BIOL 1202
General Biology II Lecture

CHAPTER 27
Bacteria and Archaea
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CH 27 Learning Objectives

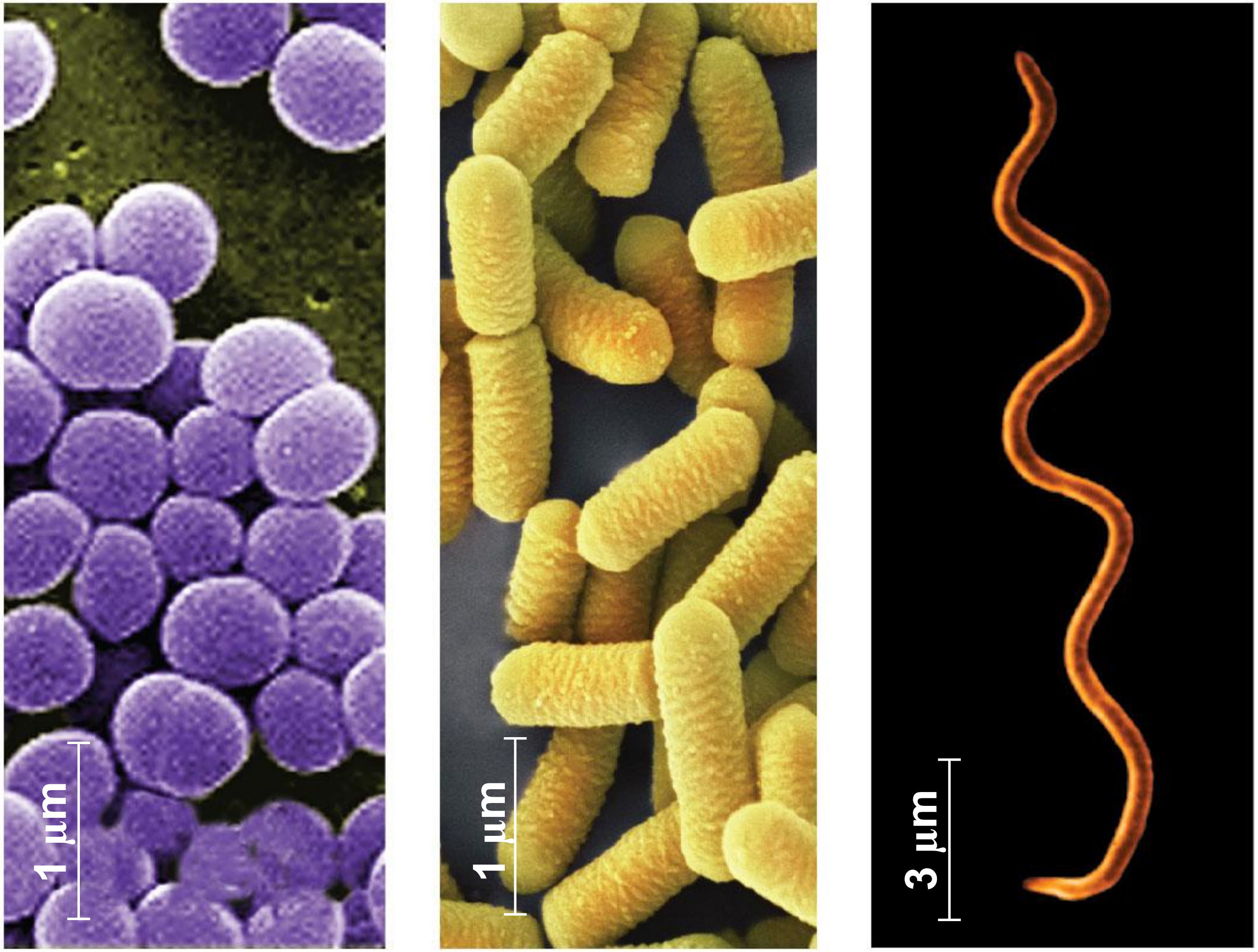
1. Describe the possible structure of the tree of all life.
2. Describe structural and functional adaptations of prokaryotes.
3. Identify sources of genetic diversity in prokaryotes.
4. Give examples of nutritional and metabolic adaptations in prokaryotes.
5. Identify major phylogenetic groups of prokaryotes.
6. Describe ecological roles played by prokaryotes.
7. Give examples of beneficial and harmful effects that prokaryotes have on humans.

I would suggest completing the crossword puzzle to help you understand the terminology and correlate how the terms relate to topics covered in this chapter.

Concept 27.1: Structural and functional adaptations contribute to prokaryotic success

- Prokaryotes were the first organisms to inhabit the Earth and are the most abundant organisms
- They represent 2 domains: Bacteria and Archaea
- They thrive almost everywhere, including places too acidic, salty, cold, or hot for most other organisms
- Most are unicellular, some species form colonies
- Most prokaryotic cells are 0.5–5 µm, much smaller than the 10-100 µm of many eukaryotic cells
- Prokaryotic cells have a variety of shapes
- The three most common shapes are spheres (***cocci***), rods (***bacilli***), and spirals/helical (***spirilli***)

Figure 27.2



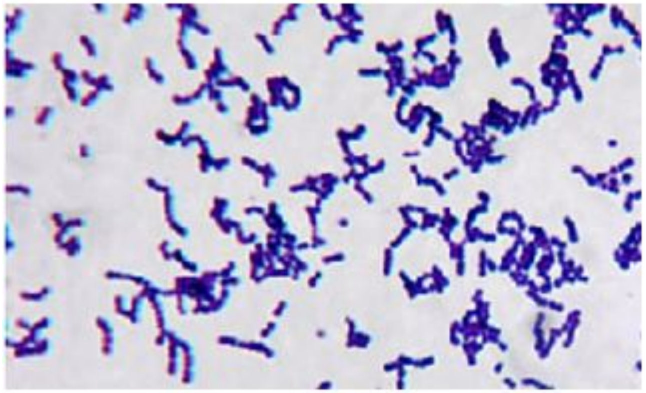
Cocci
(Ball-shaped)

Bacilli
(Rod-shaped)

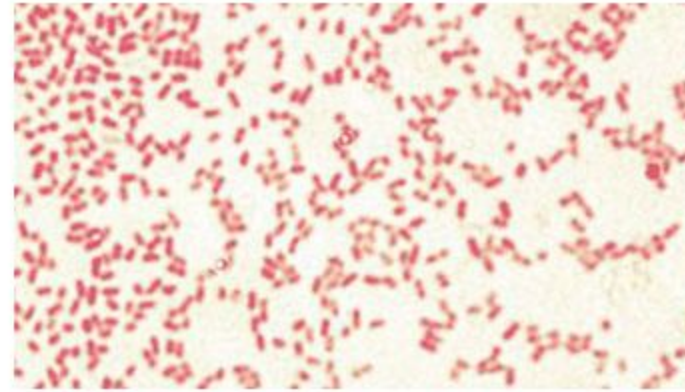
Spirilli
(Spiral-shaped)

