

## Chapter 27 – Bacteria and Archaea

## I. What Are the Bacteria and Archaea?

- A. **Bacteria** and **Archaea** make up the most diverse of the kingdoms.
- B. Bacteria and Archaea are the most abundant, ubiquitous organisms on Earth.
- C. Bacteria and Archaea live almost anywhere and eat almost anything.

## II. Why Do Scientists Study Bacteria and Archaea?

- A. A small percentage of bacteria that inhabit the human body are pathogenic and cause disease.
  - 1. Late 1800s Robert Koch hypothesized bacteria may be responsible for causing infectious disease.
    - a. He tested hypothesis by studying anthrax, which infects grazing animals.
    - b. Koch -four postulates required to establish a causative link between a specific microbe and a disease:
    - c. Koch demonstrated that for anthrax, all four postulates were true.
    - d. **Koch's postulates** became the basis for the **germ theory of disease**.
  - 2. **Antibiotics** are molecules that kill bacteria.
    - a. Developed in the late 1920s- these drugs have been useful in combating infectious disease.
    - b. Drug-resistant bacterial strains.
- B. **Bioremediation**: The use of bacteria and archaea to clean up human pollution
  - 1. Most pollution is caused by organic solvents and fuels leaking into water supplies.
  - 2. Sediments where these compounds accumulate can become **anoxic**—devoid of oxygen.
  - 3. Biologists trying to clean up pollution face some problems:
  - 4. Biologists are now trying to use bioremediation strategies that use bacteria and archaea to degrade such pollutants.
- C. Understanding how some bacteria thrive in extreme conditions may help advance industrial technology.
  - 1. **Extremophiles** are bacteria that live in high-salt, high- or low-temperature, or high-pressure habitats.
  - 2. Basic scientific curiosity seeks to understand how the enzymes of these species can function under such conditions.
  - 3. Practical questions of interest to industry drive the study of these organisms.
  - 4. Astrobiologists use extremophiles as model organisms in the search for extraterrestrial life.
- D. Global Change
  - 1. The **Oxygen Revolution**—cyanobacteria are thought to have given Earth its oxygen atmosphere.
    - a. Climatologists believe no free O<sub>2</sub> existed in atmosphere for 2.5 billion yrs.
    - b. Cyanobacteria, photosynthetic bacteria, were first organisms to perform **oxygenic photosynthesis** (releases oxygen as a by-product).
    - c. Once O<sub>2</sub> was abundant in the oceans, cells could use it as an electron acceptor.
  - 2. **Nitrogen fixation**
    - a. Plant growth is often limited by the availability of nitrogen.
    - b. Nitrates as a pollutant

## III. How Do Biologists Study Bacteria and Archaea?

- A. Bacteria are important **model organisms** for all fields of biology.
  - 1. However, our understanding of bacteria is now advancing more rapidly than any other biological field.
  - 2. Understanding prokaryotic diversity is now a major field in biology.
- B. Using **enrichment cultures** to study where and how bacteria and archaea live
  - 1. Enrichment cultures involve establishing a specific set of living conditions.
  - 2. Cells that thrive under specific conditions will increase and are isolated and studied in detail.
  - 3. Example: Discovering bacteria from the depths of the Earth
- C. Using **direct sequencing** to identify species that cannot be grown in enrichment culture
  - 1. Direct sequencing allows biologists to name and characterize organisms that have never been seen.
  - 2. How is a direct sequencing experiment performed?
  - 3. Direct sequencing has changed the way we think about archaea.
    - a. Scientists once classified prokaryotes into four basic groups:
      - (1) **halophiles**; salt-lovers
      - (2) **Sulfate-reducers** that produce hydrogen sulfide as a by-product
      - (3) **Methanogens** that produce methane as a by-product
      - (4) Extreme **thermophiles** that grow best at high temperatures
    - b. However, direct sequencing experiments demonstrated that archaeal habitats are even more diverse than originally thought.

A new lineage, Korarchaeota, was identified (may be diverse enough to constitute a new kingdom).

- D. Evaluating molecular phylogenies using data from enrichment cultures and direct sequencing studies
1. Phylogenetic trees are diagrams that illustrate the hypothesized evolutionary relationships between several analyzed species.
  2. In the 1960s data from rRNA infers evolutionary relationships of a diverse group of organisms.
    - a. The end product of this effort is known as the tree of life.
    - b. Prokaryotes subdivided into two new domains; bacteria and archaea.
    - c. Bacteria seem to be the first lineage to emerge, implying that archaea and eukaryotes are more closely related than they are to bacteria.
    - d. Further analysis has identified several **monophyletic groups** within each of these domains.

