Bacterial Structure and Function

Lecture 5

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Bacterial cell structure

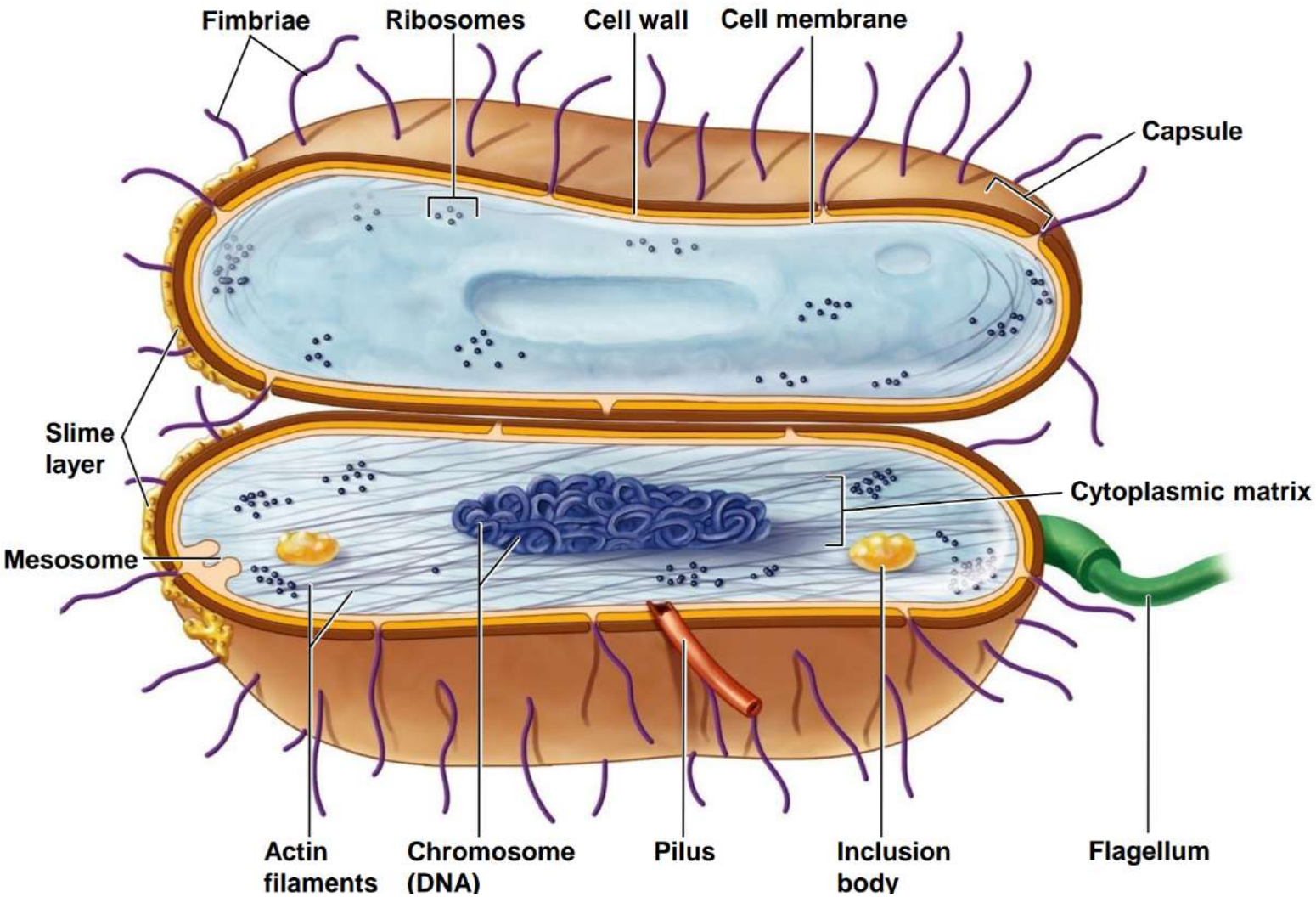
Organized into 3 categories :

- ✓ **Internal Structures**: Cytoplasm, nucleoid, bacterial chromosome, plasmid, ribosomes, endospores, mesosome and storage granules.

- ✓ **Cell envelope**: cell membrane, peptidoglycan cell wall or an outer lipid membrane (only found in Gram-negative cells).

