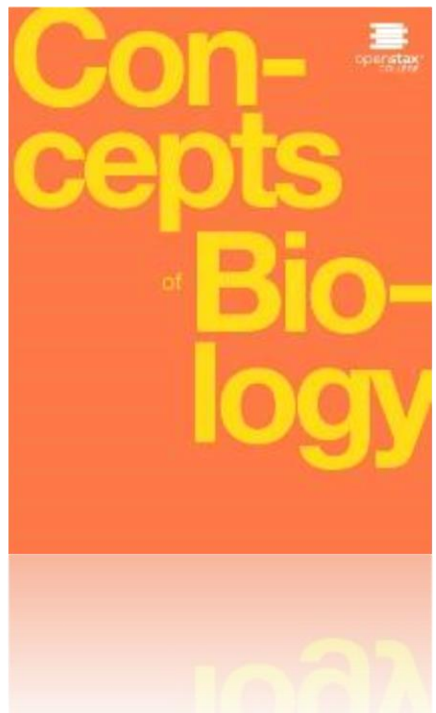
CONCEPTS OF BIOLOGY

Chapter 13 DIVERSITY OF MICROBES, FUNGI, AND PROTISTS

PowerPoint Image Slideshow



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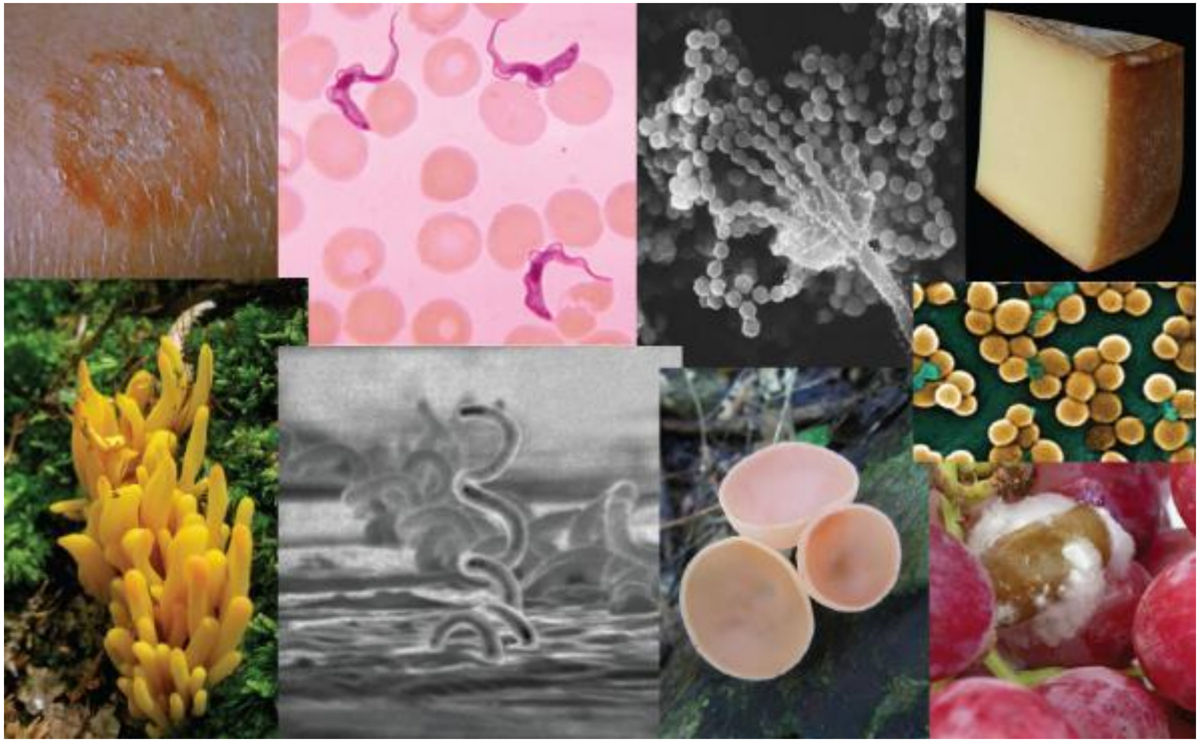
INTRODUCTION

- Until the late 20th century, scientists grouped living things into 5 kingdoms
- Now they are grouped into 3 Domains (Archaea, Bacteria and Eukarya) based on differences in cell membrane structure and in rRNA (ribosomal RNA).
- Bacteria and Archaea are **prokaryotes**→ organisms that lack a nucleus and membrane bound organelles
  - These 2 groups are very different from each other
  - Prokaryotes were the first organisms on earth and currently inhabit every habitat on earth, even the harshest environments. They also live on or inside other living things.
- The domain Eukarya contains all the **eukaryotes**→ organisms that possess a nucleus and membrane bound organelles
  - Contains the kingdoms Plantae, Fungi and Animalia
  - Also contains a diverse group called protists

FIGURE 13.1 DIVERSITY OF LIVING ORGANISMS



Living things are very diverse, from simple, single-celled bacteria to complex, multicellular organisms. (credit "ringworm": modification of work by Dr. Lucille K. Georg, CDC; credit "Trypanosomes": modification of work by Dr. Myron G. Schultz, CDC; credit "tree mold": modification of work by Janice Haney Carr, Robert Simmons, CDC; credit "coral fungus": modification of work by Cory Zanker; credit "bacterium": modification of work by Dr. David Cox, CDC; credit "cup fungus": modification of work by "icelight"/Flickr; credit "MRSA": modification of work by Janice Haney Carr, CDC; credit "moldy grapefruit": modification of work by Joseph Smilanick)

PROKARYOTIC DIVERSITY (13.1)

- Prokaryotes were the first life forms on earth and probably appeared about 3.9 BYA (billion years ago).
- The earth is about 4.54 billion years old based on radioactive dating of meteorite material that was part of the original material that formed the solar system.
- The early earth had no oxygen present, so only organisms that can grow without oxygen (**anaerobic organisms**) existed at first.
- Organisms that could photosynthesize (**cyanobacteria**, also called blue-green algae) evolved and added oxygen to the atmosphere (Figure 13.2).
    - This increase in oxygen concentration allowed the evolution of other life forms.
- The first life forms were subjected to strong radiation from the sun and most likely thrived where they were protected (like in the deep ocean or under the earth's surface). They needed to be able to survive high temperatures and harsh conditions.

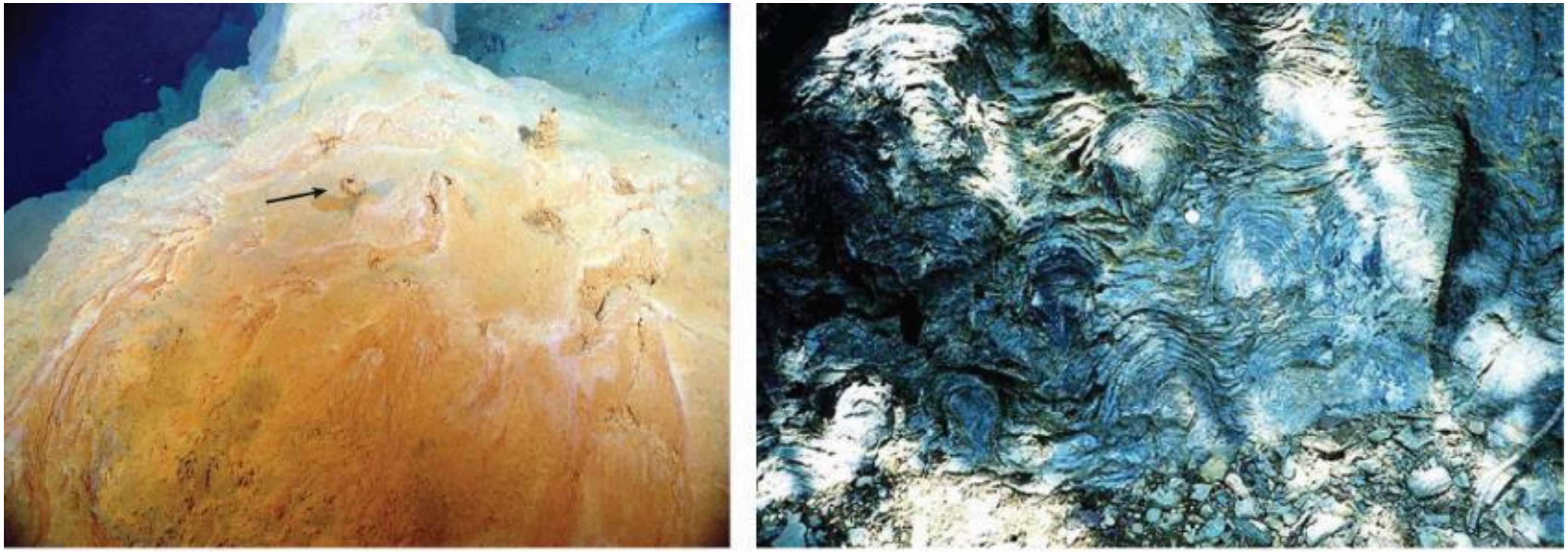
FIGURE 13.2 CYANOBACTERIA IN A HOT SPRING

This hot spring in Yellowstone National Park flows toward the foreground. Cyanobacteria in the spring are green, and as water flows down the heat gradient, the intensity of the color increases because 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)

PROKARYOTIC DIVERSITY 1 OF 3 (13.1)

- Fossilized **microbial mats** represent the earliest record of life on earth. A microbial mat is a large multilayered sheet of prokaryotes including bacteria and archaea (Figure 13.3).
- Microbial mats often obtain their energy from **hydrothermal vents**, which are fissures in the surface of the earth that releases geothermally heated water (Figure 13.3)
- A **stromatolite** is a sedimentary structure formed when minerals are precipitated from water by prokaryotes in a microbial mat (Figure 13.3).

FIGURE 13.3 HYDROTHERMAL VENTS AND STROMATOLITES



(a) (b)

(a) This microbial mat grows over a hydrothermal vent in the Pacific Ocean. Chimneys such as the one indicated by the arrow allow gases to escape.

(b) This photo shows stromatolites that are nearly 1.5 billion years old, found in Glacier National Park, Montana.(credit a: modification of work by Dr. Bob Embley, NOAA PMEL; credit b: modification of work by P. Carrara, NPS)

PROKARYOTIC DIVERSITY 2 OF 3 (13.1)

- Many prokaryotes thrive in environments that would kill a plant or animal.
- Bacteria and Archaea that grow in extreme environments are called extremophiles. They can be found
    - In the ocean depths
    - In hot springs
    - In very dry places
    - In harsh chemicals
    - In high radiation
    - In the Arctic and Antarctic
- Extremophiles open up the possibility of finding life other places in the solar system, which have harsher environments that earth.

CONCEPT IN ACTION

Watch a video showing the Director of the Planetary Science Division of NASA discussing the implications that the existence of extremophiles on earth have on the possibility of finding life on other planets of our solar system, such as Mars.

