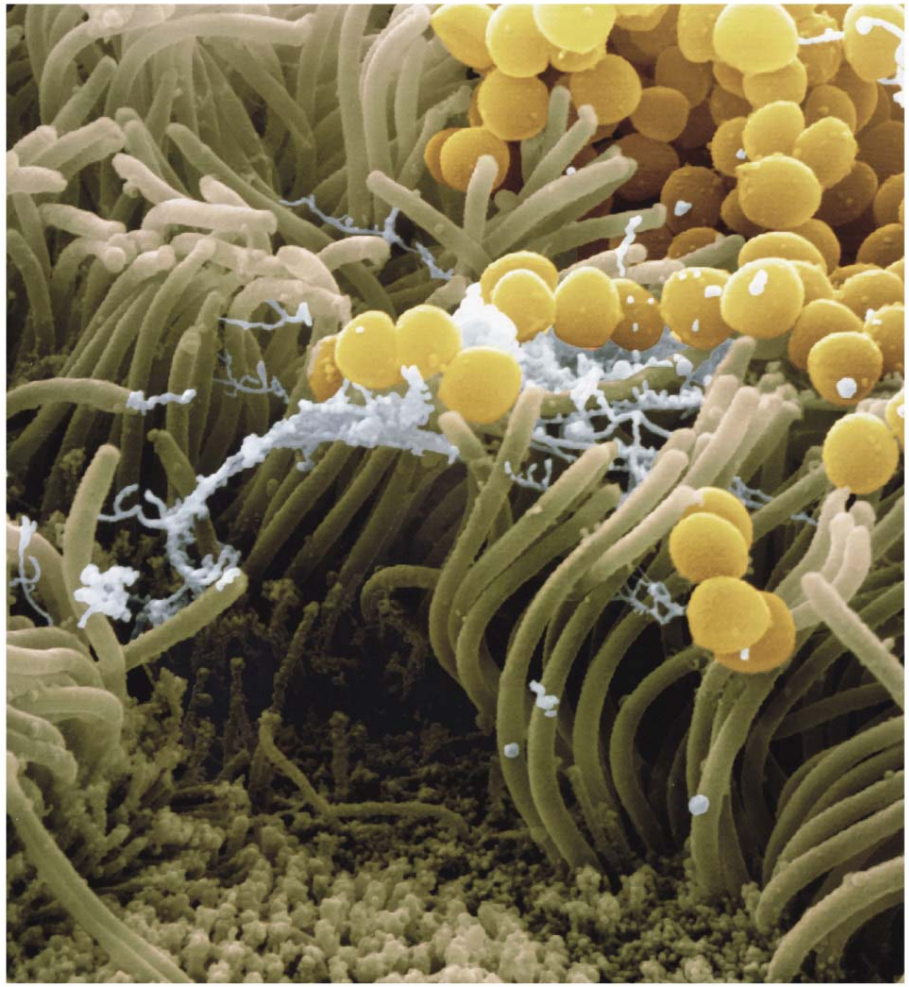
Chapter 1

The Microbial World and You



Microbes in Our Lives

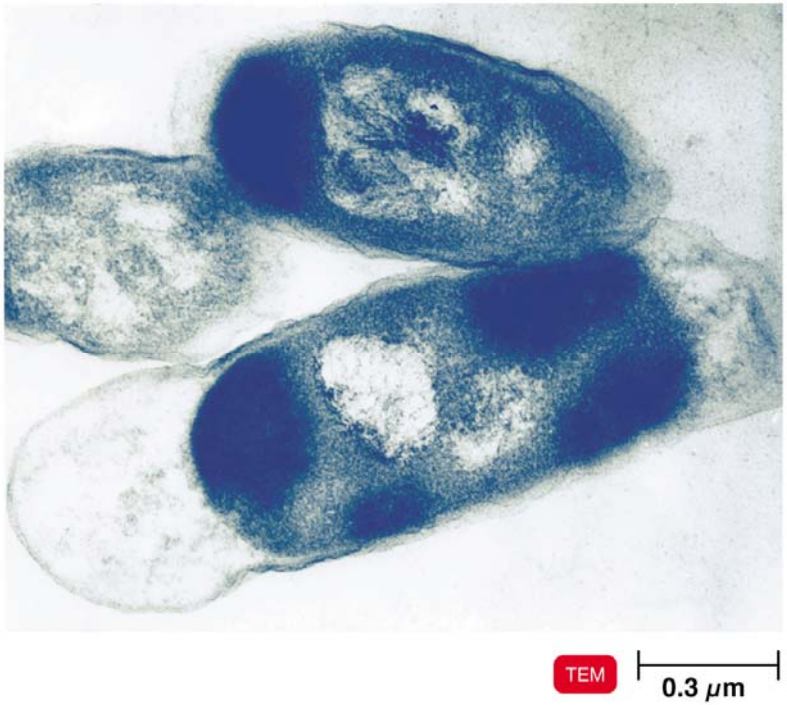
- **Microorganisms** are organisms that are too small to be seen with the unaided eye
  - e.g. bacteria, virus, protozoa, fungus, helminthes
- *Germ* refers to a rapidly growing cell
- Pathogen = microbe that will cause a disease in a healthy person
- Opportunistic microbe = able to cause a disease in a person with a weakened immune system

Microbes in Our Lives

- Decompose organic waste // recycle necessary for life (carbon cycle / nitrogen cycle / sulfur cycle)
- Are producers in the ecosystem by photosynthesis
- Produce industrial chemicals such as ethanol and acetone
- Produce fermented foods such as vinegar, cheese, and bread
- Produce products used in manufacturing (e.g., cellulase) and disease treatments (e.g. insulin)

Microbes in Our Lives
Designer Jeans: Made by Microbes?

- Stone-washing: *Trichoderma*
- Cotton: *Gluconacetobacter*
- Debleaching: mushroom peroxidase
- *E. coli* bacteria produce indigo from tryptophan
- Plastic: bacterial polyhydroxyalkanoate

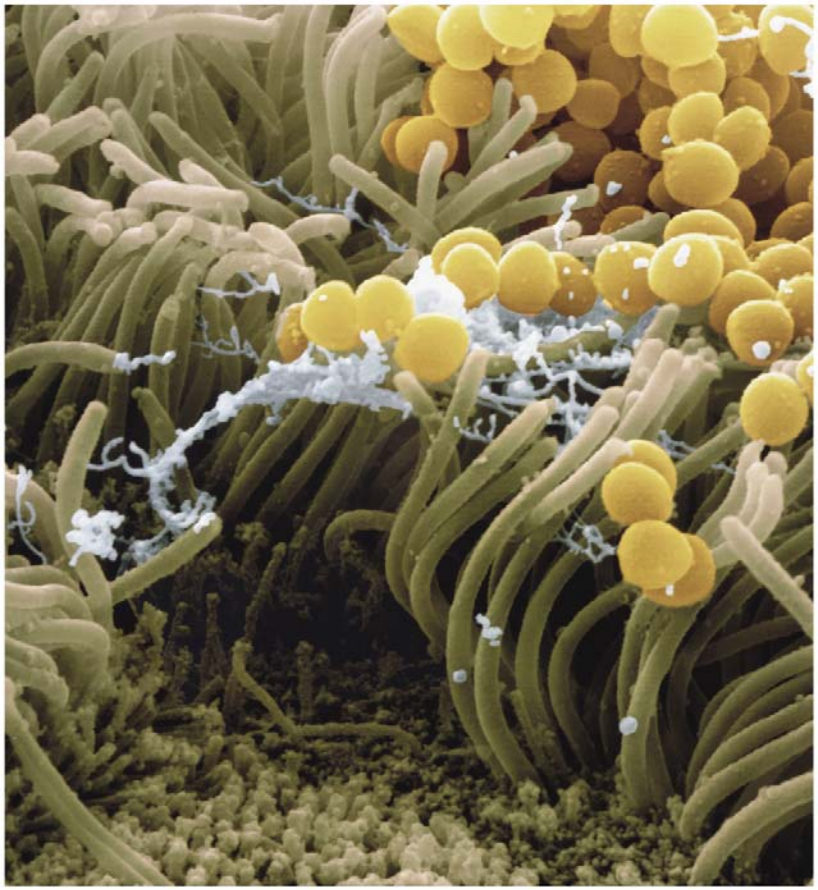


Indigo-producing *E. coli* bacteria.

Knowledge of Microorganisms

- Allows humans to
  - Prevent food spoilage
  - Prevent disease occurrence
  - Develop chemotherapies against microbes
- Led to aseptic techniques to prevent contamination in medicine and in microbiology laboratories

Humans are multi-cellular organisms, consisting of 50 trillion cells, however. There are 500 trillion bacteria living on our skin or on our mucous membranes of the gastrointestinal tract, urogenital tract, respiratory tract, and digestive tract. Some are even in our blood. If you add the total bacterial weight, it would be about two pounds. So what is the relationship between us and our bacteria? Who benefits? How do we protect ourselves from pathogens?

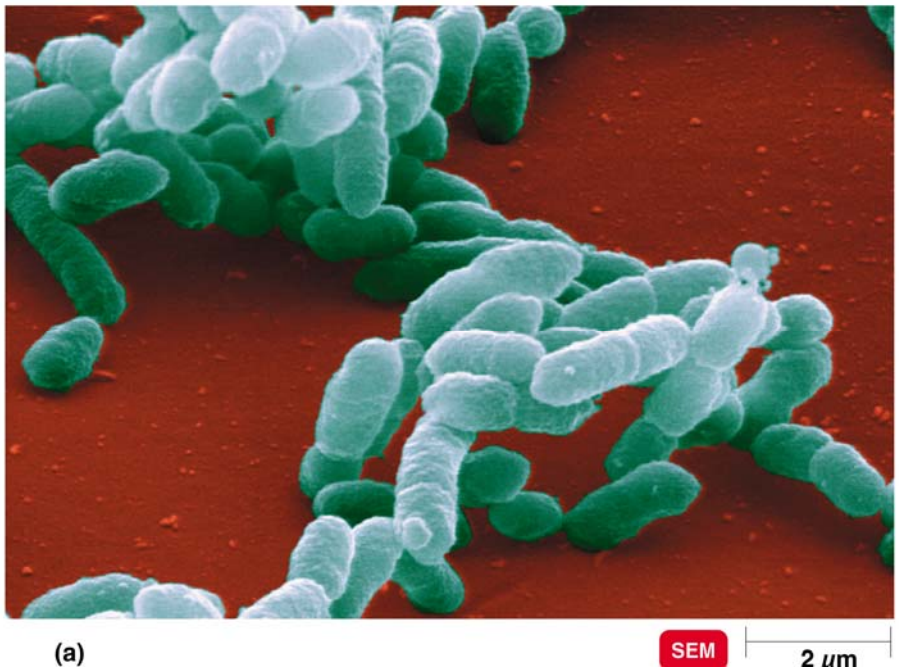


Types of Microorganisms

- Bacteria
- Archaea
- Fungi
- Protozoa
- Algae
- Viruses
- Multicellular parasitic animals / *helminthes*

