

# BIOLOGY 2e

## Chapter 22 PROKARYOTES: BACTERIA AND ARCHAEA

PowerPoint Image Slide Show



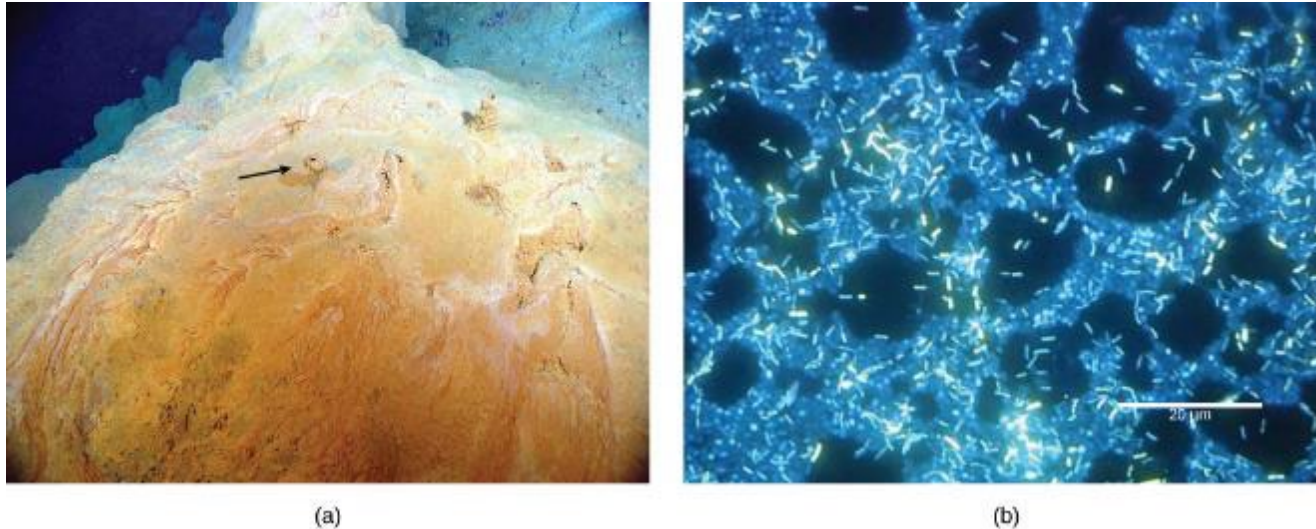
## FIGURE 22.1



Certain prokaryotes can live in extreme environments such as the Morning Glory pool, a hot spring in Yellowstone National Park. The spring's vivid blue color is from the prokaryotes that thrive in its very hot waters.

(credit: modification of work by Jon Sullivan)

## FIGURE 22.2



This (a) microbial mat, about one meter in diameter, grows over a hydrothermal vent in the Pacific Ocean in a region known as the “Pacific Ring of Fire.” The mat helps retain microbial nutrients. Chimneys such as the one indicated by the arrow allow gases to escape. (b) In this micrograph, bacteria are visualized using fluorescence microscopy.

(credit a: modification of work by Dr. Bob Embley, NOAA PMEL, Chief Scientist; credit b: modification of work by Ricardo Murga, Rodney Donlan, CDC; scale-bar data from Matt Russell)

## FIGURE 22.3



(a)



(b)

(a) These living stromatolites are located in Shark Bay, Australia. (b) These fossilized stromatolites, found in Glacier National Park, Montana, are nearly 1.5 billion years old.

(credit a: Robert Young; credit b: P. Carrara, NPS)

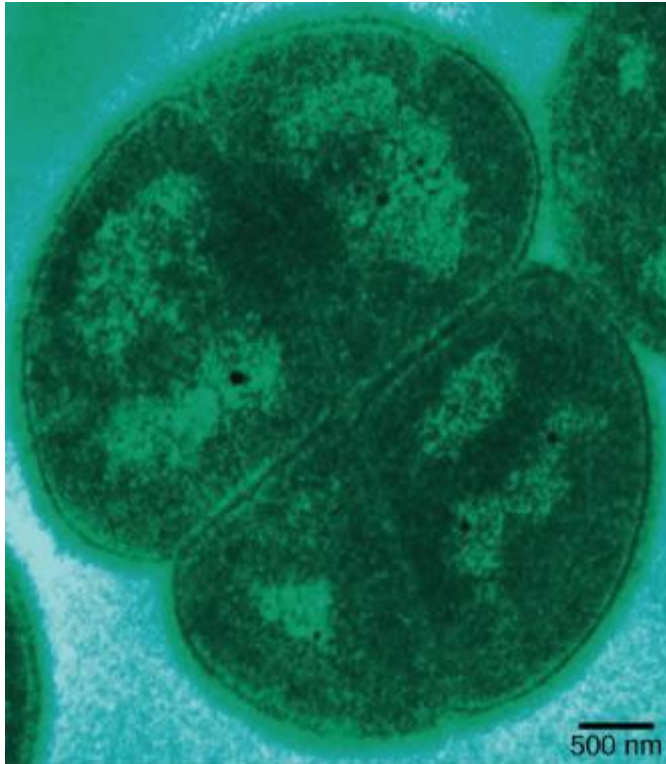
## FIGURE 22.4



This hot spring in Yellowstone National Park flows toward the foreground. Cyanobacteria in the spring are green, and as water flows down the gradient, the intensity of the color increases as cell density increases. The water is cooler at the edges of the stream than in the center, causing the edges to appear greener.

(credit: Graciela Brelles-Mariño)

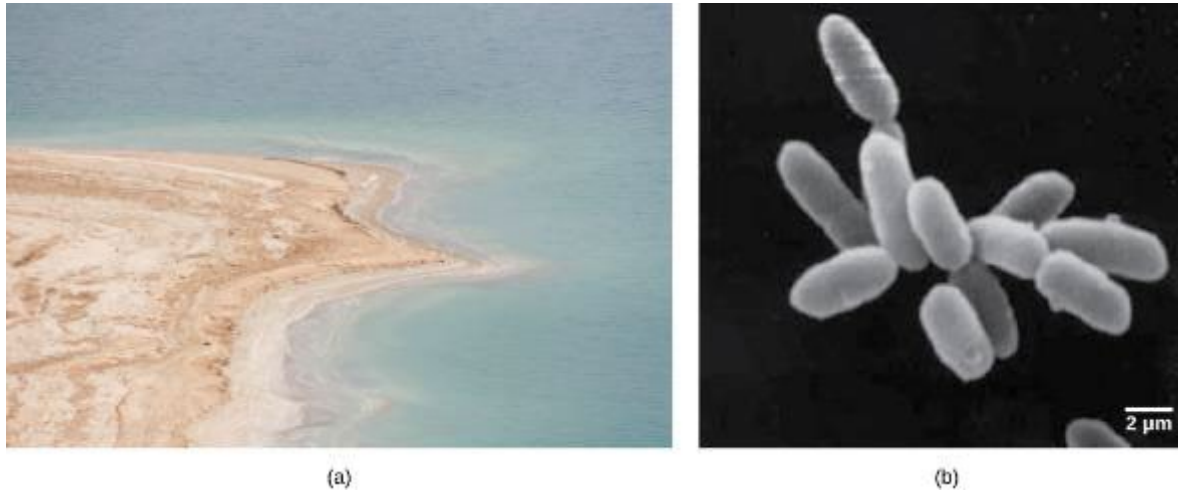
## FIGURE 22.5



*Deinococcus radiodurans*, visualized in this false color transmission electron micrograph, is a prokaryote that can tolerate very high doses of ionizing radiation. It has developed DNA repair mechanisms that allow it to reconstruct its chromosome even if it has been broken into hundreds of pieces by radiation or heat.

