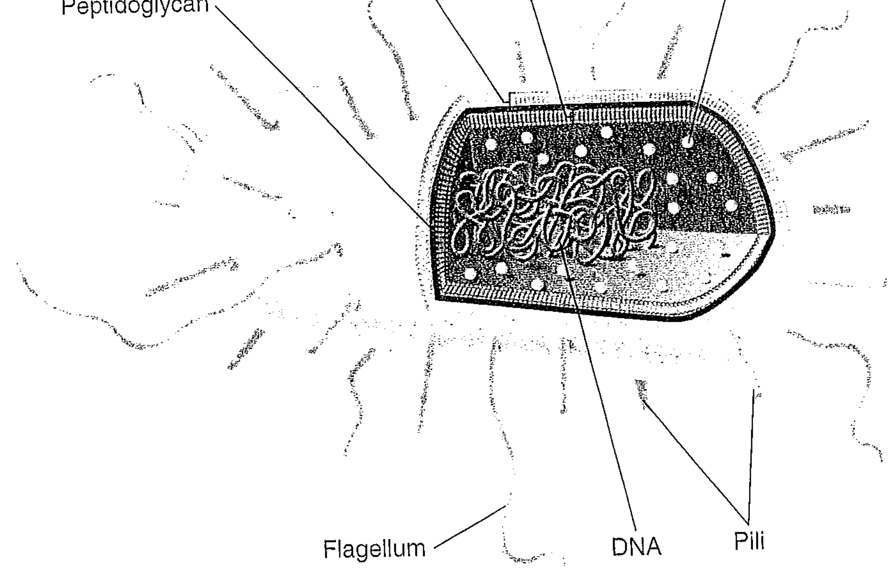


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Figure 19–2 A bacterium such as *E. coli* has the basic structure typical of most prokaryotes: cell wall, cell membrane, and cytoplasm. Some prokaryotes have flagella that they use for movement. The pili are involved in cell-to-cell contact. **The cell walls of eubacteria contain peptidoglycan.**

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 are needed to classify this group. Eubacteria live almost everywhere. They live in fresh water, salt water, on land, and on and within the human body. **Figure 19–2** shows a diagram of *Escherichia coli,* a typical eubacterium that lives in human intestines.

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. Inside the cell wall is a cell membrane that surrounds the cytoplasm. Some eubacteria have a second membrane, outside the cell membrane, that makes them especially resistant to damage.

Archaebacteria Under a microscope, archaebacteria look very similar to eubacteria. They are equally small, lack nuclei, have cell walls, but chemically archaebacteria are quite different. **Archaebacteria lack the peptidoglycan of eubacteria and also have different membrane lipids. 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 archaebacteria live?*

Identifying Prokaryotes

Because prokaryotes are so small, it may seem difficult to tell one type of prokaryote from another. **Prokaryotes are identified by characteristics such as shape, the chemical nature of their cell walls, the way they move, and the way they obtain energy.**

Shapes Look at the different shapes of the 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).

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). The violet stain, applied first, stains peptidoglycan cell walls. This is followed by an alcohol treatment that tends to wash out the stain. Gram-positive bacteria have thick peptidoglycan walls that retain the dark color of the violet stain even after the alcohol wash. Gram-negative bacteria have much thinner walls inside an outer lipid layer. Alcohol dissolves the lipid and removes the dye from the walls of these bacteria. The counterstain then makes these bacteria appear pink or light red.

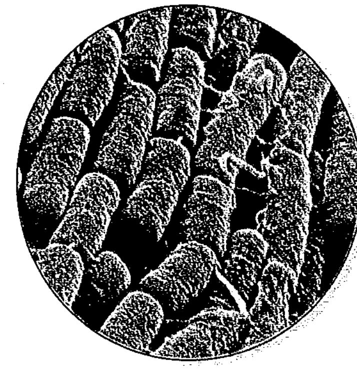
Movement You can also identify prokaryotes by whether they move and how they move. Some prokaryotes do not move at all. Others are propelled by flagella, whiplike structures used for movement. Other prokaryotes lash, snake, or spiral forward. Still others glide slowly along a layer of slimelike material they secrete.

Metabolic Diversity

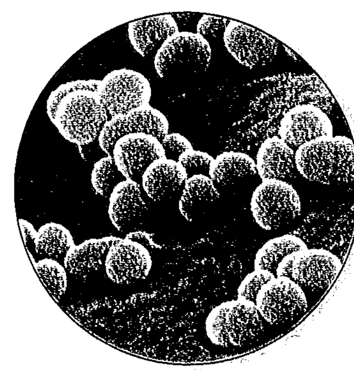
No characteristic of prokaryotes illustrates their diversity better than the ways in which they obtain energy. Depending on their source of energy and whether or not they use oxygen for cellular respiration, prokaryotes can be divided into two main groups. Most prokaryotes are heterotrophs, meaning that they get their energy by consuming organic molecules made by other organisms. Other prokaryotes are autotrophs and make their own food from inorganic molecules.

Heterotrophs Most heterotrophic prokaryotes must take in organic molecules for both energy and a supply of carbon. These prokaryotes are called **chemoheterotrophs** (kee-moh-HET-ur-oh-trohfs). Most animals, including humans, are chemoheterotrophs. A smaller group of heterotrophic prokaryotes are called **photoheterotrophs** (foh-toh-HET-ur-oh-trohfs). These organisms are photosynthetic, using sunlight for energy, but they also need to take in organic compounds as a carbon source.

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).