Bacteria

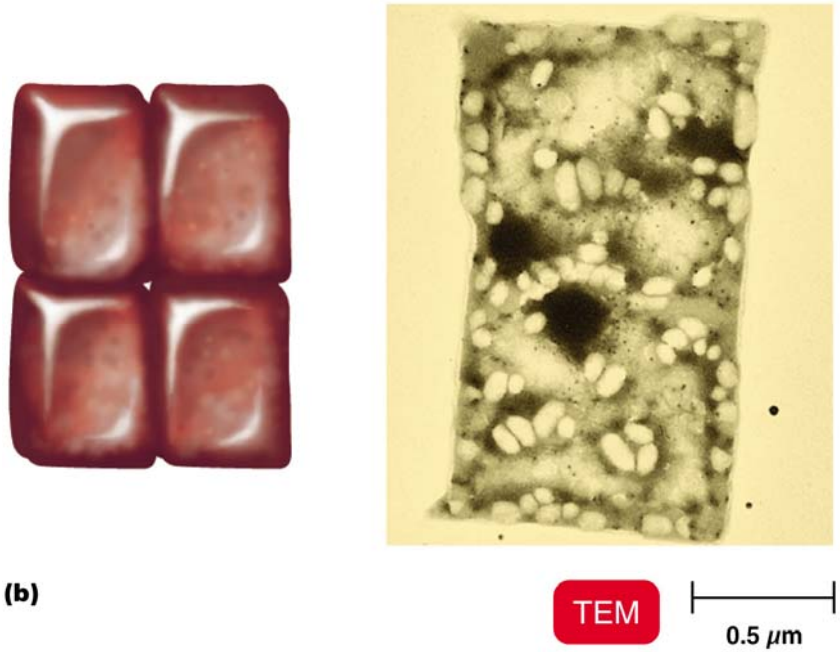
- Prokaryotes
- Peptidoglycan cell walls
- Binary fission
- For energy, use organic chemicals, inorganic chemicals, or photosynthesis



The rod-shaped bacterium *Haemophilus influenzae,* one of the bacterial causes of pneumonia.

Archaea

- Prokaryotic
- Lack peptidoglycan
- Extreme environments
- Include
  - Methanogens (produce methane)
  - Extreme halophiles (salt lovers)
  - Extreme thermophiles (heat lovers)



Star-shaped and rectangular prokaryotes.

Fungi

- Eukaryotes
- Chitin cell walls
- Use organic chemicals for energy
- Molds and mushrooms are multicellular, consisting of masses of mycelia // composed of filaments called hyphae
- Yeasts are unicellular

Mucor, a common bread mold, is a type of fungus.

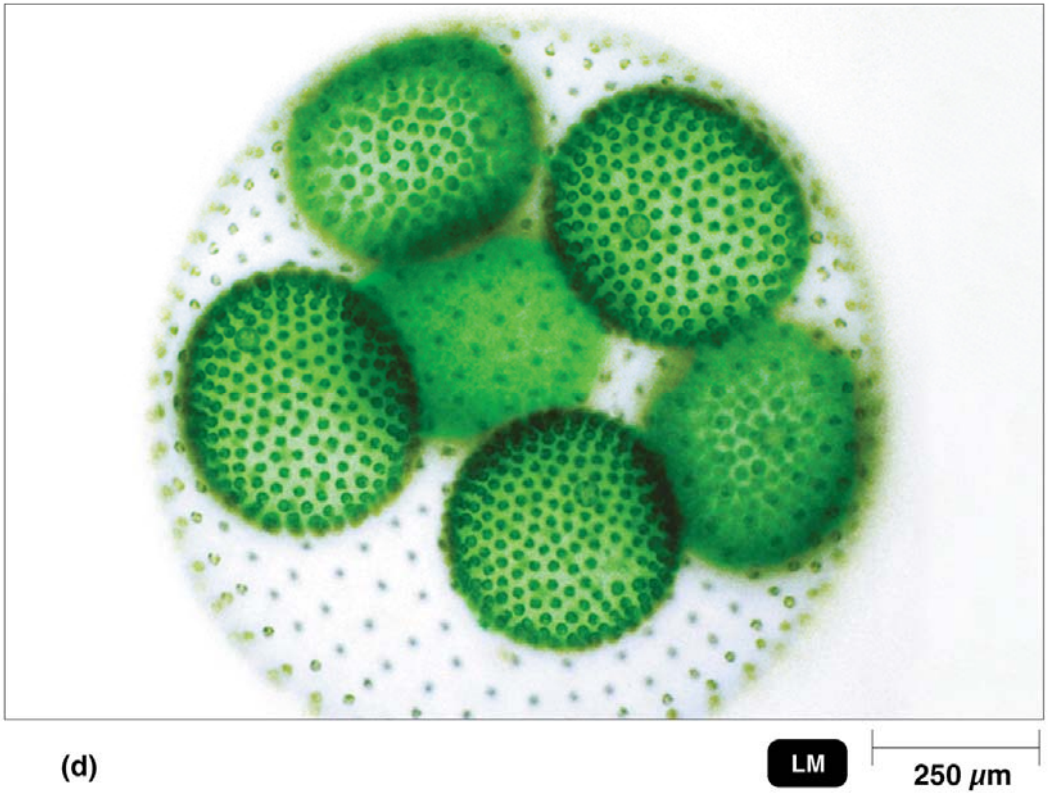
Protozoa

- Eukaryotes
- Absorb or ingest organic chemicals
- May be motile via
  - Pseudopods
  - Cilia
  - flagella

An ameba, a protozoan, approaching a food particle.

Algae

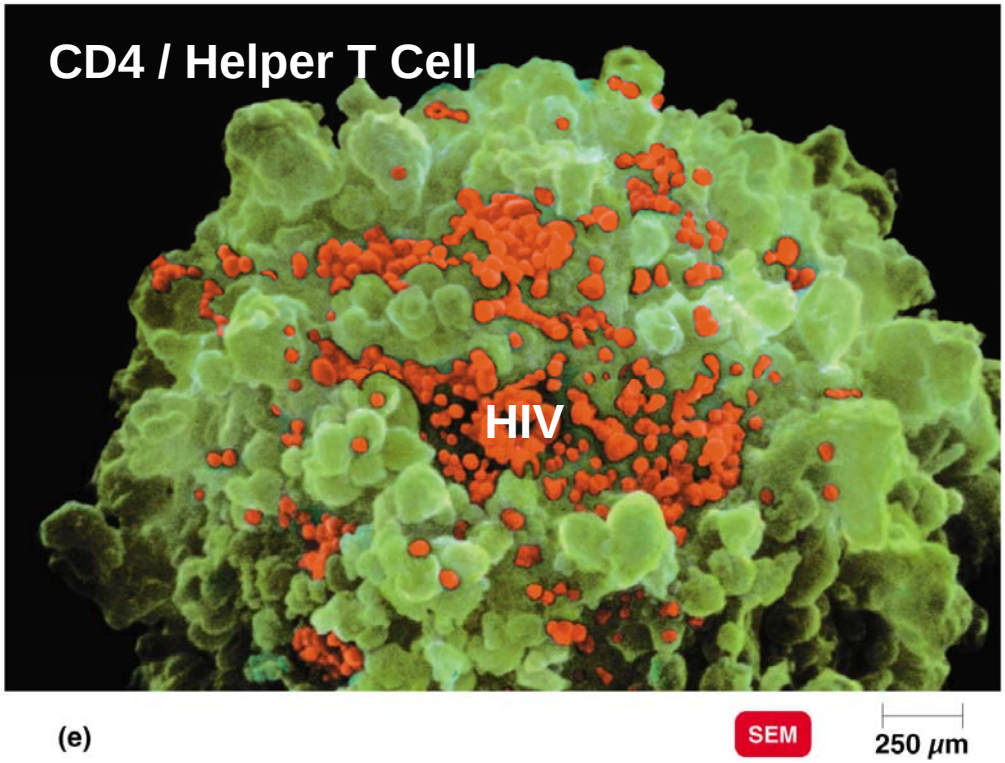
- Eukaryotes
- Cellulose cell walls
- Use photosynthesis for energy
- Produce molecular oxygen and organic compounds



The pond alga *Volvox*.

Viruses

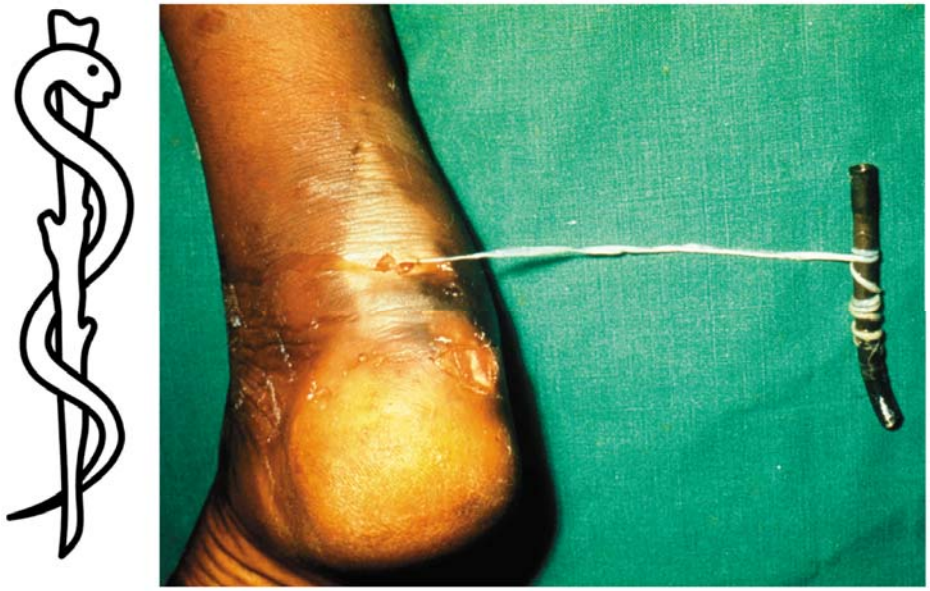
- Acellular // active or inactive but “never alive or dead”
- Obligate intracellular parasite
- Consist of DNA or RNA core
- Core is surrounded by a protein coat
- Coat may be enclosed in a lipid envelope



Several human immunodeficiency viruses (HIVs), the causative agent of AIDS, budding from a $CD4^+$ T cell.

Multicellular Animal Parasites

- Eukaryotes
- Multicellular animals
- Parasitic flatworms and roundworms are called *helminthes*
- Microscopic in larva stage of life cycles



A parasitic guinea worm *(Dracunculus medinensis)* is removed from the subcutaneous tissue of a patient by winding it onto a stick. This procedure may have been used for the design of the symbol in part (a).