Cell-Surface Structures

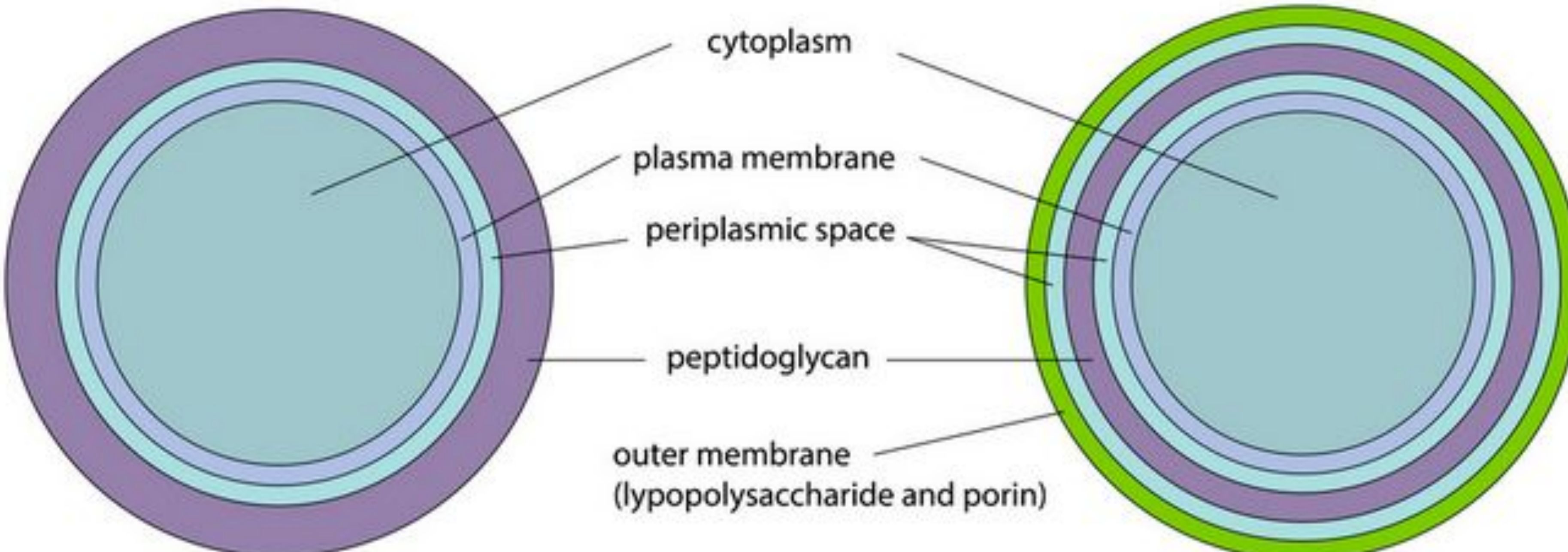
- The cell wall maintains cell shape, protects, and prevents it from bursting in a hypotonic environment
- Most bacterial cell walls contain **peptidoglycan**, a network of sugar polymers x-linked by polypeptides
- Archaea contain polysaccharides and proteins but lack peptidoglycan
- **Gram stain** is used to classify bacteria
- **Gram-positive** bacteria have simpler walls with a large amount of peptidoglycan, they stain **PURPLE**
- **Gram-negative** bacteria have less peptidoglycan and an outer membrane that contains lipopolysaccharides, they stain **PINK**



Gram positive



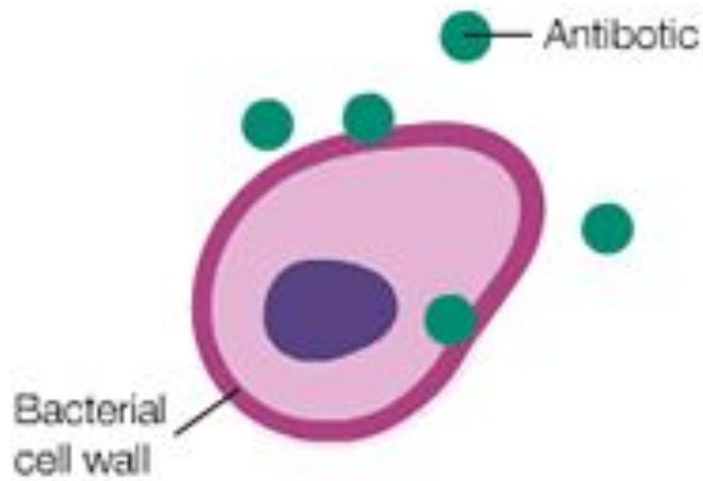
Gram negative



Antibiotics used:
Erythromycin, Penicillin

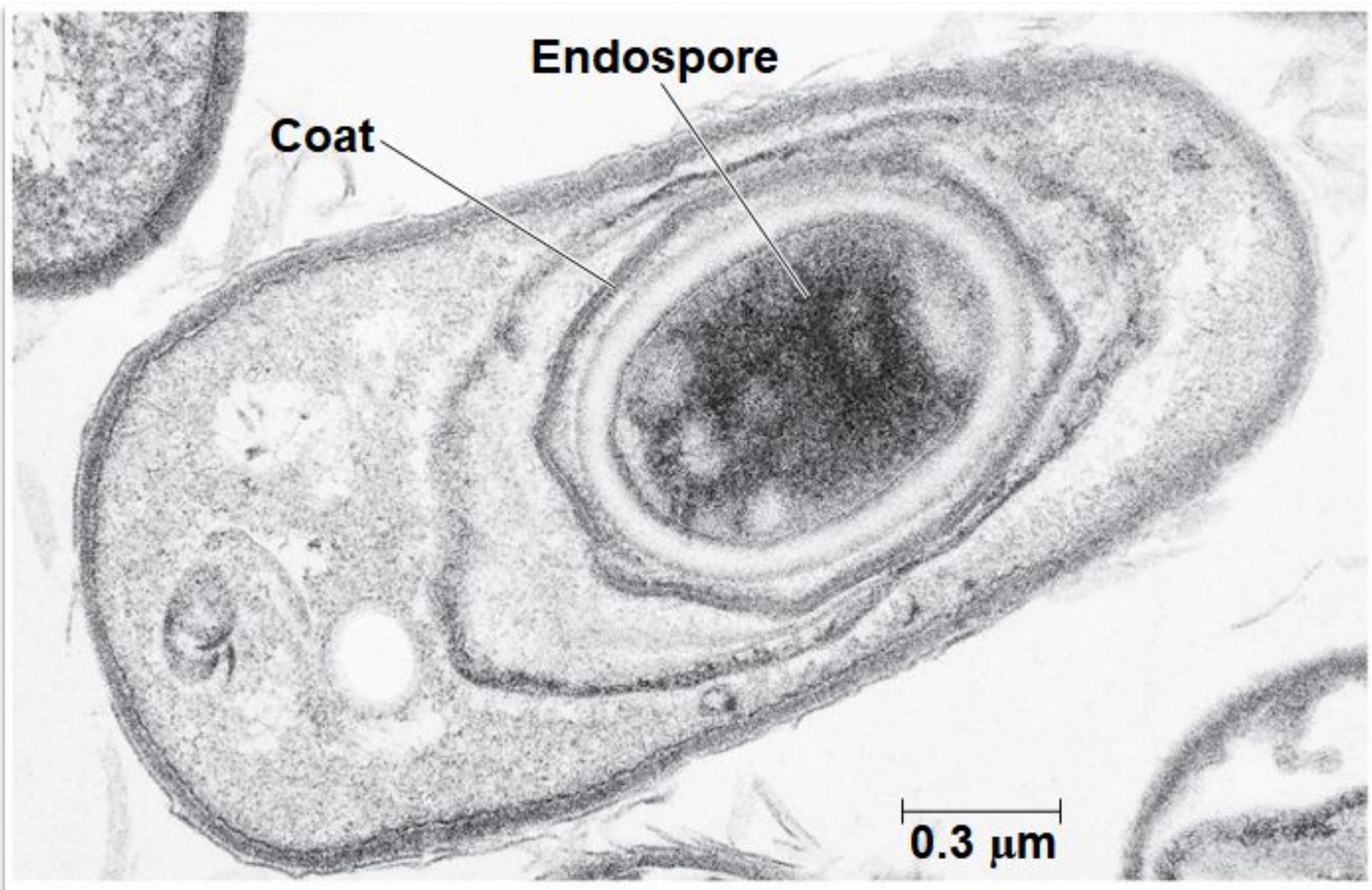
Antibiotics used:
Ciprofloxin, Gentamycin