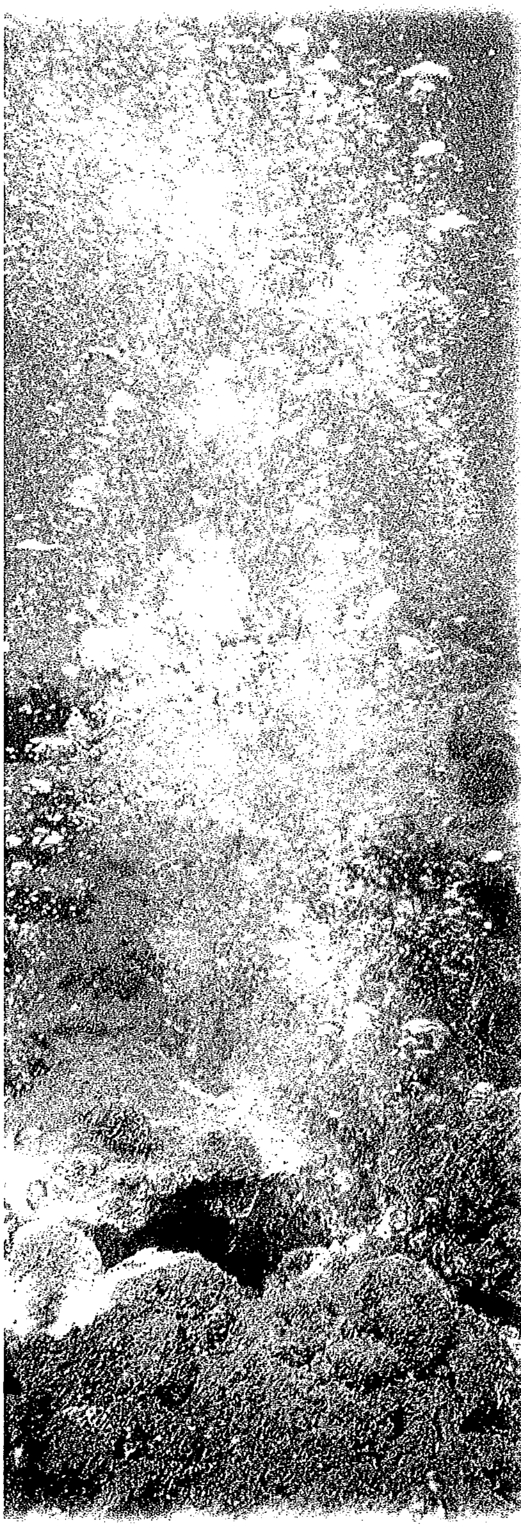


Bacilli
(magnification: 3738×)



Cocci
(magnification: 30,000×)

Spirilla
(magnification: about 7000×)



▲ **Figure 19–4** Ocean vents, such as this one, are often home to a variety of organisms, including tube worms and other exotic organisms. **Applying Concepts** *Would photoautotrophs survive in this environment? Why or why not?*

Autotrophs Other groups of prokaryotes are autotrophs. Some autotrophs, the **photoautotrophs** (foh-toh-AW-toh-trohfs), use light energy to convert carbon dioxide and water to carbon compounds and oxygen in a process similar to that used by green plants. As you might expect, these organisms are found where light is plentiful, such as 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 water, salt water, and even on land. In fact, cyanobacteria are often the very first species to recolonize the site of a natural disaster such as a volcanic eruption.

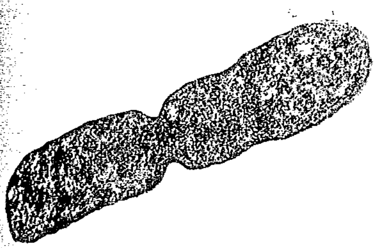
Other prokaryotes can perform chemosynthesis and are called **chemoautotrophs** (kee-moh-AW-toh-trohfs). Like photoautotrophs, chemoautotrophs make organic carbon molecules from carbon dioxide. Unlike photoautotrophs, however, they do not require light as a source of energy. Instead, they use energy directly 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 19–4.**

✓CHECKPOINT *What are the two groups of autotrophs found in prokaryotes?*

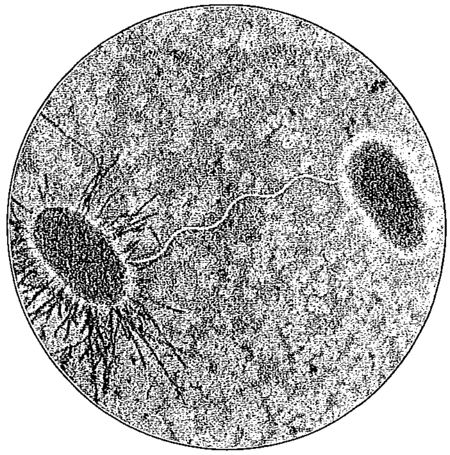
Releasing Energy Like all organisms, bacteria need a constant supply of energy. This energy is released by the processes of cellular respiration or fermentation or both. Organisms that require a constant supply of oxygen in order to live are called **obligate aerobes.** (*Obligate* means that the organisms are obliged, or required, by their life processes to live only in that particular way.) *Mycobacterium tuberculosis,* the bacterium that causes tuberculosis, is an obligate aerobe.

Some bacteria, however, do not require oxygen and, in fact, may be killed by it! These bacteria are called **obligate anaerobes,** and they must live in the absence of oxygen. *Clostridium botulinum* 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.

A third group of bacteria can survive with or without oxygen and are known as **facultative anaerobes.** (*Facultative* means that the organisms are able to function in different ways, depending on their environment.) Facultative anaerobes do not require oxygen, but neither are they killed by its presence. Their ability to switch between the processes of cellular respiration and fermentation means that facultative anaerobes are able to live just about anywhere. *E. coli* is a facultative anaerobe that lives anaerobically in the large intestine and aerobically in sewage or contaminated water.



Binary Fission
(magnification: 26,500×)



Conjugation
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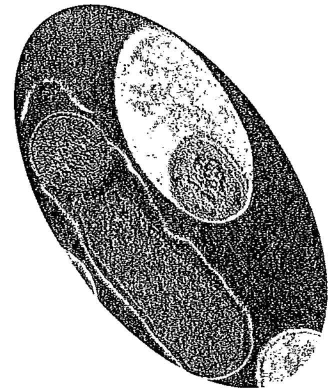

Spore Formation
(magnification: 7800×)

Figure 19–5 Most prokaryotes reproduce by binary fission, producing two identical "daughter" cells. Some prokaryotes take part in conjugation, in which genetic information is transferred from one cell to another by way of a hollow bridge. Other prokaryotes produce endospores, which allow them to withstand harsh conditions. **Comparing and Contrasting** *Compare the process of conjugation to binary fission.*

Growth and Reproduction

When conditions are favorable, bacteria 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 bacterium and if all of its offspring divided every 20 minutes, in just 48 hours 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.

Binary Fission When a bacterium 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.

Conjugation Many bacteria are also able to exchange genetic information by a process called conjugation. During **conjugation,** a hollow bridge forms between two bacterial cells, and genes move from one cell to the other. This transfer of genetic information increases genetic diversity in populations of bacteria.