Link to Video

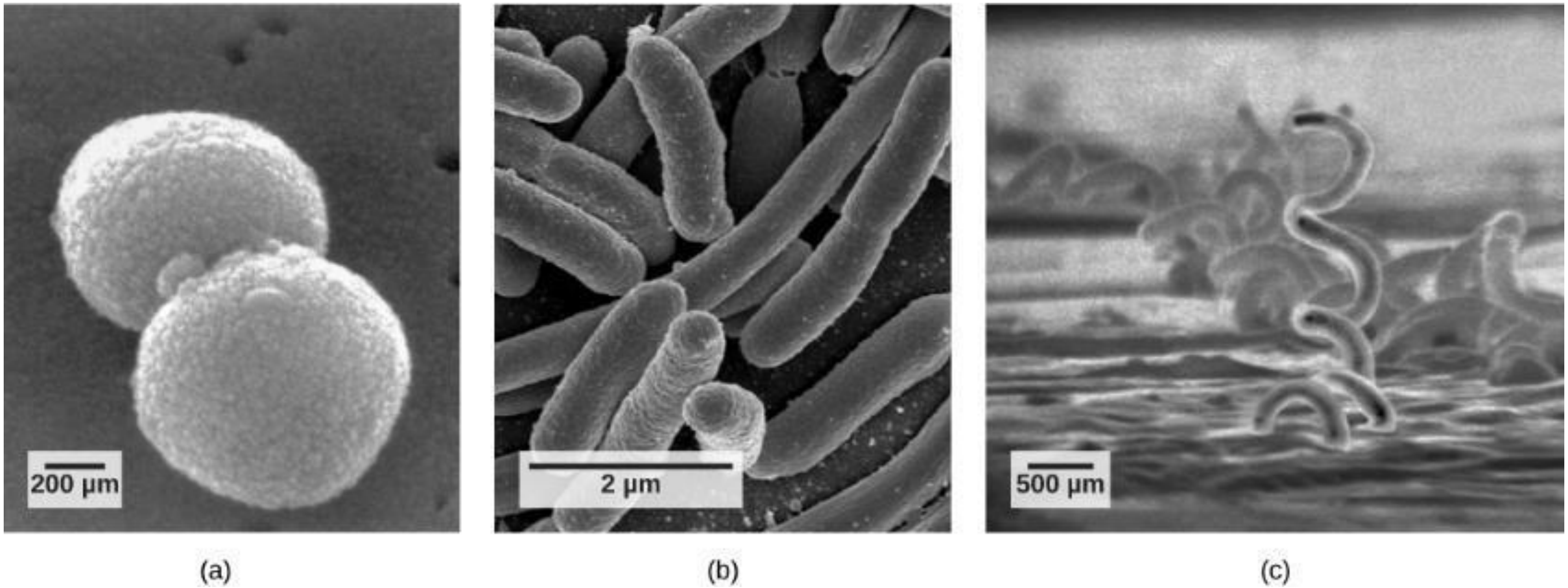
PROKARYOTIC DIVERSITY 3 OF 3 (13.1)

- Prokaryotes tend to live in communities where they can interact.
- A **biofilm** is a microbial community held together in a gummy-textured material.
  - Biofilms grow attached to surfaces and are present almost everywhere.
  - Biofilms are difficult to destroy because they are resistant to common forms of sterilization.
- There are many differences between prokaryotic and eukaryotic cells. However, **all cells** have 4 structures in common:
  - A **plasma (cell) membrane** (functions to separate the cell from its environment)
  - **Cytoplasm** (a jellylike material inside the cell)
  - **Genetic material** (DNA and RNA)
  - **Ribosomes** (functions in protein synthesis)

THE PROKARYOTIC CELL 1 OF 2 (13.1)

- Prokaryotes have 3 basic shapes (Figure 13.4):
  - Cocci (spherical)
  - Bacilli (rods)
  - Spirilla (spiral)
- Prokaryotes are unicellular with no nucleus.
- Prokaryotes have a single circular chromosome
- Most prokaryotes have a rigid **cell wall** outside the plasma membrane which differs in chemical composition between Archaea and Bacteria.
  - The cell wall is protective and helps the cell to maintain its shape.
  - The cell wall also helps to prevent cells from bursting when they take in water.

FIGURE 13.4 PROKARYOTIC SHAPES

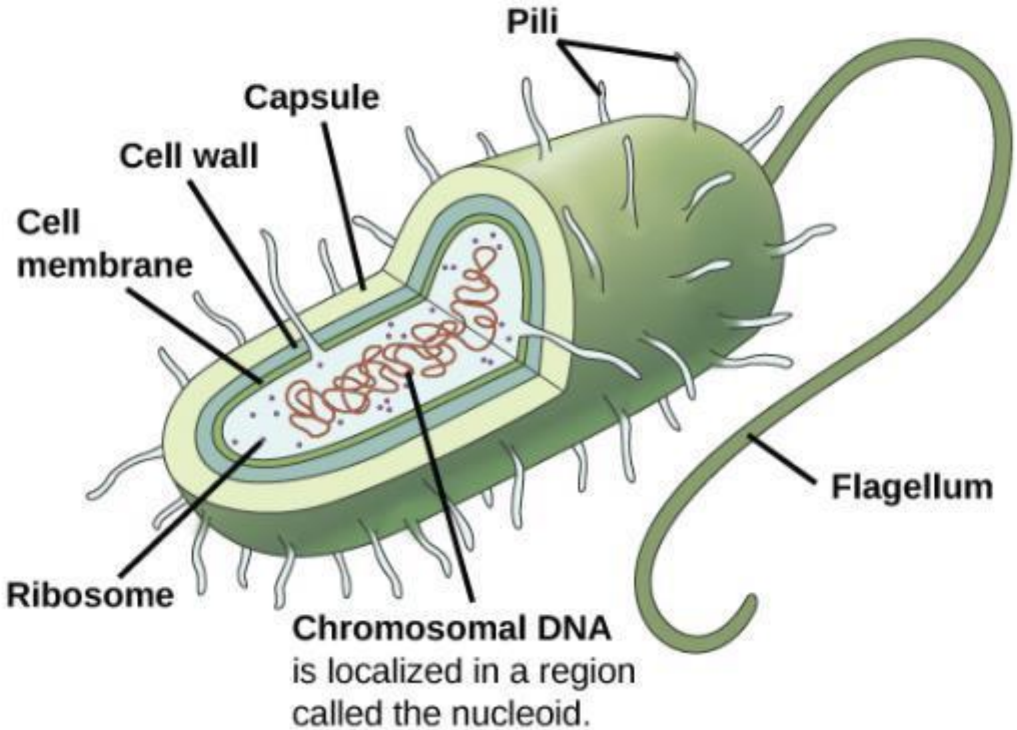


Many prokaryotes fall into three basic categories based on their shape: (a) cocci, or spherical; (b) bacilli, or rod-shaped; and (c) spirilla, or spiral-shaped. (credit a: modification of work by Janice Haney Carr, Dr. Richard Facklam, CDC; credit c: modification of work by Dr. David Cox, CDC; scale-bar data from Matt Russell)

THE PROKARYOTIC CELL 2 OF 2 (13.1)

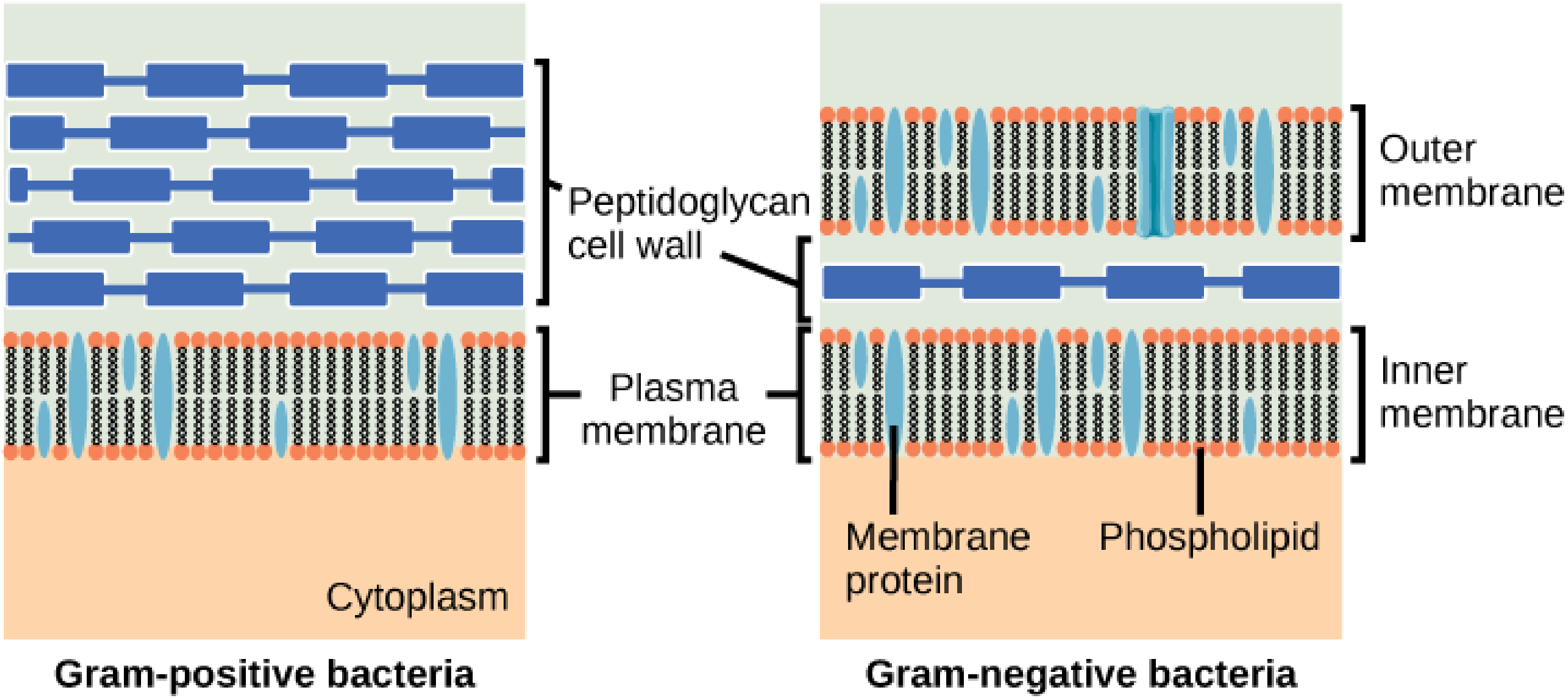
- Other structures that can be found in some prokaryotes (Figure 13.5):
  - **Capsule**→ enables the organism to attach to surfaces and protects it from dehydration
  - **Flagella**→ used for locomotion
  - **Pili**→ used to attach to surfaces and for conjugation
  - **Plasmids**→ small circular pieces of DNA (in addition to the main chromosome)
- Bacteria are divided into two major groups based on a staining procedure called the **Gram Stain**. The two groups stain differently because their cell walls are different (Figure 13.6)
  - Gram positive bacteria have thick cell walls
  - Gram negative bacteria have thin cell walls but also have an outer membrane

FIGURE 13.5 A TYPICAL BACTERIUM



The features of a typical bacterium cell are shown.

FIGURE 13.6 GRAM POSITIVE VS GRAM NEGATIVE BACTERIA



Bacteria are divided into two major groups: Gram-positive and Gram-negative. Both groups have a cell wall composed of peptidoglycans: 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.