- Many antibiotics target peptidoglycan and damage bacterial cell walls

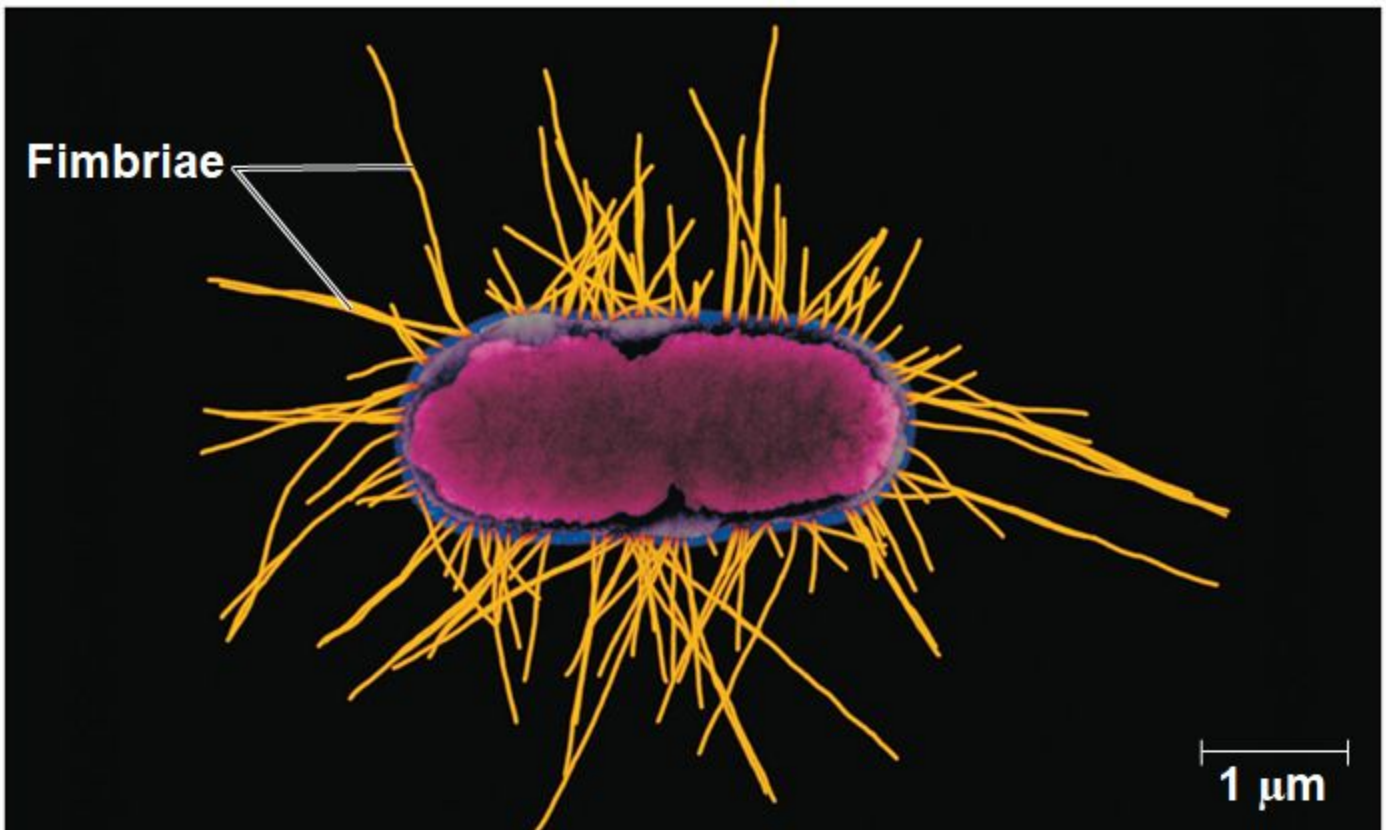


- Gram-positive bacteria are particularly susceptible to this type of antibiotics
- A sticky outer layer of polysaccharide or protein called a **capsule** is present in some prokaryotes
- The capsule allows adherence to the substrate, or other individuals, and can shield pathogenic bacteria from the host immune system

- Many prokaryotes form metabolically inactive **endospores**, which can remain viable in harsh conditions for centures (spores in tombs of Egyptian pharaohs)



- Some prokaryotes have hair-like appendages called **fimbriae** that allow them to stick to their substrate or other individuals in a colony
- **Pili** (or sex pili) are longer than fimbriae and allow prokaryotes to exchange DNA

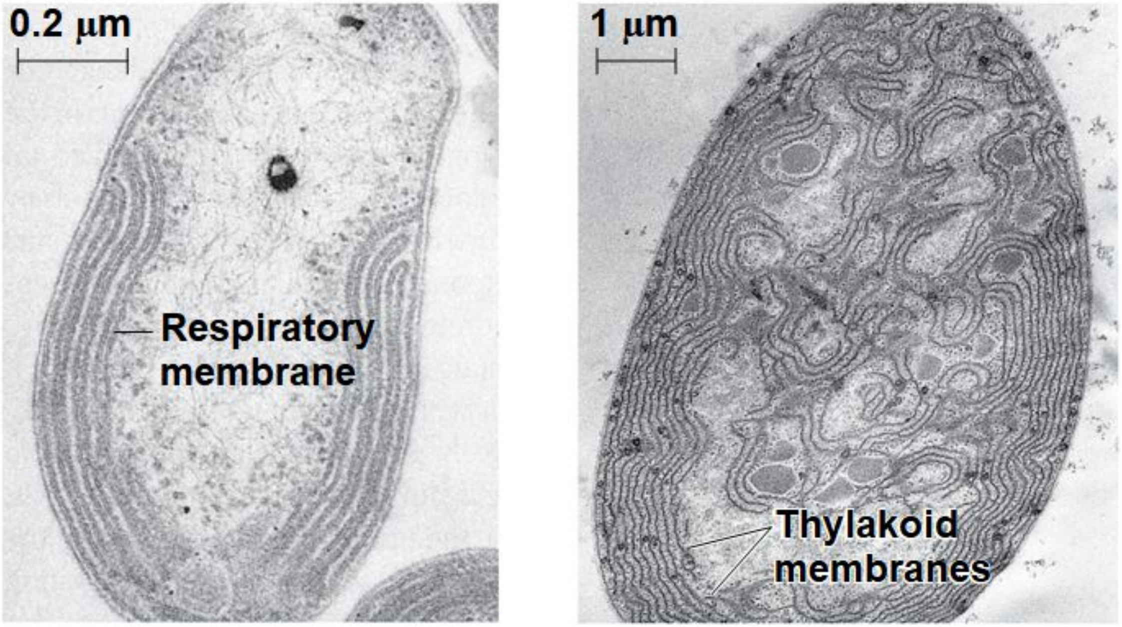


Motility

- About half of all prokaryotes exhibit **taxis**, the ability to move toward or away from a stimulus
  - EX: Chemotaxis is the movement toward or away from a chemical stimulus
- Flagella are the most common structures used by prokaryotes for movement
- Flagella may be scattered about the surface or concentrated at one or both ends of the cell
- The flagella of prokaryotes and eukaryotes differ in structure, mechanism of propulsion, and composition
- Flagella likely evolved as existing proteins were added to an ancestral secretory system

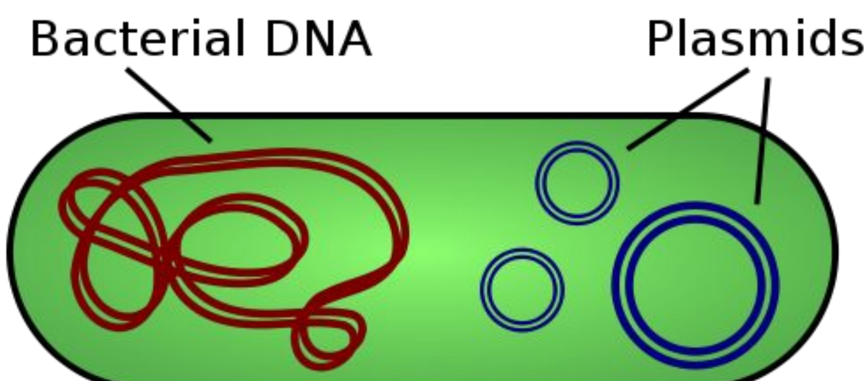
Internal Organization and DNA

- Prokaryotic cells usually lack complex compartmentalization
- Some prokaryotes do have specialized membranes that perform metabolic functions
- These are usually infoldings of the plasma membrane