Spore Formation 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. Spores can remain dormant for months or even years while waiting for more favorable growth conditions. The ability to form spores makes it possible for some bacteria to survive harsh conditions that might otherwise kill them. The bacterium *Bacillus anthracis,* which causes the disease anthrax, is one such bacterium. The ability to form these endospores has led some groups to develop anthrax as a biological warfare agent.

▶ **Figure 19–6** **Bacteria help to break down the nutrients in this tree, allowing other organisms to use the nutrients.** In this way, bacteria help maintain equilibrium in the environment.

Importance of Bacteria

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 are decomposers that break down the nutrients in dead matter and the atmosphere. Still other bacteria have human uses.**

Decomposers Every living thing depends directly or indirectly on a supply of raw materials. If these materials were lost when an organism died, life could not continue. Before long, plants would drain the soil of minerals and die, and animals that depend on plants for food would starve. As decomposers, bacteria help the ecosystem recycle nutrients, therefore maintaining equilibrium in the environment. When a tree dies, such as the one in **Figure 19–6**, armies of bacteria attack and digest the dead tissue, breaking it down into simpler materials, which are released into the soil. Other organisms, including insects and fungi, also play important roles in breaking down dead matter.

Bacteria also help in sewage treatment. Sewage contains human waste, discarded food, and 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.

Nitrogen Fixers Plants and animals depend on bacteria for nitrogen. You may recall that plants need nitrogen to make amino acids, the building blocks of proteins. Nitrogen gas (N_2) makes up approximately 80 percent of Earth's atmosphere.

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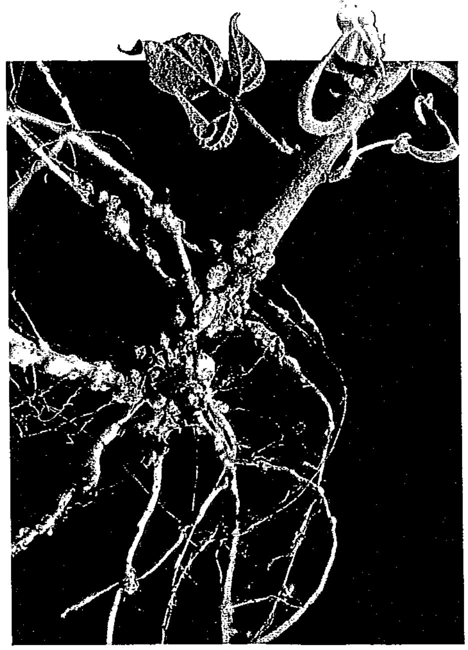
However, plants cannot use nitrogen gas directly. Nitrogen must first be changed chemically to ammonia (NH_3) or other nitrogen compounds. Expensive synthetic fertilizers contain these nitrogen compounds, but certain bacteria in the soil produce them naturally. The process of converting nitrogen gas into a form plants can use is known as **nitrogen fixation.** Nitrogen fixation allows nitrogen atoms to continually cycle through the biosphere.

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, on the roots of the soybean plant, as shown in **Figure 19–7.** The plant provides a source of nutrients for *Rhizobium*, which converts nitrogen in the air into ammonia, helping the plant. Thus, soybeans have their own fertilizer factories in their roots!



▲ **Figure 19–7** The knoblike structures on the roots of this soybean plant are called nodules. Within these nodules are populations of the nitrogen-fixing bacteria *Rhizobium.* **Applying Concepts** *What is the name of the relationship between* Rhizobium *and soybean plants?*

Human Uses of Bacteria Many of the remarkable properties of bacteria provide us with products we depend on every day. For example, bacteria are used in the production of a wide variety of foods and beverages. Bacteria can also be used in industry. One type of bacteria 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.

Our intestines are inhabited by large numbers of bacteria, including *E. coli*. The term *coli* was derived from the fact that these bacteria were discovered in the human colon, or large intestine. In the intestines, the bacteria are provided with a warm and safe home, plenty of food, and free transportation. These bacteria also make a number of vitamins that the body cannot produce by itself. So both we and the bacteria benefit from this symbiotic relationship.

Biologists continue to discover new uses for bacteria. For example, 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.

19–1 Section Assessment

1. **Key Concept** Describe the characteristics of the two kingdoms of prokaryotes.
2. **Key Concept** What factors can be used to identify prokaryotes?
3. **Key Concept** Give one example of how bacteria maintain equilibrium in the environment.
4. Identify the parts of a prokaryote.
5. What are some ways that prokaryotes obtain energy?
6. **Critical Thinking Inferring** Why might an infection by Gram-negative bacteria be more difficult to treat than a Gram-positive bacterial infection?

Thinking Visually

Making a Venn Diagram
Create a Venn diagram that illustrates the similarities and differences between eubacteria and archaebacteria. *Hint*: Before you start, you may want to list the similarities and differences.

19–2 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
prophage
retrovirus

Reading Strategy: Using Visuals As you read about viral replication in this section, trace each step in **Figure 19–10.** Then, list the steps, and write a few sentences to describe each step.

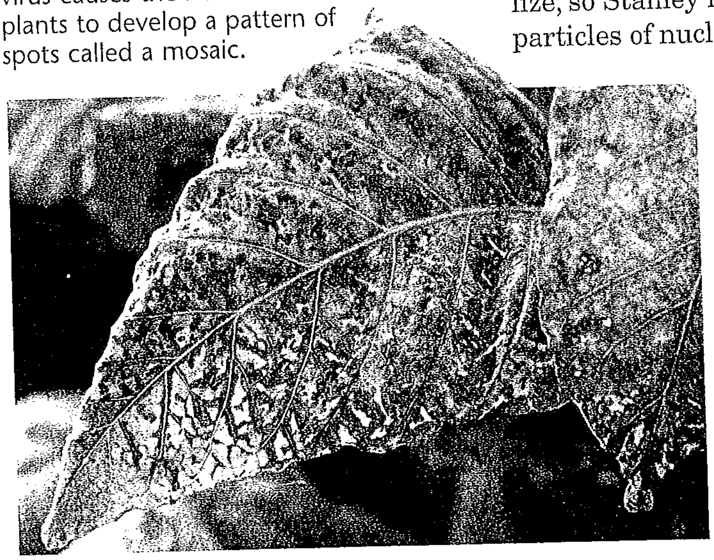
Imagine that you have been presented with a great puzzle. Farmers have begun to lose a valuable crop to a plant disease. The disease produces large pale spots on the leaves of plants similar to those shown in **Figure 19–8.** The diseased leaves look like mosaics of yellow and green. As the disease progresses, the leaves turn completely 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 appears where you put the drops. Could the source of the disease be in the juice?

