ARKAN
ACADEMY

MICROBIOLOGY 1

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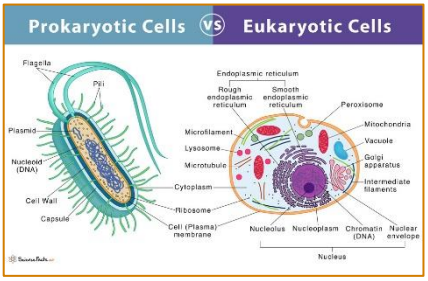
2025

Study smarter, not harder!

Characteristics of Prokaryotic and Eukaryotic Cells

- **Prokaryotes vs. Eukaryotes**
  - All living cells are classified to prokaryotes & eukaryotes

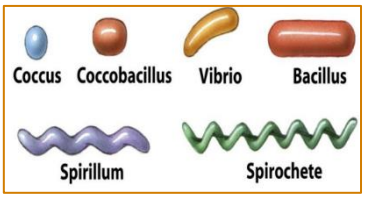


    1. **Prokaryotes**
       - ✓ *Lack* true nucleus
       - ✓ *Single*-celled
       - ✓ *Bacteria* & *Archaea*
    2. **Eukaryotes**
       - ✓ *True* nucleus
       - ✓ *Single*-celled or *multi*cellular
       - ✓ Plants, animals, fungi, protists (amoeba, paramecium, malaria parasite)
  - Similarities
    - ✓ Surrounded by *cell membrane* (plasma membrane) which defines the boundaries of living cell
    - ✓ Encodes genetic information in *DNA*
  - Major differences

Prokaryotes	Eukaryotes
DNA in circular chromosome, in nuclear region (*nucleoid*) not surrounded by membrane	DNA in paired chromosomes, in *nucleus* surrounded by membrane nuclear envelope
Lack organelles that are membrane enclosed	*Organelles* surrounded by membranes
Reproduction by *binary fission*	*Mitosis* and/or *meiosis*

  - Classification of organisms All living cells are classified to 3 domains
    1. Archaea = ancient (archaeobacteria)
    2. Bacteria (eubacteria)
    3. Eukarya
  - Archaea & bacteria are prokaryotes while eukarya are eukaryotes
  - So far archaea are not known to cause disease.
    - ✓ Found in hydrothermal vents & extreme environment

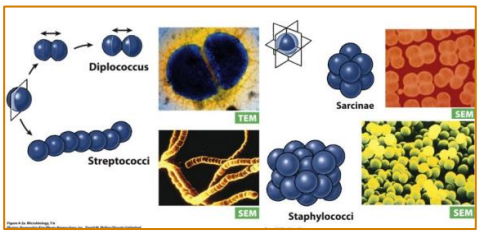
- **Prokaryotes**
  - **Size**
    - ✓ Bacteria are among the *smallest* organisms
    - ✓ Most bacterial cells are *0.5-2.0 µm* (or 0.5-5.0 µm) in diameter
    - ✓ *Exceptions*:
      - Mycoplasma only measures 0.3 µm while Cyanobacteria can be up to 60 µm long
  - **Shape**
    - ✓ *Spherical* (coccus/*cocci*)
    - ✓ *Rod*-shaped (bacillus/*bacilli*) Some bacteria are considered coccobacilli
    - ✓ *Spiral*: which can be comma-shaped (*vibrio*), rigid wavy-shaped (*spirillum*) or corkscrew-shaped (*spirochete*)
    - ✓ Other *atypical shapes*: *spindle* shape, square, lobed, triangular
    - ✓ Some bacteria vary widely in single culture, a phenomenon known as *pleomorphism*



➢ **Arrangement**

- Variable *arrangements* of groups of cells may result due to *cell division* without full separation

1. Cocci
   - Division in *1* plane →*diplo* (pair)
   - Division in *2* planes → *tetrads* (4 cells in a cube)
   - Division in *3* planes → *sarcinae* (8 cells in a cube)
   - Division in *chains* → *strepto*
   - *Random* division → *grapelike* clusters (staphylo)



