Origin of Viruses

Although viruses are smaller and simpler than the smallest cells, they could not have been much like the first living things. Viruses are completely dependent upon living cells for growth and reproduction, and they cannot live outside their host cells. Thus 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 and have continued to evolve, along with the cells they infect, over billions of years.

17–1 SECTION REVIEW

1. What is a virus?
2. List and describe the parts of a bacteriophage.
3. Describe two methods of viral infection.
4. **Critical Thinking—Applying Concepts** How can a virus be helpful to its host?

17–2 Bacteria—Prokaryotic Cells

Guide For Reading

- How are prokaryotes classified?
- How do bacteria obtain energy?
- How do bacteria grow and reproduce?
- How do bacteria affect other living things?

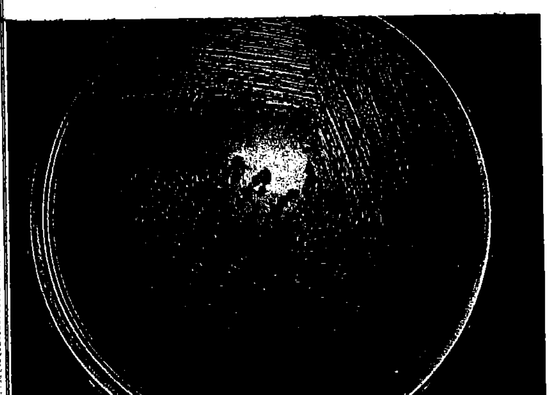
Imagine living all your life as the only family on your street. Then, on a morning like any other, you open the front door and there are houses all around you, cars and bicycles on the street, neighbors tending their gardens, children walking to school. Where did they come from? What if the answer turned out to be that they were always there—you just couldn't see them? In fact, they 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 being the only family on the block to just one family in a crowded community? A bit of a shock?

Because of Robert Hooke and Anton van Leeuwenhoek, the human species had just such a shock. The invention of the light microscope opened our eyes to what the world around us is really like. And it opened our eyes almost overnight. Suddenly we saw that the block is very crowded!

Microscopic life covers nearly every square centimeter of planet Earth. What form does that microscopic life take? As you learned in Chapter 5, there are cells of every size and shape imaginable, even in a drop of pond water. The smallest and most common of these cells are the **prokaryotes**. Prokaryotes are cells that do not have a nucleus.

Where do we find prokaryotes? Everywhere! Prokaryotes exist in almost every place on Earth. They grow in numbers so great that they form colonies you can see with the unaided eye.

Figure 17–7 With a nutrient-rich culture medium on which to grow, these bacteria have produced thousands of colonies.



Classification of Prokaryotes

All prokaryotes are placed in one of two kingdoms: the Eubacteria or the Archaebacteria. These kingdoms are the first large groups of organisms we shall consider as we examine each of the six kingdoms of living things. The **bacteria,** or one-celled prokaryotes, in these two kingdoms include a wide range of organisms that live in every imaginable habitat on Earth.

Bacteria range in size from 1 to 10 micrometers (one micrometer is equal to one thousandth of a millimeter). Bacteria are much smaller than eukaryotic cells, or cells with a nucleus, which generally range from 10 to 100 micrometers in diameter. The reason for the difference in size is that bacteria do not contain the complex range of membrane-enclosed organelles that are found in most eukaryotic cells.

EUBACTERIA The Eubacteria (yoo-bak-TEER-ee-uh) make up the larger of the two prokaryote kingdoms. Eubacteria are generally surrounded by a cell wall composed of complex carbohydrates that protects the cell from injury. Within the cell wall is a cell membrane that surrounds the cytoplasm. Some eubacteria are surrounded by two cell membranes, making them especially resistant to damage. In some organisms, long whiplike flagella protrude from the membrane through the cell wall. Flagella are used for movement.

Within the kingdom Eubacteria there is a wide range of organisms that have many different lifestyles. The variety is so great, in fact, that biologists have not been able to agree on exactly how many phyla to divide the kingdom into. Some eubacteria live in the soil. Others infect larger organisms and produce disease. Some eubacteria are simple, and contain few internal structures. Other eubacteria contain elaborate systems of internal membranes and compartments.

