Bacteria
The First Microbes

Looking Ahead
• On completing this chapter, you should be able to:
  – Appreciate the enormous span of time for which bacteria have existed on Earth and understand their contributions to the formation of the world as we know it;
  – Summarize the various forms of known bacteria and define many of the submicroscopic structures associated with a bacterial cell;
  – Describe the process by which bacteria reproduce and grasp the significance of the frequency of bacterial replication;

Looking Ahead
• On completing this chapter, you should be able to:
  – Identify some of the environments in which bacteria thrive and recognize the different types of cultivation techniques available for growing bacteria in the laboratory;
  – Outline several important groups of bacteria in order to appreciate their diversity;
  – Identify the importance of bacteria in the disease process and briefly summarize some of the mechanisms of bacterial disease and body resistance.
Origins of Life

- Earth is 4.5 billion years old
- Life appeared as prokaryotes (bacteria) 3.5 billion years ago
- They were the only inhabitants of the planet for two billion years.
- Eukaryotes arose 1.5 billion years ago
- During time when only bacteria lived, the cyanobacteria developed
  - Photosynthesis
  - Evolution of O₂ into the atmosphere
  - Paved the way for more complex life forms
- Bacteria have evolved to fill almost every environmental niche on the planet.
  - Organisms can be found in deep ocean vents, mountaintops, deserts, and the poles.
  - A single pinch of soil can contain over a billion bacteria.
- A small percentage of these are dangerous to man. Most serve a role in the environment.

Figure 5.1: The bacteria on Earth.

General characteristics

- Much smaller than eukaryotic cells
- Very simple cells
- Lack a nucleus
  - Have a single chromosome loop of DNA
Bacterial Structure and Physiology

- **General morphology**
  - Three major forms
    - Bacillus (pl., bacilli)
    - Coccus (pl., cocci)
    - Spiral-shaped
      - Spirillum (pl., spirilla)
      - Spirochete (pl., spirochetes)
  - Other forms
    - Vibrio (some consider a spiral)
    - Square (rare)
    - Star (rare)
    - Triangle (rare)

Figure 5.2: Variations in bacterial structure

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Bacterial Structure and Physiology

- **General morphology**
  - Bacillus size
    - 0.5-20 μm
    - Extraordinary example of 750 μm

Figure 5.2: Variations in bacterial structure

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Bacterial Structure and Physiology

- **General morphology**
  - Coccus size and arrangement
    - Approximately 0.5 μm diameter
    - Diplococci (two)
    - Tetrads (four)
    - Sarcinae (cubical cluster)
    - Streptococci
    - Staphylococci

- The shape and arrangement are important clues to identifying which organism you are dealing with.

Figure 5.2: Variations in bacterial structure
Bacterial Structure and Physiology

• Staining procedures
  – Required because of size
  – Required because bacteria are transparent
  – Simple stain (one dye): example methylene blue
  – Gram stain (multiple dyes, a key factor in differentiating cells)
    • Gram-positive bacteria appear blue-purple
    • Gram-negative bacteria appear orange-red

Figure 5.3: Stain Reactions in Microbiology: The simple stain technique and the Gram stain technique

More on gram stains.

• A gram stain is key in identifying the type of organism.
• Some antibiotics are more effective on gram + but less so on gram –
• Some antiseptics are less effective on gram negative.
• Cell wall structure determines whether a cell is gram + or –

Bacterial Structure and Physiology

• Surface structures
  – Cell wall
    • Contains Peptidoglycan
    • Thin in Gram-negatives
    • Thick in Gram-positives
    • Site for the activity of many antibiotics
  – Plasma membrane
    • Fluid mosaic model
    • Proteins
    • Small carbohydrates
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**Bacterial Structure and Physiology**

- **Surface structures**
  - Outer membrane
    - Present only in Gram-negative bacteria
  - Periplasm between plasma and outer membranes
    - Glycocalyx (allows adhesion and resists phagocytosis)
      - Not present in all bacteria
      - "Capsule," if tight
      - "Slime layer," if loose
  - Present in many pathogenic organisms because it allows adhesion, prevents drying and makes organisms resistant to some aspects of our immune system.

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**Bacterial Structure and Physiology**

- **Surface structures**
  - Glycocalyx
    - Provides protection
    - Dessication
    - Chemicals
    - Environment
  - Provides adhesive properties for bacteria
  - Flagellum (pl., flagella)
    - Hair-like structure
    - Movement results in motility

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**Bacterial Structure and Physiology**

- **Surface structures**
  - Pilus (pl., pili)
    - Hair-like structure
    - Hollow tube
    - Permit exchange of genetic information between bacteria
    - Can function as an attachment factor for some bacteria.
Figure 5.11: TEM of the heterotrophic bacterium Escherichia coli with pili (X40,000)

Bacterial Structure and Physiology

- Cytoplasmic structures
  - Nucleoid
    - Location of bacterial DNA
    - Single, double-stranded, circular chromosome
  - Plasmids (not necessary for cells but may confer resistance to antibiotics)
    - Small, circular DNA
    - Extrachromosomal
    - Replicate independently
  - Ribosomes (sites of protein production)
  - tRNAs
  - Soluble cytoplasmic contents

Bacterial Structure and Physiology

- Cytoplasmic structures
  - Endospores/spores
    - Typical in the genuses of Bacillus and Clostridium
    - Made by cells when the environment becomes unable to support the cell. It is a little like hibernation.
    - Contain DNA copy of genome
    - Heat resistant (requires steam and pressure to destroy)
    - Environmentally resistant
    - Can be dormant for thousands of years
    - Bacillus anthracis spores can be used as an agent of bioterrorism.
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The formation of a bacterial spore.