IV. What themes Occur in the Diversification of Bacteria and Archaea?

A. Morphological Diversity

1. What do all bacteria and archaea have in common?
  - a. Unicellular
  - b. Lack membrane-bound organelles
  - c. Divide via **binary fission**.
2. Differences in bacteria and archaea-
  - a. different cell membrane and cell-wall components.
  - b. different systems for transcription and translation.
  - c. Bacterial cells have plasmids - can be transferred between individuals via **conjugation**.
3. How are different types of bacteria different from one another?
  - a. Bacteria come in many different shapes & sizes.
  - b. Many bacteria are motile, moving via flagella or gliding.
  - c. Bacteria have cell walls with different morphologies. (**Gram negative & Gram positive**)

B. Metabolic diversity; where do bacteria and archaea get the energy to make ATP, and where do they get carbon to build macromolecules?

1. Energy sources and carbon sources vary allowing bacteria & archaea to occupy almost any habitat on Earth.
  - a. **Phototrophs** use the energy in light to energize electrons to fuel cellular respiration.
  - b. **Organotrophs** use highly reduced organic molecules.
  - c. **Lithotrophs** oxidize inorganic ions.
  - d. Bacteria and archaea obtain carbon through carbon dioxide or methane.
2. Cellular respiration: variation in electron donors and electron acceptors
  - a. Cellular respiration- process by which energy transferred via redox reaction through a series of enzymatic steps & electron carriers, to an electron acceptor while energy is harnessed to make ATP.
  - b. **Molecular fuel** and **final electron acceptor** vary in bacterial species.
  - c. Importance of the metabolic diversity of bacteria
3. Fermentation
  - a. **Fermentation** - making ATP from reduced organic compounds without electron transport chains.
  - b. Fermentation -no outside electron acceptor (less efficient than respiration)
  - c. Some bacteria ferment glucose to either ethanol or lactic acid.
  - d. Other bacteria use various other reduced organic compounds as fermentable substrates.
  - e. Ability to ferment a variety of different substrates extends habitats that bacteria and archaea can occupy.
4. Photosynthesis
  - a. **Phototrophs** use the kinetic energy of light to raise electrons to a high energy state.
  - b. Photosynthesis requires a source of electrons.
    - (1) Cyanobacteria and plants—water is the electron source; O<sub>2</sub> is released as a by-product.
    - (2) Other anaerobic bacteria use different electron donors:
5. Some phototrophic bacteria, other than cyanobacteria, use different types of chlorophyll:
  - a. Seven different **bacteriochlorophylls** have been identified, each with a unique absorption spectrum.
  - b. Hypothesis: Photosynthetic species whose chlorophylls absorb different wavelengths of light can coexist side by side without competing for light.
  - c. If so, then having different chlorophylls has been an important contributor to bacteria biodiversity.
6. Pathways for fixing carbon
  - a. Cyanobacteria make their own organic building-block molecules by fixing CO<sub>2</sub> (as do plants).
  - b. Some bacteria and archaea fix carbon from non-CO<sub>2</sub> sources:
  - c. Different mechanisms for fixing carbon