You use a light 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 hypothesize that the juice must contain disease-causing agents so small that they are not visible under the microscope. Although you cannot see the disease-causing particles, you're sure they are there. You give them the name *virus*, from the Latin word for "poison."

If you think you could have carried out this investigation, congratulations! You're walking in the footsteps of a 28-year-old Russian biologist, Dmitri Ivanovski. In 1892, Ivanovski identified the cause of tobacco mosaic disease as juice extracted from infected plants. In 1897, Dutch scientist Martinus Beijerinck suggested that tiny particles in the juice caused the disease, and he named these particles viruses.

▼ **Figure 19–8** Tobacco mosaic virus causes the leaves of tobacco plants to develop a pattern of spots called a mosaic.

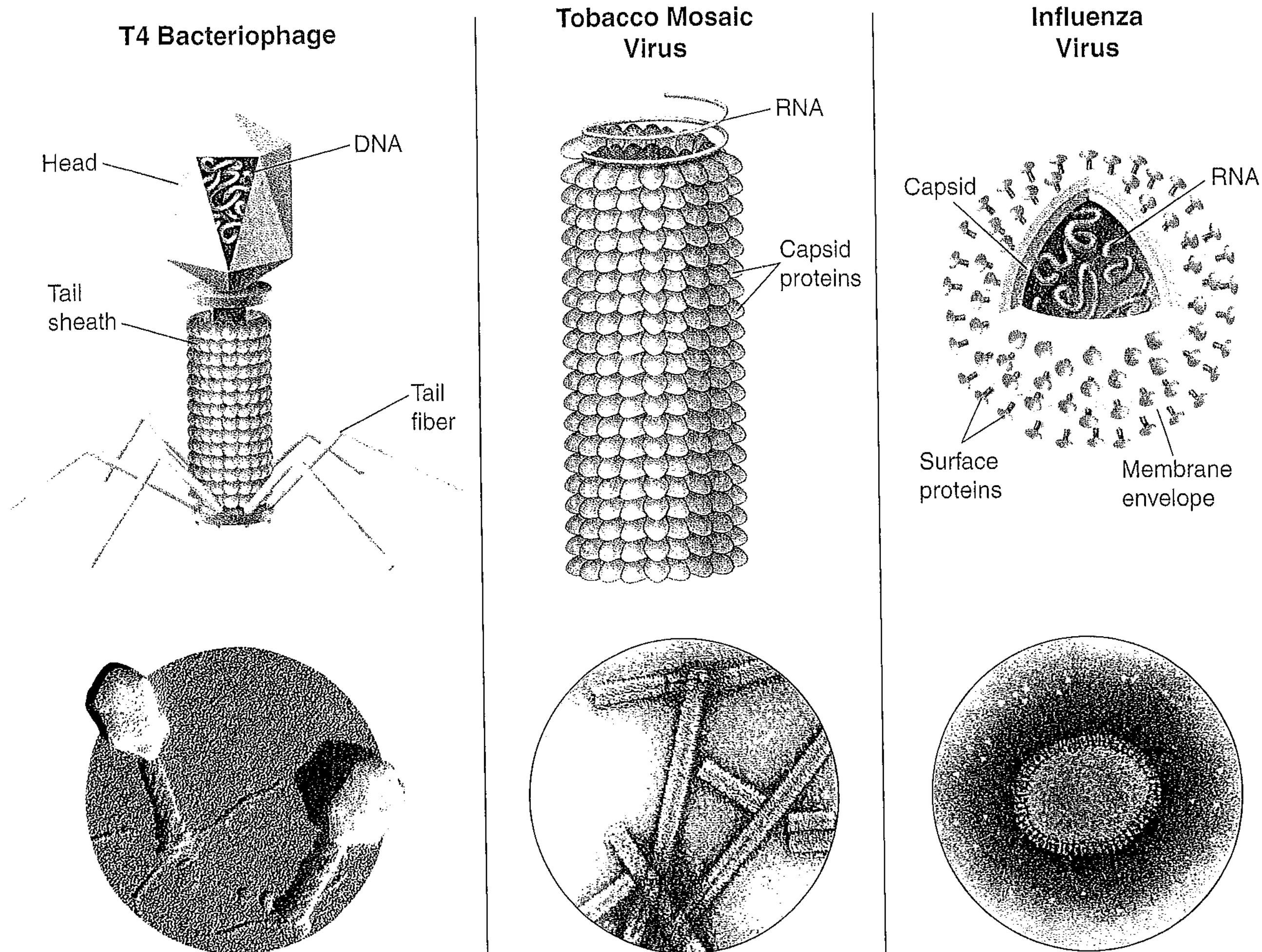


What Is a Virus?

In 1935, the American biochemist Wendell Stanley obtained crystals of tobacco mosaic virus. Living organisms do not crystallize, so Stanley inferred that viruses were not alive. **Viruses are particles of nucleic acid, protein, and in some cases, lipids.** Viruses can reproduce only by infecting living cells. Viruses differ widely in terms of size and structure, as you can see in **Figure 19–9.** As different as they are, all viruses have one thing in common: They enter living cells and, once inside, use the machinery of the infected cell to produce more viruses.

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 DNA or RNA surrounded by a protein coat.** The simplest viruses contain only a few genes, whereas the most complex may have more than a hundred genes.

FIGURE 19–9 VIRUS STRUCTURES



T4 Bacteriophage (magnification: 82,000×)

Tobacco Mosaic Virus (magnification: 200,000×)

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

A virus's 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 receptors on the surface of a cell and "trick" the cell into allowing it inside. Once inside, the viral genes are expressed. The cell transcribes and translates the viral genetic information into viral capsid proteins. Sometimes that genetic program causes the host cell to make copies of the virus, and in the process the host cell is destroyed.