Taxonomy Classification

Taxonomy = science of classifying living organisms

Organized into descending ranks, beginning with the most general all-inclusive taxonomic category

Ending with the smallest and most specific category:

Domain (Bacteria / Archaea / Eukaryote)
Kingdom
Phylum or Division
Class
Order
Family
Genus
Species

DOMAIN: Eukarya (all eukaryotic organisms)

Eukaryotic, heterotrophic and mostly multicellular

Kingdom: Animalia

Kingdom: Protista

Includes protozoa and algae

Possess notochord, dorsal nerve cord, pharyngeal slits (if only in embryo)

Phylum: Chordata

Phylum: Ciliophora

Only protozoa with cilia

Possess hair, mammary glands

Class: Mammalia

Class: Hymenostomea

Single cells with regular rows of cilia; rapid swimmers

Digital dexterity, large cerebral cortex, slow reproductive rate, long life span

Order: Primates

Order: Hymenostomatida

Elongated oval cells with cilia in the oral cavity

Large brain, no tail, long upper limbs

Family: Hominoidea

Family: Parameciidae

Cells rotate while swimming and have oral grooves

Genus: *Homo*

Erect posture, large cranium, opposable thumbs

Species: *sapiens*

Humans

Genus: *Paramecium*

Pointed, cigar-shaped cells with macronuclei and micronuclei

Species: *caudatum*

Cells cylindrical, long, and pointed at one end

Naming and Classifying Microorganisms

- Linnaeus established the system of scientific nomenclature
- Each organism has two names: the **genus** and **specific epithet (i.e. species)**
- E.g. - Staphylococcus aureus
  - Genus - describes the clustered (*staphylo*-) spherical (*cocci*) cells
  - Species - aureus describes the gold-colored colonies

Binomial Nomenclature

Scientific names are italicized when they are written in print and underlined when they are written by hand

The genus is capitalized // the specific epithet is lowercase

After first use in literature // scientific names may be abbreviated with the first letter of the genus and the specific epithet:

When the name is abbreviated, the genus name is abbreviated to the first initial followed by a period and the full species name is written

e.g. Escherichia coli / E. coli

Scientific Names

- Preferred naming method uses “Latinized” names and are used worldwide
- Another early trend was to honor the scientist who discovered the microbe by using their name // this method is no longer preferred

Scientific Names

- *Escherichia coli* and *Staphylococcus aureus* are found in the human body
- *E. coli* is found in the large intestine
- *S. aureus* is on skin

The Woese - Fox System of Classification

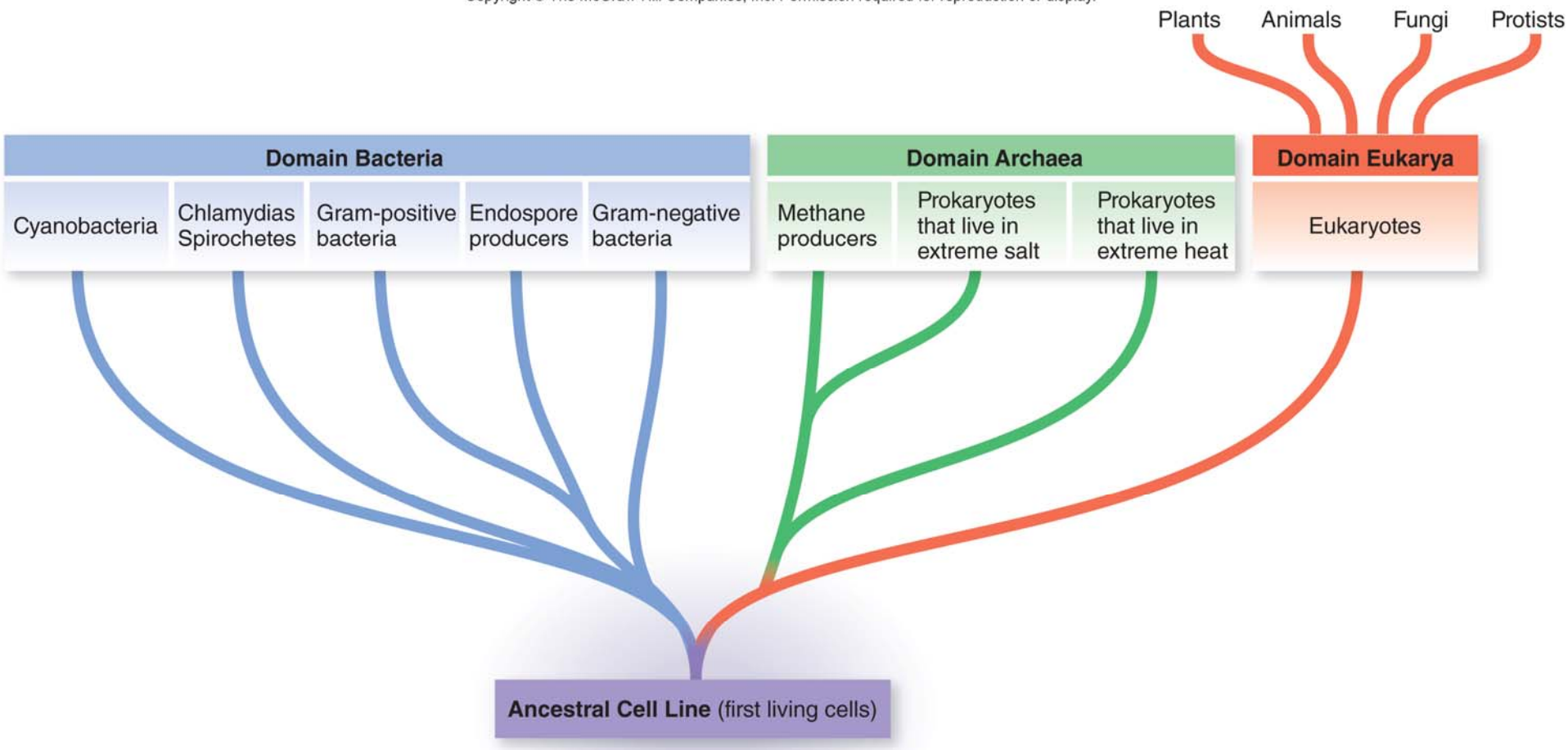
Today we classify organisms using a “molecular-biology signature” /// used to determine the “evolutionary relationship” between organism.

Classification based on conserved small subunit ribosomal RNA sequences (ssu rRNA) analysis

Using this type of analysis demonstrated another prokaryotic domain called Archaea (i.e. archaea and bacteria are both prokaryotic cells)

Based on ssu rRNA an entirely new domain system was proposed // three domains – *all living organisms will fit into one of these three domains.*

Bacteria / Archaea / Eukarya



Evolution (Fact or Fiction?)

Scientific knowledge is based on facts found true by the Scientific Method / Hypothesis must be proven and verified by piers before the knowledge is considered a law or theory (scientific knowledge)

Evolution = accumulation of changes in genetic code that occur in organisms over a period of time

Natural Selection = determines which genes are best suited for any given environment // mutations may cause a random change in genetic code which then gives advantage of one member of a group over another member // natural selection will determine which set of genes are passed on // e.g. brown vs polar bears

Theory of Evolution

> Observable phenomenon / testable by science / years of proofs / can not be disproved / well-established natural phenomenon – Therefore it is scientific fact !!! Beyond Dispute !!! There is no other competing theory to explain evolution, period !!!

The Big Bang and Microbes

The Big Bang occurred over 13+ billion yrs ago

Earth formed 4.5 billion yrs ago

Bacteria evolved 3.5 billion yrs ago // Prokaryotic structure = pre-nucleus membrane / sole occupant of earth for almost 2 billion years

Eukaryotic form of cell / true nucleus / more complex / evolved 1.8 billion years ago

Eukaryotic cell type evolved into multi-cellular organisms

Bacteria are ubiquitous – live in places where other organisms can not survive

Note: first terrestrial animals emerged from the oceans approximately 450 mya

Microbes Shaped the Development of Earth

Microbes are main force to drive structure and content of the soil / water / atmosphere

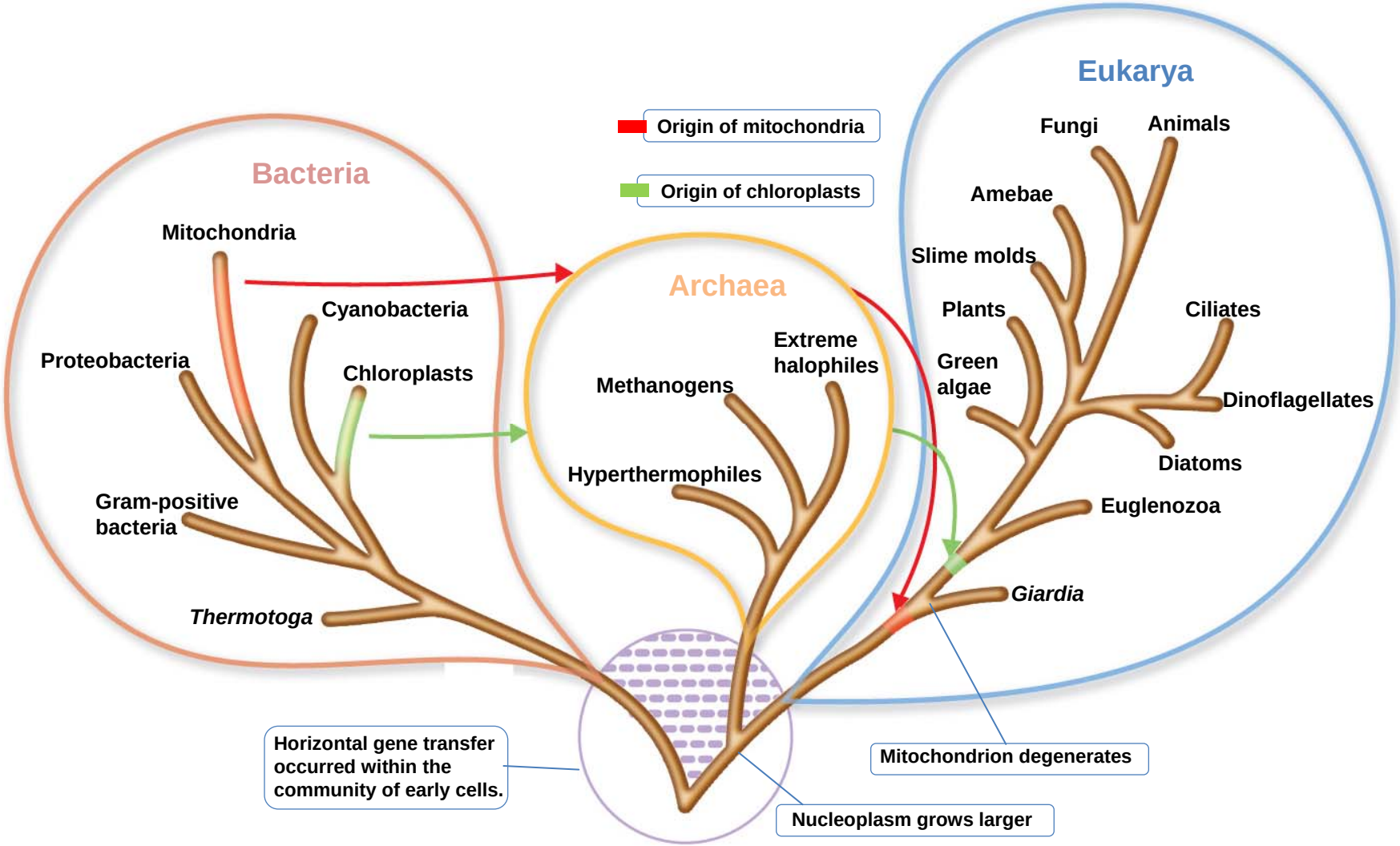
Produces gases like CO2 / NO / CH4

These gases regulate the temperature of Earth!

