Prokaryotic Profiles: The Bacteria and Archaea

Chapter 3

To run the animations you must be in Slideshow View. Use the buttons on the animation to play, pause, and turn audio/text on or off. Please note: once you have used any of the animation functions (such as Play or Pause), you must first click in the white background before you advance the next slide.
Prokaryotic Form and Function

• Prokaryotes can be distinguished from eukaryotes by:
  - the way their DNA is packaged (lack of nucleus and histones)
  - the makeup of their cell wall (peptidoglycan and other unique chemicals)
  - their internal structure (lack of membrane-bounded organelles)
The Structure of the Prokaryotic Cell

• **All** bacterial cells possess:
  - a cell membrane
  - cytoplasm
  - ribosomes
  - a cytoskeleton
  - one (or a few) chromosome(s)

• **Most** bacterial cells possess:
  - a cell wall
  - a surface coating called a glycocalyx
The Structure of the Prokaryotic Cell (cont’d)

• Some but not all bacterial cells possess:
  - flagella, pili, and fimbriae
  - an outer membrane
  - plasmids
  - inclusions
  - endospores
  - intracellular membranes
Prokaryotic Cell

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In All Bacteria

- Cell (cytoplasmic) membrane—A thin sheet of lipid and protein that surrounds the cytoplasm and controls the flow of materials into and out of the cell pool.
- Bacterial chromosome or nucleoid—Composed of condensed DNA molecules. DNA directs all genetics and heredity of the cell and codes for all proteins.
- Ribosomes—Tiny particles composed of protein and RNA that are the sites of protein synthesis.
- Actin cytoskeleton—Long fibers of proteins that encircle the cell just inside the cell membrane and contribute to the shape of the cell.
- Cytoplasm—Water-based solution filling the entire cell.

In Some Bacteria

- Fimbriae—Fine, hairlike bristles extending from the cell surface that help in adhesion to other cells and surfaces.
- Outer membrane—Extra membrane similar to cell membrane but also containing polysaccharides. Controls flow of materials, and portions of it are toxic to mammals when released.
- Inclusion/Granule—Stored nutrients such as fat, phosphate, or glycogen deposited in dense crystals or particles that can be tapped into when needed.
- Flagellum—Specialized appendage attached to the cell by a basal body that holds a long, rotating filament. The movement pushes the cell forward and provides motility.
- Plasmid—Double-stranded DNA circle containing extra genes.
- Capsule (tan coating)—A coating or layer of molecules external to the cell wall. It serves protective, adhesive, and receptor functions. It may fit tightly or be very loose and diffuse. Also called slime layer and glycocalyx.
Prokaryotic Shapes and Arrangements

• Most prokaryotes exist as unicellular organisms - sometimes they can act as a group, in colonies or in biofilms

• On average, prokaryotic cells are 1 μm (microns) - can range from 0.05 -0.2 μm (“nanobes”) to 750 μm

• Cells of one species may vary in shape and size - this is **pleomorphism** caused by variations in cell wall structure
### Table 3.1 Bacterial Shapes

<table>
<thead>
<tr>
<th>Shape</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Cocccus</td>
<td>If the cell is spherical or ball-shaped, the prokaryote is described as a cocccus (kōk’-us). Cocci (kōk’-sī) can be perfect spheres, but they also can exist as oval, bean-shaped, or even pointed variants. This is a Deinococcus (2,000×).</td>
</tr>
<tr>
<td>(b) Rod/Bacillus</td>
<td>A cell that is cylindrical is termed a rod, or bacillus (bā sil’-lus). There is also a genus named Bacillus. Rods are also quite varied in their actual form. Depending on the species, they can be blocky, spindle-shaped, round-ended, long and threadlike (filamentous), or even club-shaped or drumstick-shaped. Note: When a rod is short and plump, it is called a coccobacillus. This is a Lactobacillus (5,000×).</td>
</tr>
<tr>
<td>(c) Vibrio</td>
<td>A rod that is gently curved is a vibrio (vib’-ree-oh). This is a Vibrio cholerae (13,000×).</td>
</tr>
<tr>
<td>(d) Spirillum</td>
<td>A bacterium having a slightly curled or spiral-shaped cylinder is called a spirillum (spyril’-em). a rigid helix, twisted twice or more along its axis (like a corkscrew). This is an Aquaspirillum (7,500×).</td>
</tr>
<tr>
<td>(e) Spirochete</td>
<td>Another spiral cell containing periplasmic flagella is the spirochete, a more flexible form that resembles a spring. These are spirochetes (14,000×).</td>
</tr>
<tr>
<td>(f) Branching filaments</td>
<td>A few bacteria produce multiple branches off of a basic rod structure, a form called branching filaments. This is a Streptomyces (1,500×).</td>
</tr>
</tbody>
</table>