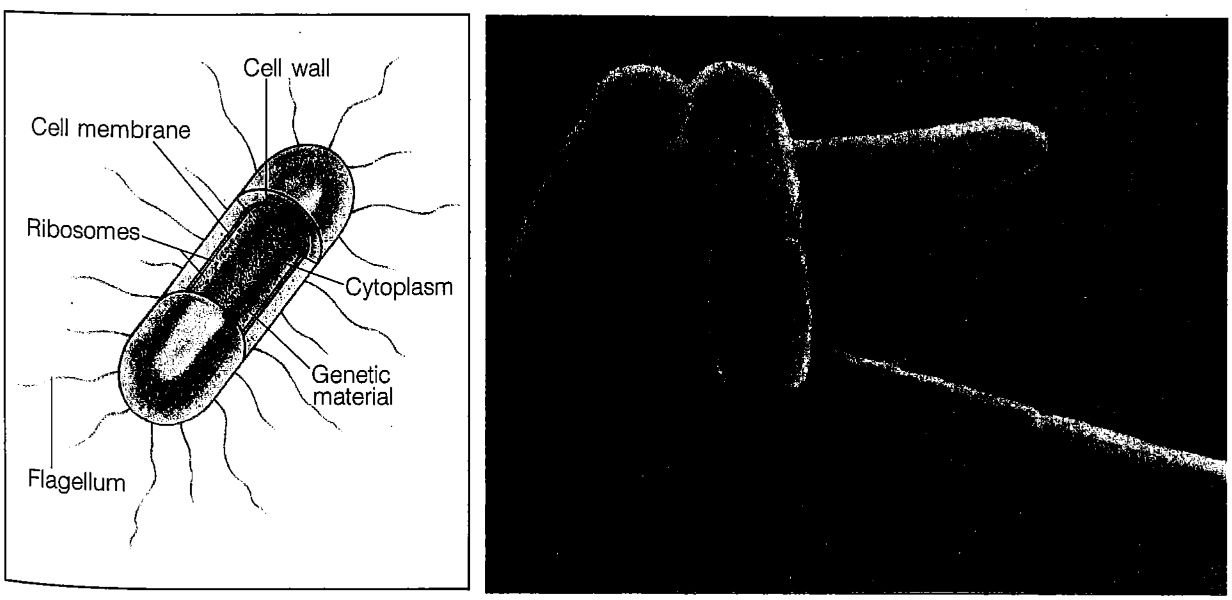


Figure 17–8 *A bacterium such as* E. coli *(right) has the basic structure typical of most bacteria: cell wall, cell membrane, region of genetic material, and cytoplasm. Note the flagella projecting from the cell surface.*

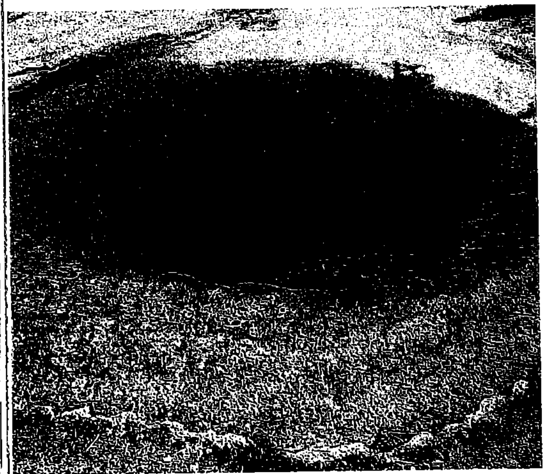


Figure 17–9 *Some archaebacteria can survive in many environments that support no other forms of life, such as in a near-boiling hot spring called Morning Glory Pool in Yellowstone National Park, Wyoming.*

Some of the most important eubacteria are the cyanobacteria (sigh-uh-noh-bak-TEER-ee-uh), also known as blue-green bacteria. These organisms are photosynthetic, meaning that they use the energy of sunlight to make their own food. At one time, cyanobacteria were called blue-green algae, but today we use the word algae only for eukaryotes. In fact, only a few blue-green bacteria are blue-green in color. Those cyanobacteria that are blue-green in color contain a pigment called phycocyanin. They also contain chlorophyll *a*, which you will recall from Chapter 6 is green. The presence of these two pigments gives the name blue-green to the entire group of cyanobacteria. The presence of other pigments, however, may change the color of these bacteria to yellow, brown, or even red.

Cyanobacteria contain membranes that carry out the light reactions of photosynthesis. These membranes contain the photosynthetic pigments and are quite different from and simpler than the chloroplasts (organelles that trap light energy and convert it to chemical energy) in plant cells.

Cyanobacteria are found throughout the world—in fresh and salt water and on land. A few species can survive in extremely hot water, such as that in hot springs. Others can 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.

The prochlorobacteria (proh-klor-oh-bak-TEER-ee-uh) are a newly discovered group of organisms that contain chlorophyll *a* and *b*. The presence of these pigments makes prochlorobacteria more similar to chloroplasts of green plants than to cyanobacteria. For this reason, prochlorobacteria are sometimes called Prochlorophyta (*-phyta* means plants) to emphasize this similarity. To date, only two species of prochlorobacteria have been discovered.