Enormous underground microbe communities influence weathering of planet resulting in mineral extraction and new soil formation

Bacteria and fungi /// Assist plants obtain nutrients and protect plants from diseases

Classification of Microorganisms



The Three-Domain System.

The Cell Theory

Single Most Important Theory in Biology

The cell theory holds true for all living things, no matter how big or small.

Since according to research, cells are common to all living things, any one cell can provide information about all life.

Because all cells come from other cells, scientists can study cells to learn about growth, reproduction, and all other functions that living things perform.

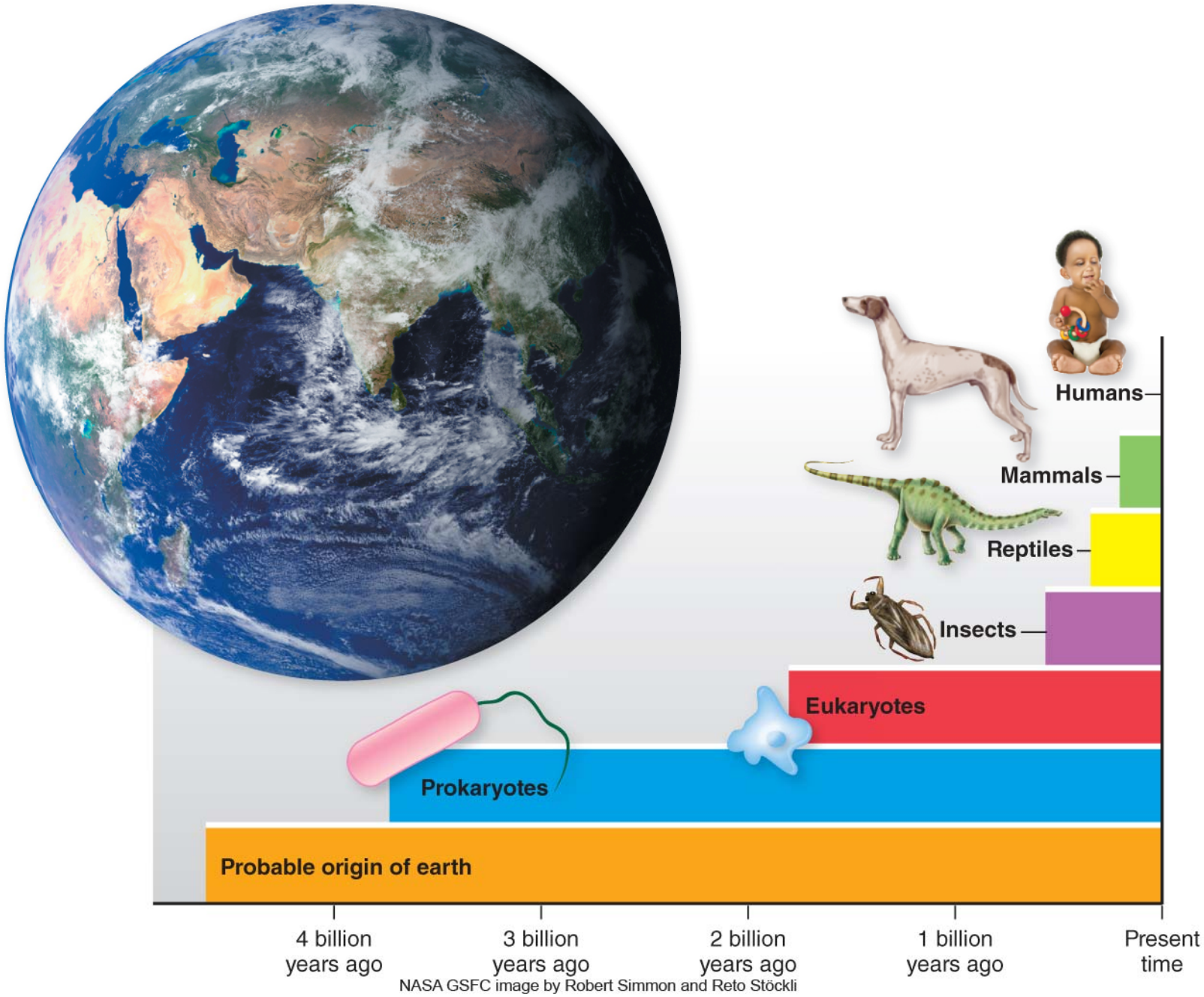
By learning about cells and how they function, you can learn about all types of living things.

Cells are the building blocks of life

The Cell Theory / Key Ideas

(This Is the Most Important Theory in Biology)

- **All living organisms composed of cells and cell products.**
- **The cell is the simplest structural and functional unit of life. // cells are alive!**
- **An organism's structure and functions are due to the activities of its cells.**
- **Cells only come from preexisting cells /// not from nonliving matter.**
- **Cells of all species have many fundamental similarities in their chemical composition and metabolic mechanisms.**
- ***All life traces its ancestry to the same original cells***



NASA GSFC image by Robert Simmon and Reto Stöckli

Important Moments in History

- 1665: Robert Hooke reported after viewing cork under a magnifying glass that living things are composed of little boxes, he called them cells
- The first microbes were observed in 1673
- 1673–1723: Anton van Leeuwenhoek described live microorganisms
- 1858: Rudolf Virchow said cells arise from preexisting cells // led to the formulation of the Cell Theory

The Golden Age of Microbiology

- 1857–1914
- Beginning with Pasteur's work / but many contributed
- Pasteur's discoveries included the relationship between microbes and disease, immunity, and antimicrobial drugs

Louis Pasteur (1822–1895) Demonstrated that life did not arise spontaneously from nonliving matter.

The Debate over Spontaneous Generation

- **Spontaneous generation**: the hypothesis that living organisms arise from nonliving matter // a “vital force” permeating the air forms life
- **Biogenesis**: the hypothesis that living organisms arise only from preexisting life
- Pasteur performed the definitive experiment to disprove spontaneous generation // the swan glass experiments

Spontaneous Generation

Now discredited belief that invisible vital forces present in matter led to the creation of life *(at one time it was dogma!)*

Even after the discovery of microbes in 1600 the idea of spontaneous generation persisted among some trained scientists / based on these observations:

> Meat left out in the open soon produced maggots
> Mushrooms appeared on rotting wood
> Rats / mice emerged from piles of litter

Two competing hypothesis (abiogenesis vs biogenesis) persisted for 200 years!

The Experiment

1800’s chemist and microbiologist Louis Pasteur devised experiment to disprove abiogenesis

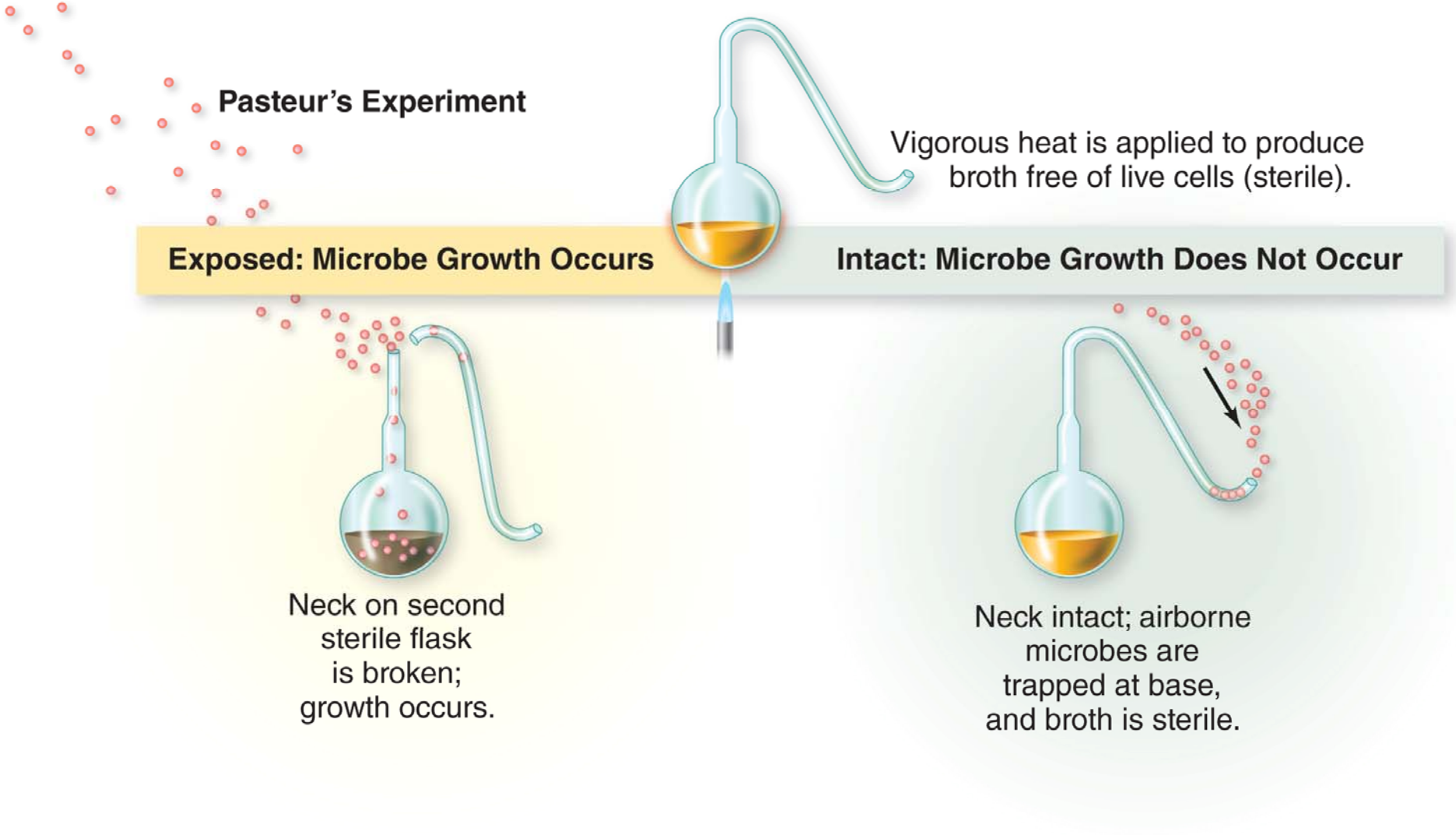
His primary work involved the fermentation of beer / believed fermentation was caused by microbes found in the air

