Prokaryotic Cell
Structure & Function
How are Prokaryotes Different from Eukaryotes?

• The way their DNA is packaged
  – No nucleus
  – Not wrapped around histones

• The makeup of their cell wall
  – Bacteria- peptidoglycan
  – Archae- tough and made of other chemicals, distinct to them

• Their internal structures
  – No complex, membrane-bound organelles
4.1 Prokaryotic Form and Function

Prokaryotic cell

External
- Appendages
  - Flagella
  - Pili
  - Fimbriae
- Glycocalyx
- Capsule, slime layer

Cell envelope
- (Outer membrane)
- Cell wall
- Cell membrane

Internal
- Cytoplasm
- Ribosomes
- Inclusions
- Nucleoid/chromosome
- Actin cytoskeleton
- Endospore
Structures in bacterial cells

Structures common to all bacterial cells
- Cell membrane
- Cytoplasm
- Ribosomes
- One (or a few) chromosomes

Structures found in most bacterial cells
- Cell wall
- Surface coating or glycocalyx

Structures found in some bacterial cells
- Flagella
- Pili
- Fimbriae
- Capsules
- Slime layers
- Inclusions
- Actin cytoskeleton
- Endospores
Glycocalyx (pink 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.

Bacterial chromosome or nucleoid—Composed of condensed DNA molecules. DNA directs all genetics and heredity of the cell and codes for all proteins.

Plasmid—Double-stranded DNA circle containing extra genes.

Pilus—An elongate, hollow appendage used in transfers of DNA to other cells.

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.

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.

Fimbriae—Fine, hairlike bristles extending from the cell surface that help in adhesion to other cells and surfaces.

Inclusion/Granule—Stored nutrients such as fat, phosphate, or glycogen deposited in dense crystals or particles that can be tapped into when needed.

Cell wall—A semirigid casing that provides structural support and shape for the cell.

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.

Outer membrane—Extra membrane similar to cell membrane but also containing lipopolysaccharide. Controls flow of materials and portions of it are toxic to mammals when released.

Endospore (not shown)—Dormant body formed within some bacteria that allows for their survival in adverse conditions.

Cytoplasm—Water-based solution filling the entire cell.
Bacterial Internal Structure

- Contents of the Cell **Cytoplasm**
  - Gelatinous solution
  - Site for many biochemical and synthetic activities
  - 70%-80% water
  - Also contains larger, discrete cell masses (chromatin body, ribosomes, granules, and actin strands)
  - Location of growth, metabolism, and replication
Bacterial Chromosome

- Single circular strand of DNA
- Aggregated in a dense area of the cell-the nucleoid

Plasmids
- Nonessential, circles of DNA (5-100 genes)
- Present in cytoplasm but may become incorporated into the chromosomal DNA
- Often confer protective traits such as drug resistance or the production of toxins and enzymes
- Pass on in conjugation
Inclusions

• Inclusions- also known as *inclusion bodies*
  – Some bacteria lay down nutrients in these inclusions during periods of nutrient abundance
  – Serve as a storehouse when nutrients become depleted
  – Some enclose condensed, energy-rich organic substances
  – Some aquatic bacterial inclusions include gas vesicles to provide buoyancy and flotation
Granules

• A type of inclusion body
• Contain crystals of inorganic compounds
• Are not enclosed by membranes
• Staining of some granules aids in identification.
The Glycocalyx

- a coating of repeating polysaccharide, protein, or both
- Protects the cell
- Can help the cell adhere to the environment
- **Slime layer** - a loose shield that protects some bacteria from loss of water and nutrients
- **Capsule** - when the glycocalyx is bound more tightly to the cell and is denser and thicker
Functions of the Glycocalyx

Many pathogenic bacteria have glycocalyxes
• Protect the bacteria against phagocytes
• Important in formation of biofilms
• _Streptococcus_
  – form a biofilm & eventually a buildup of plaque.
  – The slime layer of _Gram+ Streptococcus mutans_ allows it to accumulate on tooth enamel (yuck mouth and one of the causes of cavities).
  – Other bacteria in the mouth become trapped in the slime
Prokaryotes - **Glycocalyx**

2. **Capsule**

- Polysaccharides firmly attached to the cell wall.
- Capsules adhere to solid surfaces and to nutrients in the environment.
- Adhesive power of capsules is a major factor in the initiation of some bacterial diseases.
- Capsule also protect bacteria from being phagocytized by cells of the hosts immune system.
Bacterial **Endospores**: An Extremely Resistant Stage

- Dormant, tough, non-reproductive structure produced by small number of bacteria.