2. Bacilli - Can only divide in *one plane*; either end-to-end or side-by-side
3. Spiral bacteria - *Not* generally *grouped* together

- **Structure of Bacterial Cells:** [cell envelope]

1. Cell Wall

➢ The cell wall is a semi-rigid structure that lies *outside* the cell membrane

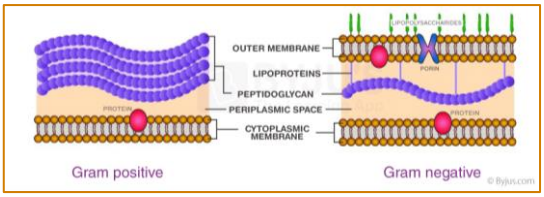
➢ *Functions* of the bacterial cell wall:

1. Maintains the characteristic *cell shape*
   - If the cell wall is digested by certain enzymes, the cell will become spherical
2. *Prevents* the cell from *bursting* when fluids flow into the cell by osmosis (allows a high cell turgidity)

➢ The bacterial cell wall is *porous* and *doesn't control* the entry of molecules into the cell.

➢ *Components* of the bacterial *cell wall*:

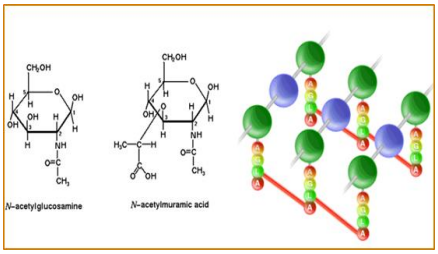
1. Peptidoglycan
2. Outer membrane (G-ve)
3. Periplasmic space (periplasm only in G+ve)



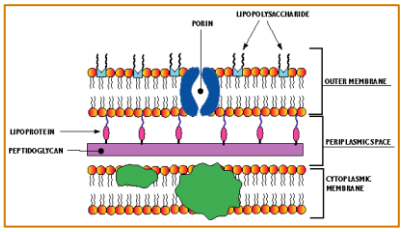
1. Peptidoglycan (murein)
   - ✓ Most *important* component of bacterial cell wall
   - ✓ Function: forms a *supporting* net around bacteria like multiple chain-link fence
   - ✓ Composition:
     1. A covalently linked polymer composed of alternating molecules of N-acetylglucoseamine (gluNAc) and N-acetylmuramic acid (murNAc)
        - Autolysin enzyme is involved in this process
     2. Polymer chains are cross-linked by tetrapeptides (chains of 4 amino acids)
        - *Different bacteria* can have *different* amino acids in the *terapeptide* chain

❖ *G+ve* bacteria have an additional molecule on the cell wall called *teichoic acid* (phosphate-glycerol-sugar alcohol) which extends beyond the rest of cell wall and even the capsule

❖ The exact *function* of teichoic acid is still unclear but it is thought to
   - Act as a passageway to *ions movement*
   - Facilitate the *attachment* of bacteriophages



1. **Outer membrane** of the cell wall of G-ve bacteria
   - ✓ Function: acts as a coarse *sieve* & has little control on movement of substances in & out of cells
     - Considered as one of the reasons why G-ve bacteria are less sensitive to penicillin (prevents their entry)



   - ✓ Composition :
     1. A phospholipid bilayer
     2. Lipoproteins:
        - ✓ Important part of G-ve
        - ✓ Faction:
          - A. Structural Support: anchor [attached] the outer membrane to the peptidoglycan layer.
          - B. Identification: Used to identify G-ve bacteria
          - C. Endotoxins (pyrogens): Integral part of outer membrane & not released unless the cell wall of dead bacteria is broken down
        - ✓ LPS consists of **two components**::
          - **Polysaccharide part**: Repeating sugar units, used to identify different G-ve bacteria and includes the O-antigen.
          - **Lipid A**: Responsible for the toxic properties of G-ve bacteria, potentially causing fever, blood vessel dilation (systemic vasodilation**)**, and can lead to septic shock.
     3. Prions: proteins form water-filled channels allowing the transport of small to medium-sized molecules