ARCHAEBACTERIA Recent studies of prokaryotes have confirmed that one group of organisms is so different from those organisms in the Eubacteria kingdom that it should be considered as a separate kingdom. The organisms in this kingdom, called the Archaebacteria (ahr-kee-bak-TEER-ee-uh), lack an important carbohydrate found in the cell walls of nearly all eubacteria. They also have different types of lipids in their cell membranes, different types of ribosomes, and some very different gene sequences. The archaebacteria include organisms that live in extremely harsh environments. For example, one group of archaebacteria lives in oxygen-free environments such as thick mud and the digestive tracts of animals. These archaebacteria are called **methanogens** because they produce methane gas. Other archaebacteria live in extremely salty environments, such as the Great Salt Lake in Utah, or in extremely hot environments, such as hot springs where temperatures approach the boiling point of water.

Identifying Prokaryotes

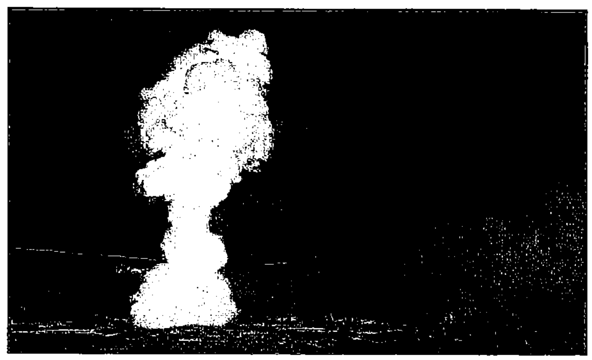
Identifying living organisms can be a simple task. If we were given an unknown plant or animal, we would search through the photographs and diagrams in a reference book until we found one that resembled our unknown specimen. Such a method works for organisms that we can identify by appearance. But what about bacteria? How can they be identified?

CELL SHAPE One way in which bacteria can be identified is by their shape. **Bacteria have three basic shapes: rod, sphere, and spiral.** Rod-shaped bacteria are called **bacilli**

Biology Update *Heat-stable Enzymes*

Prospecting the New Wild West

Established in 1872, Yellowstone National Park is the oldest national park in the United States. Every year, millions of visitors enjoy the park's natural beauty and the diversity of its wildlife. It now turns out that there may be something else in Yellowstone—a treasure. No, the treasure isn't buried gold or silver. The treasure may be Yellowstone's unique forms of life.



Organisms living in geysers such as Old Faithful in Yellowstone Park may be the source of heat-stable enzymes that have a variety of applications in biochemistry and medicine.

"Digging" for Enzymes

More than 60 percent of all the hot springs and geysers on Earth are found in Yellowstone Park's 10,000 geothermal sites. These regions contain bacteria and other microorganisms adapted to some of the harshest environments on Earth. In 1997, knowing that only a tiny fraction of these sites have been explored biologically, a mining corporation signed a "bio-prospecting" agreement with Yellowstone. The company hopes to find powerful heat-stable enzymes in these organisms that can be used in medicine, food production, and industrial chemistry.

By sharing royalties from the products it develops with the park itself, the corporation's unique form of prospecting may not only advance industry but also help preserve the features that made the park so special in the first place. What do you think about the idea of bioprospecting?

Get an update on bioprospecting at our Internet site: ***http://www.phschool.com***