(credit: modification of work by Michael Daly; scale-bar data from Matt Russell)

## FIGURE 22.6



(a) The Dead Sea is hypersaline. Nevertheless, salt-tolerant bacteria thrive in this sea. (b) These halobacteria cells can form salt-tolerant bacterial mats.

(credit a: Julien Menichini; credit b: NASA; scale-bar data from Matt Russell)

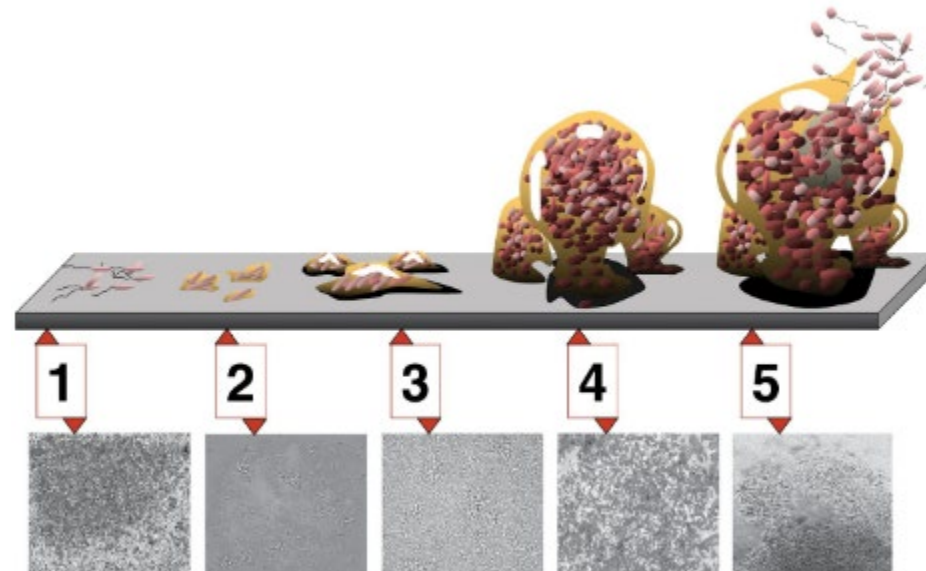
## FIGURE 22.7



In these agar plates, the growth medium is supplemented with red blood cells. Blood agar becomes transparent in the presence of hemolytic *Streptococcus*, which destroys red blood cells and is used to diagnose *Streptococcus* infections. The plate on the left is inoculated with non-hemolytic *Staphylococcus* (large white colonies), and the plate on the right is inoculated with hemolytic *Streptococcus* (tiny clear colonies). If you look closely at the right plate, you can see that the agar surrounding the bacteria has turned clear.

(credit: Bill Branson, NCI)

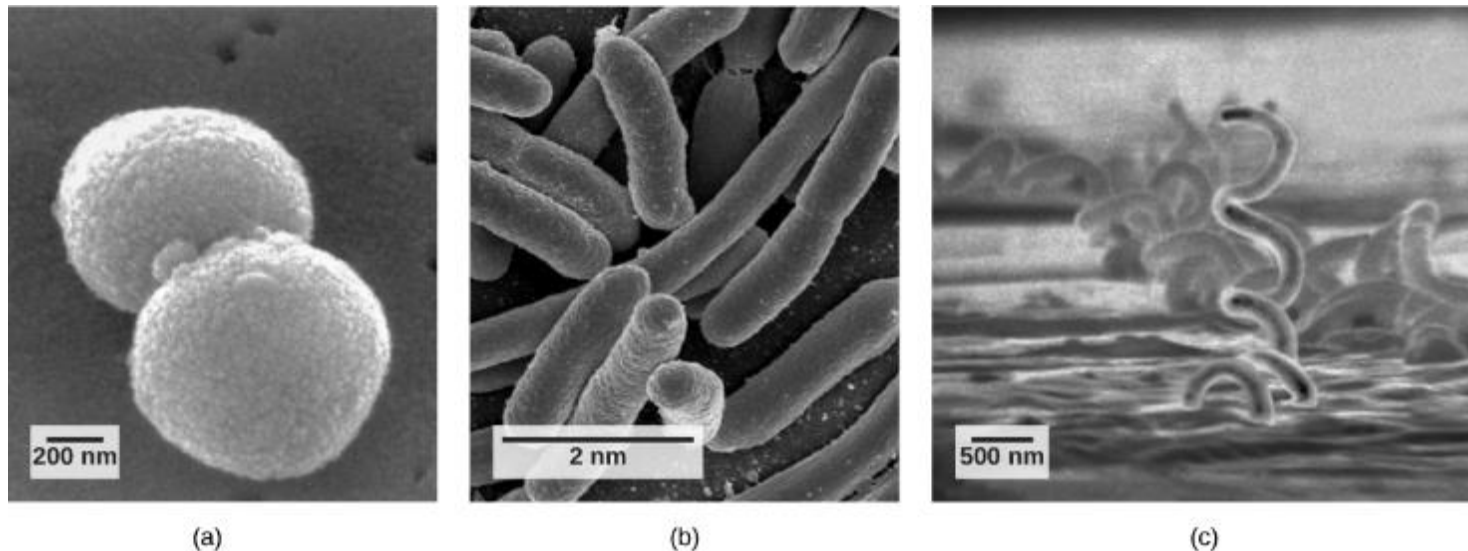
## FIGURE 22.8



Five stages of biofilm development are shown. During stage 1, initial attachment, bacteria adhere to a solid surface via weak van der Waals interactions. During stage 2, irreversible attachment, hairlike appendages called pili permanently anchor the bacteria to the surface. During stage 3, maturation I, the biofilm grows through cell division and recruitment of other bacteria. An extracellular matrix composed primarily of polysaccharides holds the biofilm together. During stage 4, maturation II, the biofilm continues to grow and takes on a more complex shape. During stage 5, dispersal, the biofilm matrix is partly broken down, allowing some bacteria to escape and colonize another surface. Micrographs of a *Pseudomonas aeruginosa* biofilm in each of the stages of development are shown.

(credit: D. Davis, Don Monroe, PLoS)

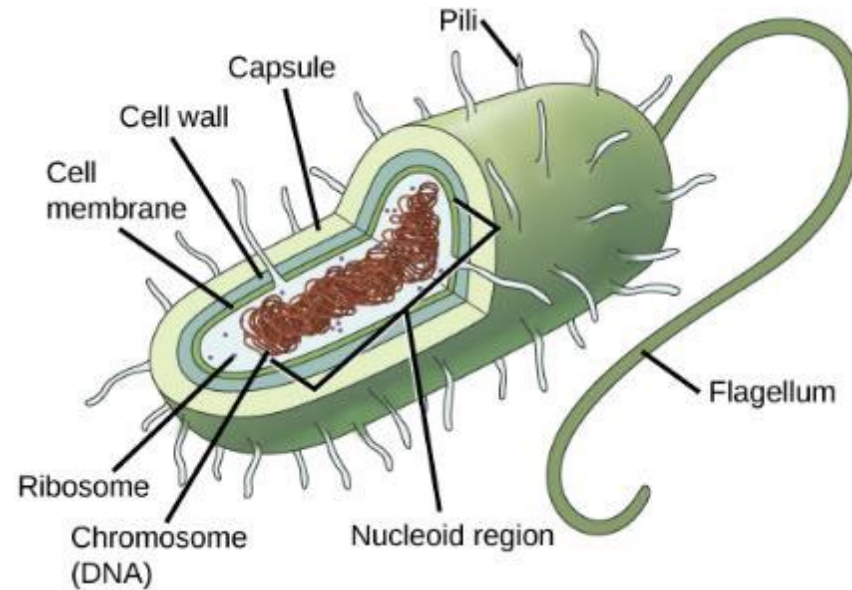
## FIGURE 22.9



Prokaryotes fall into three basic categories based on their shape, visualized here using scanning electron microscopy: (a) cocci, or spherical (a pair is shown); (b) bacilli, or rod-shaped; and (c) spirilli, or spiral-shaped.