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 infect plant cells; most animal viruses infect only certain related species of animals; and bacterial viruses infect only certain types of bacteria. Viruses that infect bacteria are called **bacteriophages.**

✓CHECKPOINT *What happens when a cell transcribes a viral gene?*

▲ **Figure 19–9** Viruses come in a wide variety of sizes and shapes. **A typical virus is composed of a core of either DNA or RNA, which is surrounded by a protein coat, or capsid.**

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Discovery EDUCATION

To find out more about the transmission of a virus, view track 10 "Influenza: Tracking a Virus" on the *BioDetectives* DVD.

Viral Infection

Once the virus is inside the host cell, two different processes may occur. Some viruses replicate themselves immediately, killing the host cell. Other viruses replicate themselves in a way that doesn't kill the host cell immediately. These two processes are shown in **Figure 19–10.**

Lytic Infection Bacteriophage T4 is an example of a bacteriophage that causes a lytic infection. **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 protein capsid that is activated by contact with a host cell. It then injects its DNA directly into the cell. 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 is translated into viral proteins that act like a molecular wrecking crew, chopping up the cell DNA, a process that shuts down the infected host cell.

The virus then uses the materials of the host cell to make thousands of copies of its own DNA molecule. The viral DNA gets assembled into new virus particles. 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 an outlaw in the American Old West. First, the outlaw eliminates the town's existing authority (host cell DNA). Then, the outlaw demands to be outfitted with new weapons, horses, and riding equipment by terrorizing the local people (using the host cell to make viral proteins and viral DNA). Finally, the outlaw forms a gang that leaves the town to attack new communities (the host cell bursts, releasing hundreds of virus particles).

Lysogenic Infection Other viruses, including the bacteriophage lambda, cause **lysogenic infections** in which a host cell makes copies of the virus indefinitely. **In a lysogenic infection, a virus integrates its DNA into the DNA of the host cell, and the viral genetic information replicates along with the host cell's DNA.** Unlike lytic viruses, lysogenic viruses do not lyse the host cell right away. Instead, a lysogenic virus remains inactive for a period of time.

The viral DNA that is embedded in the host's DNA is called a **prophage.** The prophage may remain part of the DNA of the host cell for many generations before becoming active. A virus may not stay in the prophage form indefinitely. Eventually, any one of a number of factors may activate the DNA of a prophage, which will then remove itself from the host cell DNA and direct the synthesis of new virus particles.

The steps of lytic and lysogenic infections may be different from those of other viruses when they attack eukaryotic cells. Most animal viruses, however, show patterns of infection similar to either the lytic or lysogenic patterns of infection of bacteria.

igure 19–10 Bacteriophages may fect cells in two ways: lytic infection nd lysogenic infection.

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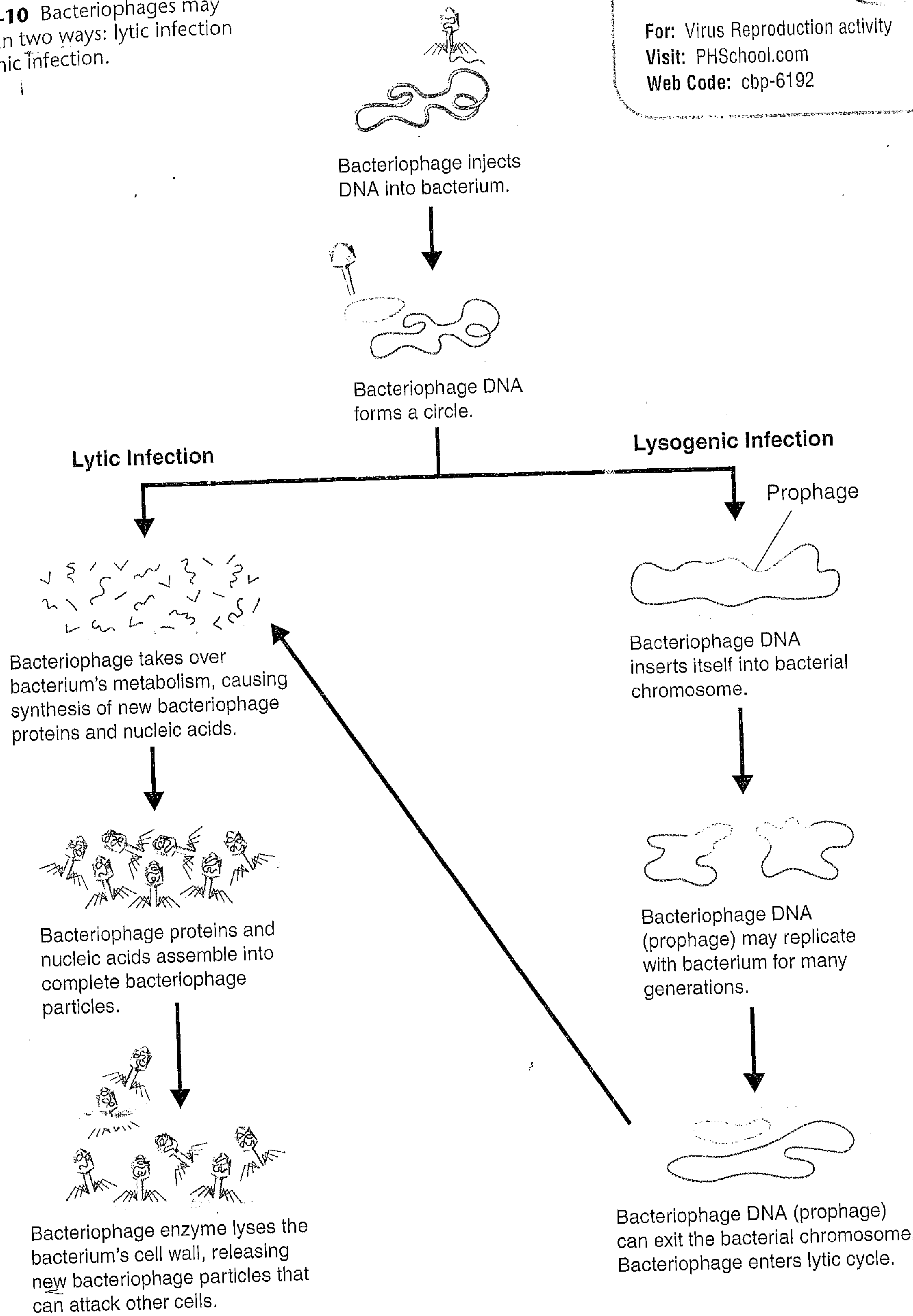

Quick Lab

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 19–9** on page 479.
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?
4. **Asking Questions** Write two or more questions about the relationship between viruses and single-celled organisms.
5. **Using Models** Suggest ways you can use models to investigate one of your questions in question 4. Suggest an alternative for the virus model you made in this activity.