2. **Periplasmic space**
   - ✓ It is the gap between cell membrane & outer membrane (cell wall)
     - More observed in G-ve bacteria
     - G+ve have a periplasm ,but not a periplasmic space
   - ✓ Function:
     1. It is an active area of metabolism
     2. Contains digestive enzymes to destroy harmful substances
     3. Contains 'transport proteins' to transfer metabolites into the bacterial cytoplasm
   - ✓ The 'periplasm' consists of peptidoglycan, proteins & metabolites usually found in the periplasmic space

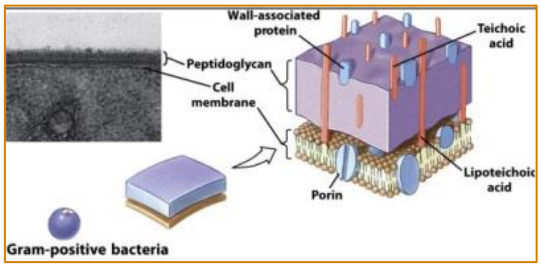
➢ Distinguishing bacteria by their cell walls based on their reaction to stains

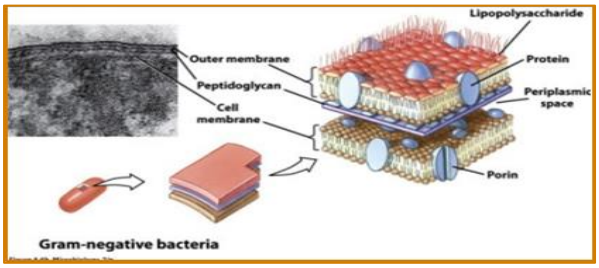
I. **Gram +ve bacteria** :

- Have a *thick peptidoglycan* layer (20-80nm, 60-90% of the cell wall) and *very little* protein
- When digested, they become **protoplasts** (cells with only the membrane and no cell wall), which burst in hypotonic solutions.
- The thick cell wall retains the *crystal violet-iodine dye*.
  - ❖ Stain retention is related to wall thickness, not peptidoglycan.
  - ❖ **Yeast cells**, which lack peptidoglycan, can also retain the stain.
- Physiological *damage* and aging can make G+ve bacteria leaky, causing the dye complex to escape and *appear* like *G-ve* bacteria.
  - ❖ This is why staining should be done on cultures less than 24 hours old

II. Gram -ve bacteria :

- Thinner but more complex cell wall compared to G+ve.
- Contains *10-20% peptidoglycan*, with the rest made up of *polysaccharides, proteins, and lipids.*
- The cell wall *includes* an outer membrane and a periplasmic space.
- If digested, it becomes a **spheroplast** (cell membrane and most of the outer membrane remain)
- **Staining**:
  - G-ve bacteria do not retain crystal violet-iodine dye during decolorization.
  - This is due to their thin peptidoglycan layer, as well as the presence of lipoproteins and lipopolysaccharides **(**LPS**)** in the outer membrane.





III. Acid-fast bacteria:

- Have *thick cell wall* like G+ve, 60% is lipid which much less peptidoglycan.
- Can be stained by *gram stain*, and will stain as stain as G+ve.
- Acid fast *staining*:
  - *Carbolfuchsin* binds to cytoplasm & resists removal by acid-alcohol mix.
  - The high lipid content makes acid-fast organisms *impermeable to most stains* and helps protect them from acids and alkalis.
- *Growth characteristics*:
  - Acid-fast bacteria grow *slowly* because the lipids *impede nutrient entry* into cells.
  - The cells use *much energy to synthesize lipids.*

Characteristics of the Cell Walls of Gram-Positive, Gram-Negative, and Acid-Fast Bacteria