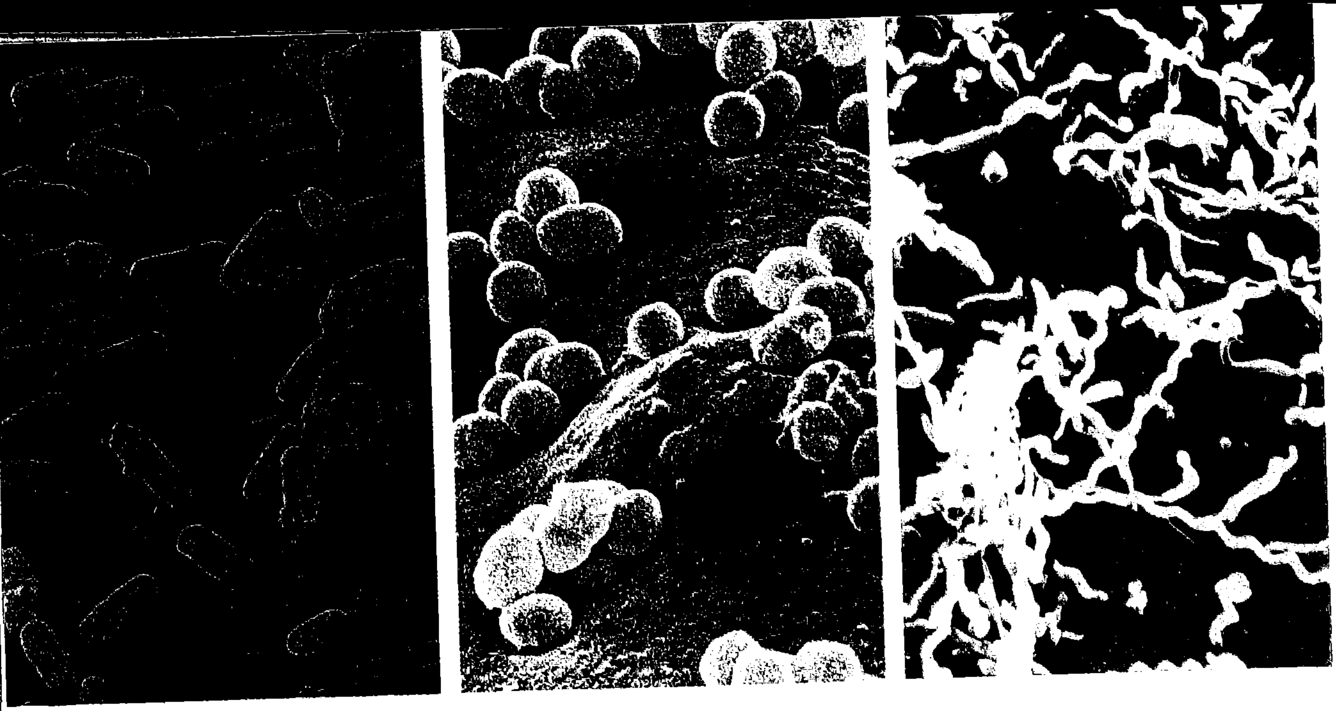
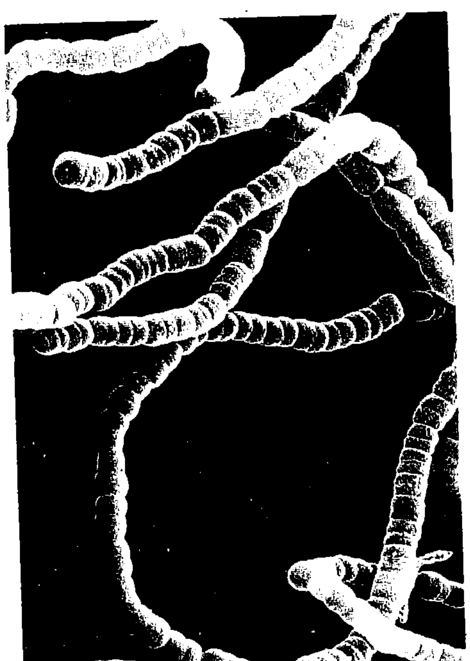


Figure 17–10 *Bacteria have three basic shapes. Rod-shaped bacteria are called bacilli (left), spherical bacteria are called cocci (center), and spiral-shaped bacteria are called spirilla (right).*

(buh-SIHL-igh; singular: bacillus). Spherical bacteria are called **cocci** (KAHK-sigh; singular: coccus). And spiral-shaped bacteria are called **spirilla** (spigh-RIHL-uh; singular: spirillum). See Figure 17–10.

Individual bacterial cells can also arrange themselves in a number of different ways. For example, cocci sometimes grow in colonies containing two cells. Many cocci, including the disease-causing bacteria *Streptococcus* and *Pneumococcus*, may form long chains. A few others, such as *Staphylococcus*, form large clumps or clusters. These differences are very helpful in distinguishing one kind of bacteria from another.

Figure 17–11 *Some spherical bacteria like these streptococci form long chains.*



Unfortunately, many bacteria look the same under the microscope. So we need to find another characteristic by which to distinguish one type from another. Fortunately, there are three other characteristics of bacteria that improve our ability to identify them: their cell walls, the kind of movement they are capable of, and how they obtain energy.

CELL WALL The chemical nature of bacterial cell walls can be studied by means of a method called Gram staining—which is named after its inventor, the Danish physician Hans Christian Gram. Gram's stain consists of two dyes—crystal violet (purple) and safranine (red).

When Gram added his stain to bacteria, he noticed that the bacteria took up either the purple dye or the red dye. The bacterial cells with only one thick layer of carbohydrate and protein molecules outside the cell membrane took up the crystal violet. They appeared purple under the light microscope. These bacteria are called Gram-positive bacteria. The bacterial cells with a second, outer layer of lipid and carbohydrate molecules took up the safranine. They appeared red under the microscope. These bacteria are called Gram-negative bacteria.

BACTERIAL MOVEMENT We can also identify bacteria by studying how they move. Some bacteria are propelled by means of one or more flagella. Others lash, snake, or spiral forward. Still others glide slowly along a layer of slimelike material that they secrete themselves. And there are some bacteria that do not move at all.