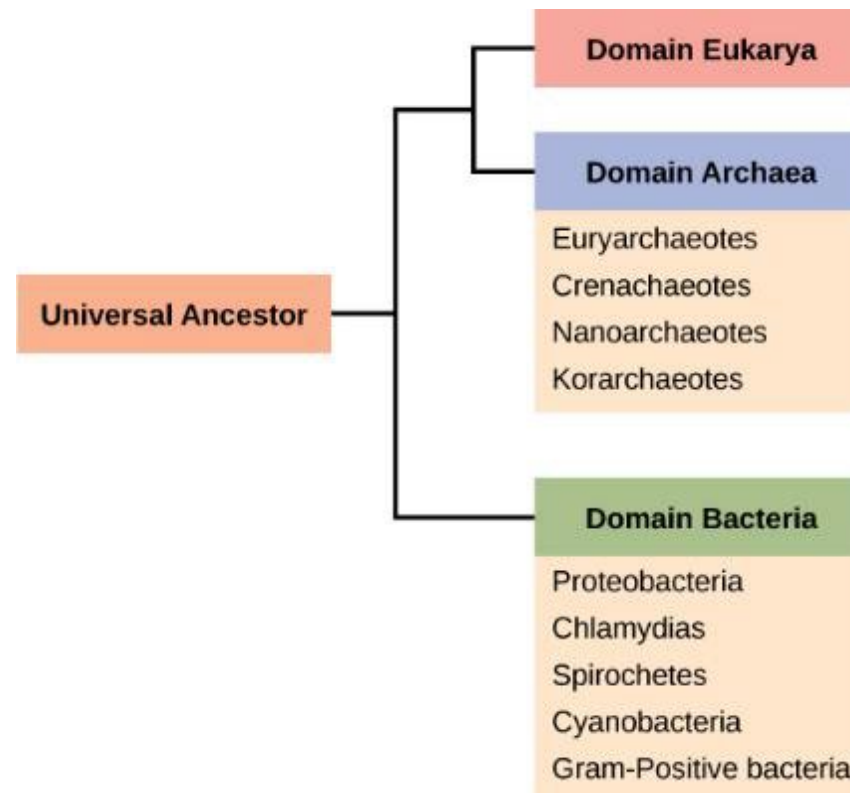
(credit a: modification of work by Janice Haney Carr, Dr. Richard Facklam, CDC; credit c: modification of work by Dr. David Cox; scale-bar data from Matt Russell)

## FIGURE 22.10






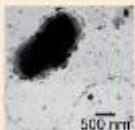

The features of a typical prokaryotic cell are shown.

## FIGURE 22.11



The three domains of living organisms. Bacteria and Archaea are both prokaryotes but differ enough to be placed in separate domains. An ancestor of modern Archaea is believed to have given rise to Eukarya, the third domain of life. Major groups of Archaea and Bacteria are shown.

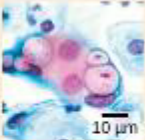

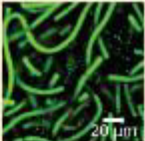

# FIGURE 22.12

Bacteria of Phylum Proteobacteria		
Class	Representative organisms	Representative micrograph
<b>Alpha Proteobacteria</b> Some species are photoautotrophic but some are symbionts of plants and animals and others are pathogens. Eukaryotic mitochondria are thought to be derived from bacteria in this group.	<i>Rhizobium</i> Nitrogen-fixing endosymbiont associated with the roots of legumes  <i>Rickettsia</i> Obligate intracellular parasite that causes typhus and Rocky Mountain Spotted Fever (but not ricketts, which is caused by Vitamin C deficiency)	 <p><i>Rickettsia rickettsia</i>, stained red, grow inside a host cell.</p>
<b>Beta Proteobacteria</b> This group of bacteria is diverse. Some species play an important role in the nitrogen cycle.	<i>Nitrosomas</i> Species from this group oxidize ammonia into nitrite.  <i>Spirillum minus</i> Causes rat-bite fever	 <p><i>Spirillum minus</i></p>
<b>Gamma Proteobacteria</b> Many are beneficial symbionts that populate the human gut, but others are familiar human pathogens. Some species from this subgroup oxidize sulfur compounds.	<i>Escherichia coli</i> Normally beneficial microbe of the human gut, but some strains cause disease  <i>Salmonella</i> Certain strains cause food poisoning or typhoid fever  <i>Yersinia pestis</i> Causative agent of Bubonic plague  <i>Pseudomonas aeruginosa</i> Causes lung infections  <i>Vibrio cholera</i> Causative agent of cholera  <i>Chromatium</i> Sulfur-producing bacteria that oxidize sulfur, producing H <sub>2</sub> S	 <p><i>Vibrio cholera</i></p>
<b>Delta Proteobacteria</b> Some species generate a spore-forming fruiting body in adverse conditions. Others reduce sulfate and sulfur.	<i>Mycobacteria</i> Generate spore-forming fruiting bodies in adverse conditions  <i>Desulfovibrio vulgaris</i> Anaerobic, sulfate-reducing bacterium	 <p><i>Desulfovibrio vulgaris</i></p>
<b>Epsilon Proteobacteria</b> Many species inhabit the digestive tract of animals as symbionts or pathogens. Bacteria from this group have been found in deep-sea hydrothermal vents and cold seep habitats.	<i>Campylobacter</i> Causes blood poisoning and intestinal inflammation  <i>Helicobacter pylori</i> Causes stomach ulcers	 <p><i>Campylobacter</i></p>

Phylum *Proteobacteria* is one of up to 52 bacteria phyla. *Proteobacteria* is further subdivided into five classes, Alpha through Epsilon.

(credit “*Rickettsia rickettsia*”: modification of work by CDC; credit “*Spirillum minus*”: modification of work by Wolfram Adlassnig; credit “*Vibrio cholera*”: modification of work by Janice Haney Carr, CDC; credit “*Desulfovibrio vulgaris*”: modification of work by Graham Bradley; credit “*Campylobacter*”: modification of work by De Wood, Pooley, USDA, ARS, EMU; scale-bar data from Matt Russell)