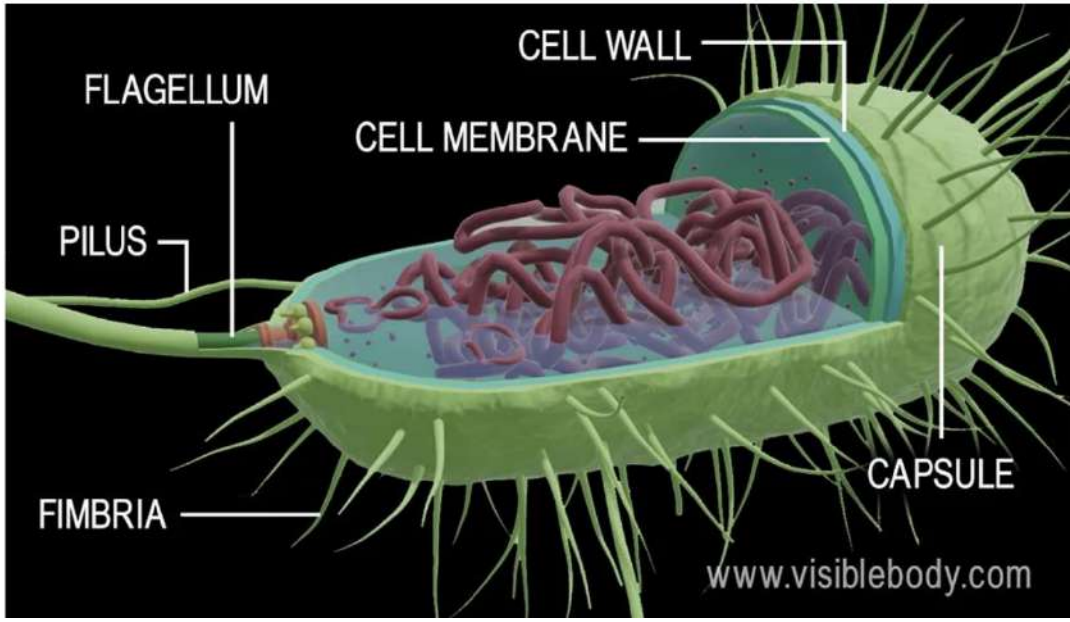
- ➢ **External structures** (appendages & coverings): flagella, fimbriae, sex pilus and glycocalyx

Structure of a bacterial cell



External Structures

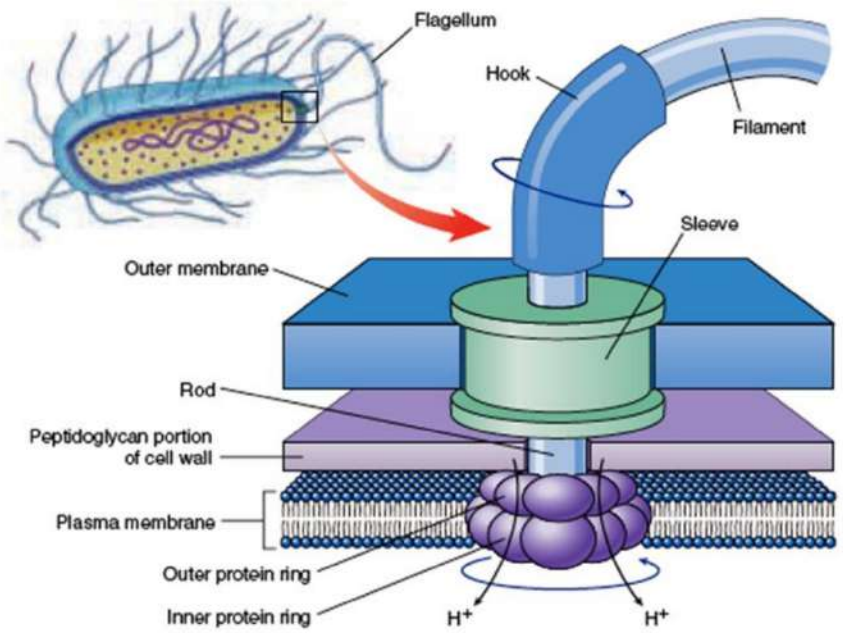
- Appendages
  - Two major groups of appendages:
    1. Fagella and axial filaments (periplasmic flagella) for Motility
    2. Fimbriae and pili –Attachment or channels
- Glycocalyx – surface coating