Characteristic	Gram-Positive Bacteria	Gram-Negative Bacteria	Acid-Fast Bacteria
Peptidoglycan	Thick layer	Thin layer	Relatively small amount
Teichoic acid	Often present	Absent	Absent
Lipids	Very little present	Lipopolysaccharide	Mycolic acid and other waxes and glycolipids
Outer membrane	Absent	Present	Absent
Periplasmic space	Absent	Present	Absent
Cell shape	Always rigid	Rigid or flexible	Rigid or flexible
Results of enzyme digestion	Protoplast	Spheroplast	Difficult to digest
Sensitivity to dyes and antibiotics	Most sensitive	Moderately sensitive	Least sensitive

➢ **Controlling bacteria by damaging cell wall**

- ✓ ***Antibiotics*** like *penicillins* and *cephalosporins* block the final stage of peptidoglycan synthesis by inhibiting the formation of peptidoglycan cross-links.
- ✓ ***Lysozyme*** enzyme (found in tears and other body fluids) digests *peptidoglycan*

- **Wall-deficient bacteria**
  - ✓ *Mycoplasma*: Lack a cell wall, but are protected from osmotic swelling and bursting by *sterols* that strengthen the cell membrane. Mycoplasma can vary in shape.
  - ✓ Some bacteria genera have a cell wall but can lose the ability to form it. These *wall-deficient strains* are called *L-forms*.
    - The loss of the cell wall can occur naturally or due to chemical treatments (e.g., cell wall inhibitors).
    - L-forms are associated with *chronic or recurrent diseases*.

2. Cell Membrane (plasma membrane)

- Composed of *phospholipids* and *proteins*.
- Phospholipids form bilayer: phosphate (hydrophilic) and fatty acid non polar chains (hydrophobic).
  - ✓ Mycoplasma has additional sterols to add rigidity to their membrane
- *Fluid Mosaic Model:*
  - ✓ The membrane is *dynamic* and *constantly* changing.
  - ✓ In the fluid mosaic model, phospholipids are in a fluid state, and proteins form a mosaic pattern.
- *Protein molecules* in the membrane:
  - ✓ Some extend through membrane and act as carriers or form pores for material entry.
- *Functions* of cell membrane:
  - ✓ Forms *boundary* between the cell & its environment
  - ✓ *Regulates movement* of materials in & out the cell (permeability barrier).
  - ✓ Performs some functions *carried out* by other organelles in eukaryotes
    - Synthesis of cell wall component
    - Assists in DNA replication
    - Secretes proteins
    - Respiration (instead of mitochondria) & captures energy as ATP
    - Contains bases of appendages (e.g. flagella)
- Cell membrane is *dynamic*:
  - ✓ Lipids and proteins *change position* and materials flow through pores & through lipids selectively.
  - ✓ Some *antimicrobials kill* bacteria by causing *leaks* in cell membrane (i.e. polymyxin and daptomycin)

- **Structure of Bacterial Cells: Internal Structures**

1. Cytoplasm

- ✓ *Semifluid* substance inside cell membrane
- ✓ *Composed* of 4/5 water, 1/5 of substances dissolved in water (enzymes, proteins, carbohydrates, lipids, & ions)
- ✓ Most anabolic & catabolic *reactions* occur in cytoplasm

2. Ribosomes

- ✓ *Consist* of RNA & protein
- ✓ *Function* : protein synthesis
- ✓ Abundant in *cytoplasm* of bacteria & often grouped in long chains (*polyribosomes*)
- ✓ Ribosomes *shape*: spherical, contain large & small subunits
- ✓ *Size & subunit* of ribosome is determined by sedimentation rate (Svedberg units).
  - Whole bacterial ribosome = 70S, composed of 30S + 50S subunits, eukaryote's ribosome 80S composed of 40S + 60S. Certain antibiotics act on 70S but not 80S (selectivity).