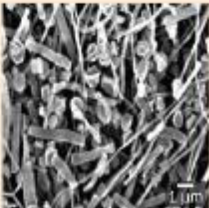
# FIGURE 22.13

Bacteria: Chlamydia, Spirochaetae, Cyanobacteria, and Gram-positive		
Phylum	Representative organisms	Representative micrograph
<b>Chlamydias</b> All members of this group are obligate intracellular parasites of animal cells. Cells walls lack peptidoglycan.	<i>Chlamydia trachomatis</i> Common sexually transmitted disease that can lead to blindness	 <p>10 μm</p> <p>In this pap smear, <i>Chlamydia trachomatis</i> appear as pink inclusions inside cells.</p>
<b>Spirochetes</b> Most members of this species, which has spiral-shaped cells, are free-living anaerobes, but some are pathogenic. Flagella run lengthwise in the periplasmic space between the inner and outer membrane.	<i>Treponema pallidum</i> Causative agent of syphilis  <i>Borrelia burgdorferi</i> Causative agent of Lyme disease	 <p>500 nm</p> <p><i>Treponema pallidum</i></p>
<b>Cyanobacteria</b> Also known as blue-green algae, these bacteria obtain their energy through photosynthesis. They are ubiquitous, found in terrestrial, marine, and freshwater environments. Eukaryotic chloroplasts are thought to be derived from bacteria in this group.	<i>Prochlorococcus</i> Believed to be the most abundant photosynthetic organism on earth; responsible for generating half the world's oxygen	 <p>20 μm</p> <p><i>Prochlorococcus</i></p>
<b>Gram-positive Bacteria</b> Soil-dwelling members of this subgroup decompose organic matter. Some species cause disease. They have a thick cell wall and lack an outer membrane.	<i>Bacillus anthracis</i> Causes anthrax  <i>Clostridium botulinum</i> Causes Botulism  <i>Clostridium difficile</i> Causes diarrhea during antibiotic therapy  <i>Streptomyces</i> Many antibiotics, including streptomycin, are derived from these bacteria.  <i>Mycoplasmas</i> These tiny bacteria, the smallest known, lack a cell wall. Some are free-living, and some are pathogenic.	 <p>10 μm</p> <p><i>Clostridium difficile</i></p>

Chlamydia, Spirochetes, Cyanobacteria, and Gram-positive bacteria are described in this table. Note that bacterial shape is not phylum-dependent; bacteria within a phylum may be cocci, rod-shaped, or spiral.

(credit “Chlamydia trachomatis”: modification of work by Dr. Lance Liotta Laboratory, NCI; credit “Treponema pallidum”: modification of work by Dr. David Cox, CDC; credit “Phormidium”: modification of work by USGS; credit “Clostridium difficile”: modification of work by Lois S. Wiggs, CDC; scale-bar data from Matt Russell)

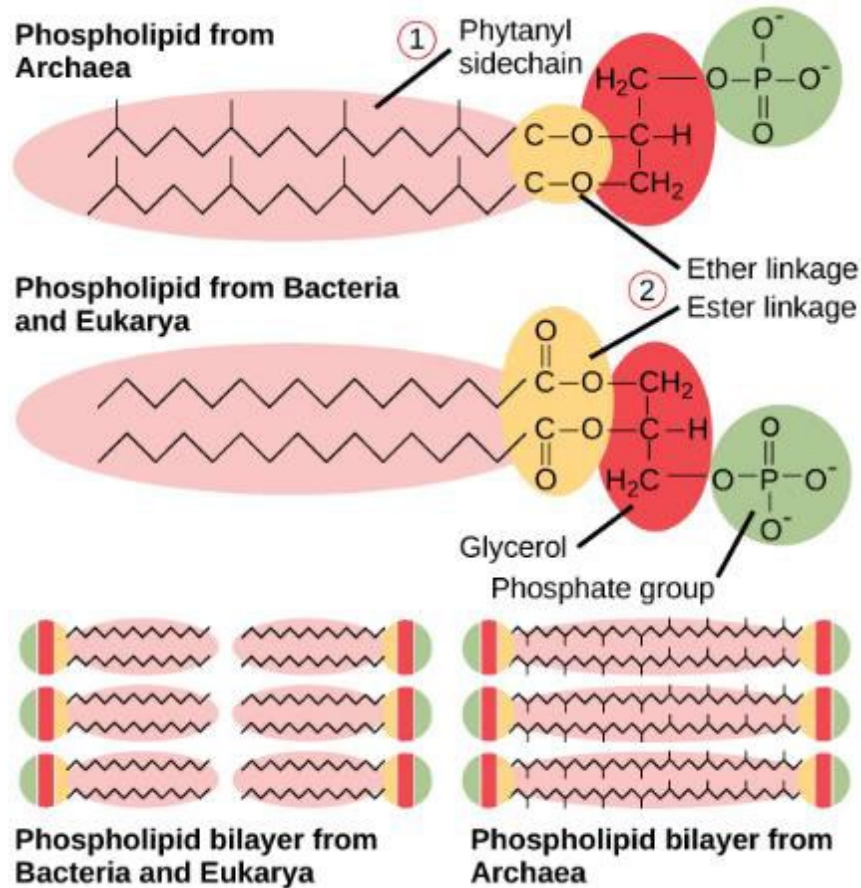
# FIGURE 22.14

Archaea		
Phylum	Representative organisms	Representative micrograph
<b>Euryarchaeota</b> This phylum includes methanogens, which produce methane as a metabolic waste product, and halobacteria, which live in an extreme saline environment.	<b>Methanogens</b> Methane production causes flatulence in humans and other animals.  <b>Halobacteria</b> Large blooms of the salt-loving archaea appear reddish due to the presence of bacteriorhodopsin in the membrane. Bacteriorhodopsin is related to the retinal pigment rhodopsin.	 <p>2 μm</p> <p><i>Halobacterium</i> strain NRC-1</p>
<b>Crenarchaeota</b> Members of the ubiquitous phylum play an important role in the fixation of carbon. Many members of this group are sulfur-dependent extremophiles. Some are thermophilic or hyperthermophilic.	<b>Sulfolobus</b> Members of this genus grow in volcanic springs at temperatures between 75° and 80°C and at a pH between 2 and 3.	 <p>1 μm</p> <p><i>Sulfolobus</i> being infected by bacteriophage</p>
<b>Nanoarchaeota</b> This group currently contains only one species, <i>Nanoarchaeum equitans</i> .	<b><i>Nanoarchaeum equitans</i></b> This species was isolated from the bottom of the Atlantic Ocean and from a hydrothermal vent at Yellowstone National Park. It is an obligate symbiont with <i>Ignococcus</i> , another species of archaeobacteria.	 <p>1 μm</p> <p><i>Nanoarchaeum equitans</i> (small dark spheres) are in contact with their larger host, <i>Ignococcus</i>.</p>
<b>Korarchaeota</b> Members of this phylum, considered to be one of the most primitive forms of life, have only been found in the Obsidian Pool, a hot spring at Yellowstone National Park.	No members of this species have been cultivated.	 <p>1 μm</p> <p>This image shows a variety of korarchaeota species from the Obsidian Pool at Yellowstone National Park.</p>

Archaea are separated into four phyla: the Korarchaeota, Euryarchaeota, Crenarchaeota, and Nanoarchaeota.