Air and dust carried microbes into the nutrients which metabolized nutrients to produce alcohol

Demonstrated his idea using glass flasks with long necks

- one flask prohibited dust and air from reaching nutrients

- other flask broken neck allowed dust to enter broth

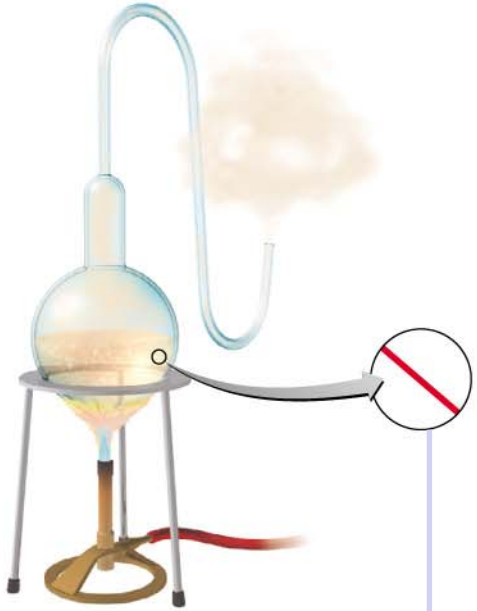


He also went on to invent pasteurization / completed some of the first studies to show human disease could be caused by infections.

1. Pasteur first poured beef broth into a long-necked flask.

Microorganisms were present in the broth.

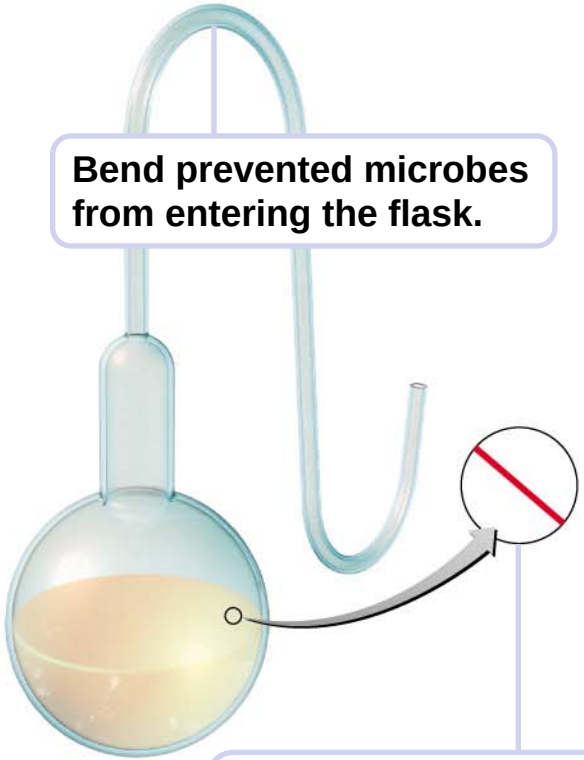
2. Next he heated the neck of the flask and bent it into an S-shape; then he boiled the broth for several minutes.



Microorganisms were not present in the broth after boiling.

3. Microorganisms did not appear in the cooled solution, even after long periods.

Bend prevented microbes from entering the flask.



Microorganisms were not present even after long periods.

Disproving the Theory of Spontaneous Generation.

Fermentation and Pasteurization

- Pasteur showed that microbes are responsible for fermentation
- **Fermentation** is the conversion of sugar to alcohol to make beer and wine (yeast)
- Microbial growth is also responsible for spoilage of food
- Bacteria that use alcohol and produce acetic acid spoil wine by turning it to vinegar (acetic acid)
- Pasteur demonstrated that these spoilage bacteria could be killed by heat that was not hot enough to evaporate the alcohol in wine (Pasteurization)
- Pasteurization is the application of a high heat for a short time

Other Important Figures in Microbiology

Dr. Oliver Wendell Holmes

Observed that women who gave birth at home experienced fewer infections than women who gave birth at a hospital

Patients who was seen by Doctors coming directly from the autopsy room had higher incidence of infections

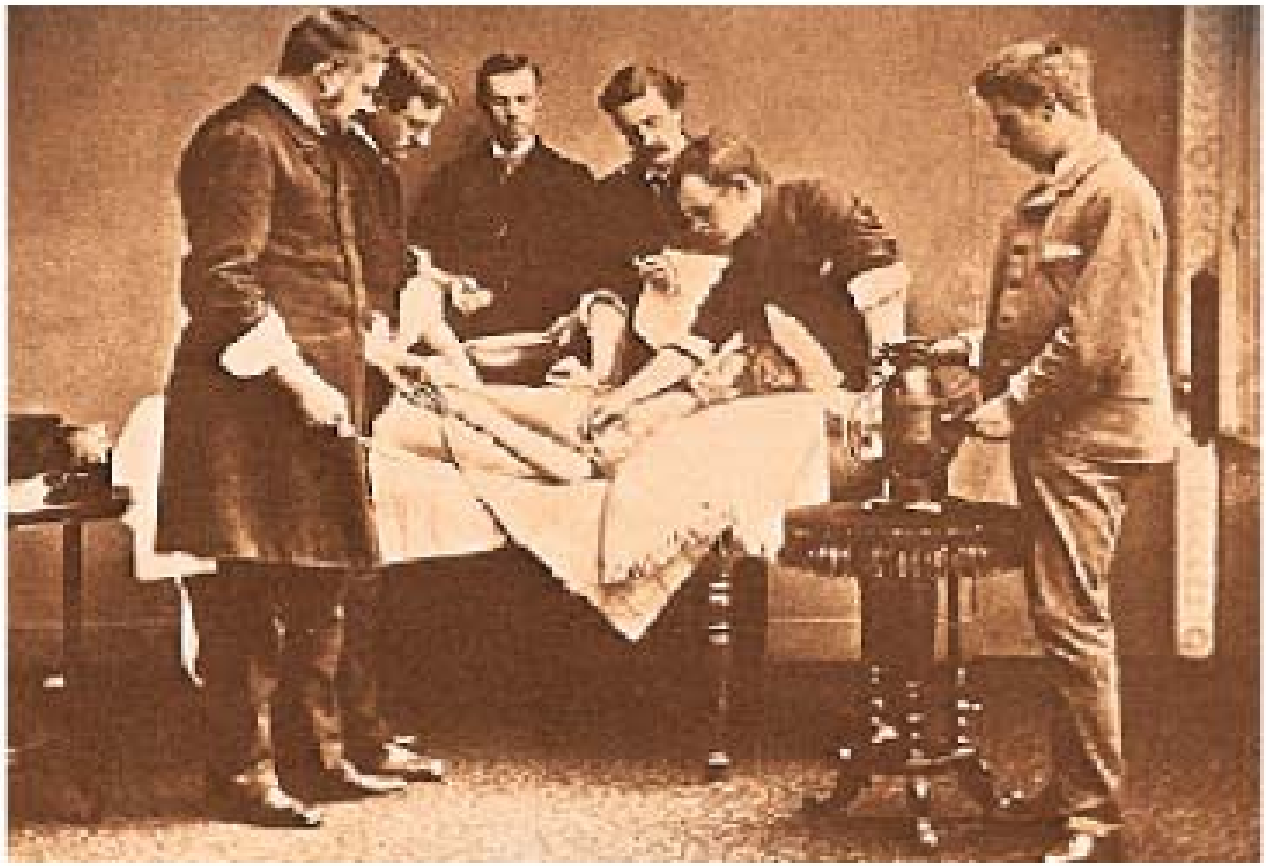
Joseph Lister – mid 1800s

- Built on Holmes & Pastures work
- This was a time when surgery was simply done in street clothes

Lister started to disinfecting hands and air with strong antiseptic chemicals (phenols) prior to surgery

Use heat to sterilize equipment

© Bettmann/Corbis



Joseph Lister (1827–1912)
Performed surgery under antiseptic conditions using phenol. Proved that microbes caused surgical wound infections.

History of Vaccinations

- Practice of inoculation may have originated in India in AD1000
- Chinese physicians widely used inoculation in the 1550s to prevent diseases. However, they did not know why or how the mechanism worked.
- Anatolian Ottoman Turks used a practice they called variolation. Powdered scabs from people infected with smallpox was used to inoculate uninfected people. These people occasionally became mildly sick but would not acquire the more deadly smallpox. Historically, smallpox would kill 30% of the infected.
- Lady Montagu, an English wife of the ambassador at Istanbul in 1716, learned about the Turks variolation and brought it back to England.
- Edward Jenner learned that people who worked with cows contracted a mild disease known as Cowpox. These people were protected from getting smallpox. In 1796 Jenner inoculated a person with cowpox virus, who was then protected from smallpox
- The word vaccination is derived from *vacca*, Latin for cow
- The protection from inoculation is called **immunity**

Koch Postulates and the Germ Theory

The postulates were formulated by Robert Koch and Friedrich Loeffler in 1884 and refined and published by Koch in 1890.

Koch's Postulates are four criteria designed to establish a causal relationship between a microbe and a disease.

Koch applied the postulates to establish the etiology (i.e. cause) of anthrax and tuberculosis

Now the postulates are generalized to prove causal relationships for the identification of many other diseases.

Koch Postulates and the Germ Theory

Koch's Postulates (Four Steps) :

The microorganism must be found in abundance in all organisms suffering from the disease, but should not be found in healthy organisms.

The microorganism must be isolated from a diseased organism and grown in pure culture.

The pure culture microorganism should cause disease when introduced into a healthy organism.

The microorganism must be re-isolated from the inoculated, diseased experimental host and identified as being identical to the original specific causative agent.

Germ Theory of Disease

States that some diseases are caused by microorganisms.

Microorganisms, too small to see without magnification, invade humans, animals, and other living hosts.

Their growth and reproduction within their hosts may cause a disease.

Microorganisms referred to as "Germ" /// virus, bacterium, protist, fungus, helminths, and prion.

Germ Theory of Disease

Microorganisms that *cause disease are called pathogens*,

The diseases they cause are called *infectious diseases*.

Even when a pathogen is the principal cause of a disease, environmental and hereditary factors often influence the severity of the disease, and whether a particular host individual becomes infected when exposed to the pathogen.

The germ theory was a scientific discovery of the late 19th century.

It supplanted earlier explanations for disease, such as Miasma Theory. (Greek idea that disease caused by bad air / in history epidemic diseases like the Black Death caused from bad air coming from rotting organic matter.)