3. **Nuclear region** (nucleoid)

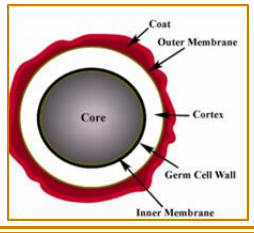
- ✓ Bacteria do ***not*** have a ***nucleus***; instead, they have a ***nuclear region*** or ***nucleoid***.
- ✓ The nuclear region contains ***DNA, proteins*** associated with it, and some ***RNA***.
- ✓ Bacteria *typically* have *one circular chromosome*, although *some* may have *two*.
- ✓ Some bacteria also contain **plasmids**, which are smaller circular DNA molecules.

4. **Inclusions**

- ✓ Small bodies known as ***granules*** or ***vesicles***
- ✓ *Granules*:
  - *Not bounded* by a membrane.
  - Contain *compacted substances* that do not dissolve in the cytoplasm.
  - Each granule holds a specific substance, such as
    - ❖ ***Glycogen*** (glucose polymer).
    - ❖ ***Polyphosphate*** (phosphate polymer to supply PO4 for metabolism)
- ✓ *Vesicles or Vacuoles*:
  - Membrane *enclosed* structures.
  - ***Gas-filled vacuoles***: Help aquatic photosynthetic bacteria control depth by regulating gas inside, ensuring optimal light exposure.
  - ***Lipid-containing vesicles***: Serve as energy stores and a carbon source for building new molecules.

5. **Endospores(bacterial spores)**

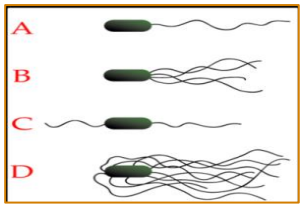
- ✓ ***Vegetative cells:*** Metabolically active cells that are metabolizing nutrients.
- ✓ Some bacteria (e.g., *Bacillus* and *Clostridium*) produce *endospores* (resting, dormant stages) to adapt to environmental stress (e.g., nutrient depletion).
- ✓ ***Spores*** help bacteria survive but *do not reproduce*. In fungi, spores function for both survival and reproduction.
- ✓ *Characteristics of Endospores:*
  - Contain *very little water* and are highly resistant to:
    - ❖ Heat, Drying, Acids, Bases, Disinfectants, Radiation
- ✓ Sporulation: The process where bacteria prepare for possible future adverse conditions.
- ✓ *Structure of Spores:*
  - The spore consists of a **core**, surrounded by:
    - ❖ *Cortex*
    - ❖ *Spore coat*
    - ❖ In some species, a delicate *exosporium* layer.
- ✓ *Key Components:*
  - Spores contain *dipicolinic acid* (not found in vegetative cells) and a large amount of *Ca++*, which, along with low water content, contributes to their heat resistance.
- ✓ *Survival:*
  - Spores can survive extreme environmental conditions for over *10,000 years*.
  - When conditions become favorable, endospores *germinate* and develop into functional vegetative cells.



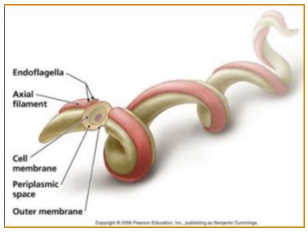
- **Structure of Bacterial Cells: External Structures**

1. **Flagella**

- ✓ Made of *protein (flagellin)* and used for *locomotion*
- ✓ The flagellum is hooked in the cell membrane and extended out of the cell
- ✓ *Types* of Flagella:
  - **A**trichous: without flagella
  - **Mon**otrichous: A single polar flagellum at one end (pole).
  - **Amph**itrichous: Two flagella, one at each end (both polar).
  - **Loph**otrichous: Two or more flagella at one or both ends
  - **Per**itrichous: Flagella distributed all over the surface



- ✓ Cocci rarely have flagella
- ✓ Movement:
  - Bacteria move forward or away from substances in the environment by a process called ***chemotaxis***
    A. *Positive* chemotaxis: movement toward an *attractant*
    B. *Negative* chemotaxis: movement away from a *repellent*
  - Mechanism of chemotaxis: Structures on the bacterial surface *detect concentration* changes over time
  - Some bacteria move toward (positive) or away (negative) from *light* in a process called ***phototaxis***
- ✓ *Axial Filament/Endoflagella*:
  - In some bacteria (e.g., ***spirochetes***), a special flagellum called axial filament or endoflagella is tightly bound around the cell, *not extending* beyond the cell wall.