(a) Aerobic prokaryote (b) Photosynthetic prokaryote

- The prokaryotic genome has less DNA than the eukaryotic genome
- Most of the genome consists of a circular chromosome
- The chromosome is not contained in a nucleus; it is located in the **nucleoid** region with no surrounding membrane
- Typical prokaryotes also have smaller rings of independently replicating DNA called **plasmids**



Reproduction

- Prokaryotes reproduce quickly by binary fission and can divide every 1-3 hours under optimal conditions
- Some species can replicate in as fast as 20 minutes
- Early medical intervention via antibiotics is key
- Key features of prokaryote biology:
  - They are small
  - They reproduce by binary fission
  - They have short generation times

Concept 27.2: Rapid reproduction, mutation, and genetic recombination promote genetic diversity in prokaryotes

- Prokaryotes have considerable genetic variation
- Three factors contribute to this genetic diversity:

1. rapid reproduction
2. mutation
3. genetic recombination

Rapid Reproduction and Mutation

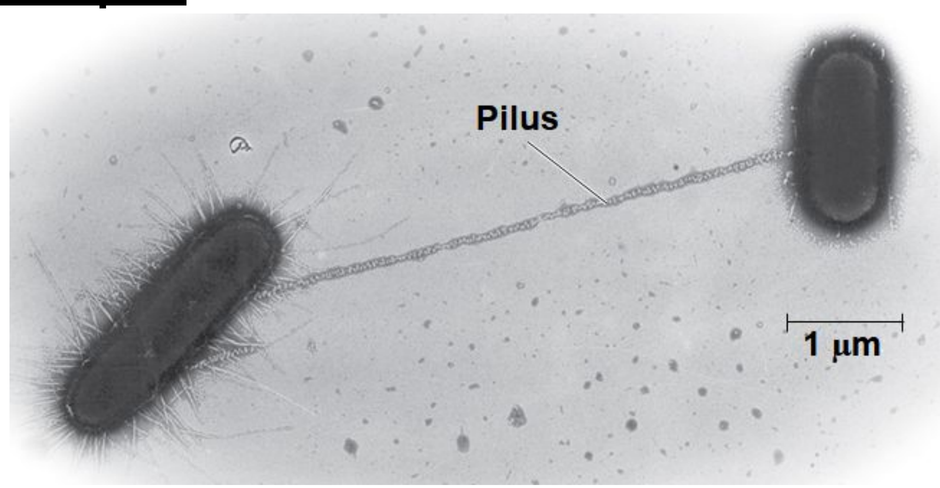
- Prokaryotes reproduce asexually; offspring cells are <u>genetically identical</u>
  - EX: *Escherichia coli* cells reproduce using <u>binary fission</u>
  - Mutation rates are low, but mutations accumulate rapidly because generation times are <u>short and populations are large</u>
- Prokaryotes have simpler cells than eukaryotes, but their rapid adaptation to <u>environmental change indicates that they are highly evolved</u>

Genetic Recombination

- Genetic recombination, the combining of DNA from two sources, contributes to diversity
- Movement of genes among individuals from different species is called horizontal gene transfer.
- A prokaryotic cell can take up and incorporate foreign DNA from the surrounding environment in a process called **transformation**.
- **Transduction** is the movement of genes between bacteria by phages (from "bacteriophages," viruses that infect bacteria)

Conjugation and Plasmids

- **Conjugation** is the process where genetic material is transferred between prokaryotic cells.
- In bacteria, the DNA transfer is always one way.
- A donor cell attaches to a recipient by a **pilus** and transfers DNA through a structure called the "conjugation or mating bridge"
- A piece of DNA called the **F factor** is required for the production of pili



The F Factor as a Plasmid or in the Chromosome

- Cells **containing** the **F plasmid** function as DNA ***donors*** during conjugation
- Cells **without** the F factor function as DNA ***recipients*** during conjugation
- The F factor is transferable during conjugation
- Provided some of the F plasmid's DNA is transferred, the recipient cell becomes a recombinant cell
- A cell with the F factor built into its chromosome functions as a donor during conjugation
- Called Hfr cells (for ***H***igh ***f***requency of ***r***ecombination)
- The recipient becomes a recombinant bacterium, with DNA from two different cells

R Plasmids and Antibiotic Resistance (Article)

- **R plasmids** carry genes for antibiotic resistance
- Antibiotics kill sensitive bacteria, but **not** bacteria with specific R plasmids
- Through natural selection, the fraction of bacteria with genes for resistance increases in a population exposed to antibiotics.
- Many R plasmids have genes that encode pili, making it possible for resistance genes to be transferred between bacterial cells
- Some R plasmids carry antibiotic resistance genes
- Antibiotic-resistant strains of bacteria are becoming more common, making infections hard to treat

Concept 27.3: Diverse nutritional and metabolic adaptations have evolved in prokaryotes

- Prokaryotes can be categorized by how they obtain energy and sources of carbon:

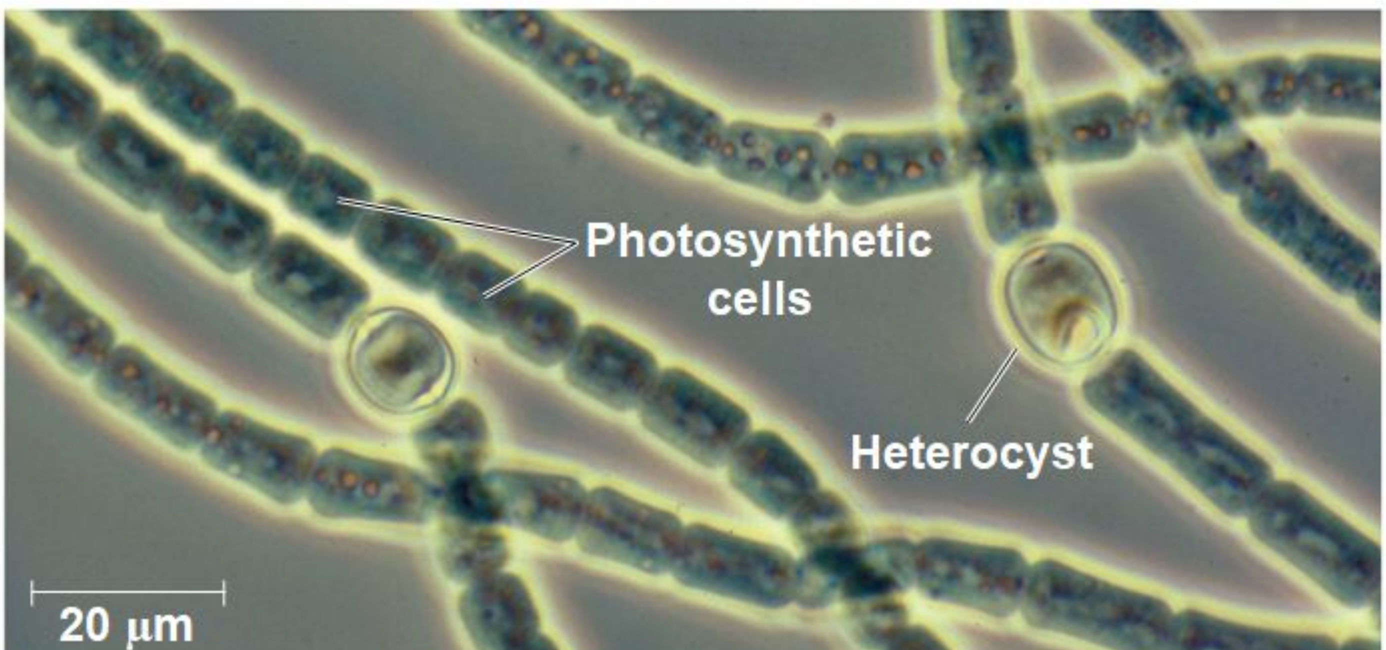
1. **Photoautotrophs**: energy source is LIGHT; carbon source is CO_2, HCO_3^-; cyanobacteria & algae
2. **Chemoautotrophs**: energy source is INORGANIC COMPOUNDS (H_2S, NH_3, Fe^{2+}); carbon source is CO_2, HCO_3^-; *Sulfolobus* (volcanic spring bacteria, low pH)
3. **Photoheterotrophs**: energy source is LIGHT; carbon source is organic compounds; *Rhodobacter* (salt-water bacteria)
4. **Chemoheterotrophs**: energy source is ORGANIC COMPOUNDS; carbon source is organic compounds; *Clostridium* (food poisoning bacteria)