(a,b): CDC/Janice Haney Carr; (c): Fig 2b from Jacob S. Teppema, "In Vivo Adherence and Colonization of Vibrio Cholerae Strains that differ in Hemagglutinating Activity and Motility" Journal of Infection and Immunity, 55(9): 2093–2102, Sept. 1987. Reprinted by permission of American Society for Microbiology; (d): USDA/Photo by De Wood. Digital coloration by Chris Pooley; (e): © VEM/Photo Researchers; (f): © Science VU/Frederick Mertz/Visiats Unlimited
Arrangement of Cocci Resulting from Different Planes of Cell Division

- **Division in one plane**
  - Diplococcus (two cells)
  - Streptococcus (variable number of cocci in chains)

- **Division in two perpendicular planes**
  - Tetrad ( cocci in packets off our)
  - Sarcina (packet of 8–64 cells)

- **Division in several planes**
  - Irregular clusters (number of cells varies)

Staphylococci and Micrococci

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External Structures

Flagella – Prokaryotic Propellers

• Bacterial locomotion

• Three distinct parts

• Comprised of many proteins

• $360^\circ$ rotation

Flagellar Arrangements

- Monotrichous: single flagellum
- Lophotrichous: small bunches or tufts of flagella
- Amphitrichous: flagella at both poles of the cell
- Peritrichous: flagella dispersed randomly over the surface of the cell
Bacterial Movement

- Bacteria move in response to chemical signals (chemotaxis)
- Receptors bind extracellular molecules, which triggers flagellum to rotate

**Runs**: smooth linear movement toward a stimulus

**Tumbles**: flagellar rotation reverses, causing the cell to stop and change its course
Prokaryotic Appendages

- Fimbriae: used for attachment
- Pili: used for attachment and genetic exchange during conjugation
Glycocalyx

• Composed of polysaccharides, proteins or both
• Varies in thickness
• Used to avoid **phagocytosis** and for **adhesion** (biofilms)

![Diagram of glycocalyx process](b: © Science VU–Charles W. Stratton/Visuals Unlimited)
Capsule

- Bound more tightly to the cell, denser and thicker than a slime layer
- Visible by negative staining
- Produces a sticky (mucoid) character to colonies
- Encapsulated bacterial cells generally have greater pathogenicity
Cell Envelope

• Lies outside of the cytoplasm

• Composed of two or three basic layers:
  - cell wall
  - cell membrane
  - outer membrane in some bacteria
Peptidoglycan Cell Wall

- Repeating framework of long glycans (sugar) chains cross-linked by short peptides (protein) fragments
- Present in most bacteria
- Provides strength to resist rupturing due to osmotic pressure

![Chemical structures of peptidoglycan](image)

(a) Glucose
(b) N-acetylglucosamine (NAG) and N-acetylmuramic acid (NAM)
Pared celular procariota

Peptidoglícano: polímero de dos azúcares modificadas (*N*-acetil glucosamina y *N*-acetil ácido murámico) y tetrapéptidos

Enlace β, 1-4

\[ \text{G} = \text{N-acetil glucosamina} \]

\[ \text{M} = \text{N-acetil ácido murámico (mureína)} \]

← tetrapéptido (4 amino ácidos)
Peptidoglícano

1X Gram +

25X Gram +
Pared celular procariota

Gram–positive
- Peptidoglycan
- Membrane

Gram–negative
- Peptidoglycan
- Membrane
- Periplasm
- Outer membrane (lipopolysaccharide and protein)
(a) The peptidoglycan can be seen as a crisscross network pattern similar to a chainlink fence.

(b) It contains alternating glycans (G and M) bound together in long strands. The G stands for N-acetyl glucosamine, and the M stands for N-acetyl muramic acid.

(c) A detailed view of the links between the muramic acids. Tetrapeptide chains branching off the muramic acids connect by interbridges also composed of amino acids. It is this linkage that provides rigid yet flexible support to the cell and that may be targeted by drugs like penicillin.
Gram Positive Cell

- Thick peptidoglycan
- Teichoic acid, lipoteichoic acid
- One membrane
Gram Negative Cell

• Thin peptidoglycan
• Lipopolysaccharide
• Two membranes
• Porins
Lipopolysaccharide

• Located in the outermost layer of the outer membrane (OM) in **gram-negative** bacteria

• Lipid A (**endotoxin**) stimulates fever and shock
Cell-Wall Deficient Bacteria

- Cell membrane stabilized by sterols, is resistant to lysis i.e. *Mycoplasma pneumoniae*
- Other cell-wall deficient types called L forms are linked to infections
Cytoplasmic Membrane