REPRODUCTION (13.1)

- Prokaryotes reproduce through a process called **binary fission**. Binary fission is asexual (basically the prokaryote copies its chromosome and splits in half).
- Binary fission does not allow prokaryotes to exchange genetic material. However, they do have 3 methods for genetic recombination:
    - **Transformation**→ the cell takes in DNA from other bacteria in its environment (alive or dead)
    - **Transduction**→ viruses that infect bacteria move DNA from one bacteria to another
    - **Conjugation**→ DNA is transferred (usually in the form of a plasmid) from one bacterium to another via a pilus

BACTERIAL DISEASES IN HUMANS 1 OF 2 (13.1)

- All **pathogenic** (disease causing) prokaryotes are bacteria. Archaea do not cause disease.
- A number of **pandemics** (a widespread, usually worldwide, epidemic disease) have been documented over the last several hundred years.
- An **epidemic** is a disease that occurs in an unusually high number of individuals in a population at the same time.
- Infectious diseases remain among the leading causes of death worldwide. Medical advances like antibiotics, improvements in sanitation, and improvements in drinking water have helped but deaths due to bacterial infections continue.

BACTERIAL DISEASES IN HUMANS 2 OF 2 (13.1)

- The Black Death (1346-1361) was one of the most devastating pandemics in history. It was due to an outbreak of the bubonic plague, caused by bacteria. It is spread by fleas, living on rats. A million people died worldwide.
    - The bubonic plague struck Europe hard in the 1600's.
    - There are still 1000-3000 cases of bubonic plague each year worldwide.

CONCEPT IN ACTION

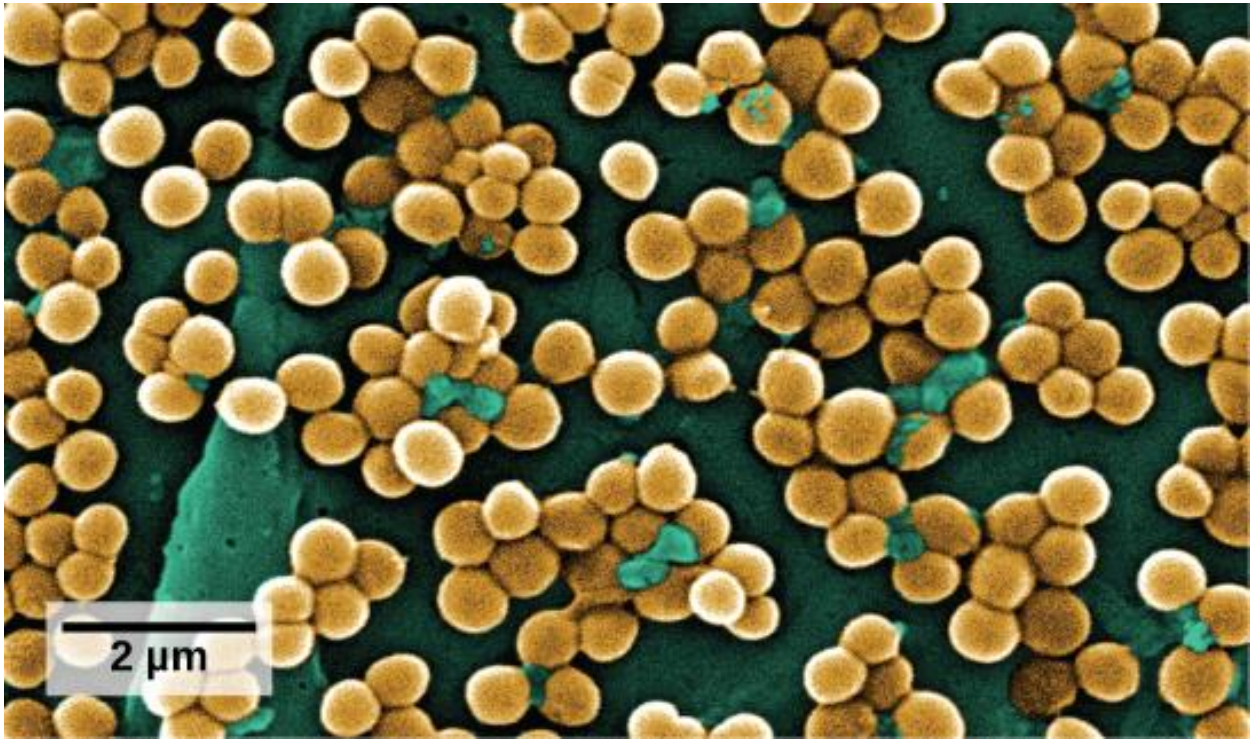
Watch a video on the modern understanding of the Black Death (bubonic plague) in Europe during the 14th century.

Link to Video

THE ANTIBIOTIC CRISIS (13.1)

- One of the main reasons for resistant bacteria is the overuse and incorrect use of antibiotics, such as not completing a full course of prescribed antibiotics.
    - The incorrect use of antibiotics results in natural selection of resistant forms of bacteria.
- Another problem is the excessive use of antibiotics in livestock. Antibiotics are not used to prevent disease, but to enhance production of their products.
- *Staphylococcus aureus* (“staph”) is a common bacterium that can live in or on the human body and is usually treatable with antibiotics.
    - A very dangerous strain called MRSA (methicillin-resistant *Staphylococcus aureus*) is resistant to many of the commonly used antibiotics (Figure 13.7). It is common in healthcare facilities and in people that live in dense groups (military personnel and prisoners for example).

FIGURE 13.7
MRSA UNDER ELECTRON MICROSCOPE



This scanning electron micrograph shows methicillin-resistant *Staphylococcus aureus* bacteria, commonly known as MRSA. (credit: modification of work by Janice Haney Carr, CDC; scale-bar data from Matt Russell)

ANTIBIOTIC CONCEPT IN ACTION

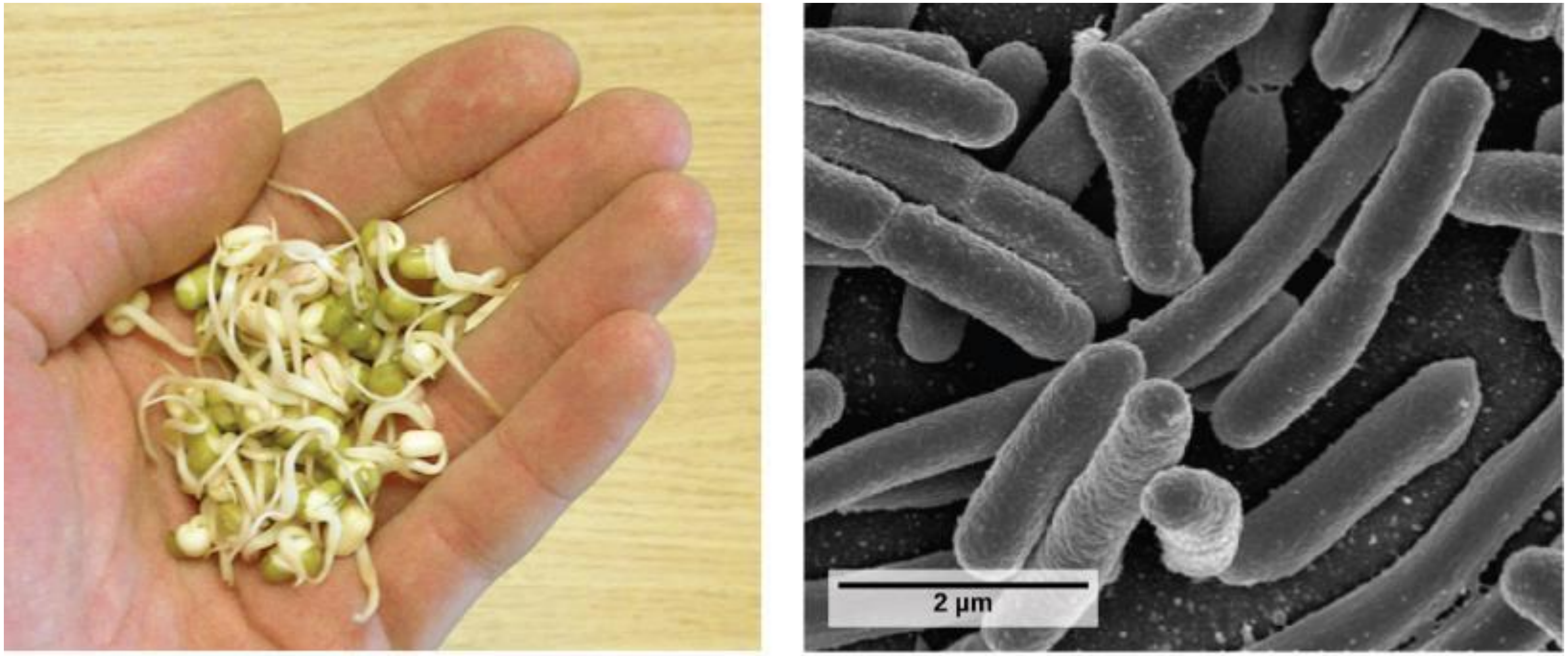
Watch a recent news report on the problem of routine antibiotic administration to livestock and antibiotic resistant bacteria.

Link to Video

FOODBOURNE DISEASES (13.1)

- A **foodborne disease** ("food poisoning") is an illness resulting from the consumption of food contaminated with pathogenic bacteria, viruses or other parasites.
- In the past, it was common to have cases of **botulism**, a potentially fatal bacterial foodborne disease. This is uncommon now due to proper sterilization and canning procedures.
- Most cases of foodborne illnesses are now linked to produce contaminated with animal waste.
    - Certain strains of *Escherichia coli* (*E. coli)* can infect humans and even be potentially fatal, although most strains are not dangerous to humans (Figure 13.8).
    - *Salmonella* is another bacterium that commonly contaminates food.
- All types of food can potentially be contaminated with harmful bacteria of different species.

FIGURE 13.8 *ESCHERICHIA COLI*



(a) (b)

(a) Locally grown vegetable sprouts were the cause of a European *E. coli* outbreak that killed 31 people and sickened about 3,000 in 2010. (b) *Escherichia coli* are shown here in a scanning electron micrograph. The strain of *E. coli* that caused a deadly outbreak in Germany is a new one not involved in any previous *E. coli* outbreaks. It has acquired several antibiotic resistance genes and specific genetic sequences involved in aggregation ability and virulence. It has recently been sequenced. (credit b: Rocky Mountain Laboratories, NIAID, NIH; scale-bar data from Matt Russell)

BENEFICIAL PROKARYOTES: FOOD AND BEVERAGES (13.1)

- Pathogens represent only a small fraction of the microbial world. Most prokaryotes are beneficial or harmless.
- Humans have used prokaryotes to produce food products, such as cheese, yogurt, sour cream, vinegar, and other fermented products for thousands of years (Figure 13.9).
- Currently, prokaryotes are being used in biotechnology applications, such as
    - genetic engineering
    - artificial selection
    - antibiotic production
    - cell culture

FIGURE 13.9 PRODUCTS DERIVED FROM PROKARYOTES

Some of the products derived from the use of prokaryotes in early biotechnology include (a) cheese, (b) salami, (c) yogurt, and (d) fish sauce. (credit b: modification of work by Alisdair McDiarmid; credit c: modification of work by Kris Miller; credit d: modification of work by Jane Whitney)

USING PROKARYOTES TO CLEAN UP OUR PLANET (13.1)

- Microbial **bioremediation** is the use of prokaryotes to remove pollutants.
- Bioremediation has been used to remove
  - Agricultural chemicals (pesticides and fertilizers) from groundwater
  - Toxic metals (selenium, mercury, arsenic) from water
- Prokaryotes are often used in the cleanup of oil spills.
  - Recent examples in the US include the Exxon Valdez in Alaska in 1989 and the BP oil spill in the Gulf in 2010 (figure 13.10)
  - Inorganic nutrients are added that help bacteria present in the water to grow. The bacteria feed on the hydrocarbons in the oil, degrading it.
  - Researchers are genetically engineering bacteria to consume petroleum products

FIGURE 13.10 EXXON VALDEZ OIL SPILL

(a) (b)

(a) Cleaning up oil after the Valdez spill in Alaska, the 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)

PROKARYOTES IN AND ON THE BODY (13.1)

- There are 10-100 times as many bacterial and archaeal cells inhabiting our bodies as we have cells in our bodies.
- **Commensalism**→ a relationship in which the bacterium benefits and the human host is neither benefitted nor harmed.
- Hundreds of species of bacteria and archaea live in the intestine (gut flora).
    - These flora have several functions, some of which include assistance with metabolism of food molecules, synthesis of vitamin K, training and maintenance of the immune system, and formation of a barrier against pathogens.
- The surface of the skin is also covered with prokaryotes. The possible benefits of skin flora has not been well studied.
- Researchers are actively studying the relationships between various diseases and alterations to the composition of human microbial flora.