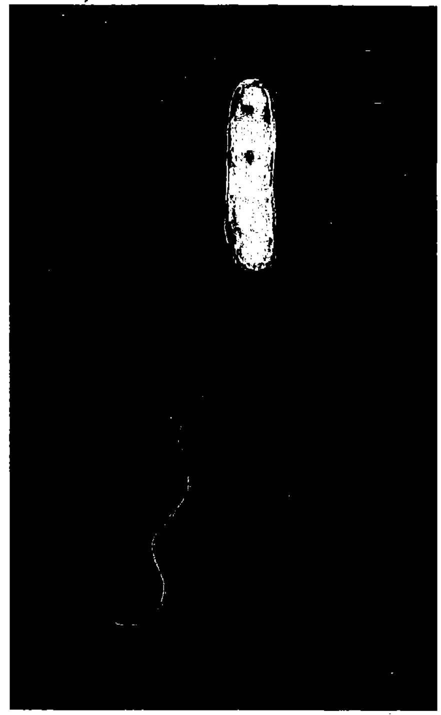


Figure 17–12 *Many types of bacteria, such as the bacterium that causes Legionnaires' disease, move by means of a whiplike flagellum.*

How Bacteria Obtain Energy

Although the structure of bacteria is rather simple, their lifestyles are remarkably complex. No characteristic of bacteria illustrates this point better than the ways in which they obtain energy.

AUTOTROPHS Bacteria that trap the energy of sunlight in a manner similar to green plants are called **phototrophic autotrophs.** Examples of phototrophic autotrophs include some photosynthetic eubacteria.

Bacteria that live in harsh environments and obtain energy from inorganic molecules are called **chemotrophic autotrophs.** The inorganic molecules that are used by chemotrophic autotrophs include hydrogen sulfide, nitrites, sulfur, and iron. *Nitrosomonas* is an example of a chemotrophic autotroph that uses ammonia and oxygen to produce energy.

HETEROTROPHS Many bacteria obtain energy by taking in organic molecules and then breaking them down and absorbing them. These bacteria are called **chemotrophic heterotrophs.** Most bacteria, as well as most animals, are chemotrophic heterotrophs.

Because we are chemotrophic heterotrophs ourselves, many bacteria compete with us for food sources. For example, *Salmonella* is a bacteria that grows in foods such as raw meat, poultry, and eggs. If these foods are not properly cooked, *Salmonella* will get to your dinner table before you do! Once there, these bacteria will not only "eat" some of the food ahead of time, but they will release poisons into the food. Food poisoning can result. The symptoms of food poisoning range from an upset stomach to serious illness.

There is another group of heterotrophic bacteria that has a most unusual means of obtaining energy. These bacteria are photosynthetic—they are able to use sunlight for energy. But they also need organic compounds for nutrition. These bacteria are called **phototrophic heterotrophs.** There is nothing quite like these organisms in the rest of the living world.

Bacterial Respiration

Like all organisms, bacteria need a constant supply of energy to perform all their life activities. This energy is supplied by the processes of respiration and fermentation. Respiration is the process that involves oxygen and breaks down food molecules to release energy. Fermentation, on the other hand, enables cells to carry out energy production without oxygen.

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**. Obligate anaerobes must live in the absence of oxygen.

An example of an obligate anaerobe is the bacterium *Clostridium botulinum*, which is often found in soil. Because *Clostridium* is unable to grow in the presence of oxygen, it normally causes very few problems. However, if these bacteria find their way into a place that is free of air (air contains oxygen) and filled with food material, they will grow very quickly. As they grow, the bacteria produce **toxins**, or poisons, that cause botulism. Botulism is a rare form of food poisoning that interferes with nerve activity and can cause paralysis and, if the breathing muscles are paralyzed, death. A perfect place for these bacteria to grow is in the space inside a can of food. Most commercially prepared canned foods are safe because the bacteria and their toxins have been destroyed by heating the foods for a long time before the cans are sealed. However, botulism is always a danger when food is canned at home. Thus experienced canners thoroughly heat food before sealing it in jars.

A third group of bacteria are those that can survive with or without oxygen. They are known as **facultative anaerobes**. Facultative anaerobes do not require oxygen, but neither are they poisoned by its presence. What does such diversity imply? It means that bacteria can live in virtually every place on the surface of planet Earth. And indeed they do! Bacteria are found in freshwater lakes and ponds, at the bottom of the ocean, at the tops of the highest mountains, in the most sterile hospital rooms, and even in our own digestive systems!

***Figure 17–13** Botulism, a kind of food poisoning, is caused by the bacterium* Clostridium botulinum. *The small round structures on some of the bacteria are endospores.*

Bacterial Growth and Reproduction

When conditions are favorable, bacteria can grow and reproduce at astonishing rates. Some types of bacteria can reproduce 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, then in just 48 hours (2 days) they would reach a mass approximately 4000 times the mass of the Earth! Fortunately for us, this does not happen. In nature, the growth of bacteria is held in check by the availability of food and the production of waste products. However, bacteria do reproduce, and they do so in a number of ways.