Flagella

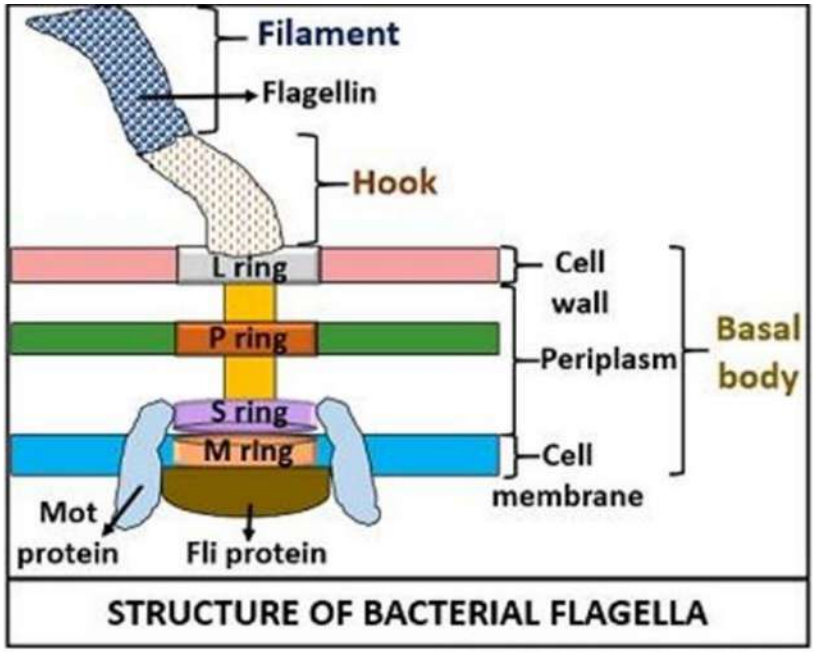
- Hair-like structure present on the cell body that is important for different physiological functions of the cell
  - Other than locomotion, flagella also regulate sensory functions in prokaryotes by **sensing** temperature and chemical variations.

- 3 parts:
  - **Filament** – long, thin, helical structure composed of protein **flagellin**
  - **Hook** – curved sheath
  - **Basal body** – stack of rings firmly anchored in cell wall



➢ Basal Body

- It is attached to the cell wall and cell membrane and embedded with the rack of rings arranged one over the other.
- The rings possess protein sub-units. It typically (**M**, **S**, **P** and **L**) rings.
- M and S rings are associated with the cytoplasmic membrane, while P and L rings are associated with the periplasmic space and cell wall.



- The protein rings serve to pump protons or H+ ions across the membrane and facilitate ATP generation. The bacterial cell harnesses ATP (Adenosine triphosphate) to rotate the rings as well as the filament.

➢ Hook

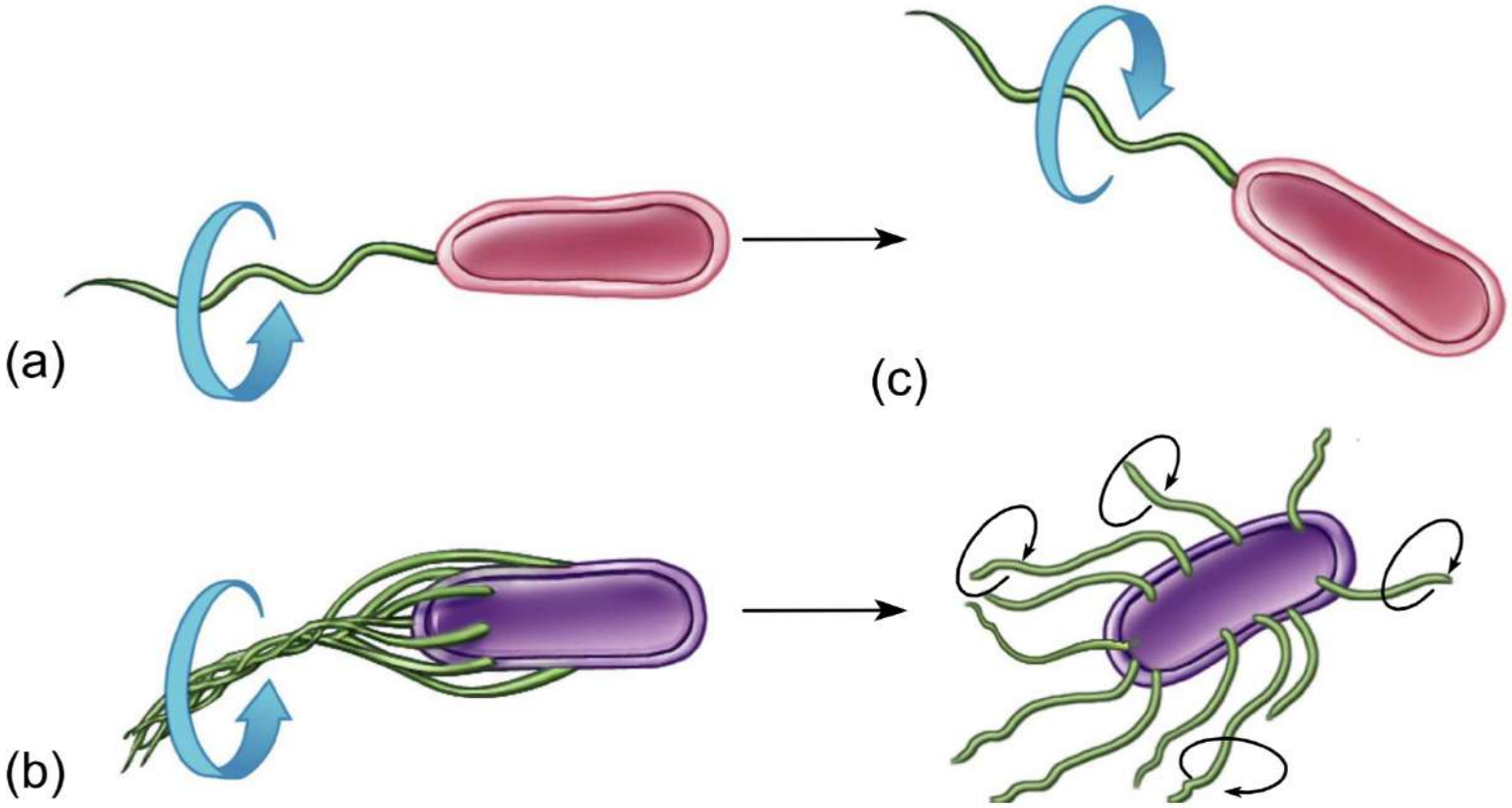
- It is the broader region present at the flagellum base.
- Hook performs a key role in **connecting** filament to the motor region or basal body.