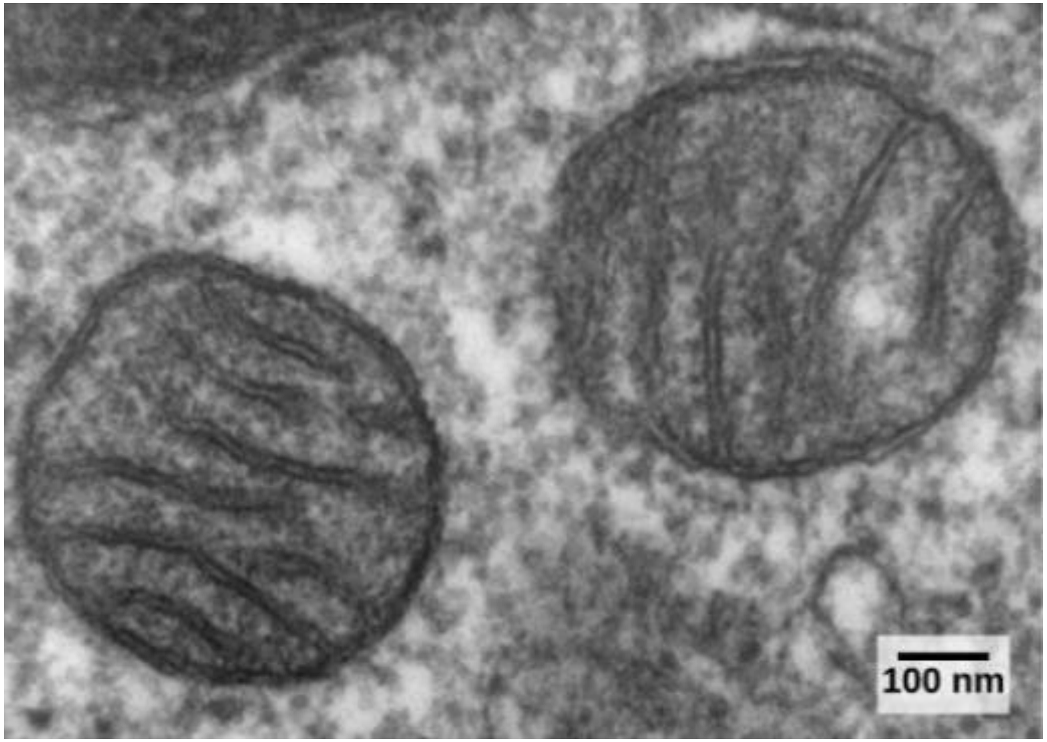
EUKARYOTIC ORIGINS AND ENDOSYMBIOSIS (13.2)

- The fossil record and genetic evidence suggest that prokaryotic cells were the first organisms on earth.
    - They originated about 3.5 BYA and were the only life forms until the first eukaryotic cells arose, about 2.1 BYA.
- The **endosymbiotic theory** states that eukaryotes are a product of one prokaryotic cell engulfing another, one living within another, and evolving together over time until the cells were no longer recognizable as separate.
- Several endosymbiotic events likely contributed to the origin of the eukaryotic cell (next few slides).
    - Events involving mitochondria
    - Events involving chloroplasts

ENDOSYMBIOSIS 1 OF 2 (13.2)

- As the earth's early atmosphere became oxygenated, evidence suggests that an ancestral cell engulfed and kept alive a free-living aerobic prokaryote.
  - This gave the host cell the ability to use oxygen to release energy.
  - Much evidence suggests that mitochondria are derived from this endosymbiotic event (Figure 13.11).
- Chloroplasts contain the green pigment chlorophyll and play a role in photosynthesis.
  - Chloroplasts are part of a group of organelles called plastids. **Plastids** are involved in the storage of substances.
  - Evidence suggests that plastids evolved from the endosymbiosis of an ancestral cell that engulfed a photosynthetic bacterium (cyanobacterium).

FIGURE 13.11 MITOCHONDRIA

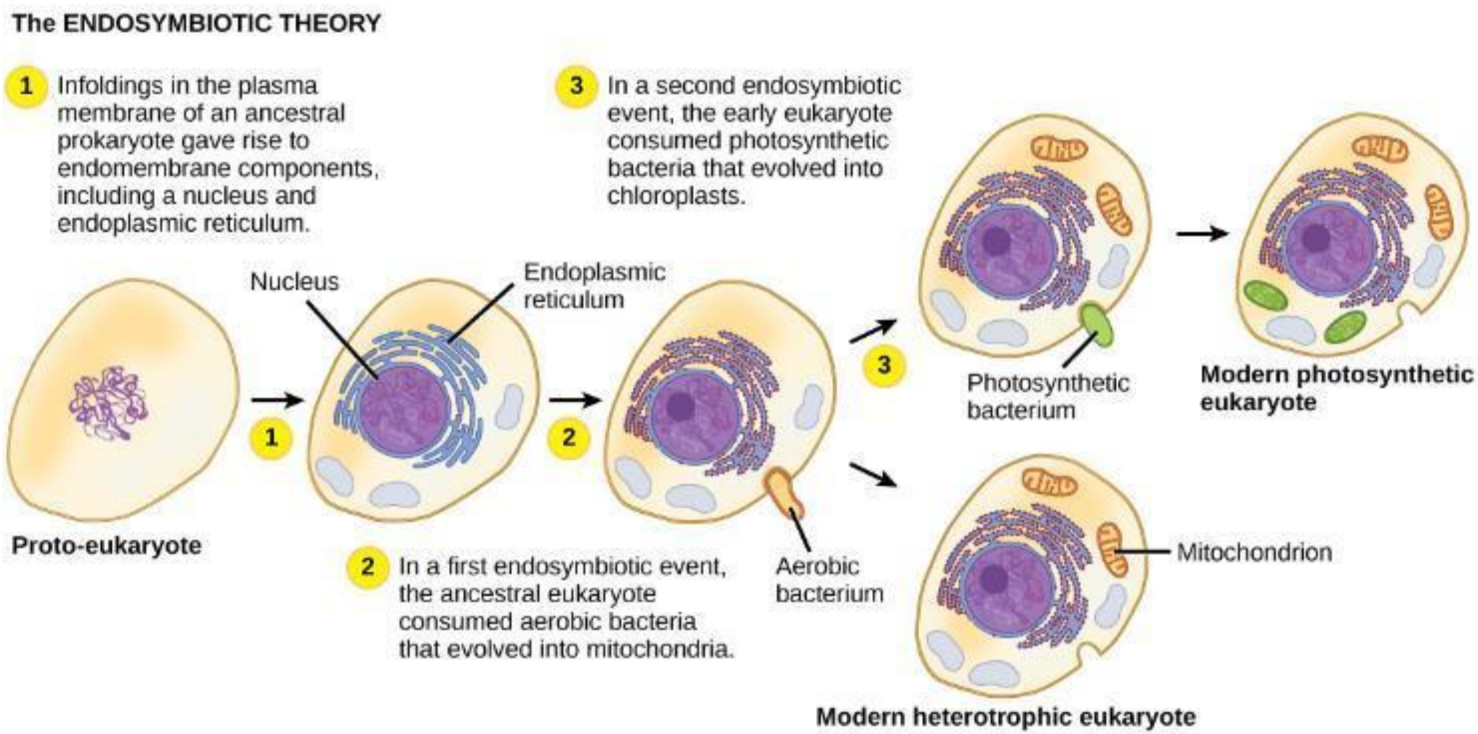


In this transmission electron micrograph of mitochondria in a mammalian lung cell, the cristae, infoldings of the mitochondrial inner membrane, can be seen in cross-section. (credit: modification of work by Louisa Howard; scale-bar data from Matt Russell)

ENDOSYMBIOSIS 2 OF 2 (13.2)

- Mitochondria likely evolved before plastids because all eukaryotes have mitochondria or mitochondria like organelles. Only certain eukaryotes (plants and algae) have plastids.
- There is some controversy regarding the events of endosymbiosis, such as which events actually took place and in what order.
    - One hypothesis of the evolutionary steps leading to the first eukaryote is presented in Figure 13.12.
- The first eukaryotes were unicellular like most protists are today.
- As eukaryotes became more complex, the evolution of multicellularity allowed cells to remain small but exhibit specialized functions.