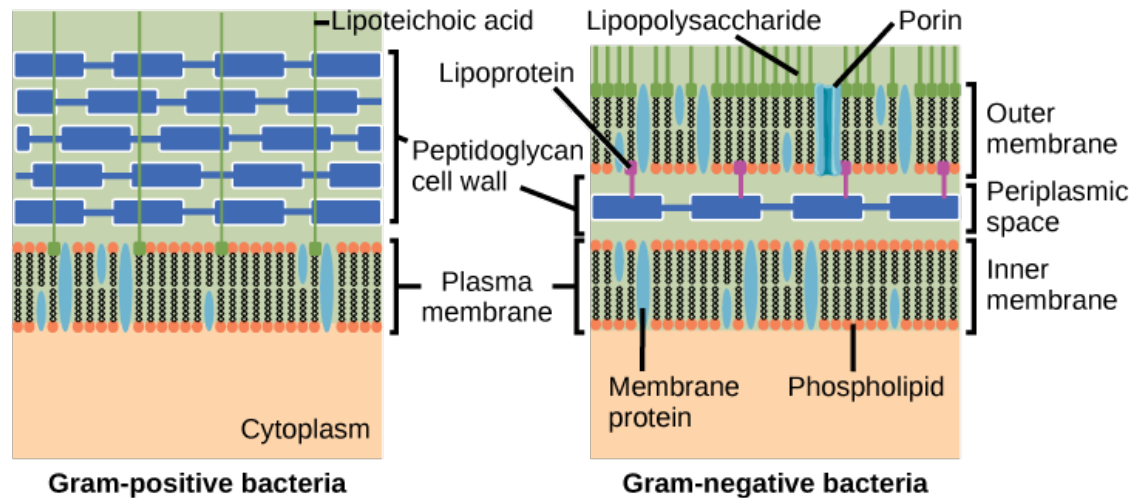
(credit “Halobacterium”: modification of work by NASA; credit “*Nanoarchaeotum equitans*”: modification of work by Karl O. Stetter; credit “korarchaeota”: modification of work by Office of Science of the U.S. Dept. of Energy; scale-bar data from Matt Russell)

# FIGURE 22.15



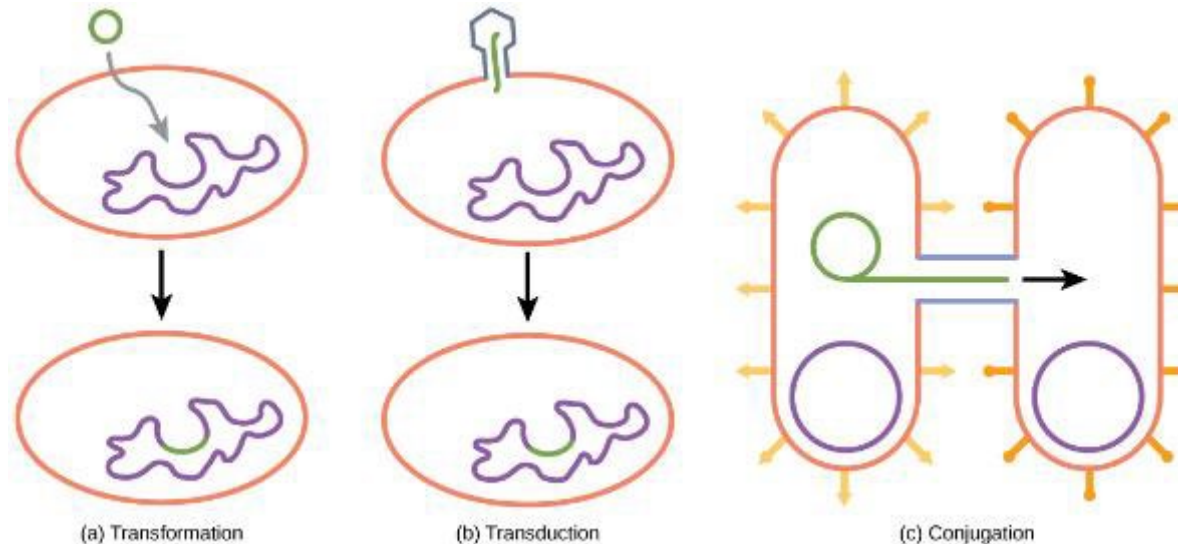
Archaeal phospholipids differ from those found in Bacteria and Eukarya in two ways. First, they have branched phytanyl sidechains instead of linear ones. Second, an ether bond instead of an ester bond connects the lipid to the glycerol.

# FIGURE 22.16



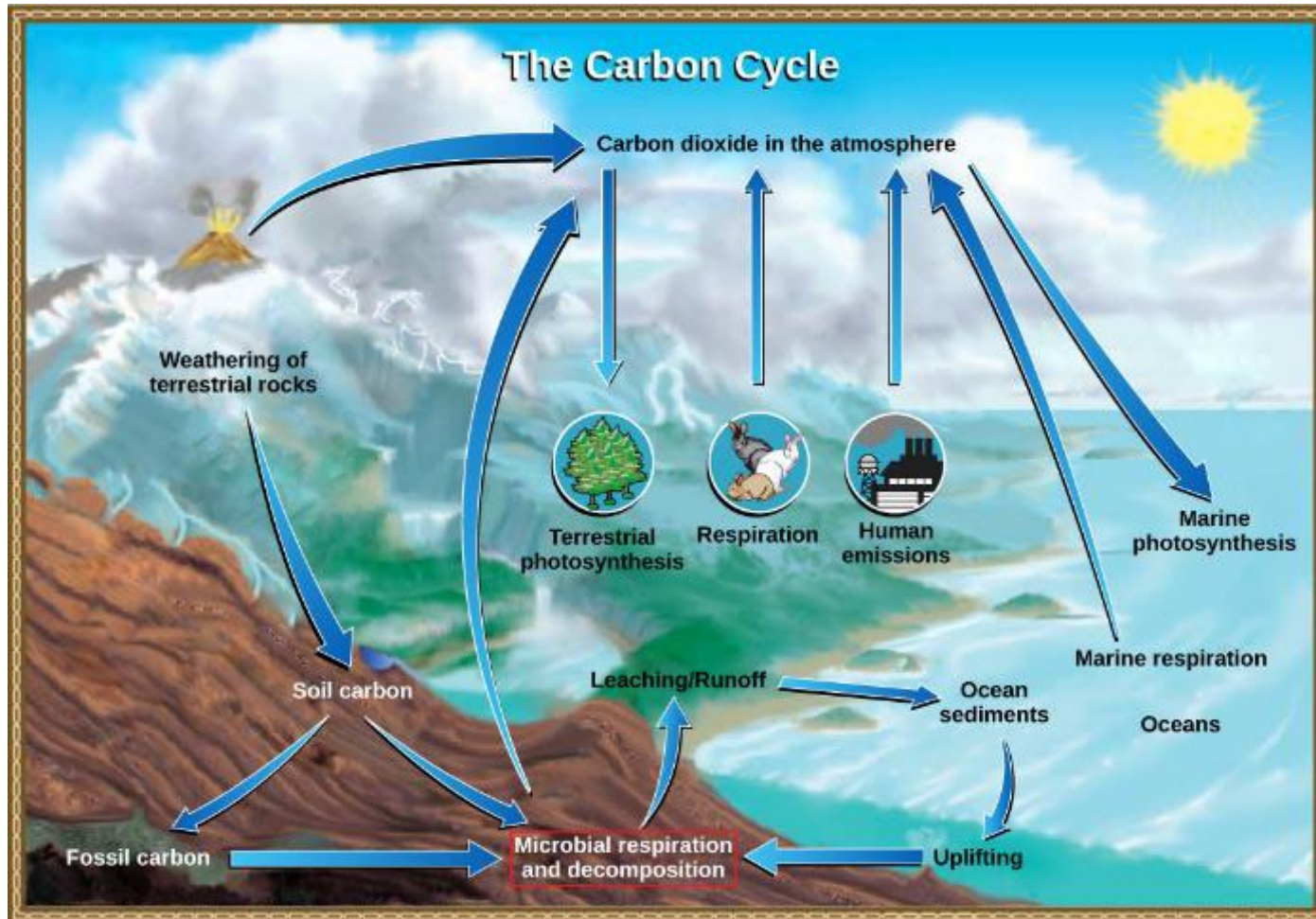
Bacteria are divided into two major groups: Gram positive and Gram negative. Both groups have a cell wall composed of peptidoglycan: in Gram-positive bacteria, the wall is thick, whereas in Gram-negative bacteria, the wall is thin. In Gram-negative bacteria, the cell wall is surrounded by an outer membrane that contains lipopolysaccharides and lipoproteins. Porins are proteins in this cell membrane that allow substances to pass through the outer membrane of Gram-negative bacteria. In Gram-positive bacteria, lipoteichoic acid anchors the cell wall to the cell membrane. (credit: modification of work by "Franciscosp2"/Wikimedia Commons)

## FIGURE 22.17



Besides binary fission, there are three other mechanisms by which prokaryotes can exchange DNA. In (a) transformation, the cell takes up prokaryotic DNA directly from the environment. The DNA may remain separate as plasmid DNA or be incorporated into the host genome. In (b) transduction, a bacteriophage injects DNA into the cell that contains a small fragment of DNA from a different prokaryote. In (c) conjugation, DNA is transferred from one cell to another via a mating bridge that connects the two cells after the sex pilus draws the two bacteria close enough to form the bridge.