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

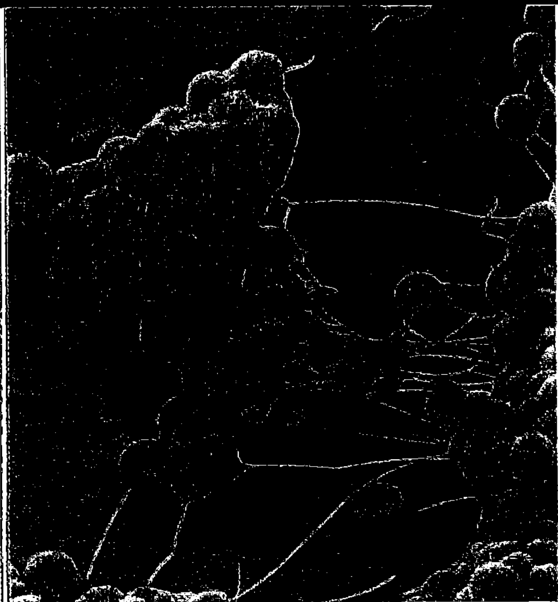
 

Figure 17–14 Most bacteria reproduce by binary fission, producing two identical cells (right). However, some bacteria reproduce by conjugation, or the transfer of parts of their genetic information from one cell to another through a protein bridge (left).

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. The bacterium *E. coli* undergoes binary fission. See Figure 17–14.

CONJUGATION Although many bacteria reproduce only through asexual binary fission, others take part in some form of sexual reproduction. Sexual reproduction involves the exchange of genetic information. One form of sexual reproduction that occurs in some bacteria is known as **conjugation**. See Figure 17–14.

During conjugation, a long bridge of protein forms between and connects two bacterial cells. Part of the genetic information from one cell, called the donor, is transferred to the other cell, called the recipient, through this bridge. When the process of conjugation is complete, the recipient cell has a different set of genes from those it had before conjugation occurred. The new combinations of genes that result from conjugation increase the genetic diversity in that population of bacteria. Genetic diversity helps to ensure that even if the environment changes, a few bacteria may have the right combinations of genes to survive.

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.

The endospore can remain dormant for months or even years, waiting for more favorable growth conditions. When conditions improve, the endospore will open and the bacterium will begin to grow again. Strictly speaking, spore formation in bacteria is not a form of reproduction because it does not result in the formation of new bacterial cells. However, the ability to form spores makes it possible for some bacteria to survive harsh conditions that would otherwise kill them.

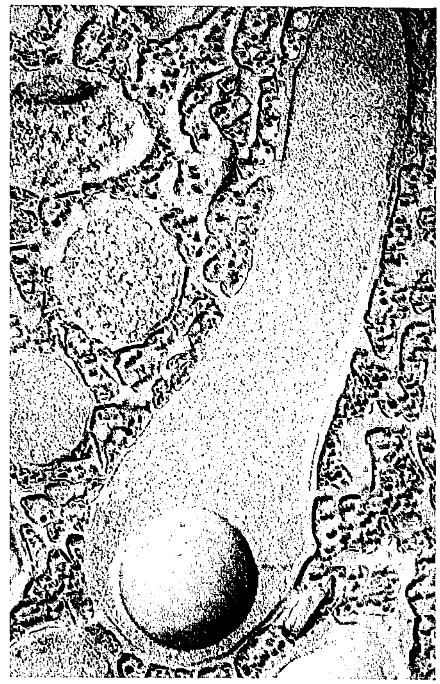


Figure 17–15 The round circle at the bottom of this electron micrograph of a bacterium is an endospore. Endospores enable bacteria to survive unfavorable conditions, such as high temperature.

Importance of Bacteria

Many of the remarkable properties of bacteria provide us with products upon which we depend every day. For example, bacteria are used in the production of a wide variety of foods and beverages, such as cheese, yogurt, buttermilk, and sour cream. Some bacteria are used to make pickles and sauerkraut, and some make vinegar from wine.

Bacteria are also used in industry. One type of bacteria can digest petroleum, which makes them 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 have been useful in synthesizing drugs and chemicals through techniques of genetic engineering.

Many kinds of bacteria develop a close relationship with other organisms in which the bacteria or the other organism or both benefit. Such a relationship is called **symbiosis** (sihm-bigh-OH-sihs). The symbiotic relationships that bacteria develop with other organisms are particularly important. Bacteria form symbiotic relationships with organisms from all of the eukaryote kingdoms.

Our intestines are inhabited by large numbers of bacteria, including *E. coli.* Indeed, the species name *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 safe home, plenty of food, and free transportation. We, in turn, get help in digesting our food. These bacteria also make a number of vitamins that we cannot produce on our own. So both we and the bacteria benefit from this symbiotic relationship.

Figure 17–16 The large round structures in this electron micrograph are cells that form the intestinal wall of the human large intestine, or colon. The smaller rod-shaped cells are the bacteria E. coli, *which inhabit the large intestine.*

Animals such as cattle are also dependent upon the symbiotic relationship they have with the bacteria in their intestines. You see, no vertebrate (animal with a backbone) can produce the enzymes necessary to break down cellulose, the principal carbohydrate in grass and hay. Bacteria living in the digestive systems of such animals can make these enzymes, thus allowing the animals to digest their food properly.