Biotechnology

- **Biotechnology**, the use of microbes to produce foods and chemicals // not new idea // centuries old

- **Recombinant DNA technology**, a new technique in biotechnology

  - Insert new genes in bacteria and fungi to produce a variety of proteins, including vaccines and enzymes

  - Missing or defective genes in human cells can be replaced in **gene therapy**

  - Genetically modified bacteria are used to protect crops from insects and from freezing

Recombinant DNA Technology

- **Microbial genetics**: the study of how microbes inherit traits
- **Molecular biology**: the study of how DNA directs protein synthesis
- **Genomics**: the study of an organism's genes; has provided new tools for classifying microorganisms
- **Recombinant DNA**: DNA made from two different sources
  - In the 1960s, Paul Berg inserted animal DNA into bacterial DNA, and the bacteria produced an animal protein

Recombinant DNA Technology

- 1941: George Beadle and Edward Tatum showed that genes encode a cell's enzymes
- 1944: Oswald Avery, Colin MacLeod, and Maclyn McCarty showed that DNA is the hereditary material
- 1961: François Jacob and Jacques Monod discovered the role of mRNA in protein synthesis
- 2016: CRIPR Cas9

The Birth of Modern Chemotherapy

- Treatment with chemicals is **chemotherapy**
- Chemotherapeutic agents used to treat infectious disease can be **synthetic drugs** or antibiotics
- **Antibiotics** are chemicals produced by bacteria and fungi that inhibit or kill other microbes (bacteria)

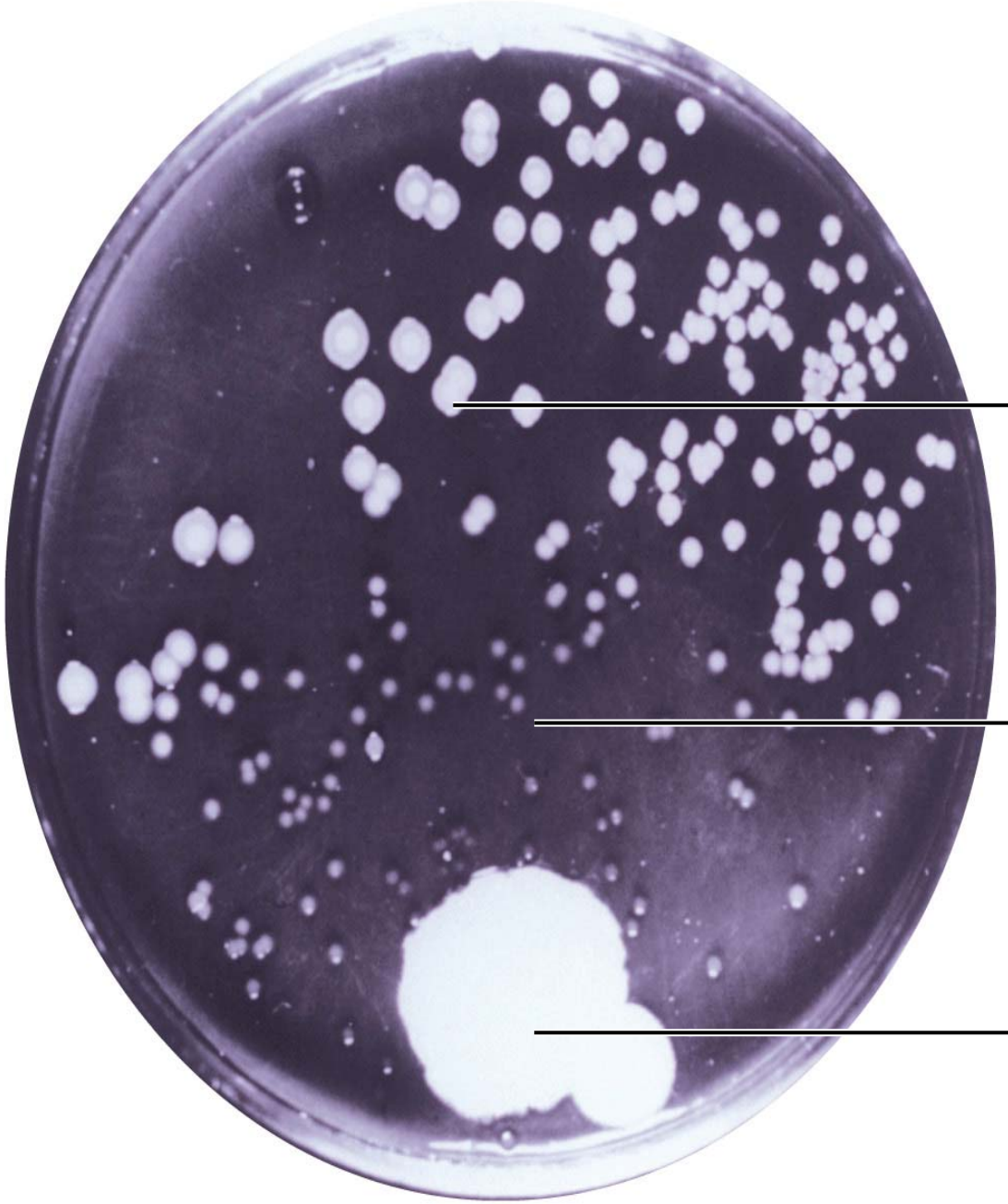
The First Synthetic Drugs

- Quinine from tree bark was long used to treat malaria
- Paul Ehrlich speculated about a "**magic bullet**" that could destroy a pathogen without harming the host
- 1910: Ehrlich developed a synthetic arsenic drug, salvarsan, to treat syphilis
- 1930s: sulfonamides were synthesized

A Fortunate Accident—Antibiotics

- 1928: Alexander Fleming discovered the first antibiotic
- Fleming observed that *Penicillium* fungus made an antibiotic, penicillin, that killed *S. aureus*
- 1940s: Penicillin was tested clinically and mass produced

The discovery of penicillin.



Bioremediation

- Bacteria degrade organic matter in sewage
- Bacteria degrade or detoxify pollutants such as oil and mercury

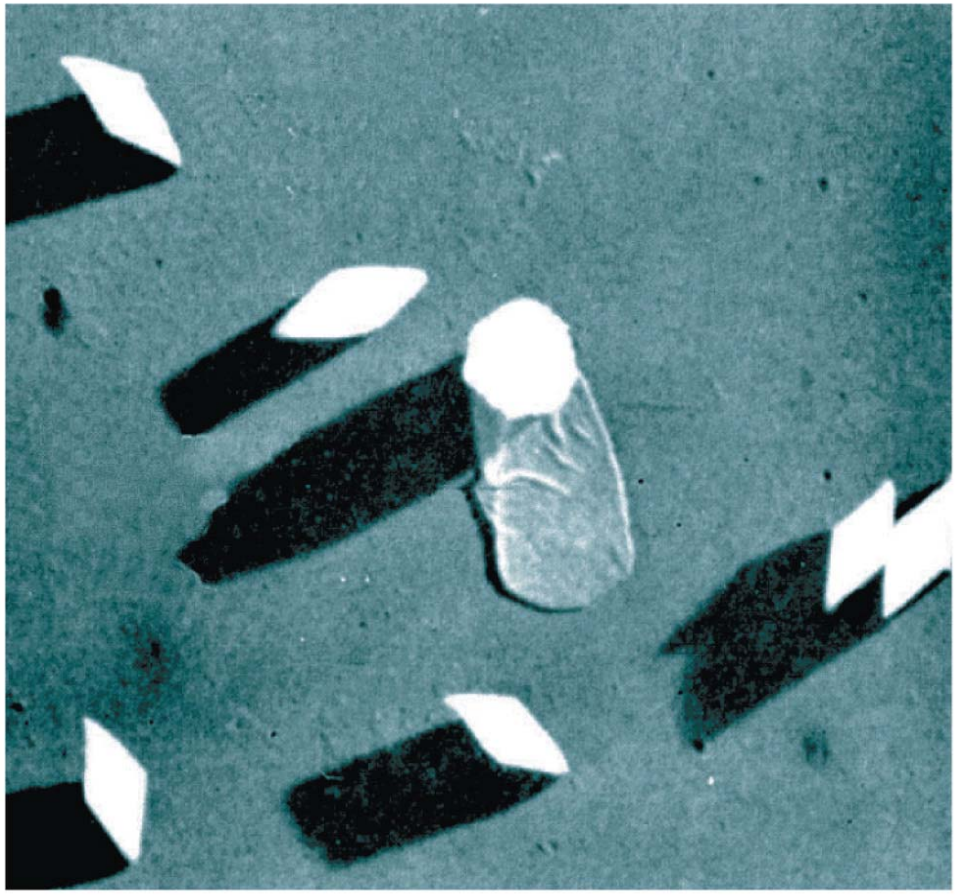
Composting municipal wastes.

Solid municipal wastes being turned by a specially designed machine

Biological Insecticides

- Microbes that are pathogenic to insects are alternatives to chemical pesticides in preventing insect damage to agricultural crops and disease transmission

- *Bacillus thuringiensis* infections are fatal in many insects but harmless to other animals, including humans, and to plants