The Role of Oxygen and Nitrogen in Metabolism

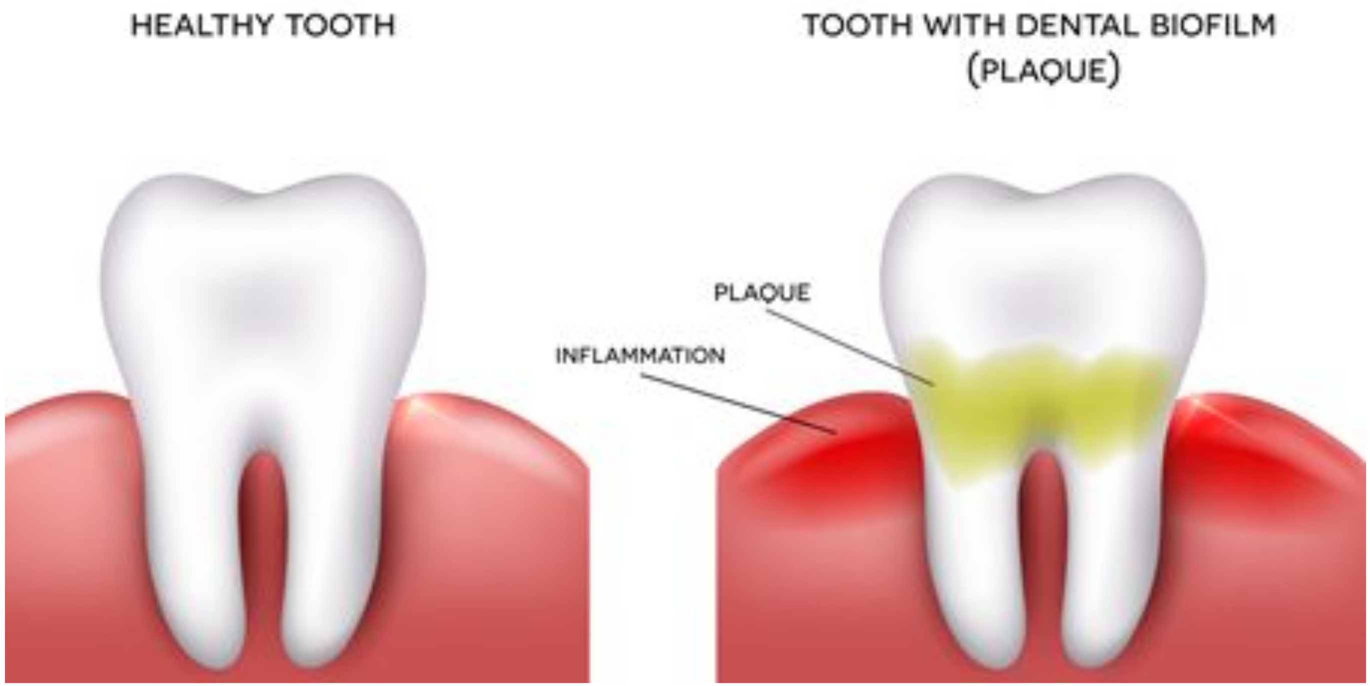
- Prokaryotic metabolism varies with respect to O_2
  - **Obligate aerobes** require O_2 for cellular respiration
  - **Obligate anaerobes** are poisoned by O_2 and live by fermentation or use substances other than O_2 for **anaerobic respiration**
  - **Facultative anaerobes** can use O_2 if it is present or carry out fermentation/anaerobic respiration if it is not
- Nitrogen is essential for the production of amino acids and nucleic acids in all organisms
- Prokaryotes can metabolize N in a variety of ways
  - EX: some prokaryotes convert nitrogen gas (N_2) to ammonia (NH_3) in a process called **nitrogen fixation**

Metabolic Cooperation

- Cooperation between prokaryotes allows them to use <u>environmental resources they could not use as individual cells</u>
- In the cyanobacterium *Anabaena*, photosynthetic cells and nitrogen-fixing cells called <u>**heterocysts** (or heterocytes) exchange metabolic products</u>



- Metabolic cooperation occurs between different prokaryotic species in surface-coating colonies called **biofilms**



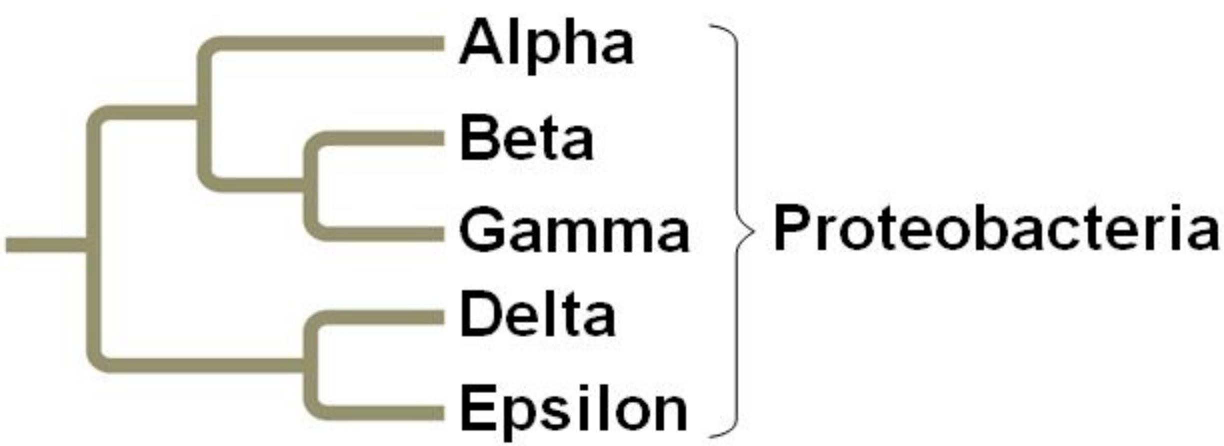
- Sulfate-consuming bacteria and methane-consuming bacteria on the ocean floor use each other's waste products

Concept 27.4: Overview of Prokaryotic Diversity

- The origin of prokaryotes dates back to 3.5 BYA
- Prokaryotes now inhabit every known environment
- Genetic analysis led to the division of prokaryotes into two domains, Bacteria and Archaea
- Advances in molecular techniques help to add new branches to the tree of life each year
- The use of polymerase chain reaction has allowed for more rapid sequencing of prokaryotes genomes
- A handful of soil may contain >10,000 species
- Horizontal gene transfer between prokaryotes obscures the root of the tree of life

Proteobacteria

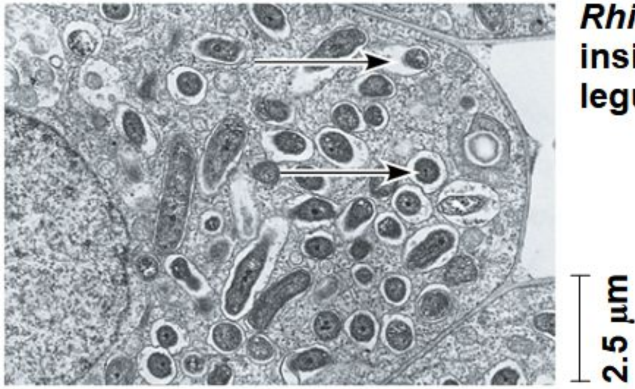
- These gram-negative bacteria include photoautotrophs, chemoautotrophs, and heterotrophs
- Some are anaerobic and others aerobic
- There are currently five subgroups of proteobacteria recognized by molecular systematists