FIGURE 13.12 ENDOSYMBIOSIS

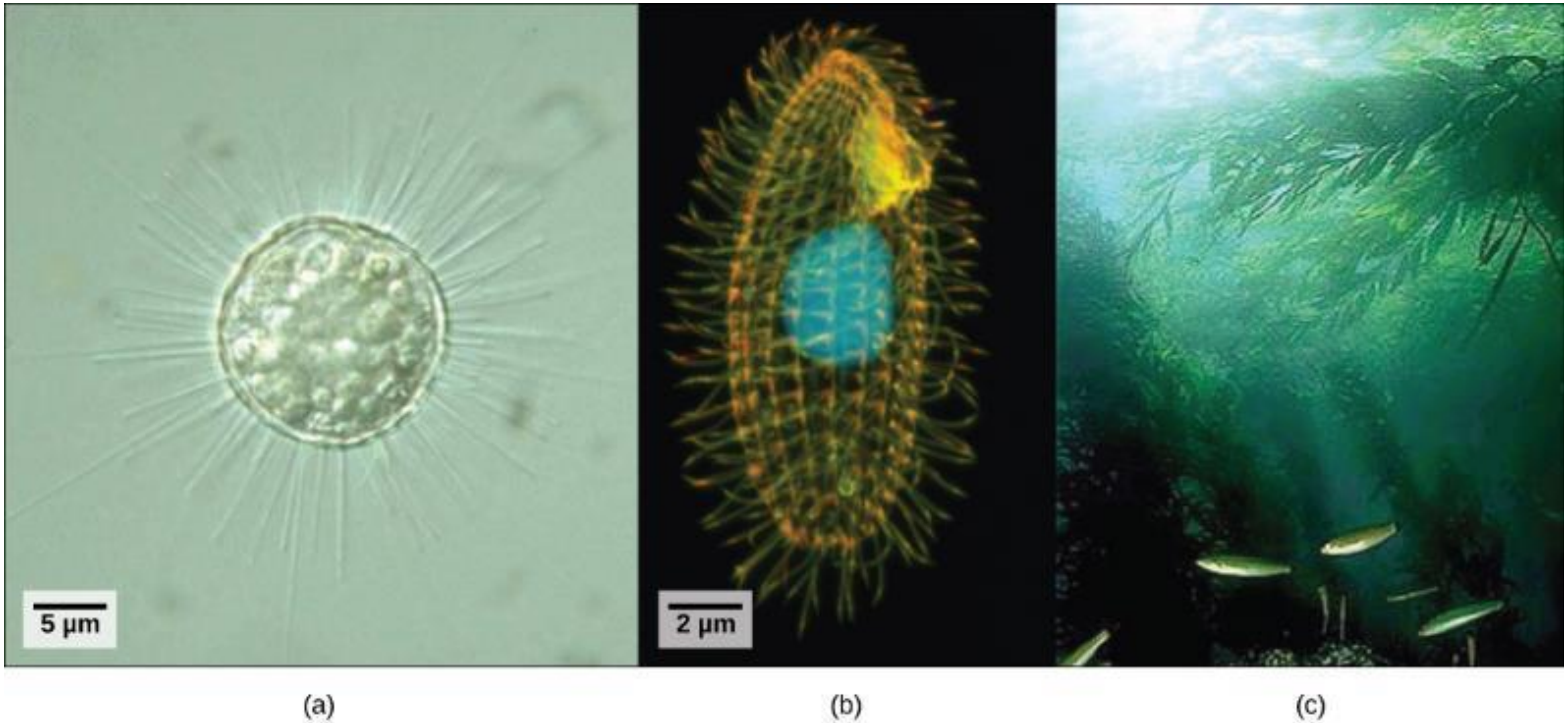


The first eukaryote may have originated from an ancestral prokaryote that had undergone membrane proliferation, compartmentalization of cellular function (into a nucleus, lysosomes, and an endoplasmic reticulum), and the establishment of endosymbiotic relationships with an aerobic prokaryote and, in some cases, a photosynthetic prokaryote to form mitochondria and chloroplasts, respectively.

PROTISTS (13.3)

- Eukaryotic organisms that did not fit the criteria for kingdoms Plantae, Animalia or Fungi historically were classified into a kingdom called **Protista**.
- Recently, protist lineages have been reassigned into new kingdoms or into other existing kingdoms.
- Protists display a large diversity of morphology, physiology and ecology. Many of them are unicellular but they can also be very large and multicellular (Figure 13.13).
- Nearly all protists exist in some type of aquatic environment, including freshwater, marine, damp soil and snow.
- Several species of protists are **parasites**→ organisms that live on or in another organism and feeds on it, often without killing it
- A few protist species decompose dead organisms or their wastes.

FIGURE 13.13 EXAMPLES OF PROTISTS



Protists range from the microscopic, single-celled (a) *Acanthocystis turfacea* and the (b) ciliate *Tetrahymena thermophila* to the enormous, multicellular (c) kelps (Chromalveolata) that extend for hundreds of feet in underwater “forests.” (credit a: modification of work by Yuiuji Tsukii; credit b: modification of work by Richard Robinson, Public Library of Science; credit c: modification of work by Kip Evans, NOAA; scale-bar data from Matt Russell)

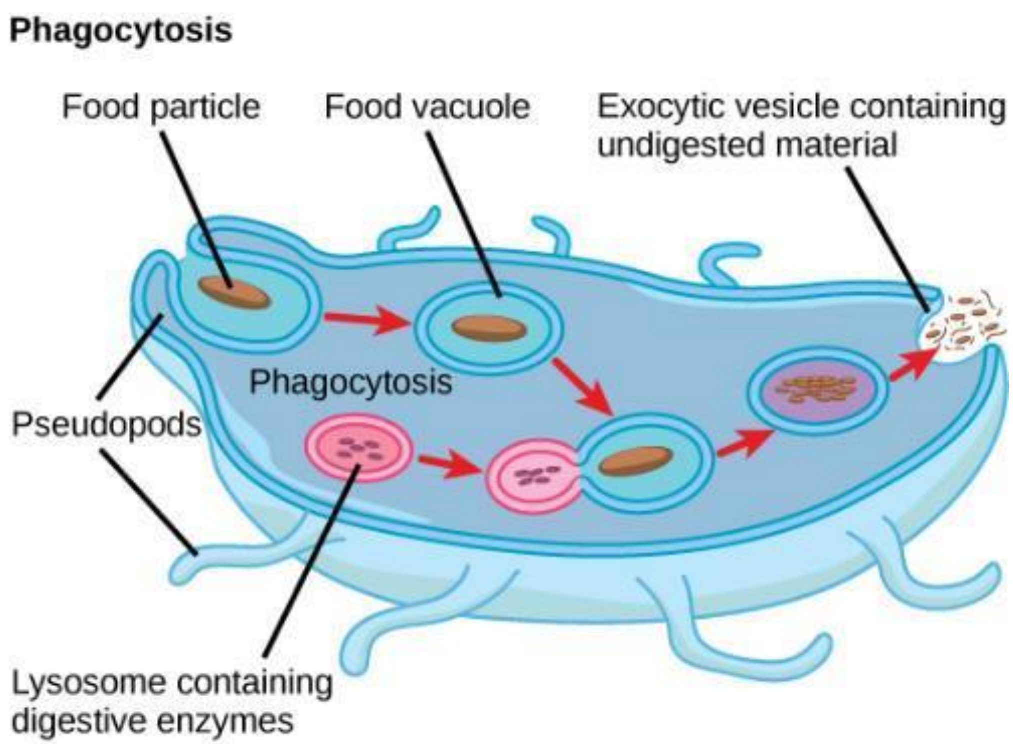
CHARACTERISTICS OF PROTISTS (13.3)

- Most protists are microscopic and unicellular but they can be multicellular. They can also live in colonies.
- Protists can be covered with:
  - animal-like cell membranes
  - plant-like cell walls
  - glassy shells
  - **pellicles**→ an outer protein covering that functions like a flexible coat of armor (prevents protist from being torn or pierced without compromising range of motion)
- The majority of protists are motile (can move), but they have evolved varied modes of movement.
  - Whip-like **flagella** (one or more)
  - Rows or tufts of **cilia** that they beat to swim
  - **Pseudopodia**, lobes of cytoplasm that they anchor to a substrate then pull the rest of the cell towards the anchor point

HOW PROTISTS OBTAIN ENERGY (13.3)

- Protists exhibit many forms of nutrition:
  - Some are photosynthetic using chloroplasts
  - Others consume organic materials (including other organisms)
  - Some absorb nutrients from dead organisms or their organic wastes
- Some protists (like *Amoeba*) use a process called **phagocytosis** to ingest particles of food (Figure 13.14).
  - Cell membrane engulfs a food particle, which is placed into a food vacuole
  - The vacuole fuses with a lysosome and the food particle is broken down into small molecules
  - Undigested remains are expelled from the cell

FIGURE 13.14 PHAGOCYTOSIS



The stages of phagocytosis include the engulfment of a food particle, the digestion of the particle using hydrolytic enzymes contained within a lysosome, and the expulsion of undigested material from the cell.

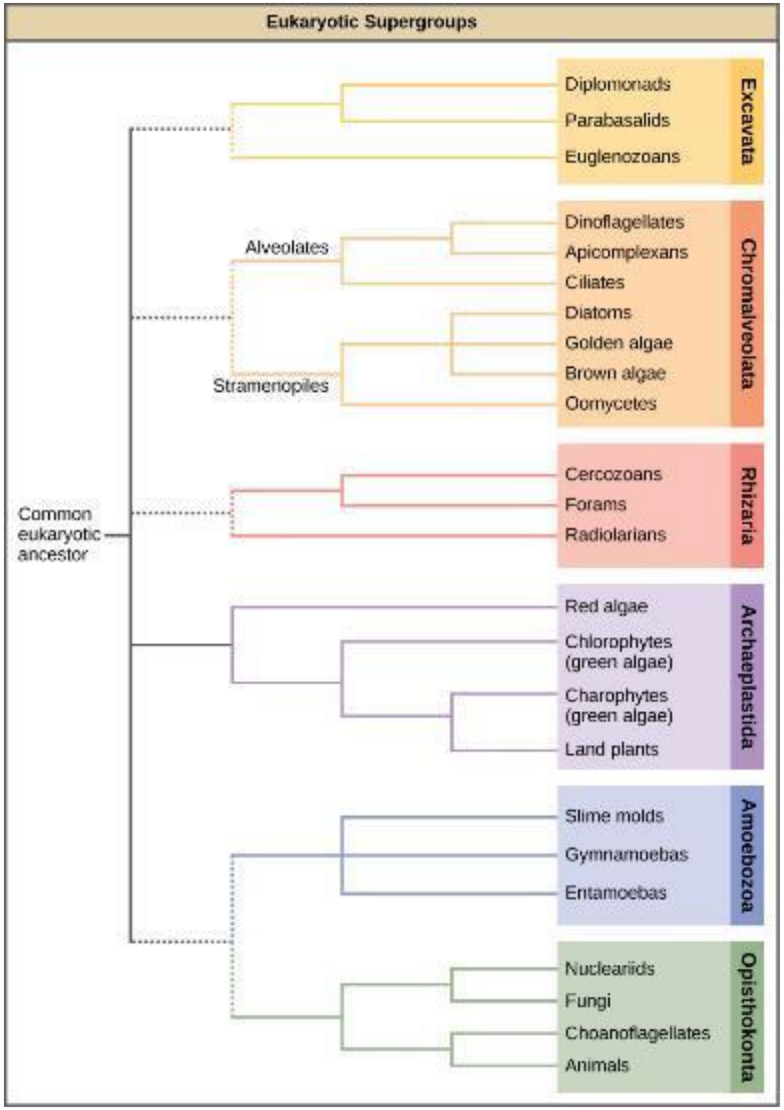
PROTISTS REPRODUCTION (13.3)

- Protists reproduce by a variety of methods:
- Asexual methods include:
    - **Binary fission** produces 2 daughter cells or many daughter cells at once
    - **Budding**, in which the protist produces tiny buds that grow to the size of the parent
- Sexual reproduction involving meiosis and fertilization also occurs in protists
- Some protists can switch from asexual to sexual reproduction when necessary
    - Sexual reproduction is more common during periods when nutrients are depleted or environmental changes occur
    - Sexual reproduction allows new combination of genes that may be better suited to survival in the new environment

PROTIST DIVERSITY (13.3)

- The relationships between protist groups and between protist groups and other eukaryotes are becoming clearer.
- Many relationships that were based on morphological similarity are being replaced by new relationships based on genetics.
- The emerging classification scheme groups the entire domain Eukarya (all the eukaryotes) into 6 “Supergroups” that contain the protists as well as the animals, plants and fungi (Figure 13.15).
- All organisms within each supergroup are believed to have evolved from a common ancestor (monophyletic group) and are more closely related to each other than to organisms outside the group.

