Chapter 27

Bacteria and Archaea

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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Overview: Masters of Adaptation

- Prokaryotes thrive almost everywhere, including places too acidic, salty, cold, or hot for most other organisms
- Most prokaryotes are microscopic, but what they lack in size they make up for in numbers
- There are more in a handful of fertile soil than the number of people who have ever lived

- They have an astonishing genetic diversity
- Prokaryotes are divided into two domains: bacteria and archaea

PLAY Video: Tubeworms

Concept 27.1: Structural and functional adaptations contribute to prokaryotic success

- Most prokaryotes are unicellular, although 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

Cell-Surface Structures

- An important feature of nearly all prokaryotic cells is their cell wall, which maintains cell shape, provides physical protection, and prevents the cell from bursting in a hypotonic environment
- Eukaryote cell walls are made of cellulose or chitin
- Bacterial cell walls contain **peptidoglycan**, a network of sugar polymers cross-linked by polypeptides

- Archaea contain polysaccharides and proteins but lack peptidoglycan
- Using the **Gram stain**, scientists classify many bacterial species into **Gram-positive** and **Gram-negative** groups based on cell wall composition
- Gram-negative bacteria have less peptidoglycan and an outer membrane that can be toxic, and they are more likely to be antibiotic resistant

- Many antibiotics target peptidoglycan and damage bacterial cell walls

- A polysaccharide or protein layer called a **capsule** covers many prokaryotes

- Some prokaryotes have **fimbriae** (also called *attachment pili*), which allow them to stick to their substrate or other individuals in a colony
- **Sex pili** are longer than fimbriae and allow prokaryotes to exchange DNA

Motility

- Most motile bacteria propel themselves by flagella that are structurally and functionally different from eukaryotic flagella
- In a heterogeneous environment, many bacteria exhibit **taxis**, the ability to move toward or away from certain stimuli

PLAY **Video: Prokaryotic Flagella (*Salmonella typhimurium*)**

Internal and Genomic Organization

- Prokaryotic cells usually lack complex compartmentalization
- Some prokaryotes do have specialized membranes that perform metabolic functions

- The prokaryotic genome has less DNA than the eukaryotic genome
- Most of the genome consists of a circular chromosome
- Some species of bacteria also have smaller rings of DNA called **plasmids**

- The typical prokaryotic genome is a ring of DNA that is not surrounded by a membrane and that is located in a **nucleoid region**

Reproduction and Adaptation

- Prokaryotes reproduce quickly by binary fission and can divide every 1–3 hours
- Many prokaryotes form metabolically inactive **endospores**, which can remain viable in harsh conditions for centuries

- Prokaryotes can evolve rapidly because of their 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:
  - Rapid reproduction
  - Mutation
  - Genetic recombination

Rapid Reproduction and Mutation

- Prokaryotes reproduce by binary fission, and offspring cells are generally identical
- Mutation rates during binary fission are low, but because of rapid reproduction, mutations can accumulate rapidly in a population
- High diversity from mutations allows for rapid evolution

Genetic Recombination

- Additional diversity arises from genetic recombination
- Prokaryotic DNA from different individuals can be brought together by transformation, transduction, and conjugation

Transformation and Transduction

- 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 bacteriophages (viruses that infect bacteria)

Conjugation and Plasmids

- **Conjugation** is the process where genetic material is transferred between bacterial cells
- Sex pili allow cells to connect and pull together for DNA transfer
- A piece of DNA called the **F factor** is required for the production of sex pili
- The F factor can exist as a separate plasmid or as DNA within the bacterial chromosome

The F Factor as a Plasmid

- 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

The F Factor in the Chromosome

- A cell with the F factor built into its chromosomes functions as a donor during conjugation
- The recipient becomes a recombinant bacterium, with DNA from two different cells
- It is assumed that horizontal gene transfer is also important in archaea

R Plasmids and Antibiotic Resistance

- **R plasmids** carry genes for antibiotic resistance
- Antibiotics select for bacteria with genes that are resistant to the antibiotics
- Antibiotic resistant strains of bacteria are becoming more common

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

- *Phototrophs* obtain energy from light
- *Chemotrophs* obtain energy from chemicals
- *Autotrophs* require CO_2 as a carbon source
- *Heterotrophs* require an organic nutrient to make organic compounds
- These factors can be combined to give the four major modes of nutrition: photoautotrophy, chemoautotrophy, photoheterotrophy, and chemoheterotrophy

Table 27-1

Table 27.1 Major Nutritional Modes

Mode of Nutrition	Energy Source	Carbon Source	Types of Organisms
Autotroph			
Photoautotroph	Light	CO_2	Photosynthetic prokaryotes (for example, cyanobacteria); plants; certain protists (for example, algae)
Chemoautotroph	Inorganic chemicals	CO_2	Certain prokaryotes (for example, *Sulfolobus*)
Heterotroph			
Photoheterotroph	Light	Organic compounds	Certain prokaryotes (for example, *Rhodobacter, Chloroflexus*)
Chemoheterotroph	Organic compounds	Organic compounds	Many prokaryotes (for example, *Clostridium*) and protists; fungi; animals; some plants

The Role of Oxygen 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 use fermentation or **anaerobic respiration**
  - **Facultative anaerobes** can survive with or without O_2

Nitrogen Metabolism

- Prokaryotes can metabolize nitrogen in a variety of ways
- In **nitrogen fixation**, some prokaryotes convert atmospheric nitrogen (N_2) to ammonia (NH_3)

Metabolic Cooperation

- Cooperation between prokaryotes allows them to use environmental resources they could not use as individual cells
- In the cyanobacterium *Anabaena*, photosynthetic cells and nitrogen-fixing cells called **heterocytes** exchange metabolic products