Retroviruses

Some viruses contain RNA as their genetic information and 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. There the retroviruses may remain dormant for varying lengths of time before becoming active, directing the production of new viruses, and causing the death 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. (The prefix *retro-* means "backward.") Retroviruses are responsible for some types of cancer in animals, including humans. The virus that causes acquired immune deficiency syndrome (AIDS) is a retrovirus.

Viruses and Living Cells

Viruses must infect a living cell in order to grow and reproduce. They also take advantage of the host's respiration, nutrition, and all the other functions that occur in living things. Therefore, viruses can be considered to be parasites. A parasite depends entirely upon another living organism for its existence, harming that organism in the process.

Viruses and Cells

Characteristic	Virus	Cell
Structure	DNA or RNA core, capsid 	Cell membrane, cytoplasm; eukaryotes also contain nucleus and organelles 
Reproduction	only within a host cell	independent cell division either asexually or sexually
Genetic Code	DNA or RNA	DNA
Growth and Development	no	yes; in multicellular organisms, cells increase in number and differentiate
Obtain and Use Energy	no	yes
Response to Environment	no	yes
Change Over Time	yes	yes

▲ **Figure 19–11** The differences between viruses and cells are listed in this chart. **Applying Concepts** *Based on this information, would you classify viruses as living or nonliving? Explain.*

Are viruses alive? If we require that living things be made up of cells and be able to live independently, then viruses are not alive. Yet, viruses have many of the characteristics of living things. After infecting living cells, viruses can reproduce, regulate gene expression, and even evolve. Some of the main differences between cells and viruses are summarized in **Figure 19–11.** Viruses are at the borderline of living and nonliving things.

Although viruses are smaller and simpler than the smallest cells, it is not likely that they could have been the first living things. Because viruses are completely dependent upon 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. Once established, however, viruses have continued to evolve, along with the cells they infect, over billions of years.

19–2 Section Assessment

1. **Key Concept** What are the parts of a virus?
2. **Key Concept** Describe the 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.

Focus on the BIG Idea

Structure and Function

Viruses and cells are similar yet different. Compare the structure of a virus to the structure of a eukaryotic cell. Organize your information in a table. You may wish to refer to Chapter 7, which discusses the structures of cells in detail.

ISSUES in Biology

Should Mass Vaccinations Be Required?

Smallpox is a deadly disease for which there is no treatment. Smallpox had been brought under control by a worldwide vaccination program. It appeared that vaccination had eradicated every trace of smallpox in nature. As a result, the routine vaccination of children against smallpox was ended in the United States in 1971. No new smallpox cases have been reported anywhere since 1978. Only two laboratories, one in Atlanta, Georgia, and the other in Russia, are known to have samples of the virus.

Today there is concern that certain infectious diseases, such as smallpox, will be used as a biological weapon. This has led authorities in the United States and other countries to order the production of new stocks of certain vaccines. Preparing millions of doses of a vaccine as a precaution against attack certainly seems like a good idea. But it also raises an important social and scientific question—should a nation require its citizens to be vaccinated against a particular disease, or should we wait until there is evidence of an outbreak of a disease in a given area?

The Viewpoints

Require Vaccinations

Human history shows just how deadly certain infectious diseases can be. Therefore, it makes sense to preempt an outbreak by requiring vaccinations as soon as enough doses of the vaccine are available. The benefits of immunity would outweigh any possible adverse reactions to the vaccine. In addition, it is cheaper to vaccinate everyone, rather than to treat infectious diseases on an individual basis.

Hold the Vaccine in Reserve

As serious as the threat from certain infectious diseases may be, we should keep in mind the rule of medicine that is taught to all doctors: First, do no harm. We already know, unfortunately, that administering vaccines to an entire population will indeed do harm. For example, U. S. health statistics

show that for every 1 million infants vaccinated for smallpox, as many as 5 may have died from reactions to the vaccine. The exact number of deaths that will result from a nationwide vaccination program is not certain, but any number of deaths is too many when the risk of infection is only hypothetical.

Research and Decide

1. **Analyzing the Viewpoints** To make an informed decision, learn more about this issue by consulting library or Internet resources. Then, list both the risks and benefits of nationwide vaccination.
2. **Forming Your Opinion** How do you balance the risks and benefits of vaccination now against the risks and benefits of stockpiling the vaccine? What factors should you consider?
3. **Role-Playing** You are a researcher for the Centers for Disease Control in Atlanta. You have been offered the chance to be inoculated with a vaccine such as smallpox. Would you get the vaccination? Explain your answer and support it with facts from your research.

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19–3 Diseases Caused by Bacteria and Viruses

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 and viruses. Bacteria and viruses are everywhere in nature, but only a few cause disease. However, these **pathogens**, or disease-causing agents, get all the attention.

Disease can be considered a conflict between the pathogen and the host. All viruses reproduce by infecting living cells, and disease results when the infection causes harm to the host. All bacteria require nutrients and energy; however, disease results when bacteria interfere with the host's ability to obtain enough of those elements to function properly.

Guide for Reading

Key Concepts

- How do bacteria cause disease?
- How can bacterial growth be controlled?
- How do viruses cause disease?

Vocabulary

pathogen
vaccine
antibiotic
viroid
prion

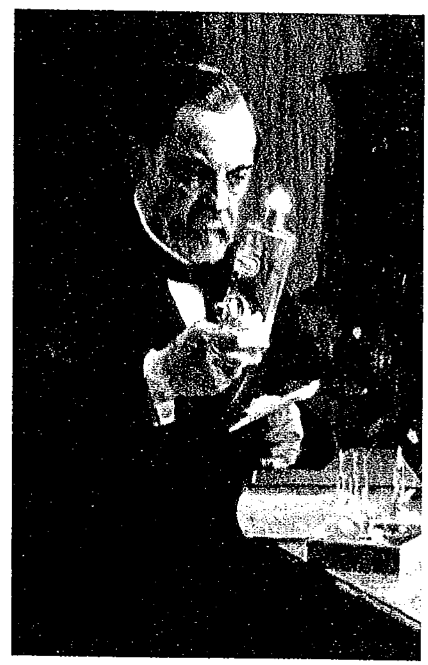
Reading Strategy: Outlining Before you read, use the headings of this section to make an outline about disease. As you read, fill in subtopics. Then, add phrases or a sentence after each to provide key information.