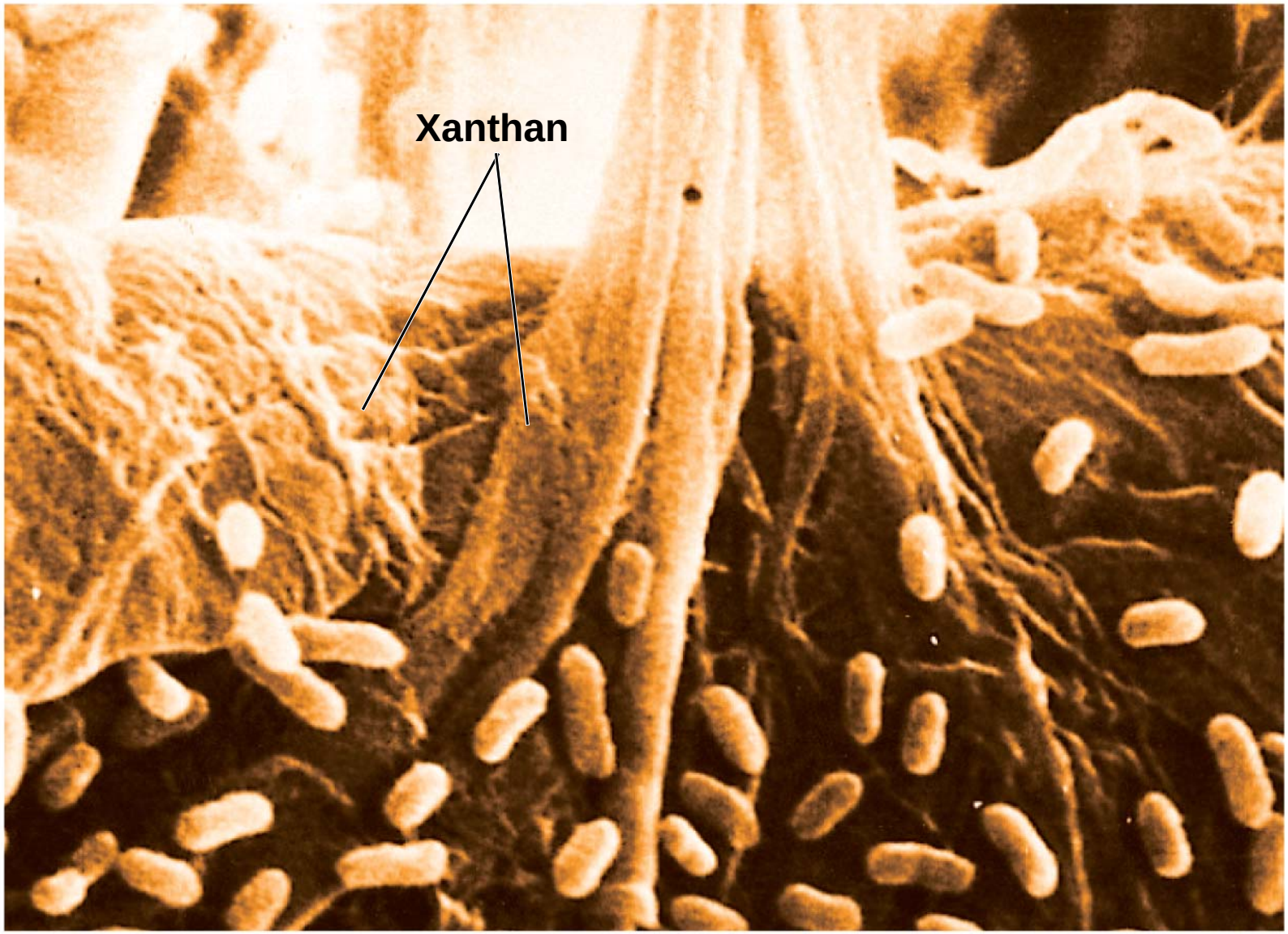
Bacillus thuringiensis. **The diamond-shaped crystals shown next to the endospore are toxic to insects that ingest them. This electron micrograph was made using the technique of shadow casting described on page 62.**

Making cheddar cheese.

(a) The milk has been coagulated by the action of rennin (forming curd) and is inoculated with ripening bacteria for flavor and acidity. Here the workers are cutting the curd into slabs.

(b) The curd is chopped into small cubes to facilitate efficient draining of whey.

(c) The curd is milled to allow even more drainage of whey and is compressed into blocks for extended ripening. The longer the ripening, the more acidic (sharper) the cheese.



Xanthomonas campestris **producing gooey xanthan.**

Normal Microbiota

- Bacteria were once classified as plants, giving rise to use of the term *flora* for microbes
- This term has been replaced by *microbiota*
- Microbes normally present in and on the human body are called **normal microbiota**

Several types of bacteria found as part of the normal microbiota on the surface of the human tongue.

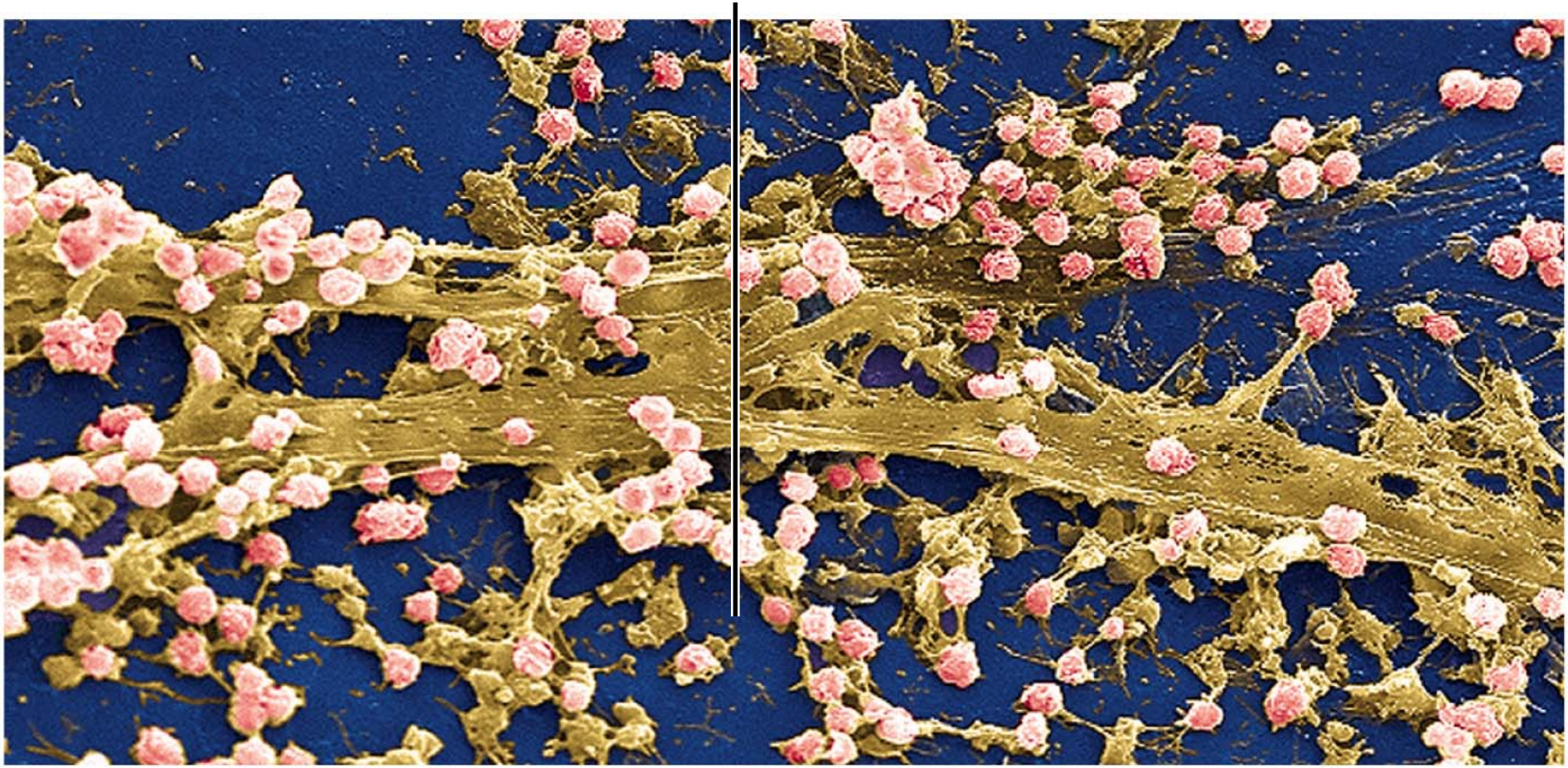
Normal Microbiota

- Normal microbiota prevent growth of pathogens
- Normal microbiota produce growth factors, such as folic acid and vitamin K
- **Resistance** is the ability of the body to ward off disease
- Resistance factors include skin, stomach acid, and antimicrobial chemicals

Biofilms

- Biofilms are communities of different bacterial species // now recognized as major medical problem
- Members of the community “talk to each other” // see Dr. Bonnie Bassler’s lecture
- Microbes attach to solid surface and grow into masses // dental placque is the most common human biofilm
- They will grow on rocks, pipes, teeth, and medical implants
- Biofilms grow slowly // Therefore they resist antibiotics

Staphylococcus



Biofilm on a catheter.

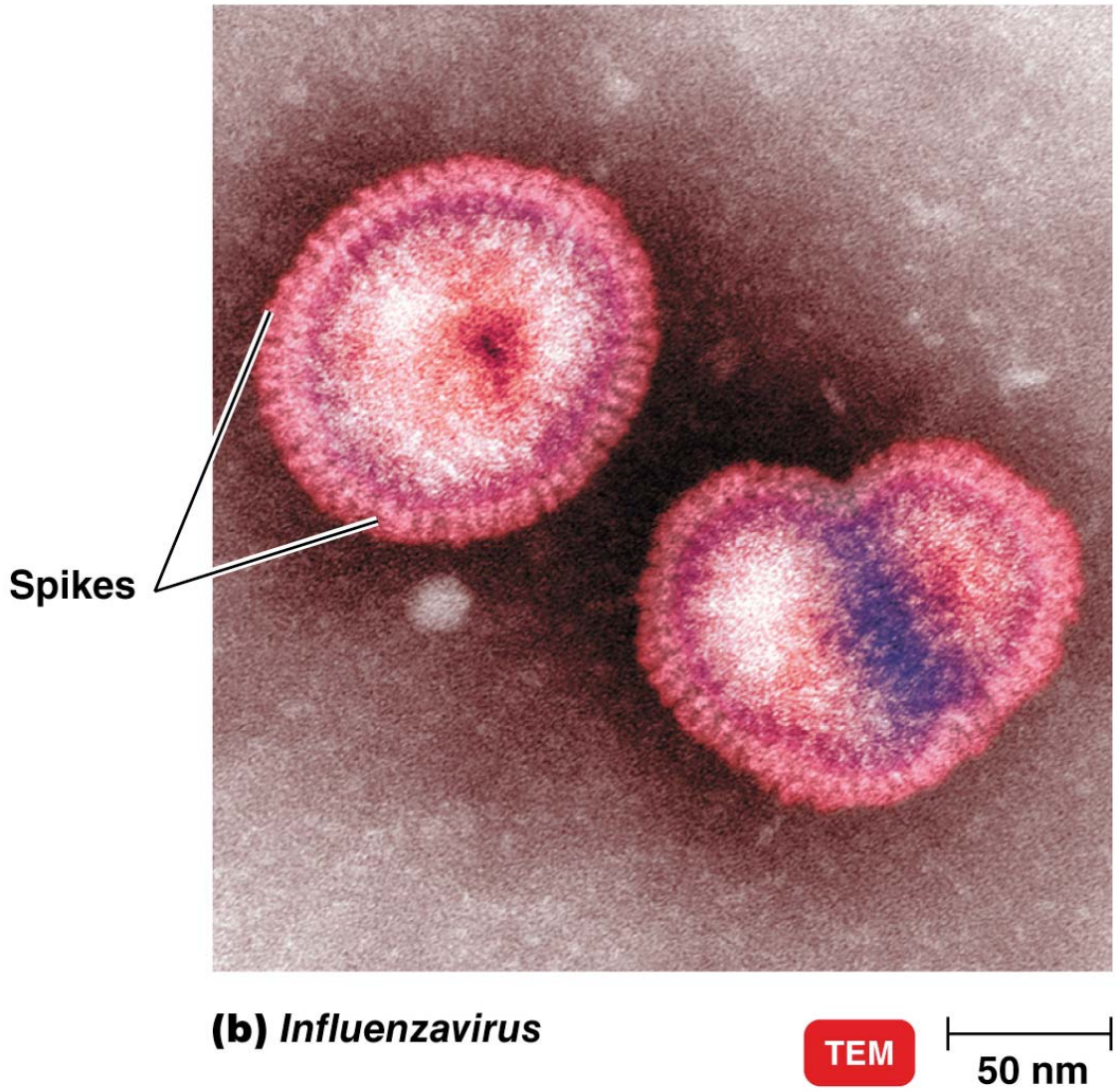
Infectious Diseases

- When a pathogen overcomes the host's resistance, disease results

- **Emerging infectious diseases (EIDs)**: new diseases and diseases increasing in incidence

Avian Influenza A

- Influenza A virus
- Primarily in waterfowl and poultry
- Sustained human-to-human transmission has not occurred yet



Morphology of an enveloped helical virus.

