I. Comparing Prokaryotic and Eukaryotic Cells: An Overview
   A. Prokaryotes
      1. Nucleus is not enclosed within the membrane.
      2. No histones are present with the DNA.
      3. No membrane bound organelles
      4. Cell walls are composed of peptidoglycan.
      5. Division is accomplished through binary fission
   B. Eukaryotes
      1. DNA is bound in a nucleus.
      2. DNA is associated with histones.
      3. Membrane bound organelles are present (i.e. mitochondria)
      4. Cell walls, if present, are chemically simple.
      5. Division is accomplished through the process of mitosis.

II. The Size, Shape, and Arrangement of Bacterial Cells
   A. Coccus (plural – cocci) – Spherical shaped bacteria
      1. Diplococci – spherical bacteria that remain joined in pairs (Neiserria)
      2. Streptococci – spherical bacteria that divide along one plane and remain connected in a chain (Streptococcus)
      3. Tetrad – spherical bacteria that divide in two planes and remain connected in an arrangement of four bacteria (Micrococcus)
      4. Sarcinae – spherical bacteria that divide in three planes and remain connected in a cubic formation (Sacrina)
      5. Staphylococci – spherical bacteria that in multiple planes and remain grouped in amorphous clusters (Staphylococcus)
   B. Bacillus (plural – bacilli) – Rod shaped bacteria
      1. Diplobacilli – bacteria that appear connected after division
      2. Streptobacilli – bacillus that are connected as a chain
      3. Coccobacilli – bacilli that have a slightly rounded shape
   C. Spiral – Spiral shaped bacteria
      1. Vibrios – bacteria that look like curved rods
      2. Spirilla – helical shaped bacteria that are rigid
      3. Spirochetes – helical shaped bacteria that are flexible
   D. Other Shapes
      1. Star-shaped
      2. Rectangular
      3. Triangular
   E. Monomorphic – bacteria that have a single genetically determined shape
   F. Pleomorphic – bacteria that have multiple possible shapes

III. Structures External to the Cell Wall
A. Glycocalyx – “sugar coat,” substances that surround the outside of the bacterial cell wall.

1. **Capsule** – organized and firmly attached to the cell wall
2. **Slime Layer** – unorganized and loosely attached to the cell wall
3. These layers can be composed of carbohydrates and/or polypeptides
4. Glycocalyx serve in many bacteria as a protection device, blocking the immune system from attacking them.

B. Flagella – (singular – flagellum) long whip-like appendages that propel bacteria

1. Terminology for flagella refers to the number present and their arrangement on the bacteria.
   a. **Atrichous** – no flagellum present
   b. **Monotrichous** – single polar flagellum
   c. **Amphitrichous** – tuft of flagella at each end of the cell
   d. **Lophotrichous** – two or more flagella at one or both ends of the cells.
   e. **Peritrichous** – flagella distributed over the entire cell

2. The basic structure of a flagellum is in three parts
   a. **Filament** – the long outermost portion forms as a helix of flagelin.
   b. **Hook** – wider base of the flagellum
   c. **Basal body** – the point of connection with the plasma membrane.

3. **Motility** – the movement of bacteria
   a. **Taxis** – movement of bacteria towards a stimulus
   b. **Chemotaxis** – movement triggered by chemicals
   c. **Phototaxis** – movement triggered by light

C. Axial Filaments – bundles of fibrils that run from the ends of the cell beneath the outer sheath and spiral around a bacteria (*Treponema*), that enable a corkscrew-like motion.

D. Fimbriae and Pili

1. **Fimbriae** – (singular – fimbria) tube-like structures that grow out of gram-negative bacteria. These occur in clumps or spread across the entire surface that allow for attachment of bacteria.
2. **Pili** – (singular – pilus) tube-like structures that occur in low numbers and allow for the transfer of DNA between bacterial cells.

IV. The Cell Wall

A. The cell wall is a semi-rigid structure that is responsible for the structure of a cell.

B. Composition and Characteristics

1. The cell wall is composed of a material called peptidoglycan
2. Peptidoglycan is a macromolecule composed of repeating carbohydrate attached by polypeptides.
3. Gram-Positive Cell Walls are composed of multiple layers of peptidoglycan that form thick, rigid structure. The wall has a complex but organized structure based on a number of components.
   a. **N-acetylglucosamine** (NAG), a carbohydrate utilized in the backbone
   b. **N-acetylmuramic acid** (NAM), a carbohydrate utilized in the backbone
   c. NAG and NAM are cross-linked with peptide sidechains and crossbridges between NAM subunits.
   d. **Teichoic acid** – alcohol and phosphate compound, in two forms.
      i. **Lipoteichoic acid** – spans the peptidoglycan layer and links to the plasma membrane.
      ii. **Wall teichoic acid** – crosslinks layers of peptidoglycan.