Bacteria in the Environment

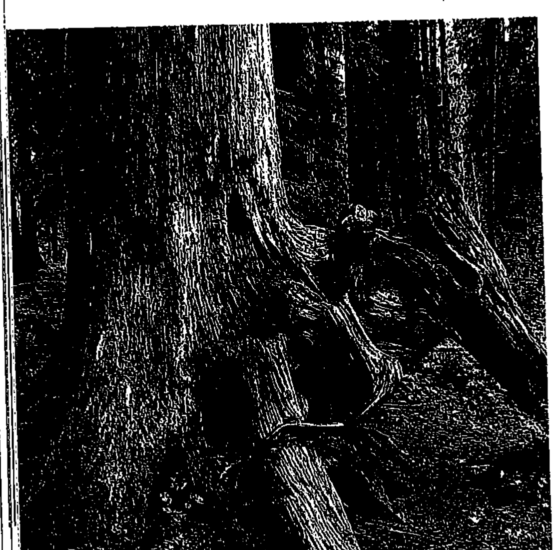
Sometimes we are bold enough to consider ourselves the principal actors on the stage of life. We tend to place other organisms in supporting roles, like the minor actors in a play. But no drama can begin without the dozens of workers who are never seen on stage. The bacteria are like these unseen stagehands. We seldom think about them, but they are absolutely vital to maintaining the kind of living world we see about us.

NUTRIENT FLOW Every living thing depends on a supply of raw materials for growth. If these materials were lost forever when an organism died, then life could not continue. Before long, plants would drain the soil of the minerals they need, plant growth would stop, and the animals that depend on plants for food would starve.

Bacteria recycle and decompose, or break down, dead material. When a tree dies and falls to the forest floor, it begins to undergo many changes. Over the course of a few summers, the bark peels off and the wood begins to weaken because it becomes infested with insects. Then the tree crumbles into the soil. Over time, the whole substance of the tree disappears. What happens to all of the material that made up the tree?

From the moment the tree dies, armies of bacteria attack and digest the dead wood, breaking it down into simpler substances. These bacteria are called **saprophytes** (SAP-ruh-fights). Saprophytes are organisms that use the complex molecules of a once-living organism as their source of energy and nutrition. Gradually, the material of the tree is recycled, enriching the soil in which it grew. Although bacteria play a major role in this process, some eukaryotic organisms, such as insects and fungi, have a supporting role.

Figure 17–17 Most bacteria are heterotrophs, or organisms that obtain food from the organic compounds of other organisms. Many of these heterotrophs live as saprophytes, decomposing dead organisms such as this tree.



SEWAGE DECOMPOSITION Humans take advantage of the ability of bacteria to decompose material in the treatment of sewage. One of the critical steps in sewage treatment is carried out by a diverse mixture of bacteria that is added directly to the waste water. Waste water contains human waste, discarded food, organic garbage, and even chemical waste. Bacteria grow rapidly in this mixture. As they grow, they break down the complex compounds in the sewage into simpler compounds. This process produces purified water, nitrogen gas and carbon dioxide gas, and leftover products that can be used as crop fertilizers.

Biology Update — Bacterial Biomass

Who Really Rules the Earth?

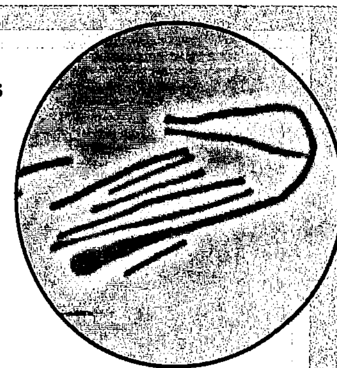
What kind of organism makes up most of the living material—the biomass—of the Earth? For many years, most biologists thought that the answer was obvious: Plants do. In fact, given the size and density of forests around the globe, many biologists would have been more specific: They would have said that most of the Earth's biomass is in the wood of trees.

This easy conclusion, however, may be wrong. After discovering microbes and other organisms thriving at the extreme conditions found in deep-ocean vents, biologists began to wonder if bacteria might be able to thrive in other unexpected places.

Looking Beneath the Earth's Surface

In the early 1990s, several groups of scientists found bacteria thriving deep within the Earth's interior, at the bottoms of deep wells and oil reservoirs, and buried beneath thousands of meters of sediment. It now seems clear that an enormous number of bacteria live deep within the Earth—so many, in fact, that Thomas Gold of Cornell University has proposed that if all these deep-dwelling bacteria were brought to the surface at the same time, the results would be stunning.

Thermophilus aquaticus *is one of many species of bacteria that live in unusual environments beneath the Earth's surface.*



Gold calculates that the total biomass of these bacteria is approximately 2×10^{14} tons. That's enough to form a layer of bacteria more than 1.5 meters thick over the entire land mass of the planet!

The real rulers of this planet may not be the plants and animals at all, but the bacteria and other microorganisms that thrive beneath our feet!