Methicillin-resistant *Staphylococcus aureus (MRSA)*

- 1950s: Penicillin resistance developed
- 1980s: Methicillin resistance
- 1990s: MRSA resistance to vancomycin reported
  - VISA: vancomycin-intermediate-resistant *S. aureus*
  - VRSA: vancomycin-resistant *S. aureus*

West Nile Encephalitis

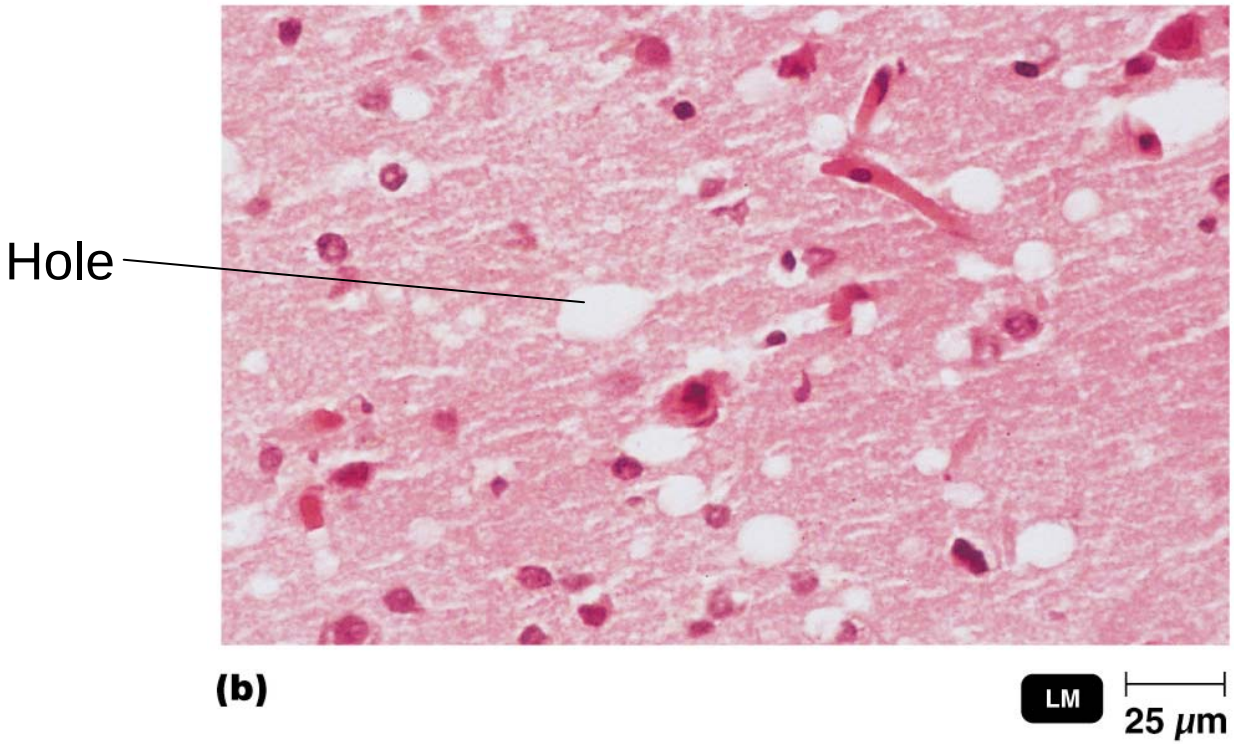
- Caused by West Nile virus
- First diagnosed in the West Nile region of Uganda
  in 1937
- Appeared in New York City in 1999
- In nonmigratory birds in 47 states

Culex **mosquito engorged with human blood. / Carrier of Arboviral Encephalitis**

Bovine Spongiform Encephalopathy

- Caused by a prion // Also causes Creutzfeldt-Jakob disease (CJD)

- New variant CJD in humans is related to cattle that have been fed sheep offal for protein



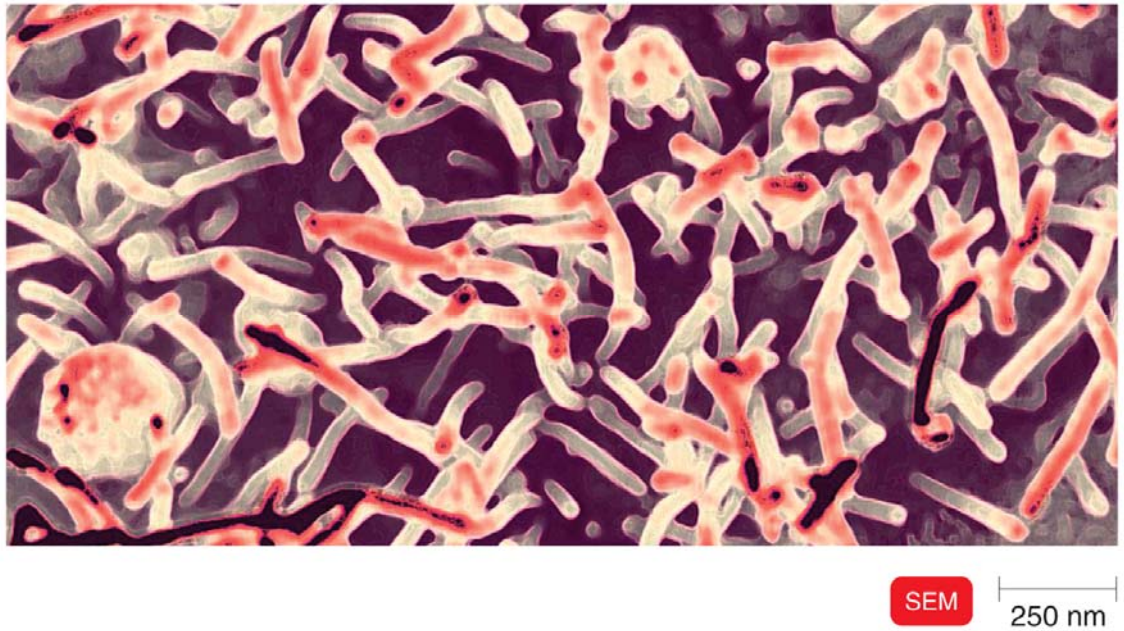
Escherichia coli O157:H7

- Toxin-producing strain of *E. coli*
- First seen in 1982
- Leading cause of diarrhea worldwide

Pedestal formation by Enterhemorrhagic *E. coli* (EHEC) O157:H7.

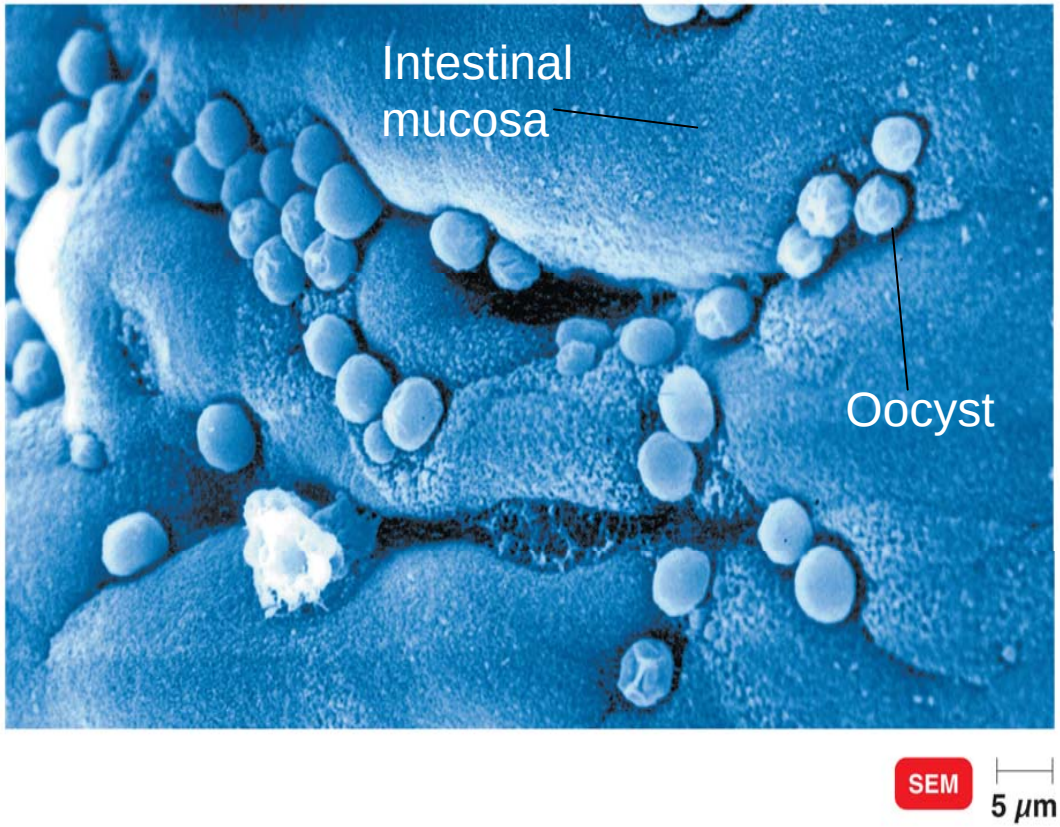
Ebola Hemorrhagic Fever

- Ebola virus
- Causes fever, hemorrhaging, and blood clotting
- First identified near Ebola River, Congo
- Outbreaks every few years



Cryptosporidiosis

- *Cryptosporidium* protozoa
- First reported in 1976
- Causes 30% of diarrheal illness in developing countries
- In the United States, transmitted via water



Acquired immunodeficiency syndrome (AIDS)

- Caused by human immunodeficiency virus (HIV)
- First identified in 1981
- Worldwide epidemic infecting 33 million people; 7500 new infections every day
- Sexually transmitted infection affecting males and females
- HIV/AIDS in the United States: 26% are female, and 49% are African American

Terminology

- **Bacteriology** is the study of bacteria
- **Mycology** is the study of fungi
- **Virology** is the study of viruses
- **Parasitology** is the study of protozoa and parasitic worms
- **Immunology** is the study of immunity // Vaccines and interferons are being investigated to prevent and cure viral diseases // The use of immunology to identify some bacteria according to serotypes was proposed by Rebecca Lancefield in 1933