PLAY **Video: Cyanobacteria (*Oscillatoria*)**

- In some prokaryotic species, metabolic cooperation occurs in surface-coating colonies called **biofilms**

Concept 27.4: Molecular systematics is illuminating prokaryotic phylogeny

- Until the late 20th century, systematists based prokaryotic taxonomy on phenotypic criteria
- Applying molecular systematics to the investigation of prokaryotic phylogeny has produced dramatic results

Lessons from Molecular Systematics

- Molecular systematics is leading to a phylogenetic classification of prokaryotes
- It allows systematists to identify major new clades

- The use of polymerase chain reaction (PCR) has allowed for more rapid sequencing of prokaryote genomes
- A handful of soil many contain 10,000 prokaryotic species
- Horizontal gene transfer between prokaryotes obscures the root of the tree of life

Archaea

- Archaea share certain traits with bacteria and other traits with eukaryotes

Table 27-2

Table 27.2 A Comparison of the Three Domains of Life

CHARACTER	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 hydrocarbons	Some branched hydrocarbons	Unbranched hydrocarbons
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
Response to the antibiotics streptomycin and chloramphenicol	Growth inhibited	Growth not inhibited	Growth not inhibited
Histones associated with DNA	Absent	Present in some species	Present
Circular chromosome	Present	Present	Absent
Growth at temperatures > 100°C	No	Some species	No

- Some archaea live in extreme environments and are called **extremophiles**
- **Extreme halophiles** live in highly saline environments
- **Extreme thermophiles** thrive in very hot environments

- **Methanogens** live in swamps and marshes and produce methane as a waste product
- Methanogens are strict anaerobes and are poisoned by O_2
- In recent years, genetic prospecting has revealed many new groups of archaea
- Some of these may offer clues to the early evolution of life on Earth

Bacteria

- Bacteria include the vast majority of prokaryotes of which most people are aware
- Diverse nutritional types are scattered among the major groups of bacteria

Proteobacteria

- These gram-negative bacteria include photoautotrophs, chemoautotrophs, and heterotrophs
- Some are anaerobic, and others aerobic

Subgroup: Alpha Proteobacteria

- Many species are closely associated with eukaryotic hosts
- Scientists hypothesize that mitochondria evolved from aerobic alpha proteobacteria through endosymbiosis

- Example: *Rhizobium*, which forms root nodules in legumes and fixes atmospheric N_2
- Example: *Agrobacterium*, which produces tumors in plants and is used in genetic engineering

Subgroup: Beta Proteobacteria

- Example: the soil bacterium *Nitrosomonas*, which converts NH_4^+ to NO_2^-

Subgroup: Gamma Proteobacteria

- Examples include sulfur bacteria such as *Chromatium* and pathogens such as *Legionella*, *Salmonella*, and *Vibrio cholerae*
- *Escherichia coli* resides in the intestines of many mammals and is not normally pathogenic

Subgroup: Delta Proteobacteria

- Example: the slime-secreting myxobacteria

Subgroup: Epsilon Proteobacteria

- This group contains many pathogens including *Campylobacter*, which causes blood poisoning, and *Helicobacter pylori*, which causes stomach ulcers

Chlamydias

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

Spirochetes

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

Cyanobacteria

- These are photoautotrophs that generate O_2
- Plant chloroplasts likely evolved from cyanobacteria by the process of endosymbiosis

Gram-Positive Bacteria

- Gram-positive bacteria include
  - Actinomycetes, which decompose soil
  - *Bacillus anthracis*, the cause of anthrax
  - *Clostridium botulinum*, the cause of botulism
  - Some *Staphylococcus* and *Streptococcus*, which can be pathogenic
  - Mycoplasms, the smallest known cells

Concept 27.5: Prokaryotes play crucial roles in the biosphere

- Prokaryotes are so important to the biosphere that if they were to disappear the prospects for any other life surviving would be dim

Chemical Cycling

- Prokaryotes play a major role in the recycling of chemical elements between the living and nonliving components of ecosystems
- Chemoheterotrophic prokaryotes function as **decomposers**, breaking down corpses, dead vegetation, and waste products
- Nitrogen-fixing prokaryotes add usable nitrogen to the environment

- Prokaryotes can sometimes increase the availability of nitrogen, phosphorus, and potassium for plant growth
- Prokaryotes can also “immobilize” or decrease the availability of nutrients

Ecological Interactions

- **Symbiosis** is an ecological relationship in which two species live in close contact: a larger **host** and smaller **symbiont**
- Prokaryotes often form symbiotic 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 harmful and beneficial impacts on humans

- Some prokaryotes are human pathogens, but others have positive interactions with humans

Pathogenic Prokaryotes

- Prokaryotes cause about half of all human diseases
- Lyme disease is an example

- Pathogenic prokaryotes typically cause disease by releasing exotoxins or endotoxins
- **Exotoxins** 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
- Many pathogenic bacteria are potential weapons of bioterrorism

Prokaryotes in Research and Technology

- Experiments using prokaryotes have led to important advances in DNA technology
- Prokaryotes are the principal agents in **bioremediation**, the use of organisms to remove pollutants from the environment

- Some other uses of prokaryotes:
  - Recovery of metals from ores
  - Synthesis of vitamins
  - Production of antibiotics, hormones, and other products

You should now be able to:

1. Distinguish between the cell walls of gram-positive and gram-negative bacteria
2. State the function of the following features: capsule, fimbriae, sex pilus, nucleoid, plasmid, and endospore
3. Explain how R plasmids confer antibiotic resistance on bacteria

4. Distinguish among the following sets of terms: photoautotrophs, chemoautotrophs, photoheterotrophs, and chemoheterotrophs; obligate aerobe, facultative anaerobe, and obligate anaerobe; mutualism, commensalism, and parasitism; exotoxins and endotoxins