V. Key Lineages of Bacteria and Archaea

A. Bacteria

1. **Spirochaetes**
  - a. Morphological diversity
    - (1) Corkscrew shape

- (2) Flagella housed in an outer sheath
- b. Metabolic diversity
  - (1) Most make ATP via fermentation.
  - (2) One species that lives in termite gut can fix nitrogen.
- c. Human and ecological impact
  - (1) Syphilis is caused by a spirochete.
  - (2) Lyme disease is caused by a spirochete.
  - (3) Live in freshwater and marine habitats; some in anaerobic conditions
- 2. **Chlamydiales**
  - a. Morphological diversity—spherical and very small
  - b. Metabolic diversity
    - (1) All species are endosymbionts and live in hosts.
    - (2) They contain few enzymes, get all nutrients from host.
  - c. Human and ecological impact
    - (1) *Chlamydia trachomatis* infections cause blindness in humans.
    - (2) Can also cause urogenital infections if passed via intercourse.
- 3. **High-GC Gram positives**
  - a. Morphological diversity
    - (1) Cell walls have a lot of peptidoglycan.
    - (2) Their DNA has a high guanine and cytosine content.
    - (3) Cells have rod or filament shapes.
    - (4) Soil-dwelling species have branched filaments called mycelia.
  - b. Metabolic diversity
    - (1) Many are heterotrophs that use organic compounds and oxygen for cellular respiration.
    - (2) Some are parasitic.
  - c. Human and ecological impact
    - (1) Many antibiotics have been isolated from *Streptomyces*.
    - (2) Tuberculosis and leprosy are caused by species from this group.
    - (3) One species is important for making Swiss cheese.
    - (4) Species in this group live in plant roots and fix nitrogen.
- 4. **Cyanobacteria**
  - a. Morphological diversity
    - (1) Cells can be solitary or colonial.
    - (2) Colonies can form flat sheets to balls.
  - b. Metabolic diversity
    - (1) All perform oxygenic photosynthesis.
    - (2) Some can fix nitrogen.
  - c. Human and ecological impact
    - (1) Produce much of the oxygen and nitrogen that other species need.
    - (2) A few species live with fungi, forming lichens.
- 5. **Low-GC Gram positives**
  - a. Morphological diversity
    - (1) Are Gram-positive, but have a low GC-content in their DNA
    - (2) Most are rod-shaped or spherical.
    - (3) Can form chains or tetrads
    - (4) Can form spores
  - b. Metabolic diversity
    - (1) Some can fix nitrogen.
    - (2) Some perform nonoxygenic photosynthesis.
    - (3) Some perform fermentation to make ATP; Others perform cellular respiration using hydrogen gas.
  - c. Human and ecological impact
    - (1) Low-GC Gram-positive species cause anthrax, botulism, tetanus walking pneumonia, gangrene, strep throat, etc.
    - (2) *Lactobacillus* is used to ferment milk to make yogurt or cheese.
- 6. **Proteobacteria**
  - a. Morphological diversity
    - (1) Can be rods, spheres, or spirals; some form stalks.
    - (2) Some are motile.
    - (3) Some can aggregate to form fruiting bodies.
  - b. Metabolic diversity
    - (1) Live in almost any habitat.
    - (2) Few to none perform oxygenic photosynthesis; some perform nonoxygenic photosynthesis.
    - (3) Most perform cellular respiration using a variety of electron donors and acceptors.
  - c. Human and ecological impact
    - (1) Pathogenic proteobacteria cause Legionnaire's disease, cholera, food poisoning, dysentery, ulcers, and diarrhea.

- (2) Some are used to make vinegar.
- (3) *Rhizobium* live in root nodules of legumes and fix nitrogen.

**B. Archaea**

**1. Crenarchaeota**

- a. Morphological diversity; Cells may be shaped like rods, discs, or spheres.
- b. Metabolic diversity
  - (1) Some species make ATP via cellular respiration with a variety of electron donors and acceptors.
  - (2) Some species make ATP via fermentation.

**2. Euryarchaeota**

- a. Morphological diversity
  - (1) Can be spherical, rod-shaped, or disc-shaped, and can aggregate in chains or balls.
  - (2) Some species have flagella.
- b. Metabolic diversity
  - (1) Many species produce methane.
  - (2) Some species that live in high-salt environments use retinal to capture light energy and perform photosynthesis.
- c. Human and ecological impact
  - (1) *Ferroplasma* live in piles of abandoned mine waste rocks and produce acids
  - (2) Methanogens live in mammal gut.

## Chapter Vocabulary

kingdom  
phyla

microbes  
microbiology  
bacteria  
archaea

pathogenic  
infectious disease  
Koch's postulates  
germ theory of disease  
antibiotics

anoxic  
decomposers  
bioremediation  
extremophiles  
astrobiologists

The oxygen revolution  
cyanobacteria  
oxygenic  
photosynthesis

nitrogen cycle  
nitrogen fixation  
nitrate pollution

enrichment culture  
thermophilic

direct sequencing  
halophiles  
sulfate reducers  
methanogens  
thermophiles  
korarchaeota  
monophyletic group

Gram-positive bacteria  
Gram-negative bacteria  
Gram stain  
fission  
plasmids  
conjugation  
conjugation tube

phototrophs  
organotrophs  
lithotrophs  
autotrophs  
heterotrophs  
cellular respiration  
fermentation  
photosynthesis  
methanotrophs

bacteria  
Spirochaetes/Spirochetes  
Chlamydiales  
Chlamydia trachomatis  
endosymbionts  
high-GC Gram positives  
mycelia  
Streptomyces  
cyanobacteria  
low-GC Gram positives  
spore  
Lactobacillus  
proteobacteria  
Rhizobium

lateral gene transfer  
paraphyletic

Archaea  
Ferroplasma