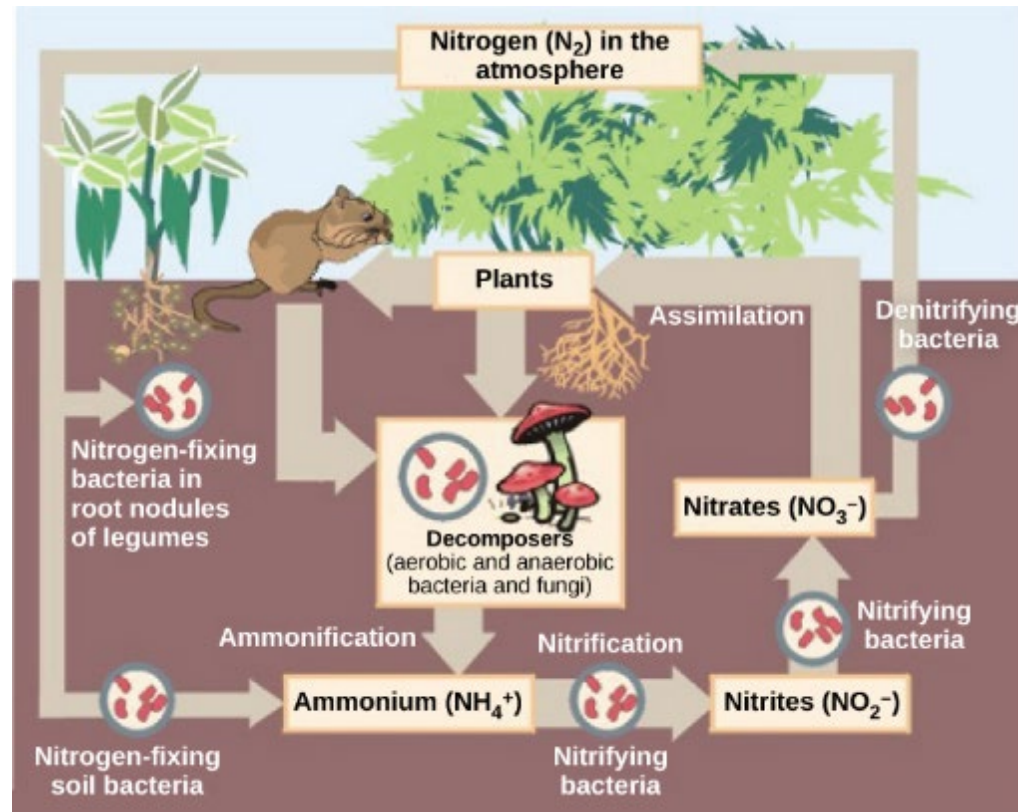
# FIGURE 22.18



Prokaryotes play a significant role in continuously moving carbon through the biosphere.

(credit: modification of work by John M. Evans and Howard Perlman, USGS)

# FIGURE 22.19



Prokaryotes play a key role in the nitrogen cycle.

(credit: Environmental Protection Agency)

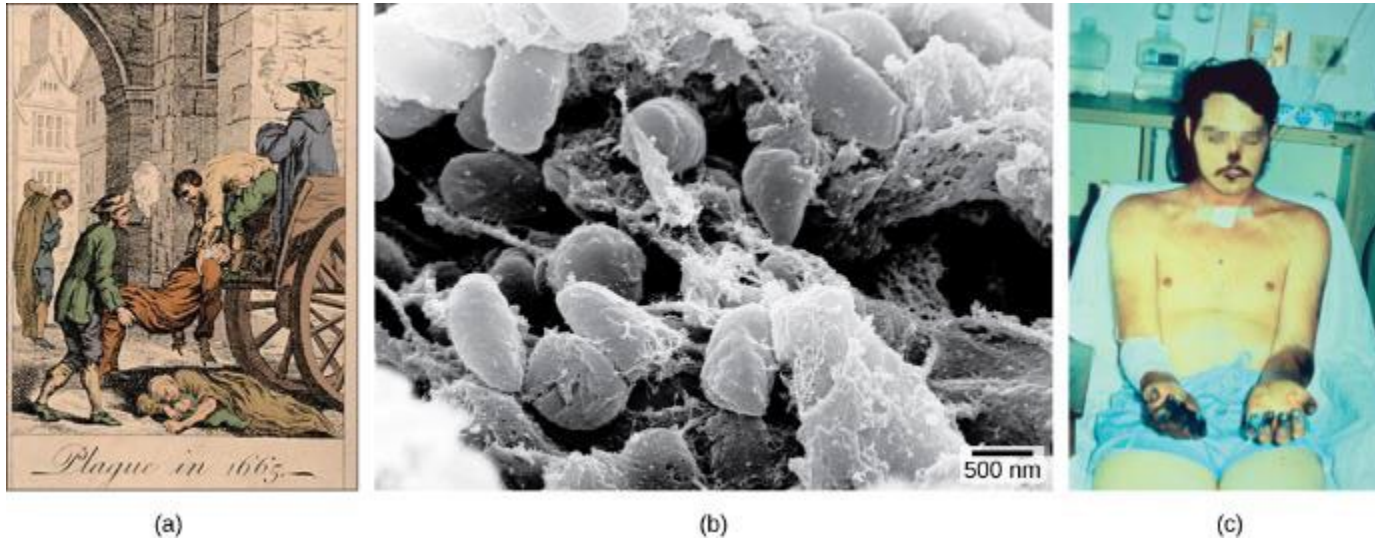
## FIGURE 22.20



*Salmonella enterica* serovar Typhi, the causative agent of Typhoid fever, is a Gram-negative, rod-shaped gamma protobacterium. Typhoid fever, which is spread through feces, causes intestinal hemorrhage, high fever, delirium and dehydration. Today, between 16 and 33 million cases of this re-emerging disease occur annually, resulting in over 200,000 deaths. Carriers of the disease can be asymptomatic. In a famous case in the early 1900s, a cook named Mary Mallon unknowingly spread the disease to over fifty people, three of whom died. Other *Salmonella* serotypes cause food poisoning.