Bacterial Disease in Humans

Many bacteria live on and within our bodies, and some bacteria even help us to perform essential functions, such as digesting our food. The growth of pathogenic bacteria, on the other hand, disrupts the body's equilibrium by interfering with its normal activities and producing disease.

The French chemist Louis Pasteur, shown in **Figure 19–12**, was the first person to show convincingly that bacteria cause disease. Pasteur helped to establish what has become known as the germ theory of disease when he showed that bacteria were responsible for a number of human and animal diseases.

Bacteria produce disease in one of two general ways. Some bacteria damage the cells and tissues of the infected organism directly by breaking down the cells for food. Other bacteria release toxins (poisons) that travel throughout the body interfering with the normal activity of the host.



▲ **Figure 19–12** By testing multiple hypotheses, Louis Pasteur was able to show that bacteria cause disease.

Using Cells for Food The bacterium *Mycobacterium tuberculosis*, which causes tuberculosis, is inhaled into the lungs, where it destroys the lung tissue. The bacterium also may enter a blood vessel and travel to new sites in the body where it destroys more tissue.

Releasing Toxins Bacterial toxins can travel throughout the body. For example, the *Streptococcus* bacterium that causes strep throat can release toxins into the bloodstream. These toxins can cause scarlet fever. A red rash appears on the skin of someone infected with scarlet fever. Diphtheria, another disease caused by the *Corynebacterium diphtheriae* bacterium, infects the tissues of the throat. *C. diphtheriae* releases toxins into the bloodstream, where they destroy tissues. Diphtheria can lead to breathing problems, heart failure, paralysis, and death.

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?**

Preventing Bacterial Disease Some of the diseases caused by pathogenic bacteria include Lyme disease, tetanus, strep throat, and tooth decay. Many bacterial diseases can be prevented by stimulating the body's immune system with vaccines. A **vaccine** is a preparation of weakened or killed pathogens. When injected into the body, a vaccine sometimes prompts the body to produce immunity to the disease. Immunity is the body's ability to destroy new pathogens. You will learn more about immunity in Chapter 40.

If a bacterial infection does occur, a number of drugs can be used to attack and destroy the invading bacteria. These drugs include antibiotics, such as penicillin and tetracycline. **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 human life expectancy during the past two centuries is an increased understanding of how to prevent and cure bacterial infections. The history of the use of vaccines is illustrated in the Biology and History timeline below.

Controlling Bacteria

Although most bacteria are harmless, and many are beneficial, the risks of bacterial infection are great enough to warrant efforts to control bacterial growth. **There are various methods used to control bacterial growth, including sterilization, disinfectants, and food processing.**

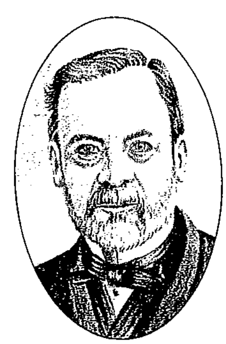
Biology and History

The History of Vaccines

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.

1769
Edward Jenner
Jenner performs the first inoculation against smallpox by infecting a boy with cowpox.

1880
Louis Pasteur develops germ theory of disease.



1881
Louis Pasteur
Pasteur develops the first effective vaccine against anthrax, a bacterial disease that affects both animals and humans.

1750 1850 1900

Sterilization by Heat One method used to control the growth of potentially dangerous bacteria is sterilization. Sterilization destroys all bacteria by subjecting them to great heat. Most bacteria cannot survive high temperatures for a long time, so most can be killed by exposure to high heat.

Disinfectants Another method of controlling bacteria is by using disinfectants—chemical solutions that kill pathogenic bacteria. Disinfectants are used in the home to clean bathrooms, kitchens, and other rooms where bacteria may flourish.

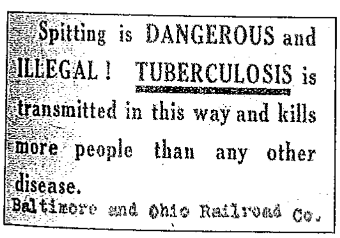
Today, some manufacturers of soaps, cleansers, and even kitchen utensils have added antibacterial chemicals to their products. If you wash your hands properly, ordinary soaps do a good job of removing bacteria. Overuse of antibacterial compounds increases the likelihood that common bacteria will eventually evolve to become resistant to them—and therefore much more dangerous and difficult to kill.

Food Storage and Processing As you read earlier, bacteria can cause food to spoil. One method of stopping food from spoiling is storing it in a refrigerator. Food that is stored at a low temperature will stay fresh longer because the bacteria will take much longer to multiply. In addition, boiling, frying, or steaming can sterilize many kinds of food. Each of these cooking techniques raises the temperature of the food to a point where the bacteria are killed.

CHECKPOINT *Why might scientists recommend the use of regular soap over antibacterial soap?*

Writing in Science

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


Spitting is DANGEROUS and ILLEGAL! TUBERCULOSIS is transmitted in this way and kills more people than any other disease.
Baltimore and Ohio Railroad Co.

1923
Albert Calmette
Camille Guérin
Calmette and Guérin develop a vaccine against tuberculosis.

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.

1952
Jonas Salk
Salk develops a polio vaccine using killed viruses.

1957
Albert Sabin
Sabin develops a polio vaccine based on live, weakened viruses.

1900 — 1950 — 2000

Viral Disease in Humans

Like bacteria, viruses produce disease by disrupting the body's normal equilibrium. In many viral infections, viruses attack and destroy certain cells in the body, causing the symptoms of the disease. Poliovirus infects and kills cells of the nervous system, producing paralysis. Other viruses cause infected cells to change their patterns of growth and development.

Unlike bacterial diseases, viral diseases cannot be treated with antibiotics. The best way to protect against most viral diseases lies in prevention, often by the use of vaccines. 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 with over-the-counter medicines. **Figure 19–13** lists some common diseases caused by both viruses and bacteria.

▼ **Figure 19–13** **Some common bacterial and viral diseases are shown in the table below.** Bacterial diseases are shown in the blue rows, while viral diseases are shown in the white rows.