FIGURE 13.15 EUKARYOTIC SUPERGROUPS

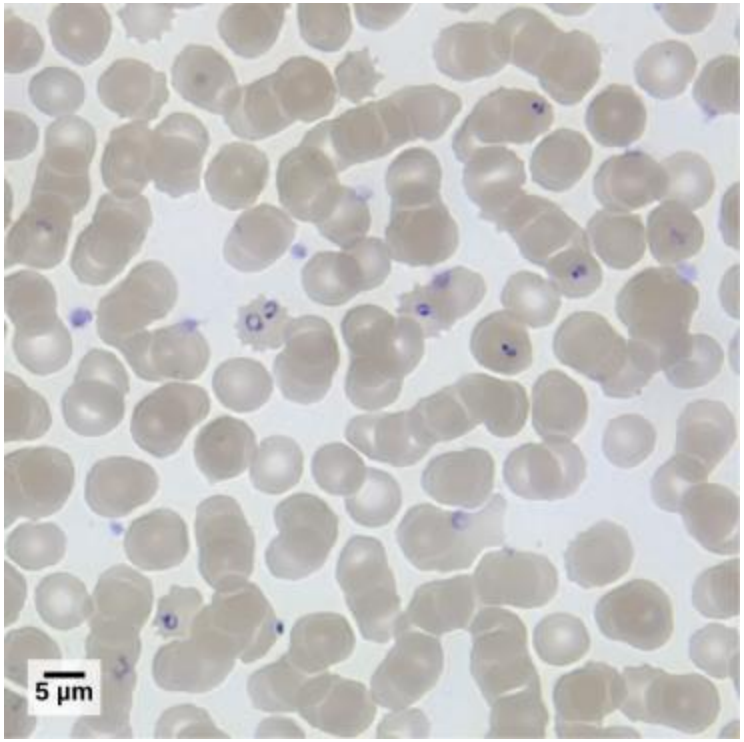


Protists appear in all six eukaryotic supergroups.

HUMAN PATHOGENS (13.3)

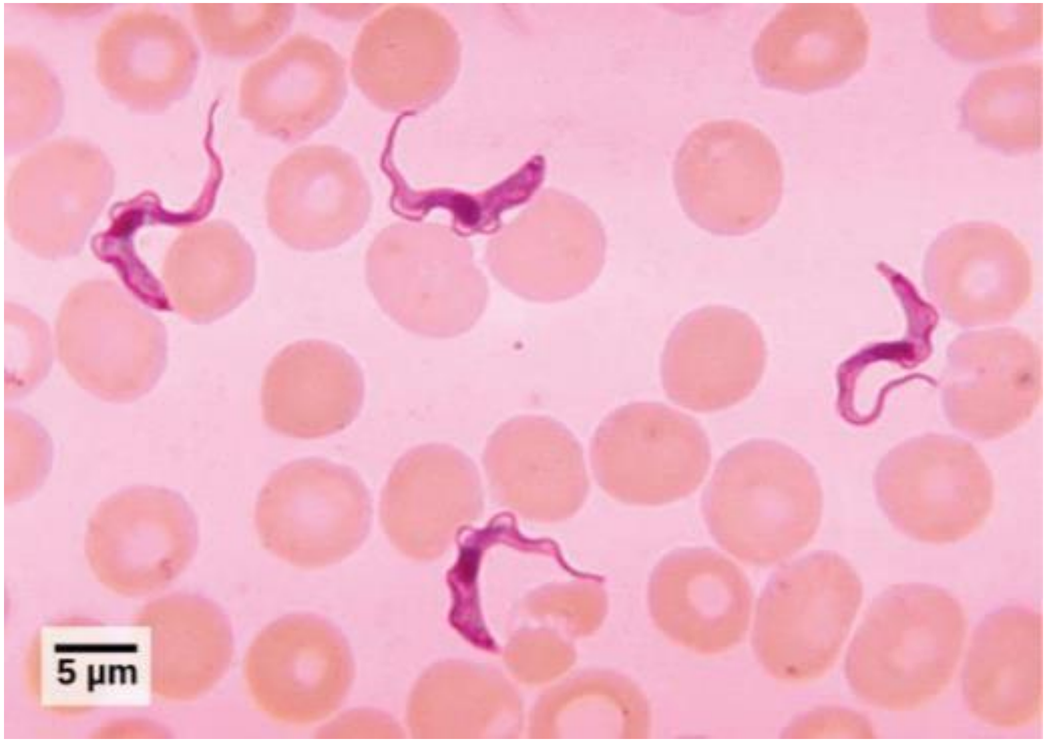
- *Plasmodium* is the protist that causes the disease malaria, which is transmitted by mosquitoes (Figure 13.16).
  - The parasite infects red blood cells and can destroy up to half of the circulating cells, leading to severe anemia.
  - It is common in tropical regions of the world, especially Africa.
  - Techniques to kill, sterilize or avoid exposure to the mosquito species are crucial to malaria control.
- Trypanosomes are responsible for sleeping sicknesses, including African sleeping sickness (Figure 13.17).
  - The protist is transmitted by an insect bite and lives in the bloodstream. The disease affects the nervous system and leads to death if untreated.
  - A trypanosome is also responsible for Chagas disease in Latin America, which affects the heart and digestive system.

FIGURE 13.16 *PLASMODIUM*



This light micrograph shows a 100x magnification of red blood cells infected with *P. falciparum* (seen as purple). (credit: modification of work by Michael Zahniser; scale-bar data from Matt Russell)

FIGURE 13.17 TRYPANOSOMES



Trypanosomes are shown in this light micrograph among red blood cells. (credit: modification of work by Myron G. Schultz, CDC; scale-bar data from Matt Russell)

PATHOGENESIS CONCEPT IN ACTION

This movie depicts the pathogenesis of *Plasmodium falciparum*, the causative agent of malaria.

Link to Video

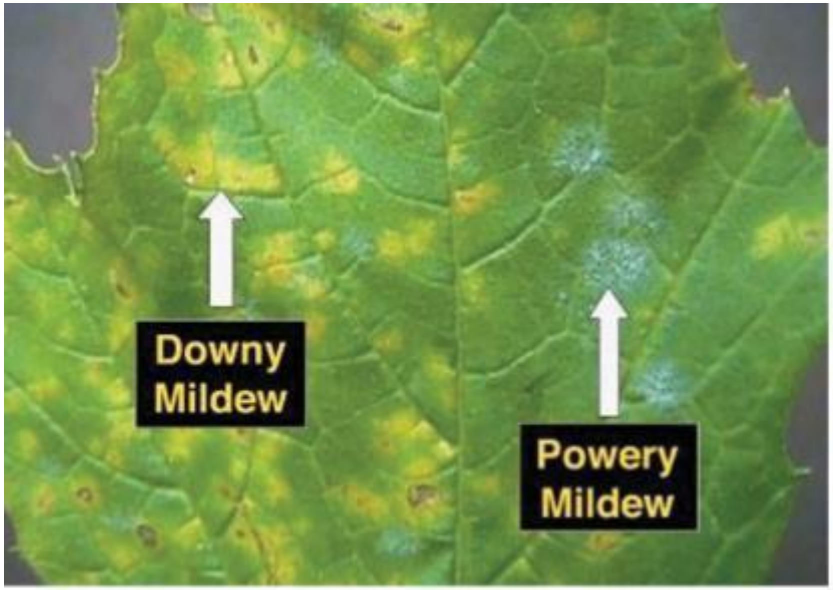
This movie discusses the pathogenesis of *Trypanosoma brucei*, the causative agent of African sleeping sickness.

Link to Video

PLANT PARASITES (13.3)

- Protist parasites of terrestrial plants include agents that destroy food crops (Figure 13.18).
    - A protist parasitizes grape plants, causing downy mildew, which stunts plant growth and produces withered leaves.
    - A protist causes potato late blight, which causes potato stalks and stems to decay into black slime. Potato late blight caused the Irish potato famine in the 19th century, which killed about 1 million people and led to the emigration from Ireland of at least 1 million more.

FIGURE 13.18 PLANT PARASITES



(a)

(b)

(a) The downy and powdery mildews on this grape leaf are caused by an infection of *P. viticola*.

(b) This potato exhibits the results of an infection with *P. infestans*, the potato late blight. (credit a: modification of work by David B. Langston, University of Georgia, USDA ARS; credit b: USDA ARS)

BENEFICIAL PROTISTS 1 OF 2 (13.3)

- Protists are essential sources of nutrition for many other organisms.
- As plankton, protists are consumed directly.
- Photosynthetic protists called dinoflagellates pass on nutrition to coral polyps in coral reefs. This is a mutually beneficial relationship because the polyps provide protection and nutrients for the dinoflagellates.
    - Corals build reefs out of calcium carbonate. Without the dinoflagellates, the polyps lose pigments and they die. This is called **coral bleaching** and is a cause of loss of coral reefs.
- Protists feed a large proportion of aquatic organisms through photosynthesis.

FIGURE 13.19 CORAL POLYPS WITH DINOFLAGELLATES

Coral polyps obtain nutrition through a symbiotic relationship with dinoflagellates.

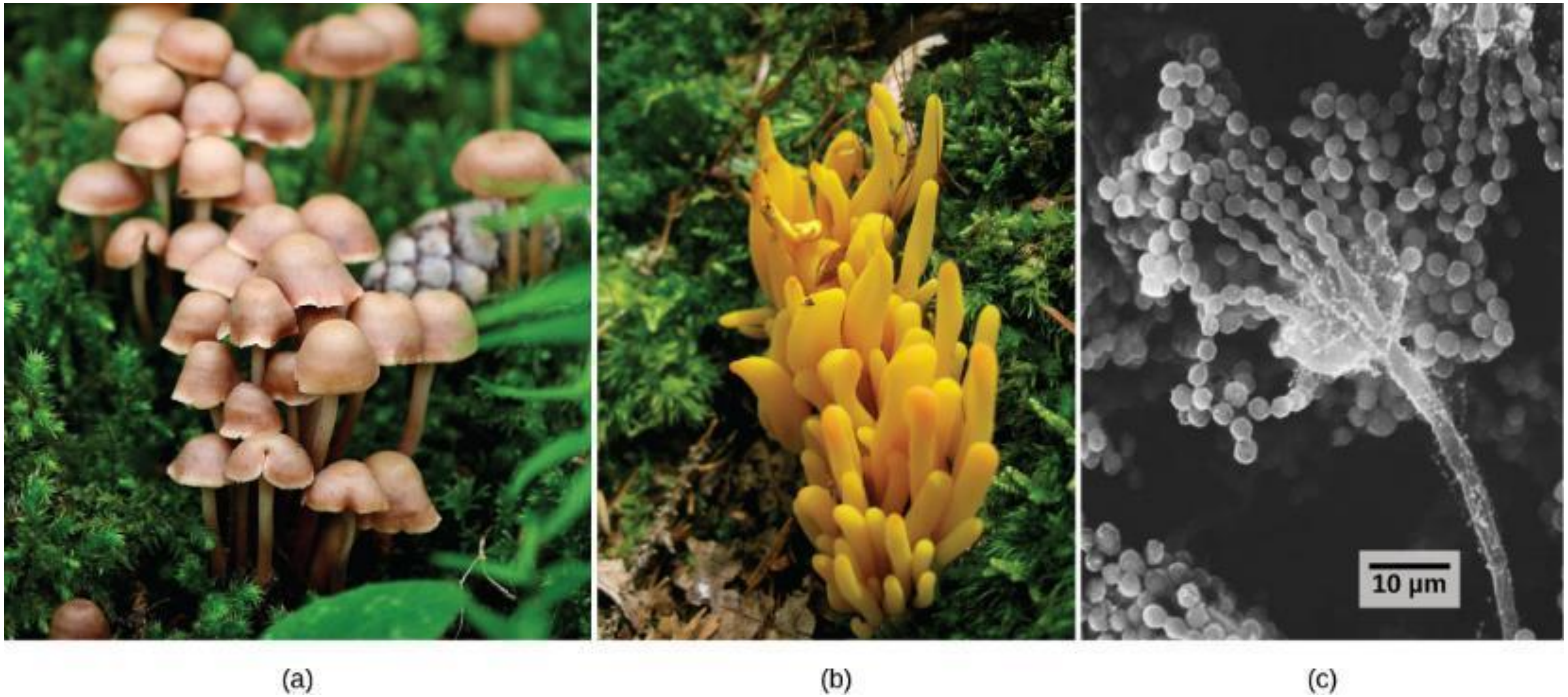
BENEFICIAL PROTISTS 2 OF 2 (13.3)

- Protists also create food sources for land-dwelling organisms such as wood eating termites and cockroaches. The protist houses a bacteria that has an enzyme that the insects use to digest the wood.
- Many fungus-like protists are **saprobes**, organisms that feed on dead organisms (like dead animals or algae) or the waste matter produced by organisms.
    - These protists return inorganic nutrients to the soil and water. This allows new plant growth.