Subgroup: Alpha Proteobacteria

- Many species are closely associated with eukaryotic hosts
- Scientists hypothesize that mitochondria evolved from aerobic alpha proteobacteria through endosymbiosis
- *Rhizobium*, which forms root nodules in legumes and fixes atmospheric N_2
- *Agrobacterium*, which produces tumors in plants and is used in genetic engineering

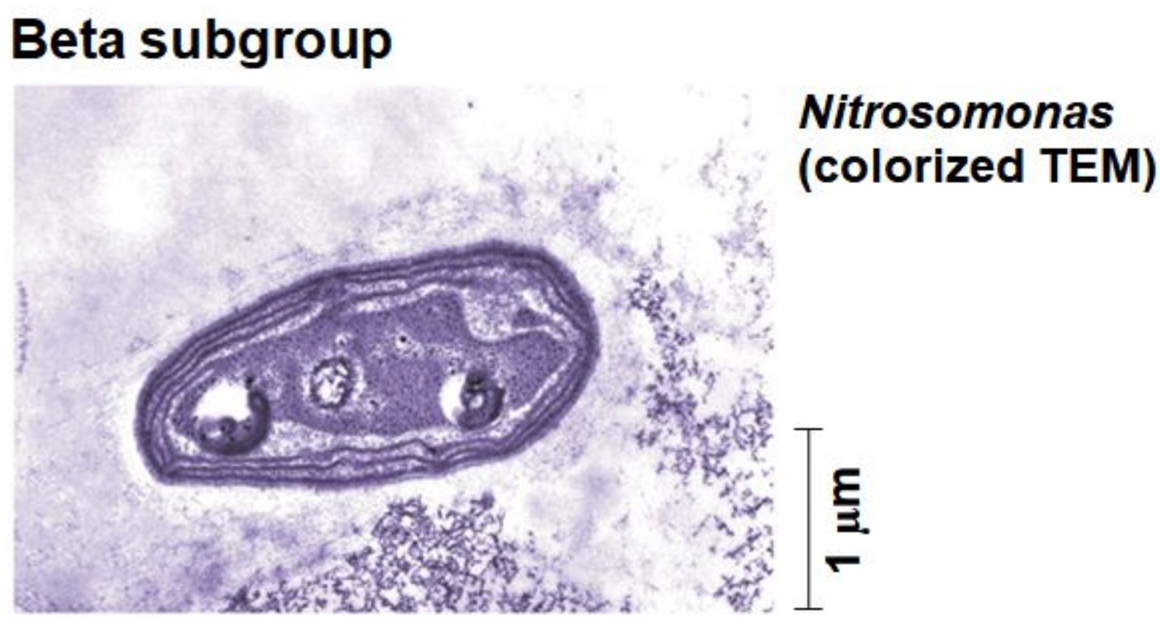
Alpha subgroup



Rhizobium (arrows) inside a root cell of a legume (TEM)

Subgroup: Beta Proteobacteria

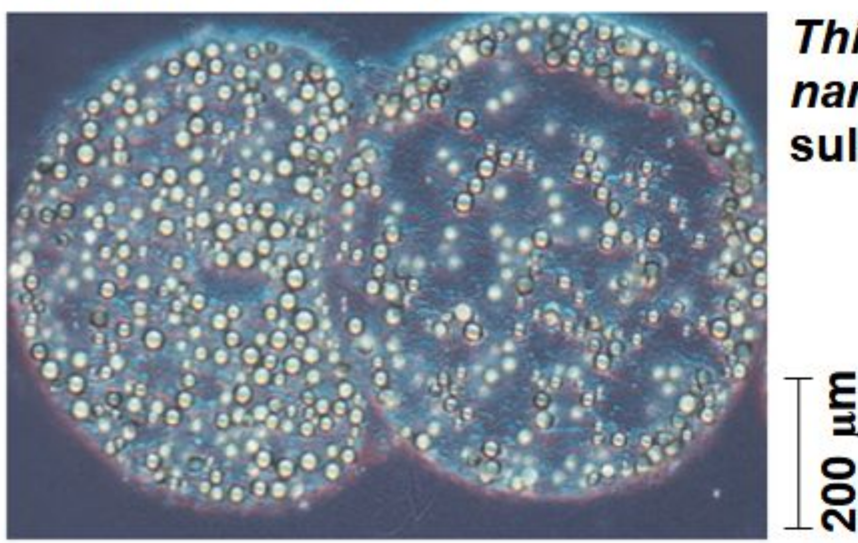
- This subgroup is nutritionally diverse.
- *Nitrosomonas,* a soil bacterium, converts NH_4^+ to NO_2^-
- Other members include aquatic species and pathogens



Subgroup: Gamma Proteobacteria

- Autotrophic members include sulfur bacteria such as *Thiomargarita namibiensis*
- Some heterotrophs are pathogenic, such as *Legionella*, *Salmonella*, and *Vibrio cholerae*
- *Escherichia coli* resides in the intestines of many mammals and is *not* normally pathogenic

Gamma subgroup

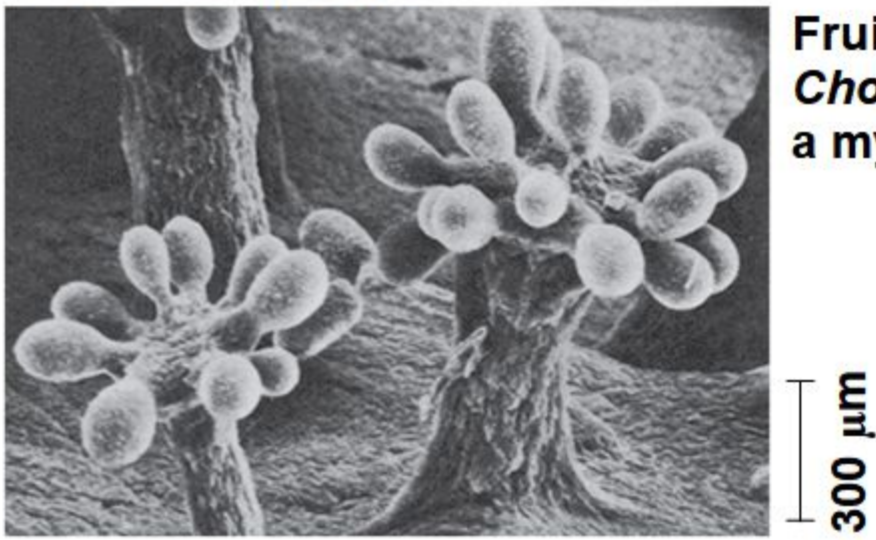


Thiomargarita namibiensis **containing sulfur wastes (LM)**

Subgroup: Delta Proteobacteria

- The slime-secreting myxobacteria, which produces drought-resistant “myxospores”
- *Bdellovibrios*, which mount high-speed attacks on other bacteria