4. Gram-Negative Cells Walls are composed of only a few layers of peptidoglycan that is covered by a second plasma membrane (outer membrane).
   a. The peptidoglycan layer is bonded to lipoproteins in the outer layer.
   b. The **periplasm** is the gel-like substance between the outer and inner membranes.
   c. Gram-negative bacteria do not contain teichoic acids.
   d. The outer membrane contains a number of modified proteins and lipids, especially **lipopolysaccharides**, which can be toxic.

C. Cell Walls and the Gram Stain Reaction

D. Atypical Cell Walls
   1. **Mycoplasma** – small wall-less bacteria whose membranes contain sterols.
   2. Acid-Fast Cell Walls – **Mycobacterium** and some **Nocardia** contain high concentrations of a waxy hydrophobic material called **mycolic acid**. This helps to prevent uptake by immune cells.

E. Damage to the Cell Wall
   1. Cell walls are a popular target for antimicrobials, since the structure has no analogies in eukaryotes.
   2. An enzyme that is naturally produced by some eukaryotic cells, **lysozyme**, can digest peptidoglycan.
   3. Gram-positive bacterial cells without their cell wall are referred to as **protoplast**. Protoplasts are typically spherical and capable of continuing their metabolism.
4. Gram-negative bacterial cells have to be exposed to something to disrupt their outer membranes before they can be attacked by lysozyme, the resulting form is called a spheroplast.

5. Both protoplasts and spheroplasts are sensitive to disruption by osmotic lysis (rupturing of cells by osmotic pressure).

V. The Plasma Membrane
A. The Plasma Membrane – a thin lipid bilayer that encases the cytoplasm of the cell.
B. The plasma membrane is composed of phospholipids in a lipid bilayer arrangement, where the hydrophilic heads point out and the hydrophobic tails are sequestered to the center.
C. Proteins are also part of the plasma membrane.
D. The plasma membrane is a dynamic material in which all components are capable of movement laterally through the surface; this dynamic arrangement is called the fluid mosaic model.
E. Functions
1. Selective Permeability – (semipermeability) The property of allowing certain ions and molecules to pass while blocking others.
2. Nutrient breakdown
3. Energy production
F. Plasma Membranes can be disrupted by some antibiotics, especially polymyxins.
G. Movement of Materials across Membranes
1. Passive Process – does not require energy to occur
   a. Simple Diffusion – the net overall movement of ions or molecules from a location of high concentration to low concentration.
   b. Facilitated Diffusion – Diffusion that occurs through a protein called a transporter.
   c. Osmosis – the net movement of solvent molecules across a semipermeable membrane from an area of high concentration to that of low concentration.
      i. Osmotic pressure – the pressure required to prevent the movement of pure water across a semipermeable membrane.
      ii. Isotonic – solutes concentration is equal inside and outside a membrane
      iii. Hypotonic – solutes are at a lower concentration outside the cell than inside
      iv. Hypertonic – solutes are at a higher concentration outside the cell than inside
2. Active Processes – movement across a membrane that requires energy.
   a. Active Transport – The cell uses ATP to pump materials against the gradient.
b. Prokaryotes possess a special type of active transport called **group translocation**, in which the transported substance is chemically altered so that the membrane is impermeable to the new material.

VI. **Cytoplasm** – the substance that makes up the interior of the cell. It is mainly a gel-like material made of approximately 80% water.

VII. **The Nuclear Area (Nucleoid)**
A. The **nucleoid** of the bacterial contains a nonsequestered bacterial chromosome.
B. Bacteria also contain independent circular DNA fragments called **plasmids**.

VIII. **Ribosomes**
A. Ribosomes are the site of protein synthesis
B. Ribosomes are significantly different between eukaryotic and prokaryotic cells, allowing for selective inhibition with antibiotics.

IX. **Inclusions** – reserve deposits of material in the cytoplasm
A. **Metachromatic Granules (Volutin)** – inorganic stores of phosphate present in cells that live in phosphate-rich regions.
B. **Polysaccharide Granules** – Typically consist of glycogen or starch
C. **Lipid Inclusions** – composed of a unique polymer in bacteria called poly-β-hydroxybutyric acid
D. **Sulfur Granules** – Inclusions of sulfur that serve as energy reserves for “sulfur bacteria.”
E. **Carboxysomes** – Inclusions that contain the enzyme ribulose 1,5-diphosphate carboxylase, a necessary enzyme for photosynthesis.
F. **Gas Vacuoles** – inclusions made of several hundred cylindrical gas vesicles that are utilized for buoyancy.
G. **Magnetosomes** – inclusions composed of iron oxide

IX. **Endospores**
A. **Endospores** are the dormant state that some bacteria can produce in response the adverse environmental conditions. (notably *Bacillus* and *Clostridium*)
B. Almost exclusive to gram-positive bacteria, but one gram-negative species, *Coxiella burnetti*, does produce a similar structure.
C. The process of endospore production is called **sporulation**.
D. Endospores do not undergo metabolism and have very little water.
E. The water in endospores is replaced with Calcium ions and Dipicolinic acid.
F. The process of endospores coming out of dormancy is called **germination**.