(credit: modification of work by NCI, CDC)

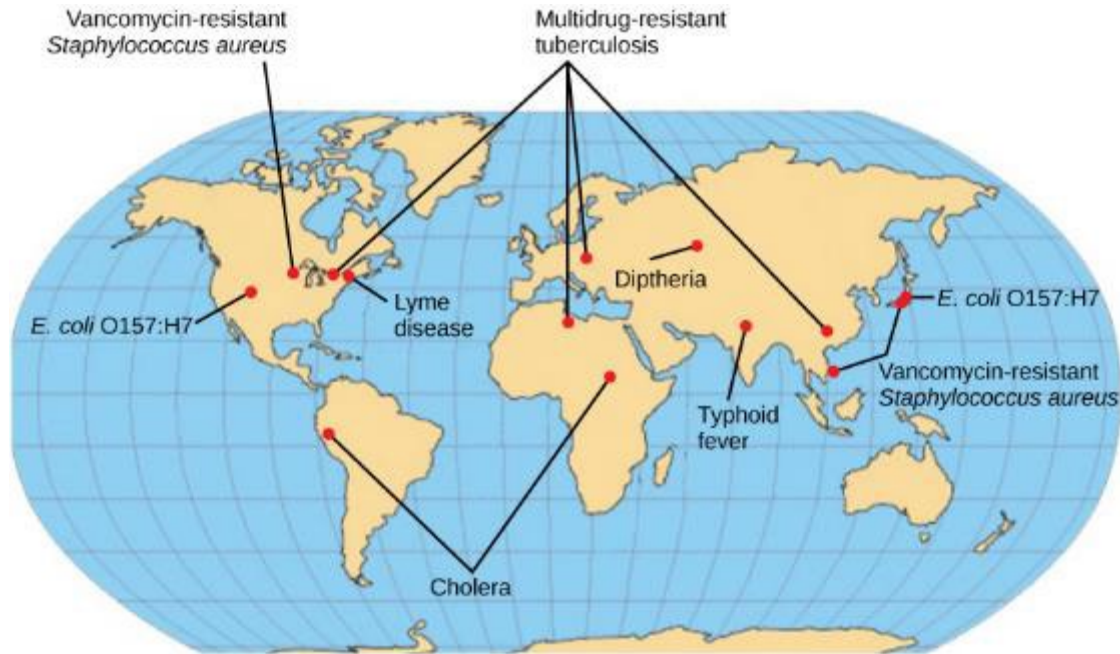
## FIGURE 22.21



The (a) Great Plague of London killed an estimated 200,000 people, or about twenty percent of the city's population. The causative agent, the (b) bacterium *Yersinia pestis*, is a Gram-negative, rod-shaped bacterium from the class Gamma Proteobacteria. The disease is transmitted through the bite of an infected flea, which is infected by a rodent. Symptoms include swollen lymph nodes, fever, seizure, vomiting of blood, and (c) gangrene.

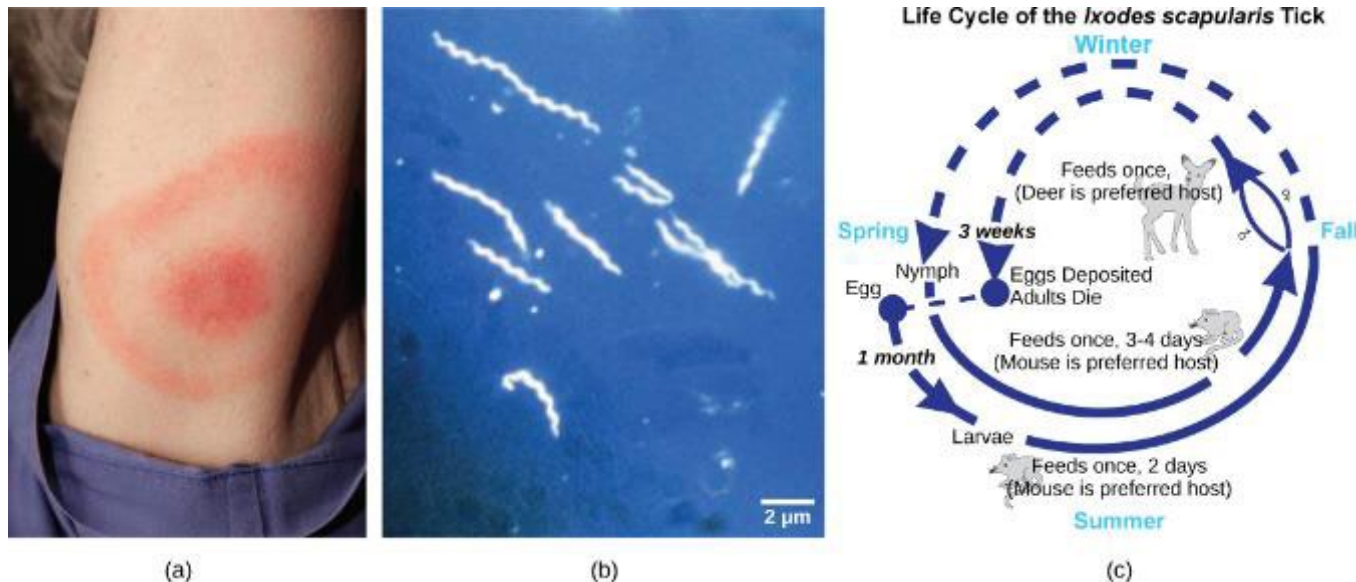
(credit b: Rocky Mountain Laboratories, NIAID, NIH; scale-bar data from Matt Russell; credit c: Textbook of Military Medicine, Washington, D.C., U.S. Dept. of the Army, Office of the Surgeon General, Borden Institute)

## FIGURE 22.22



The map shows regions where bacterial diseases are emerging or reemerging.  
 (credit: modification of work by NIH)

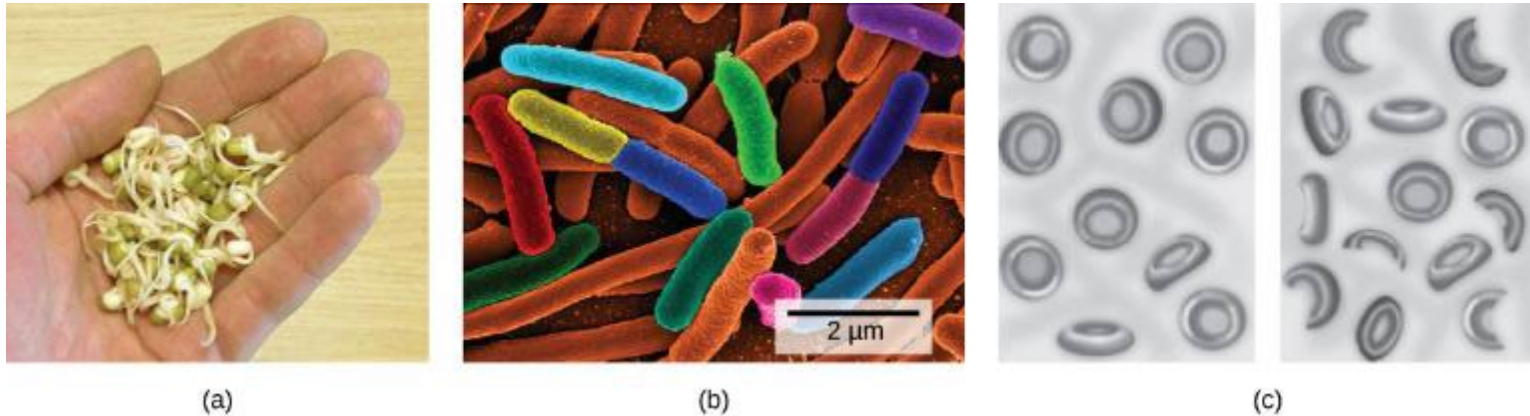
## FIGURE 22.23



Lyme disease often, but not always, results in (a) a characteristic bullseye rash. The disease is caused by a (b) Gram-negative spirochete bacterium of the genus *Borrelia*. The bacteria (c) infect ticks, which in turns infect mice. Deer are the preferred secondary host, but the ticks also may feed on humans. Untreated, the disease causes chronic disorders in the nervous system, eyes, joints, and heart. The disease is named after Lyme, Connecticut, where an outbreak occurred in 1995 and has subsequently spread. The disease is not new, however. Genetic evidence suggests that Ötzi the Iceman, a 5,300-year-old mummy found in the Alps, was infected with *Borrelia*.