Get an update on bacteria at our Internet site: ***http://www.phschool.com***

NITROGEN FIXATION All organisms on our planet are totally dependent on bacteria for nitrogen. All green plants need nitrogen to make amino acids, which are the building blocks of proteins. And because animals eat plants, plant proteins are ultimately the source of proteins for animals.

Although our atmosphere is made up of approximately 80 percent nitrogen gas (N_2), plants are not able to use the nitrogen gas. Neither can most other organisms. Living organisms generally require that nitrogen be "fixed" chemically in the form of ammonia (NH_3) and related nitrogen compounds. Chemists can make synthetic nitrogen-containing fertilizers by mixing nitrogen gas and hydrogen gas, heating the mixture to 500°C, and then squeezing it to 300 times the normal atmospheric pressure. The process is expensive, time-consuming, and sometimes dangerous.

In contrast to this difficult process, many cyanobacteria and other bacteria can take nitrogen from the air and convert it to a form that plants can use. This conversion process is known as **nitrogen fixation.** Bacteria are the only organisms capable of performing nitrogen fixation.

Many plants have symbiotic relationships with nitrogen-fixing bacteria. The soybean, which hosts the bacterium *Rhizobium*, is among the best known. *Rhizobium* grows in nodules, or knobs, that form on the roots of the soybean plant. The soybean plant provides a home and a source of nutrients for the nitrogen-fixing *Rhizobium*; the bacterium fixes nitrogen directly from the air into ammonia for the plant. All plants benefit from the nitrogen-fixing ability of monerans, but soybeans are a step ahead. With a little help from their "friends," soybeans have their own fertilizer factories built right into their roots.

As you have learned, eukaryotes are dependent upon bacteria to fix nitrogen and release it into the environment. And it is because of the nitrogen-fixing ability of these organisms that more than 170 million metric tons of nitrogen are released into the environment every year.

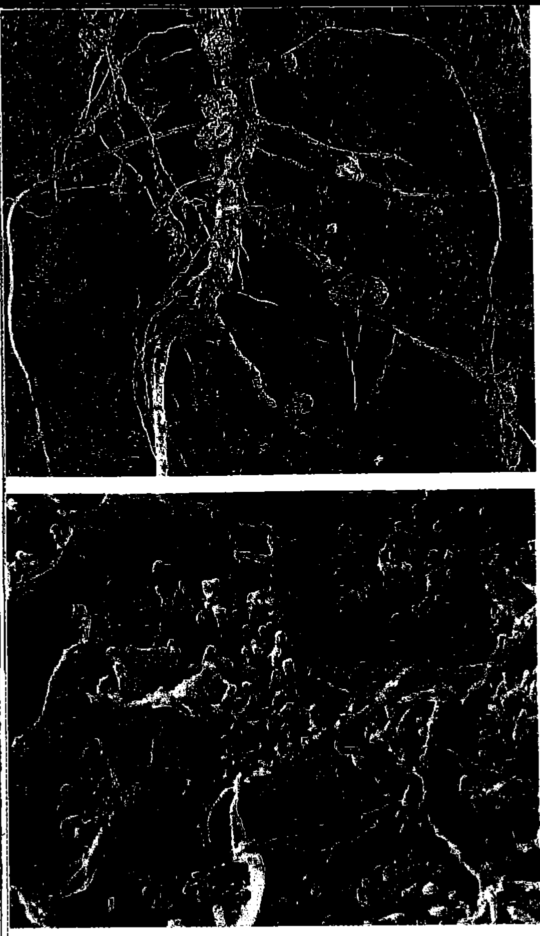


Figure 17–18 *The knoblike structures growing on the roots of this soybean plant are called nodules (top). Within these nodules are the nitrogen-fixing bacteria* Rhizobium, *which have a characteristic rod-shaped appearance (bottom).*

17–2 SECTION REVIEW

1. Describe the major groups of prokaryotes.
2. Compare the three basic shapes of bacteria.
3. Distinguish between autotrophic and heterotrophic bacteria. Between obligate aerobes, obligate anaerobes, and facultative anaerobes.
4. Describe binary fission and conjugation.
5. List some ways in which bacteria are important.
6. **Critical Thinking—Making Predictions** Suppose bacteria lost the ability to fix nitrogen. How would this affect other organisms?

Guide For Reading

- What are some diseases caused by viruses and bacteria? How are these diseases prevented and cured?
- How is the growth of bacteria controlled?

17–3 Diseases Caused by Viruses and Bacteria

Contrary to popular belief, only a small number of viruses and bacteria are capable of producing disease in humans. Despite their small numbers, these **pathogens,** or disease-producing agents, are responsible for much human suffering.

From the point of view of a microorganism, however, disease is nothing more than a conflict of lifestyles. All viruses infect living cells, and disease results when the infection causes harm to the host. All bacteria require nutrients and energy, and disease results only when bacteria interfere with the host in obtaining them.