- Resistant to radiation, desiccation, lysozyme, temperature, starvation, and chemical disinfectants.

- Endospores are commonly found in soil and water, where they may survive for very long periods of time.
Prokaryotes

Cytoskeleton

- Cellular "scaffolding" or "skeleton" within the cytoplasm.

- Major advance in prokaryotic cell biology in the last decade has been discovery of the prokaryotic cytoskeleton.

- Up until recently, thought to be a feature only of eukaryotic cells.
Prokaryotes

Ribosomes

- Found within cytoplasm or attached to plasma membrane.
- Made of protein & rRNA.
- Composed of two subunits.
- Cell may contain thousands.
- Protein synthesis
The Cell Envelope: The Boundary layer of Bacteria

- Majority of bacteria have a cell envelope
- Lies outside of the cytoplasm
- Composed of two or three basic layers
  - Cell membrane
  - Cell wall
  - In some bacteria, the outer membrane
Plasma Membrane

• Separates the cell from its environment

• Phospholipid bilayer with proteins embedded in two layers of lipids (lipid bilayer)

• Functions
  • Provides a site for functions such as energy reactions, nutrient processing, and synthesis
  • Regulates transport (selectively permeable membrane)
  • Secretion
Differences in Cell Envelope Structure

• The differences between **gram-positive** and **gram-negative** bacteria lie in the cell envelope

• Gram-positive
  – Two layers
  – Cell wall and cytoplasmic membrane

• Gram-negative
  – Three layers
  – Outer membrane, cell wall, and cytoplasmic membrane
Bacterial Cell Wall

- **Peptidoglycan** is a huge polymer of interlocking chains of alternating monomers.
- Provides rigid support while freely permeable to solutes.
- Backbone of peptidoglycan molecule composed of two amino sugar derivatives of glucose. The “glycan” part of peptidoglycan:
  - N-acetylg glucosamine (NAG)
  - N-acetylmuramic acid (NAM)
- NAG / NAM strands are connected by interlocking peptide bridges. The “peptid” part of peptidoglycan.
Structure of the Cell Wall

- Provides shape and strong structural support
- Most are rigid because of peptidoglycan content

- Target of many antibiotics - disrupt the cell wall, and cells have little protection from lysis
- Gram-positive cell (2 layers)
  - A thick (20 to 80 nm) peptidoglycan cell wall and membrane

- Gram-Negative Cell (3 layers)
  - Outer membrane
  - Single, thin (1 to 3 nm) sheet of peptidoglycan (Periplasmic space surrounds the peptidoglycan)
  - Cell membrane
Figure 4.14
The Gram-Negative Outer Membrane

• Similar to the cell membrane, except it contains specialized polysaccharides and proteins
• Outermost layer- contains lipopolysaccharide (LPS)
• Innermost layer- phospholipid layer anchored by lipoproteins to the peptidoglycan layer below
• Outer membrane serves as a partial chemical sieve
  – Only relatively small molecules can penetrate
  – Access provided by special membrane channels formed by porin proteins
Practical Considerations of Differences in Cell Envelope Structure

• Outer membrane- an extra barrier in gram-negative bacteria
  – Makes them impervious to some antimicrobial chemicals
  – Generally more difficult to inhibit or kill than gram-positive bacteria

• Cell envelope can interact with human tissues and cause disease
  – *Corynebacterium diphtheriae*
  – *Streptococcus pyogenes*
From the peptidoglycan inwards all bacteria are very similar. Going further out, the bacterial world divides into two major classes (plus a couple of odd types). These are:

- **Gram-positive**
- **Gram-negative**
Prokaryotes - Cell Wall
Gram-Positive & Gram-Negative