Bacterial and Viral Diseases

Disease	Effect on Body	Transmission
Lyme disease	"Bull's-eye" rash at site of tick bite, fever, fatigue, headache	Bite from an infected tick
Tetanus	Lockjaw, stiffness in neck and abdomen, difficulty swallowing, fever, elevated blood pressure, severe muscles spasms	Bacteria enters the body through a break in the skin
Tuberculosis	Fatigue, weight loss, fever, night sweats, chills, appetite loss	Bacterial particles are inhaled
Bacterial meningitis	High fever, headache, stiff neck, nausea, fatigue	Bacteria are spread in respiratory droplets caused by coughing and sneezing; close or prolonged contact with someone infected with meningitis
Strep throat	Fever, sore throat, headache, fatigue, nausea	Direct contact with mucus from an infected person or direct contact with infected wounds or breaks in the skin
Common cold	Sneezing, sore throat, fever, headache, muscle aches	Contact with contaminated objects; droplet inhalation
Influenza	Body aches, fever, sore throat, headache, dry cough, fatigue, nasal congestion	Flu viruses spread in respiratory droplets caused by coughing and sneezing
AIDS	Helper T cells, which are needed for normal immune system function, are destroyed	Contact with contaminated blood or bodily fluids; pregnant women to babies during delivery or during breastfeeding
Chicken pox	Skin rash of blisterlike lesions	Virus particles are spread in respiratory droplets caused by coughing and sneezing; highly contagious
Hepatitis B	Jaundice, fatigue, abdominal pain, nausea, vomiting, joint pain	Contact with contaminated blood or bodily fluids
West Nile	Fever, headache, body ache	Bite from an infected mosquito

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: master's 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.

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Viral Disease in Animals

Viruses produce serious animal diseases as well. An epidemic of foot-and-mouth (or hoof-and-mouth) disease, caused by a virus that infects cattle, sheep, and pigs, swept through parts of Europe in the late 1990s. Thousands of cattle were destroyed in efforts to control the disease. American authorities took special precautions to guard against the spread of the foot-and-mouth virus to North America.

Viral Disease in Plants

Many viruses, including tobacco mosaic virus, infect plants. These viruses pose a serious threat to many agricultural crops. Farmers in many countries, including the United States, struggle to control them. Like other viruses, plant viruses contain a core of nucleic acid and a protein coat.

Unlike animal viruses, most plant viruses have a difficult time entering the cells they infect. This is partly because plant cells are surrounded by tough cell walls that viruses alone cannot break through. As a result, most plant viruses are adapted to take advantage of breaks in the cell wall caused by even minor damage to plant tissues. Viruses can enter through tears in leaf tissue, breaks in stems or roots, or simply through microscopic cell wall damage caused by human or animal contact with the plant.

▲ **Figure 19–14** 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?*

Once inside the plant, many viruses spread rapidly, causing severe tissue damage, mottled leaves, and wilting, and sometimes killing the infected plant. Plant viruses infect many valuable fruit trees, including apples and peaches, and have caused serious losses in the potato crop.

Viroids and Prions

Scientists have discovered two other viruslike particles that also cause disease: viroids and prions. Viroids cause disease in plants. Prions cause disease in animals.

Viroids Many plants, including potatoes, tomatoes, apples, and citrus fruits, can be infected by viroids. **Viroids** are single-stranded RNA molecules that have no surrounding capsids. It is believed that viroids enter an infected cell and direct the synthesis of new viroids. The viroids then disrupt the metabolism of the plant cell and stunt the growth of the entire plant.

Prions In 1972, American 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 the disease might actually be caused by tiny particles found in the brains of infected sheep. Unlike viruses, these particles contained no DNA or RNA, only protein. Prusiner called these particles **prions,** short for "protein infectious particles." Although prions were first discovered in sheep, many animals, including humans, can become infected with prions.

There is some evidence that prions cause disease by forming protein clumps. These clumps induce normal protein molecules to become prions. Eventually, there are so many prions in the nerve tissue that cells become damaged. There is strong evidence that mad cow disease may be caused by prions.

19–3 Section Assessment

1. **Key Concept** What are the two ways that bacteria cause disease?
2. **Key Concept** Describe the three methods of preventing bacterial growth in food.
3. **Key Concept** Describe how viruses cause disease.
4. What are viroids?
5. **Critical Thinking Applying Concepts** You think you might have a bacterial infection. Would you ask for a vaccination against the bacteria? Why or why not?
6. **Critical Thinking Applying Concepts** How might epidemiologists collaborate with scientists who study viruses as they investigate viral diseases?

Writing in Science

Creative Writing

In *War of the Worlds,* Earth is invaded by aliens. No weapons can kill the invaders. Earth is saved when the invaders die from diseases they contract. Write a summary of a story about people from Earth voyaging to another planet. Include information on how the people from Earth might protect themselves from possible new diseases.

Exploration

Identifying Limits to the Growth of Bacteria

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

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

Skills

Analyzing Data, Drawing Conclusions

Data Table

Temperature	Number of Colonies	
	24 hours	48 hours
3°C		
20°C		
37°C		

Procedure

1. **Asking Questions** Read the investigation; then, write three questions about how temperature might affect the growth of bacteria.
2. **Predicting** Predict how temperature will affect the growth rate of bacterial colonies.
3. Put on your plastic gloves. Use a glass-marking pencil to label the edges of the agar plates "3°C," "20°C," and "37°C." Also, write your name on each plate.
4. 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. Place the plate labeled "3°C" in a refrigerator. Leave the plate labeled "20°C" in a place designated by your teacher. Place the plate labeled "37°C" in an incubator. Be sure to store each plate upside down.
7. Make a copy of the data table. After 24 hours, examine each plate with a hand lens. Bacterial colonies look like small white or colored dots on the agar surface. In your data table, record the number of bacterial colonies on each agar plate. Return each plate to its location.
8. After a second period of 24 hours, record in your data table the number of bacterial colonies on each agar plate. Return your agar plates to your teacher for safe disposal.
9. 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** 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.
4. **Evaluating** Do you consider your data reliable? Explain. Did the results of your experiment confirm your prediction?

Go Further

Formulating Hypotheses Propose a hypothesis about the effects of another variable on the growth of bacteria. Design an experiment that could test your hypothesis.