2. **Pili** (pilus)
- ✓ Tiny hollow projections made of *pilin* protein
- ✓ Used for bacterial *attachment*, not for movement.

3. Conjugation pili (sex pili):
- ✓ A relatively *long* pili found in some bacteria
- ✓ Attach 2 bacterial cells where DNA is *transferred* through them in a process called conjugation (like sexual reproduction).
- ✓ Conjugation may result in the *transfer of antibiotic resistance genes* between bacteria

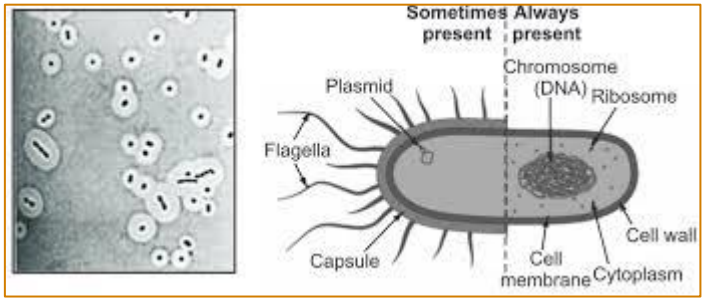
4. Attachment pili (**fimbriae**):
- ✓ *Short* type that attach bacteria to surfaces or air-water interface.
- ✓ Contributes to:
  - the **pathogenicity** (ability to produce disease) of certain bacteria by **enhancing colonization** on surface of cells of other organisms

5. Glycocalyx

- ✓ All *polysaccharide*-containing substances found external to cell wall, it includes ***capsule & slime***

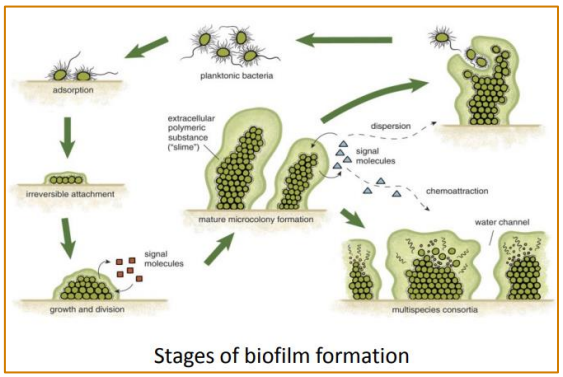
A. Capsule

- ✓ *Protective structure* outside cell wall, found in certain bacteria (not all members of a species have it)
  - e.g. Bacillus anthracis has no capsule outside an organism, but forms (mostly protein) when infecting an animal, to protect it from host defense
- ✓ It contains polysaccharide molecules arranged in loose gel with unique composition specific to the *strain*



B. Slime layer **(biofilm)**

- ✓ *Less tightly bound* to cell wall than a capsule
- ✓ *Function*:
  1. *Protects* the cell against drying
  2. Helps *trap* nutrient
  3. *Binds* cells together
  4. Enables bacteria to *adhere to objects* and surfaces (e.g., environmental surfaces, human tissues).
- ✓ ***Microbial biofilms*** are *surface-associated*, *organised*, *multicellular* communities held together by a self-produced extracellular matrix forming architecturally complex structures
- ✓ *Dental plaque* is an example on biofilms, extremely tightly bound to the tooth surface & can cause dental caries
- ✓ Biofilms are estimated to be implicated in around 80% of all chronic human infections and are important mediators of *hospital-acquired infections*.
- ✓ Biofilms constitute a ***protected mode*** of growth and bacteria within biofilms typically exhibit significantly enhanced *tolerance/resistance* to antimicrobial challenge and host defences



Stages of biofilm formation

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