Gram-positive Cell Wall
- Peptidoglycan
- Protein
- Phospholipid
- Cytoplasm

Gram-negative Cell Wall
- Peptidoglycan
- Protein
- LPS
- Lipoprotein
- Phospholipid
- Cytoplasm

GRAM POSITIVE
- Polysaccharides
- Outer Membrane
- Periplasmic Space
- Inner Membrane

GRAM NEGATIVE
- Porins
- Outer Membrane
- Periplasmic space
- Protein
- Phospholipid
Q: Why are these differences in bacterial cell wall structure so important?
Nontypical Cell Walls

• Some aren’t characterized as either gram-positive or gram-negative
• For example, *Mycobacterium* and *Nocardia*—unique types of lipids (acid-fast)
• Archaea – no peptidoglycan
• **Mycoplasmas**—lack cell wall entirely
External Structures

• **Appendages:** Cell extensions
  – Common but not present on all species
  – Can provide **motility** (*flagella* and axial filaments)
  – Can be used for attachment and mating (*pili* and *fimbriae*)
Prokaryotes - Surface Appendages

- **fimbriae**: Most Gram-negative bacteria have these short, fine appendages surrounding the cell. Gram+ bacteria don’t have.

  No role in motility. Help bacteria adhere to solid surfaces. Major factor in virulence.
  (singular: fimbria)

- **pili**: Tubes that are longer than fimbriae, usually shorter than flagella.

  Use for movement, like grappling hooks, and also use conjugation pili to transfer plasmids. (singular = pilus)
Prokaryotes - Cell Shapes

Most bacteria are classified according to shape:

1. **bacillus** (pl. **bacilli**) = rod-shaped

2. **coccus** (pl. **cocci** ... sounds like cox-eye) = spherical

3. spiral shaped
   a. **spirillum** (pl. **spirilla**) = spiral with rigid cell wall, flagella
   b. **spirochete** (pl. **spirochetes**) = spiral with flexible cell wall, axial filament

**Pleomorphism** - when cells of a single species vary to some extent in shape and size

There are many more shapes beyond these basic ones. A few examples:

- Coccobacilli = elongated coccal form
- Filamentous = bacilli that occur in long threads
- Vibrios = short, slightly curved rods
- Fusiform = bacilli with tapered ends
Figure 4.22

Coccus
- Diplococci (cocci in end-to-end pairs)
- Diplococci (cocci in side-to-side pairs)
- Tetrads (cocci in packets of 4)
- Sarcinae (cocci in packets of 8, 16, 32 cells)

Rod, or Bacillus
- Pill-shaped rods
- Cocccobacilli
- Irregular rods
- Palisades arrangement
- Spores

Curved or Spiral Forms
- Vibrios (curved rods)
- Spirilla
- Filamentous rods seen in some moldlike bacteria
- Spirochets
Arrangement, or Grouping

• Cocci- greatest variety in arrangement
  – Single
  – Pairs (diplococci)
  – Tetrads
  – Irregular clusters (staphylococci and micrococci)
  – Chains (streptococci)
  – Cubical packet (sarcina)

• Bacilli- less varied
  – Single
  – Pairs (diplobacilli)
  – Chain (streptobacilli)
  – Row of cells oriented side by side (palisades)

• Spirilla
  – Occasionally found in short chains
Prokaryotes - Arrangements of Cells

- Bacteria sometimes occur in groups, rather than singly.

- **bacilli** divide along a single axis, seen in pairs or chains.

- **cocci** divide on one or more planes, producing cells in:
  - pairs (diplococci)
  - chains (streptococci)
  - packets (sarcinae)
  - clusters (staphylococci).

- Size, shape and arrangement of cells often first clues in identification of a bacterium.

- Many “look-alikes”, so shape and arrangement not enough for id of genus and species.
Prokaryotic reproduction

• **binary fission** - this process involves copying the chromosome and separating one cell into two
  – **asexual** form of reproduction
• **Transformation** - the prokaryote takes in DNA found in its environment that is shed by other prokaryotes.
• **transduction** - bacteriophages, the viruses that infect bacteria, sometimes also move short pieces of chromosomal DNA from one bacterium to another
• **Conjugation** - DNA is transferred from one prokaryote to another by means of a pilus