FUNGI (13.4)

- The kingdom Fungi (Figure 13.20) contains an enormous variety of living organisms, including mushrooms, yeast, black mold, and *Penicillium* (the producer of the antibiotic penicillin).
- DNA comparisons have shown that fungi are more closely related to animals than to plants.
- Fungi are not capable of photosynthesis. They are decomposers and cycle nutrients by breaking down organic materials into simple molecules.
- Fungi often interact with other organisms, forming mutually beneficial (mutualistic) associations.
- Fungal infections are difficult to treat because they are also eukaryotes like humans. Thus, fungi do not respond to antibiotics like bacteria.
- Fungi have many commercial applications, like baking, brewing, wine making and the production of antibiotics.

FIGURE 13.20 DIVERSITY OF FUNGI



The (a) familiar mushroom is only one type of fungus. The brightly colored fruiting bodies of this (b) coral fungus are displayed. This (c) electron micrograph shows the spore-bearing structures of *Aspergillus*, a type of toxic fungi found mostly in soil and plants. (credit a: modification of work by Chris Wee; credit b: modification of work by Cory Zanker; credit c: modification of work by Janice Haney Carr, Robert Simmons, CDC; scale-bar data from Matt Russell)

CELL STRUCTURE AND FUNCTION (13.4)

- Fungi are eukaryotes and have a complex cellular organization.
- They have a membrane bound nucleus and many organelles.
- Fungal cells do not have chloroplasts, but many display bright colors (such as red, green or black). Some of these pigments are toxic (Figure 13.21).
- Fungal cells have a cell wall like plants. However, fungal cell walls are made of a material called **chitin** (which is also found in the exoskeletons of insects).
    - The cell wall protects the cell from drying out and from predators. The cell wall gives structure and strength to the cells.
- Most members of the kingdom Fungi are non-motile (can't move).

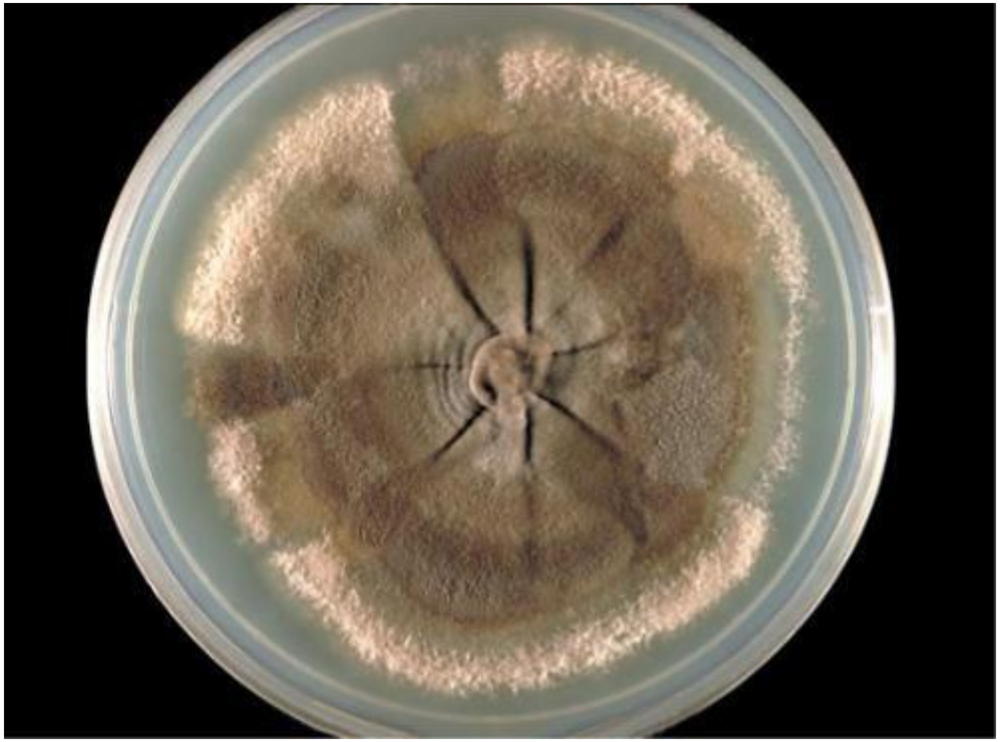
FIGURE 13.21 POISONOUS MUSHROOM

The poisonous *Amanita muscaria* is native to the temperate and boreal regions of North America. (credit: Christine Majul)

GROWTH AND REPRODUCTION 1 OF 2 (13.4)

- The vegetative body of a fungus is called a **thallus**, and can be unicellular or multicellular.
- Unicellular fungi are generally referred to as yeasts.
    - Baker's yeast and *Candida* (yeast found in vaginal infections and in thrush) are examples of yeast.
- The vegetative stage of a fungus is a tangle of thread-like structures called **hyphae** (microscopic). A mass of hyphae is called a **mycelium** (the body of a fungus).
    - A mycelium can be huge and can grow on a surface, in soil, in decaying material or even in or on living tissue.
- Most hyphae are separated by end walls called **septa**. Some groups have complete septa and some have tiny holes in the septa.

FIGURE 13.22 A FUNGAL MYCELIUM



The mycelium of the fungus *Neotestudina rosati* can be pathogenic to humans. The fungus enters through a cut or scrape and develops into a mycetoma, a chronic subcutaneous infection. (credit: CDC)

GROWTH AND REPRODUCTION 2 OF 2 (13.4)

- Fungi thrive in moist, slightly acidic environments and can grow with or without light.
- Fungi vary in their oxygen requirements. Some need oxygen to survive, some die in the presence of oxygen and some are in between.
- Fungi can reproduce sexually or asexually. They produce spores that disperse from the parent by wind or hitching a ride on an animal.
    - They produce huge numbers of spores in order to increase the likelihood that the spores will land in an environment that will support growth.

FIGURE 13.23 GIANT PUFFBALL

(a) (b)

The (a) giant puffball mushroom releases (b) a cloud of spores when it reaches maturity. (credit a: modification of work by Roger Griffith; credit b: modification of work by Pearson Scott Foresman, donated to the Wikimedia Foundation)

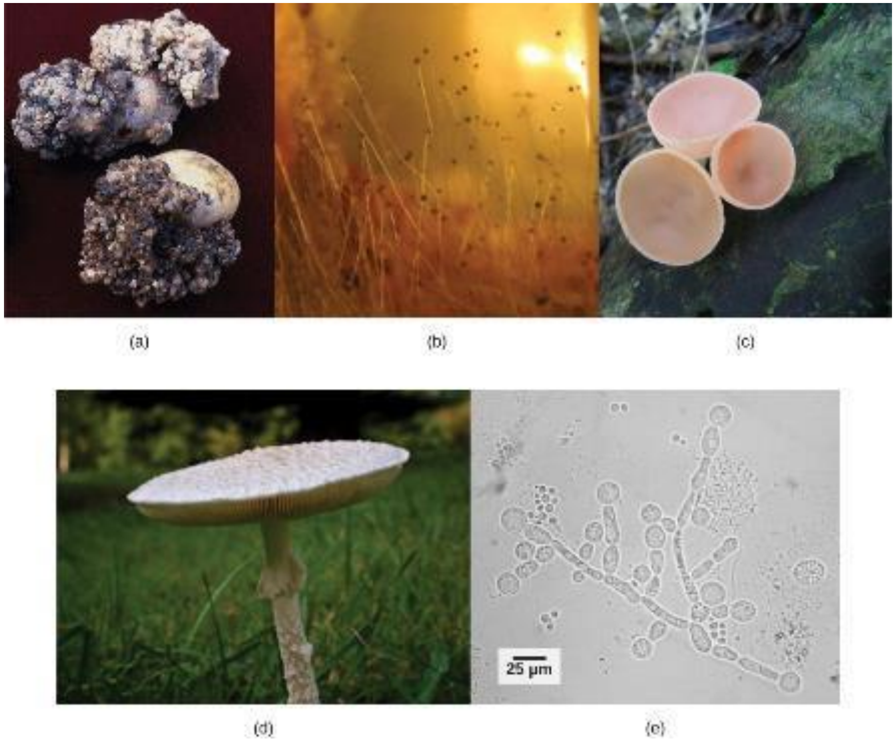
HOW FUNGI OBTAIN NUTRITION (13.4)

- Fungi are **heterotrophs**, they use organic compounds as a source of carbon. In other words, they consume other organisms for nutrition and are not photosynthetic (like animals).
- With fungi, digestion occurs before ingestion. Enzymes are secreted by the fungus onto the food source and they break down the nutrients. Then the nutrients are absorbed into the fungal mycelium.
- Most fungi are saprobes, organisms that obtain nutrients from decaying organic matter, mainly plant material.
    - Decomposers are important because they return nutrients locked in dead bodies into a form that is usable for other organisms.
- Fungi are also useful in bioremediation.