(credit a: James Gathany, CDC; credit b: CDC; scale-bar data from Matt Russell)

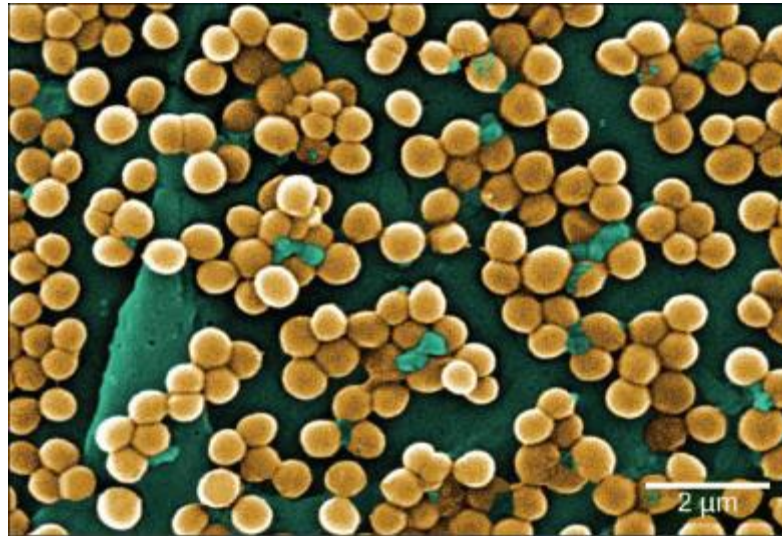
## FIGURE 22.24



(a) Vegetable sprouts grown at an organic farm were the cause of an (b) *E. coli* outbreak that killed 32 people and sickened 3,800 in Germany in 2011. The strain responsible, *E. coli* O104:H4, produces Shiga toxin, a substance that inhibits protein synthesis in the host cell. The toxin (c) destroys red blood cells resulting in bloody diarrhea. Deformed red blood cells clog the capillaries of the kidney, which can lead to kidney failure, as happened to 845 patients in the 2011 outbreak. Kidney failure is usually reversible, but some patients experience kidney problems years later.

(credit c: NIDDK, NIH)

## FIGURE 22.25



This scanning electron micrograph shows methicillin-resistant *Staphylococcus aureus* bacteria, commonly known as MRSA. *S. aureus* is not always pathogenic, but can cause diseases such as food poisoning and skin and respiratory infections.

(credit: modification of work by Janice Haney Carr; scale-bar data from Matt Russell)

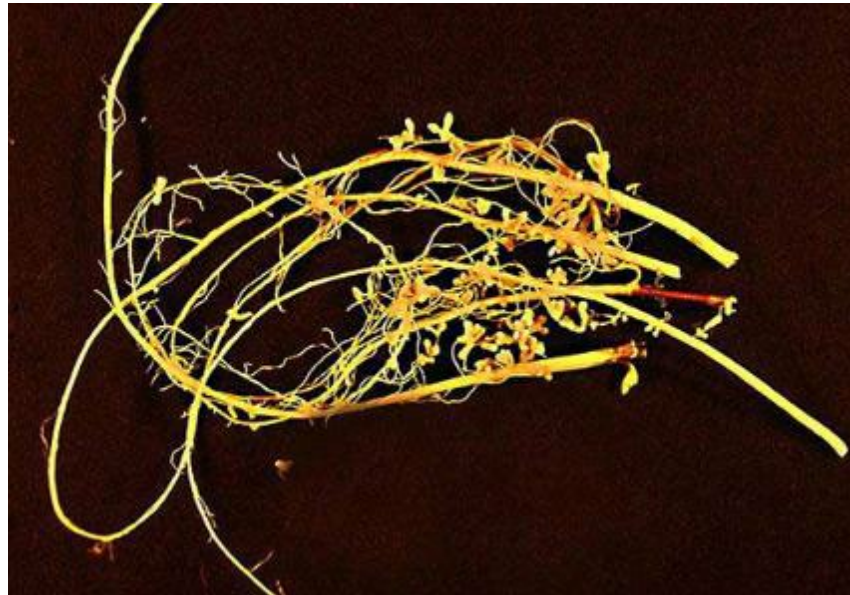
## FIGURE 22.26



Vaccinations can slow the spread of communicable diseases.

(credit: modification of work by Daniel Paquet)

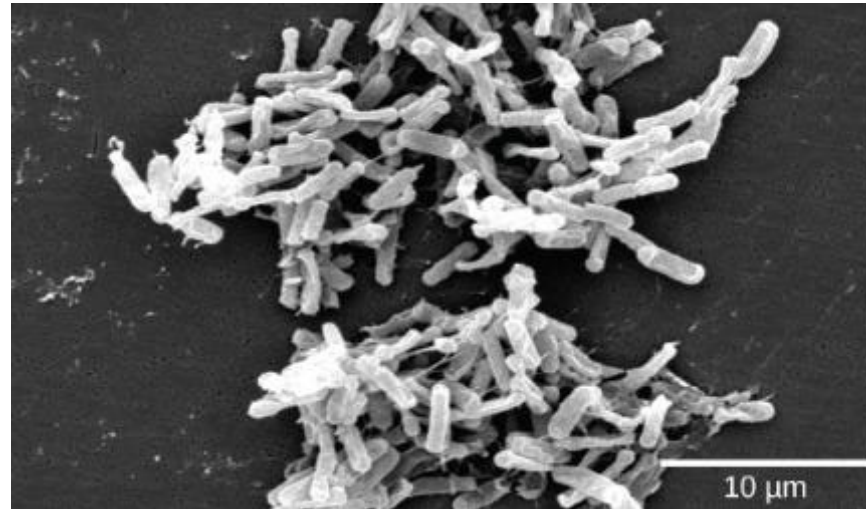
## FIGURE 22.27



Soybean (*Glycine max*) is a legume that interacts symbiotically with the soil bacterium *Bradyrhizobium japonicum* to form specialized structures on the roots called nodules where nitrogen fixation occurs.

(credit: USDA)

## FIGURE 22.28



*Clostridium difficile* is a Gram-positive, rod-shaped bacterium that causes severe diarrhea.

(credit: modification of work by CDC, HHS; scale-bar data from Matt Russell)

## FIGURE 22.29



(a)



(b)



(c)



(d)

Some of the products derived from the use of prokaryotes in early biotechnology include (a) cheese, (b) wine, (c) beer and bread, and (d) yogurt.

(credit bread: modification of work by F. Rodrigo/Wikimedia Commons; credit wine: modification of work by Jon Sullivan; credit beer and bread: modification of work by Kris Miller; credit yogurt: modification of work by Jon Sullivan)

## FIGURE 22.30



(a)



(b)

(a) Cleaning up oil after the Valdez spill in Alaska, workers hosed oil from beaches and then used a floating boom to corral the oil, which was finally skimmed from the water surface. Some species of bacteria are able to solubilize and degrade the oil. (b) One of the most catastrophic consequences of oil spills is the damage to fauna.

(credit a: modification of work by NOAA; credit b: modification of work by GOLUBENKOV, NGO: Saving Taman)