Delta subgroup

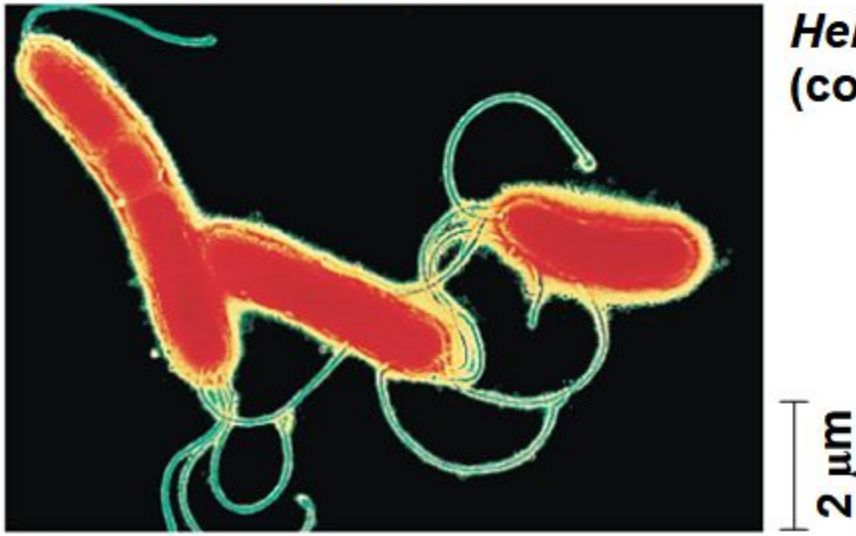


Fruiting bodies of *Chondromyces crocatus*, a myxobacterium (SEM)

Subgroup: Epsilon Proteobacteria

- Most species in this subgroup are pathogenic
- *Campylobacter*, which causes blood poisoning, and *Helicobacter pylori*, which causes stomach ulcers

Epsilon subgroup

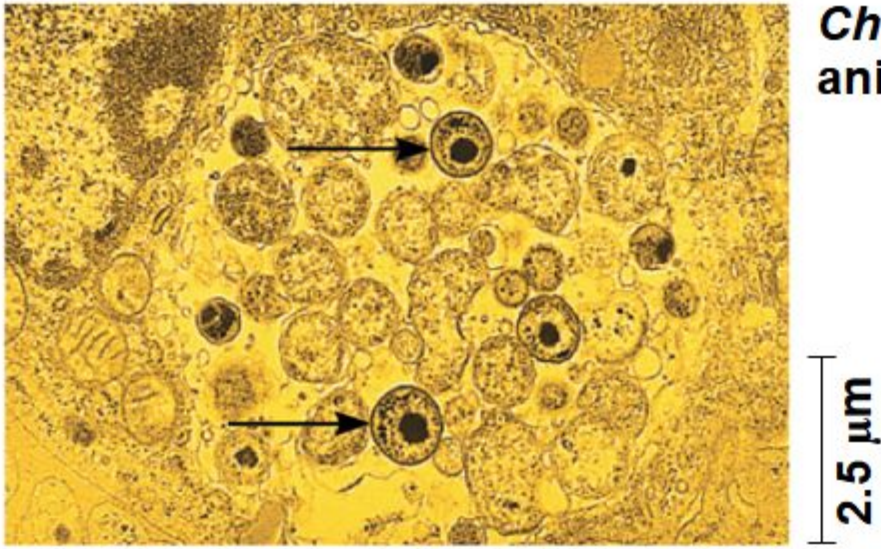


Helicobacter pylori
(colorized TEM)

Chlamydias

- These bacteria are parasites that live within animal cells
- *Chlamydia trachomatis* causes blindness and non-gonococcal urethritis by sexual transmission

Chlamydias

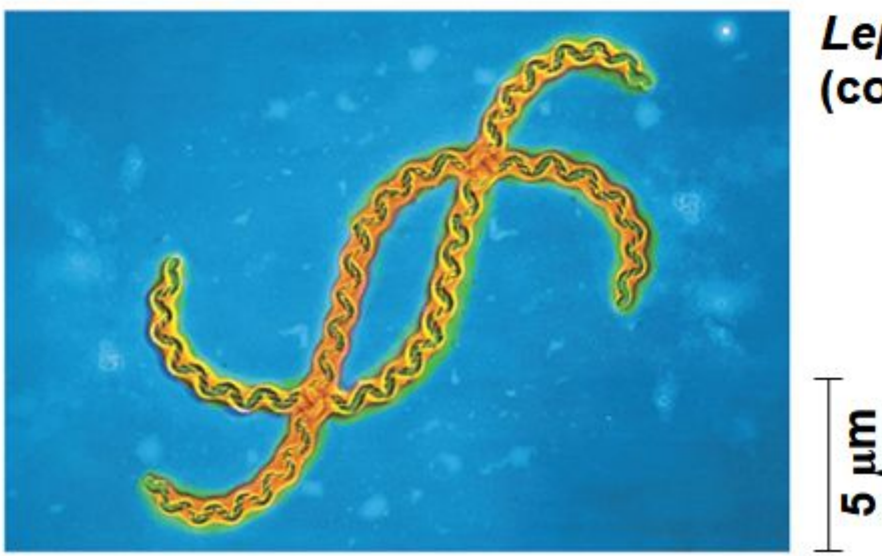


Chlamydia (arrows) inside an animal cell (colorized TEM)

Spirochetes

- These bacteria are helical gram-negative heterotrophs
- Some are parasites, including *Treponema pallidum*, which causes syphilis, and *Borrelia burgdorferi*, which causes Lyme disease

Spirochetes



***Leptospira*, a spirochete (colorized TEM)**

Cyanobacteria

- These are gram-negative <u>photoautotrophs that generate O_2</u>
- Plant chloroplasts likely evolved from cyanobacteria by the <u>process of endosymbiosis</u>
- Cyanobacteria are abundant components of <u>freshwater and marine phytoplankton</u>

Cyanobacteria

***Oscillatoria*, a filamentous cyanobacterium**

Gram-Positive Bacteria

- Gram-positive bacteria include
  - Colony-forming groups, such as actinomycetes, many of which help decompose organic matter
  - Solitary species include
    - *Bacillus anthracis*, the cause of anthrax


    - *Clostridium botulinum*, the cause of botulism
    - various *Staphylococcus* and *Streptococcus* species
  - Mycoplasmas, the smallest known cells, lack cell walls

Archaea

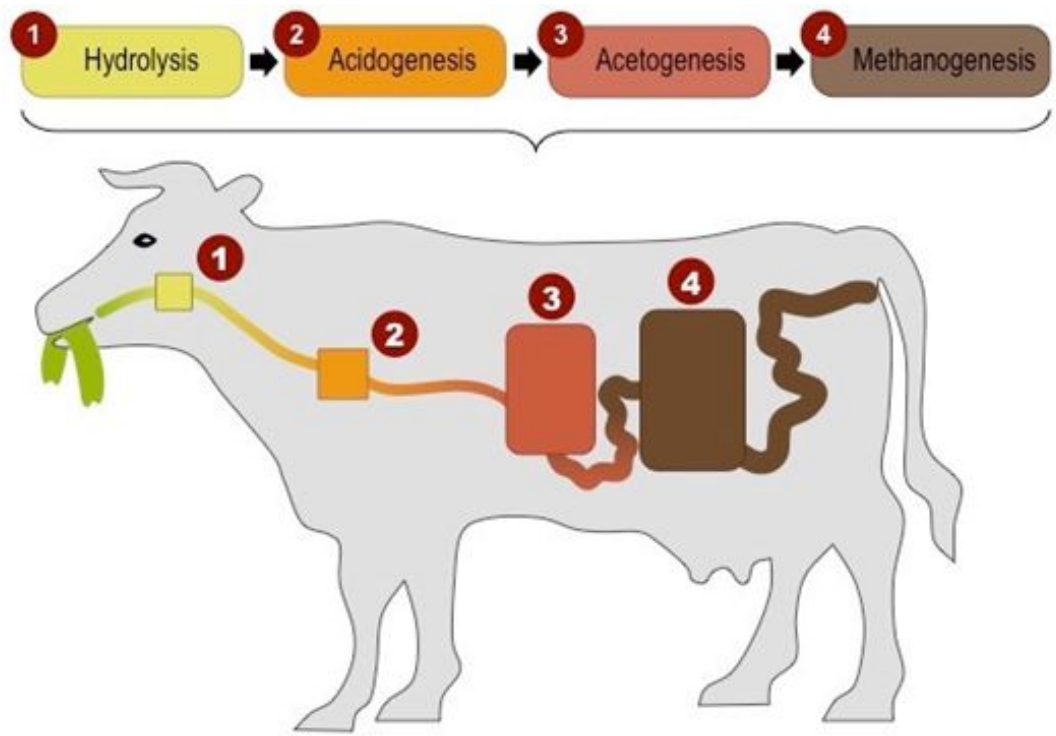
- Archaea share certain traits with bacteria and other traits with eukaryotes
- They also have many unique characteristics
- Some archaea live in extreme environments and are called **extremophiles**
- **Extreme halophiles** live in highly saline conditions
- **Extreme thermophiles** thrive in very hot environments