FUNGAL DIVERSITY (13.4)

- The kingdom Fungi contains 4 major divisions based on their mode of sexual reproduction.
    - Two other groups are also recognized.
- The major divisions are (Figure 13.24):
    - Chytridiomycota (chytrids), fungus which are responsible for the worldwide decline of amphibians.
    - Zygomycota (bread and fruit molds)
    - Ascomycota (yeast, cup fungi)
    - Basidiomycota (mushrooms, morels)

FIGURE 13.24 FUNGAL DIVERSITY

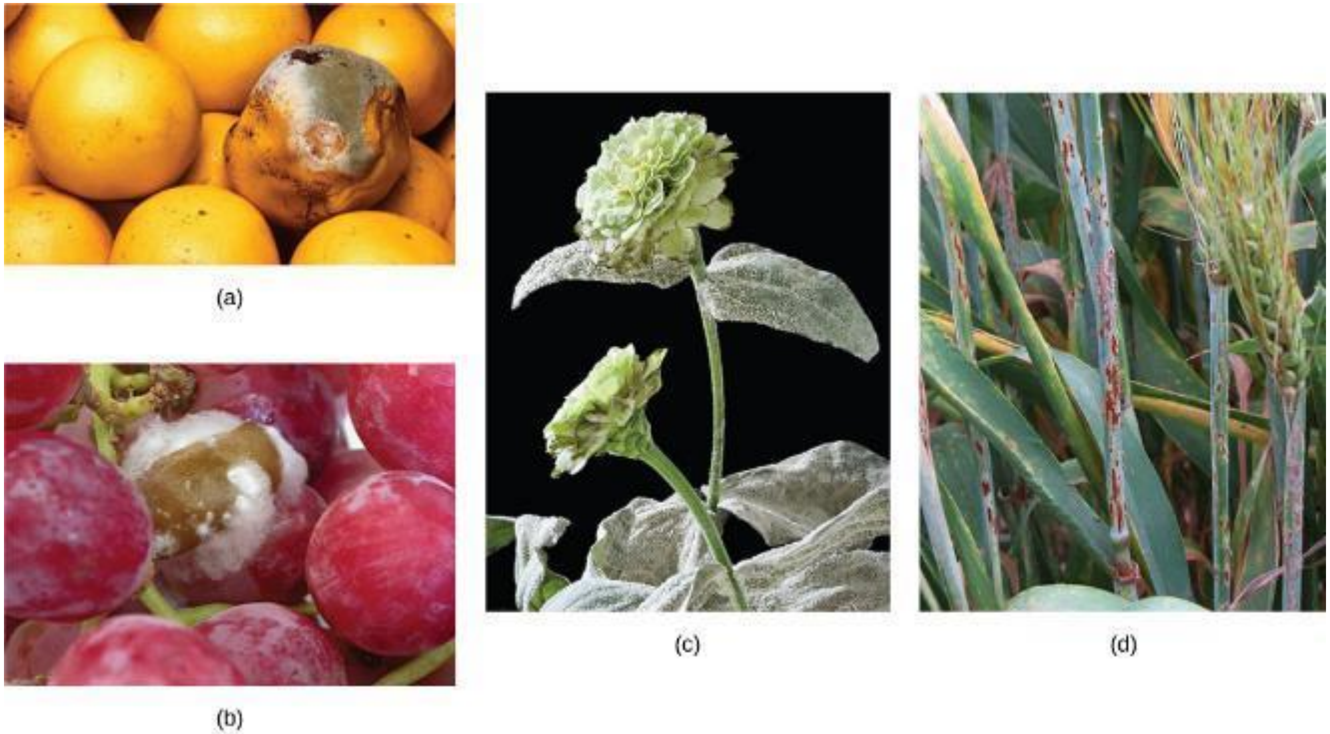


Divisions of fungi include (a) chytrids, (b) conjugated fungi, (c) sac fungi, (d) club fungi, and (e) imperfect fungi. (credit a: modification of work by USDA APHIS PPQ; credit c: modification of work by "icelight"/Flickr; credit d: modification of work by Cory Zanker; credit e: modification of work by CDC/ Brinkman; scale-bar data from Matt Russell)

PLANT PARASITES AND PATHOGENS (13.4)

- Most plant pathogens are fungi that cause tissue decay and eventual death of the host (Figure 13.25).
- Some fungi spoil crops by producing potent toxins.
- Fungi are also responsible for food spoilage and rotting of stored crops.
    - Ergot, a disease of cereal crops (like rye) is caused by a fungus. In animals, the disease caused by exposure to ergot toxins is called ergotism, and causes convulsions and hallucinations.
- Other examples of plant parasites are molds, mildews, rusts and smuts.

FIGURE 13.25



Some fungal pathogens include (a) green mold on grapefruit, (b) fungus on grapes, (c) powdery mildew on a zinnia, and (d) stem rust on a sheaf of barley. Notice the brownish color of the fungus in (b) *Botrytis cinerea*, also referred to as the “noble rot,” which grows on grapes and other fruit. Controlled infection of grapes by *Botrytis* is used to produce strong and much-prized dessert wines. (credit a: modification of work by Scott Bauer, USDA ARS; credit b: modification of work by Stephen Ausmus, USDA ARS; credit c: modification of work by David Marshall, USDA ARS; credit d: modification of work by Joseph Smilanick, USDA ARS)

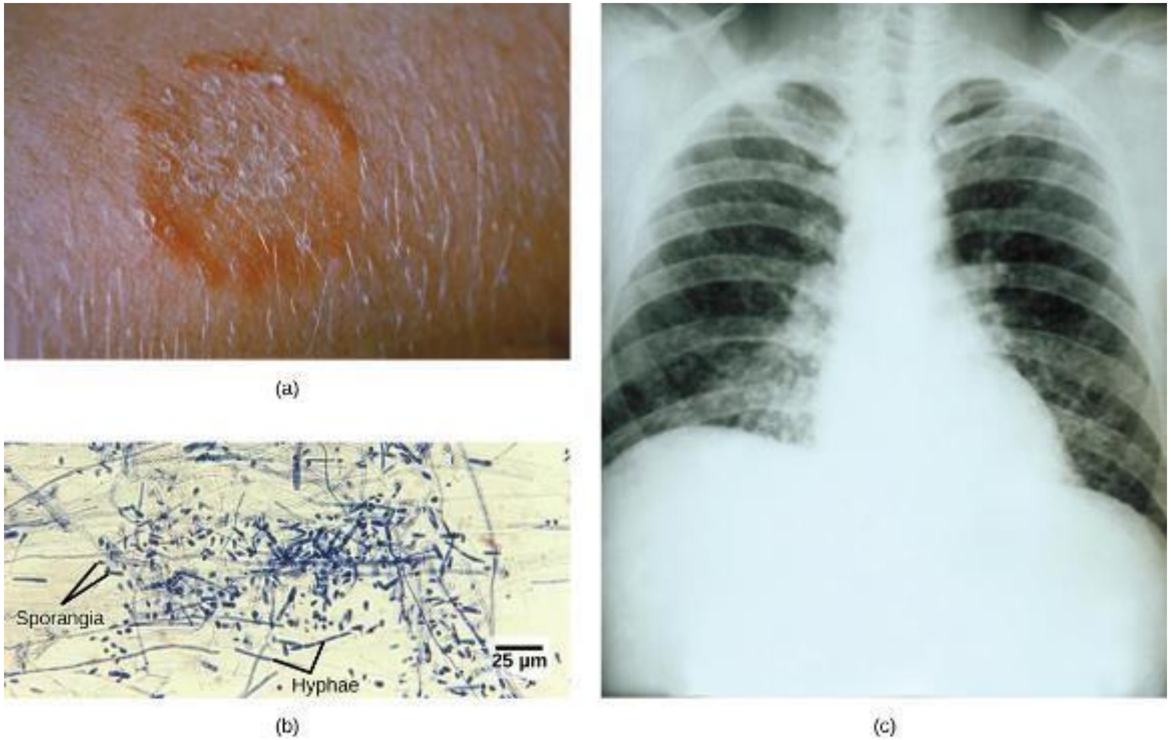
ANIMAL AND HUMAN PARASITES AND PATHOGENS 1 OF 2 (13.4)

- Fungi attack animals directly by colonizing and destroying tissues.
- Humans and other animals can be poisoned by toxic mushrooms and other fungi.
- Humans develop severe allergies to mold spores.
- Fungal infections are called **mycoses** and are usually on the skin only (Figure 13.26).
  - Examples are fungal infections of the hair, skin and nails.
  - Ringworm is not a worm, but a fungus.
  - Athletes foot, jock itch, vaginal yeast infections.
  - These infections can usually be treated with over-the-counter creams and powders, but if severe, could require prescription oral medications.

ANIMAL AND HUMAN PARASITES AND PATHOGENS 2 OF 2 (13.4)

- Systemic fungal infections spread to internal organs, most commonly through the respiratory system.
    - For example, *Histoplasma* causes pulmonary (lung) infections (Figure 13.26).
- Opportunistic mycoses are fungal infections that are either common in all environments or part of the normal biota. They affect individuals with compromised immune systems, for example AIDS patients.
- Some fungi even take on a predatory lifestyle. For example, some fungi trap nematodes (tiny worms), use their hyphae to penetrate the body and slowly digest the prey.
    - They use the worms mainly as a source of nitrogen.

FIGURE 13.26 FUNGAL INFECTIONS IN HUMANS



(a) Ringworm presents as a red ring on the skin. (b) *Trichophyton violaceum* is a fungus that causes superficial mycoses on the scalp. (c) *Histoplasma capsulatum*, seen in this X-ray as speckling of light areas in the lung, is a species of Ascomycota that infects airways and causes symptoms similar to the flu. (credit a, b: modification of work by Dr. Lucille K. Georg, CDC; credit c: modification of work by M Renz, CDC; scale-bar data from Matt Russell)

BENEFICIAL FUNGI 1 OF 3 (13.4)
IMPORTANCE TO ECOSYSTEMS

- Fungi are important to ecosystems as principle decomposers, as discussed previously.
- Fungi also participate in ecologically important symbioses.
- **Mycorrhizae** are associations between plant roots and symbiotic fungi.
    - The fungi channel water and minerals from the soil to the plant. The plant supplies photosynthetic products (sugars) to the fungus.
    - About 80-90% of plant species have mycorrhizae and do not germinate seeds properly or grow properly without them.

BENEFICIAL FUNGI 2 OF 3 (13.4)
IMPORTANCE TO ECOSYSTEMS

- **Lichens** are a fungus living in close association with a photosynthetic partner (either algae or cyanobacteria).
  - They colonize rock surfaces in otherwise barren areas, where they break down the rock in the first step towards creating soil.
  - The algae or cyanobacteria partner provides photosynthetic products to the fungus and the fungus provides protection from the elements to the photosynthetic partner.
- Fungi have also evolved mutualisms with numerous arthropods.
  - For example, leaf cutting ants in Central and South America farm fungi for their food. They cut pieces of plant leaves and pile them up in gardens, where the fungi grow and digest the leaves. Then the ants consume the fungi.

BENEFICIAL FUNGI 3 OF 3 (13.4) IMPORTANCE TO HUMANS

- Fungi are important to human life on many levels.
- They help nutrients cycle in ecosystems.
- As animal pathogens, they help to control the population of damaging pests like insects.
    - The potential to use fungi as microbial insecticides is being investigated.
- Mycorrhizae are essential for the productivity of farmland.
    - Without them, 80-90% of trees and grasses would not survive.
- Humans also eat some types of fungi, like mushrooms, morels (Figure 13.27), and truffles. Molds like *Penicillium* ripen cheeses (blue cheeses).

FIGURE 13.27 A MOREL

The morel mushroom is an ascomycete that is much appreciated for its delicate taste. (credit: Jason Hollinger)

BENEFICIAL FUNGI (13.4)
IMPORTANCE TO HUMANS

- Fermentation of grains produces beer and fruits produces wine.
    - In the process, yeast converts the grain or sugar into alcohol.
    - Yeast are also responsible for making bread rise. The carbon dioxide bubbles produced in fermentation rises the bread.
- Antibiotics are naturally produced by fungi to kill or inhibit the growth of bacteria, limiting competition with bacteria.
- Some fungi are important model organisms for research.

VOCABULARY

- Prokaryotes
- Eukaryotes
- Anaerobic
- Cyanobacteria
- Microbial mats
- Hydrothermal vents
- Stromatolite
- Biofilm
- Cell wall
- Capsule
- Flagella
- Pili
- Plasmid
- Gram stain
- Transformation
- Transduction
- Conjugation
- Pandemic
- Epidemic
- Foodborne disease
- Commensalism
- Endosymbiotic theory
- Plastids
- Parasite
- Pellicle
- Pseudopodia
- Cilia
- Phagocytosis
- Binary fission
- Budding
- Coral bleaching
- Saprobe
- Chitin
- Thallus
- Hyphae
- Mycelium
- Septa
- Heterotroph
- Mycoses
- Mycorrhizae
- Lichen