- A lipid bilayer with proteins embedded
  - bacterial cell membranes contain primarily phospholipids (30%–40% of the membrane mass) and proteins (60%–70% of the membrane mass)

- Provides a site for reactions
  - contains enzymes of respiration and ATP synthesis since prokaryotes lack mitochondria

- A major action of the cell membrane is to regulate the passage of nutrients into and out of the cell
The Cytoplasm

• 70-80% water

• Soluble proteins, salts, carbohydrates, ribosomes

• Site of nearly all chemical reactions

• Contains the DNA in the **nucleoid**
Bacterial DNA

• DNA of most bacteria exists in the form of a single circular bacterial chromosome

• DNA is aggregated in a dense area of the cell called the nucleoid

• Many bacteria contain other, nonessential pieces of DNA called plasmids
Prokaryotic Ribosome

• Two subunits (30S and 50S)

• Total size is 70S (versus 80S in eukaryotes)

• 60% rRNA and 40% protein

• Translates mRNA into proteins
+ 21 proteins

+ 34 proteins

16S rRNA

23S rRNA

5S rRNA

Mature RNAs

subunit 50S

subunit 30S

Prokaryotic ribosome 70S
Polímeros de almacenamiento de carbono: 
**poly β-hydroxybuterate**-lípido polimerizado que se almacena cuando hay fuentes de carbono en exceso

**Inclusions or Granules: Storage Bodies**

vesículas de gas: compartimiento delimitado por una membrana impermeable al agua y solutos. Solo gases pueden pasar. Presentes en bacterias planctónicas (de existencia flotante) facilita movimiento en respuesta a estímulos ambientales.
The Cytoskeleton

- Peptidoglycan layer determines shape of many bacteria
- Others use protein fibers composed of actin and tubulin to alter cell shape
Bacterial Endospores

• Dormant bodies

• Heat resistance due to calcium and dipicolinic acid content

• Cortex, spore coats protect against radiation and chemicals

• Metabolically active vegetative cells can undergo **sporulation**

• Sporulation is **not** a reproductive function for most bacteria

• When spores of *Clostridium sp.* are embedded in a wound with dead tissue, they can germinate, grow, and release toxins
A Typical Sporulation Cycle in *Bacillus* Species

1. Vegetative cell begins to be depleted of nutrients.
2. Chromosome is duplicated and separated.
3. Cell is septated into a sporangium and forespore.
4. Sporangium engulfs forespore for further development.
5. Sporangium begins to actively synthesize spore layers around forespore.
6. Cortex and outer coat layers are deposited.
7. Mature endospore
8. Frees pore is released with the loss of the sporangium.

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Archaea

- **Prokaryotic** microorganisms
- Many are found in **extreme environments** (i.e. psychrophiles)
- Different from members of the domains Bacteria and Eukarya in terms of: cell structure, metabolism, genetics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Bacteria</th>
<th>Archaea</th>
<th>Eukarya</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell type</td>
<td>Prokaryotic</td>
<td>Prokaryotic</td>
<td>Eukaryotic</td>
</tr>
<tr>
<td>Chromosomes</td>
<td>Single, or few circular</td>
<td>Single, circular</td>
<td>Several, linear</td>
</tr>
<tr>
<td>Types of ribosomes</td>
<td>70S</td>
<td>70S but structure is similar to 80S</td>
<td>80S</td>
</tr>
<tr>
<td>Contains unique ribosomal RNA signature sequences</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Number of sequences shared with Eukarya</td>
<td>1</td>
<td>3</td>
<td>(all)</td>
</tr>
<tr>
<td>Protein synthesis similar to Eukarya</td>
<td>−</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Presence of peptidoglycan in cell wall</td>
<td>+</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>Cell membrane lipids</td>
<td>Fatty acids with ester linkages</td>
<td>Long-chain, branched hydrocarbons with ether linkages</td>
<td>Fatty acids with ester linkages</td>
</tr>
<tr>
<td>Sterols in membrane</td>
<td>− (some exceptions)</td>
<td>−</td>
<td>+</td>
</tr>
</tbody>
</table>
Classification Systems

• For differentiating and identifying unknown microbial species
  i.e. *Bergey’s Manual of Determinative Bacteriology* (phenotypic data)

• For studying prokaryotic relationships and origins
  i.e. *Bergey’s Manual of Systematic Bacteriology* (rRNA sequencing data)
Species and Subspecies in Prokaryotes

- Theoretically, a collection of bacterial cells, all of which share an overall similar pattern of traits and 70%–80% of their genes.

- Members of given species can show variations:
  - **subspecies**, **strain**, or **type** are terms used to designate bacteria of the same species that have differing characteristics.
  - **serotype** refers to representatives of a species that stimulate a distinct pattern of antibody (serum) responses in their hosts.