Table 27.2

Table 27.2 A Comparison of the Three Domains of Life

CHARACTERISTIC	DOMAIN: Bacteria	Archaea	Eukarya
Nuclear envelope	Absent	Absent	Present
Membrane-enclosed organelles	Absent	Absent	Present
Peptidoglycan in cell wall	Present	Absent	Absent
Membrane lipids	Unbranched hydro-carbons	Some branched hydrocarbons	Unbranched hydro-carbons
RNA polymerase	One kind	Several kinds	Several kinds
Initiator amino acid for protein synthesis	Formyl-methionine	Methionine	Methionine
Introns in genes	Very rare	Present in some genes	Present in many genes
Response to the antibiotics strep-tomycin and chloramphenicol	Growth usually inhibited	Growth not inhibited	Growth not inhibited
Histones associ-ated with DNA	Absent	Present in some species	Present
Circular chromosome	Present	Present	Absent
Growth at tem-peratures $> 100°C$	No	Some species	No

- **Methanogens** live in <u>swamps and marshes and produce methane as a waste product</u>
- Methanogens are <u>strict anaerobes and poisoned by O_2</u>



1. Hydrolysis	Polymers → Monomers *(sugars, fatty acids, etc.)*
2. Acidogenesis	Monomers → Alcohols *(ethanol via fermentation)*
3. Acetogenesis	Alcohols → Acetate *(+ methane as a by-product)*
4. Methanogenesis	Acetate → Methane *(+ CO_2 as a by-product)*

Concept 27.5: Prokaryotes play crucial roles in the biosphere

- Prokaryotes are so important that if they were to disappear, the prospects for <u>any other life surviving on Earth would be dim</u>
- Prokaryotes play a major role in the recycling of chemical elements between the living and nonliving components <u>of the environment</u>
- Some chemoheterotrophic prokaryotes function as **decomposers**, <u>breaking down dead organisms</u>
- Prokaryotes can convert some molecules to forms that <u>can be taken up by other organisms</u>
  - EX: Under some conditions, prokaryotes can increase the availability of <u>nutrients required for plant growth</u>

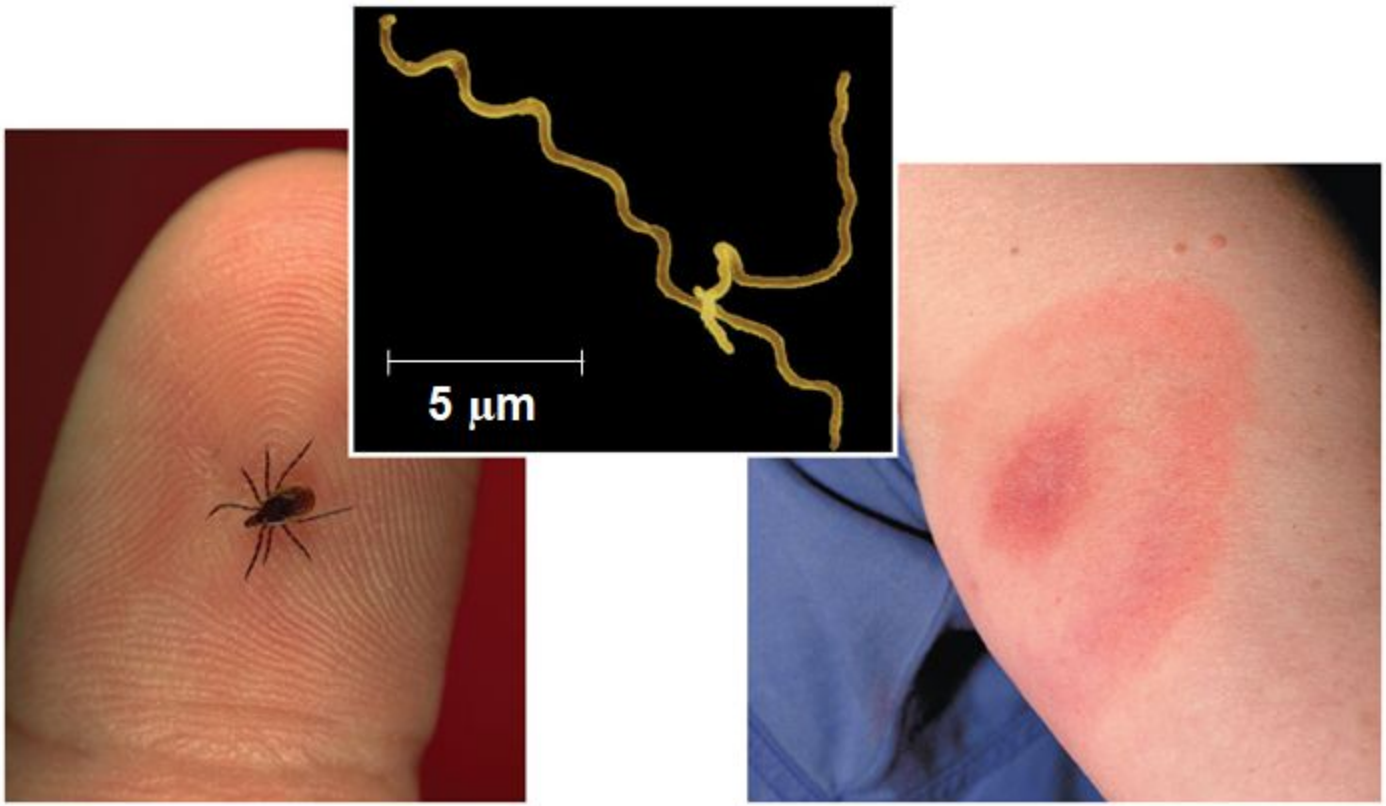
Ecological Interactions

- **Symbiosis** is an ecological relationship in which two species live in close contact: a larger **host** and smaller **symbiont**
- Prokaryotes often form symiotic relationships with larger organisms
- In **mutualism**, both symbiotic organisms benefit
- In **commensalism**, one organism benefits while neither harming nor helping the other in any significant way
- In **parasitism**, an organism called a **parasite** harms but does not kill its host
- Parasites that cause disease are called pathogens

Concept 27.6: Prokaryotes have both beneficial and harmful impacts on humans

- Some prokaryotes are human pathogens, but many others have positive interactions with humans
- Human intestines are home to about 500-1,000 species of bacteria
- Many of these are **mutualists** and break down food that is undigested by our intestines
- **Pathogenic** bacteria cause about half of all human diseases
- Some bacterial diseases are transmitted by other species
  - EX: Lyme disease is caused by a tick carrying bacteria

Figure 27.20



Lyme disease

- Pathogenic prokaryotes typically cause disease by releasing exotoxins or endotoxins
- **Exotoxins** are secreted and cause disease even if the prokaryotes that produce them are not present
- **Endotoxins** are released only when bacteria die and their cell walls break down
- Horizontal gene transfer can spread genes associated with virulence
  - EX: pathogenic strains of *E. coli* contain genes that were acquired through transduction

Prokaryotes in Research and Technology

- Experiments using prokaryotes have led to important advances in DNA technology
  - EX: *E. coli* is used in gene cloning
  - EX: the prokaryotic CRISPR-Cas system can alter genes in other organisms
- Bacteria can be used to make natural plastics
- Bacteria are also being engineered to produce ethanol from agricultural and municipal waste biomass, switchgrass, and corn
- Prokaryotes can also be used in **bioremediation**, the use of organisms to remove pollutants from the environment