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Bacterial Structure and Physiology

• Bacterial reproduction
  – Binary fission (copy DNA and split in two)
  – *E. coli*: 20 minute doubling time in optimum environment
  – Allowed uncontrolled growth 100 *E. coli* could cover the earth's surface a foot thick in 36 hours
  – Reproduction slows when nutrients become depleted

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Bacterial Structure and Physiology: reproduction

Figure 5.8: Binary fission in bacteria
Bacterial growth

- Culture media are used to grow organisms in labs
- Broth (any of a number of liquids containing nutrients)
- Agar (a gelatin derived from seaweed)
- Selective medium (will only allow some organisms to grow)
- Enriched medium
- Production of bioterrorist weapons

Figure 5.9: Use of an enriched medium

The Spectrum of Bacteria

- Archaea
  - Not viewed as true bacteria because of several structural and chemical differences.
  - Include extremophiles
    - An example is a Thermophilicophile
    - Lives in extremely hot conditions
      - Example: *Thermoacidophiles*
        - Grows at pH 1.0
        - Grows at 85°C
      - Example: *Pyrolobus fumarii*
        - Grows 150 feet below Pacific Ocean
        - Grows between 90°C and 113°C

Figure 5.10: The Habitat of Extremophiles: An alkaline spring in Yellowstone Park shows a mat of cyanobacteria in the foreground.

The Spectrum of Bacteria

- Other Archaea
  - Methanogens
    - Produce methane
    - Require only CO₂, N₂, and H₂O
    - Some live in swamps and make “swamp gas”
  - Extreme halophiles (like salt)
    - Grow in Great Salt Lake

- Photosynthetic bacteria
  - Cyanobacteria is the major form
    - Autotrophic microbes (produce own food)
    - Contain chlorophyll
    - Fix nitrogen (within specialized Cyanobacteria called heterocysts)
  - Symbiotic lifestyle with other cyanobacteria in colonies.
Important traditional bacteria

- Photosynthetic bacteria
  - Cyanobacteria is the major form
  - Autotrophic microbes (produce own food)
  - Contain chlorophyll
  - Fix nitrogen (within specialized Cyanobacteria called heterocysts)
  - Symbiotic lifestyle with other cyanobacteria in colonies.
  - Highly independent organisms.
  - Probably the first to produce oxygen in earth's atmosphere.

Cyanobacteria strands

The Spectrum of Bacteria

- Heterotrophic eubacteria (cannot make energy, must eat)
  - Commonly referenced simply as “bacteria”
  - Most are decomposers
  - Some producers
    - Azobacter and Rhizobium typical nitrogen-fixing bacteria
    - E. coli and Lactobacillus typical human inhabitants.
    - Digestive tract.
    - Female genital tract
    - Manufacturing of cheese, sour cream, yogurts etc.
Other heterotrophic eubacteria

- *Pseudomonas aeruginosa* typical for medical, industrial, environmental applications
- *Serratia marcescens* typical opportunistic pathogen
  - Herald of Alexander the Great's victory at Tyre
  - The red spots on bread were interpreted as a positive omen.
  - Easily observed indicator and can be used to trace wind patterns that could be used in bioweapons attacks.

The Spectrum of Bacteria

- Spiral and filamentous bacteria
  - Spirochetes and spirilla
  - Among these are the organisms that cause Syphilis, Lyme disease
  - Actinomycetes (form strands of independently functioning cells)
  - Streptomycetes are used to make many drugs.
    - Tetracycline
    - Erythromycin
    - Neomycin

The Spectrum of Bacteria

- Gliding and sheathed bacteria
  - Gliding bacteria produce a slime that they glide across.
  - Two important genera live in sulfur-rich muds. Both release sulfur back into the ecosystem.
    - *Beggiatoa*
    - *Thiothrix*
  - Myxobacteria: can survive by producing a sporelike body
  - Sheathed bacteria
    - Cell wall are enclosed in a sheath that protects the organism from predators; among this is the genus *Spherotilus*
The Spectrum of Bacteria

• Predatory and other bacteria
  – *Bdellovibrio*: prey on other bacteria.
  – *Bacteroides*: G- digest cellulose
• Chemolithotrophic bacteria
  – *Nitrosomonas*
  – *Nitrobacter*
• Acid-fast bacteria
  – *Mycobacteria*: 
    – *M. tuberculosis*
    – *M. leprae*

The Spectrum of Bacteria

• Submicroscopic bacteria (cannot be viewed well with a light microscope)
  – *Rickettsia*: rocky mountain spotted fever
  – *Chlamydia*: one species causes STD
  – *Mycoplasma*: only bacteria without a cell wall.

Figure 5.12: Chlamydia. Dark inclusion bodies typical of a Chlamydia infection
[Courtesy of Dr. E. Arum/Dr. N. Jacobs/CDC]
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• Bacterial pathogens
  – First observed during Golden Age of Microbiology
  – Source of disease
    • By growth
    • By production of toxins
    • By induction of overactive immune response

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Sum up:
• Read your text for clarification of topics.
• Learn the key terminology listed at the end of your chapter.