➢ Filament

- It appears like a **whip-like** structure.
- Filament seems long, coiled, thin.
- The composition of filament includes **flagellin** protein sub-units.
- Filament participates in the propulsion of bacteria.
- The bacterial flagella can move in either **anticlockwise** (counterclockwise) or **clockwise** direction.

Flagella

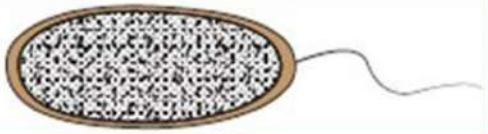
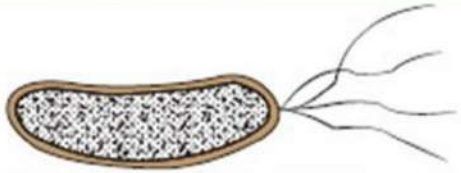
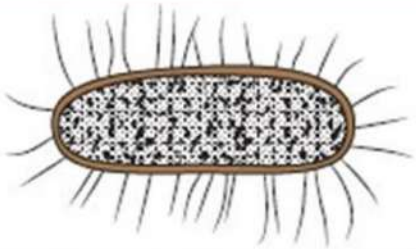
- Rotates 360°
- Functions in motility of cell through environment



Flagella Types

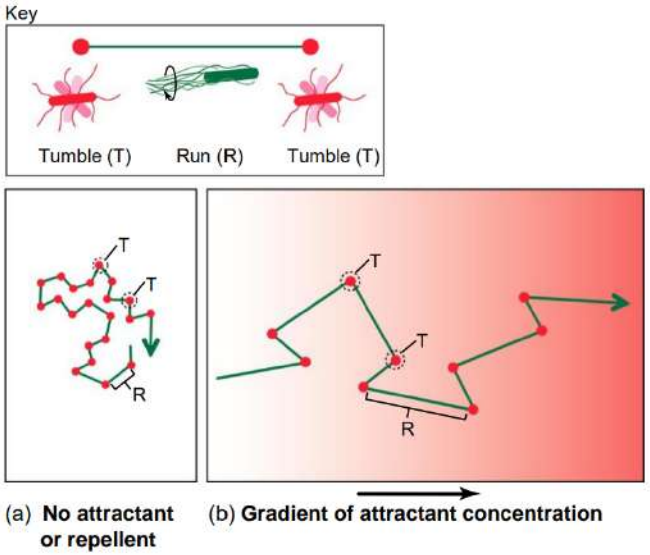
The flagella in prokaryotes are categorized into the following types, depending on their cell surface arrangement.

Table 7.1: Arrangement of bacterial flagella

Structure	Flagella type	Example
	Monotrichous(single flagella on one side)	*Vibrio cholera*
	Lophotrichous(tuft of flagella on one end)	*Pseudomonas fluorescens*
	Amphitrichous(single or tuft on both ends)	*Aquaspirillum serpens*
	Peritrichous(flagella throughout the cells)	*Salmonella typhi*

Flagellar Responses

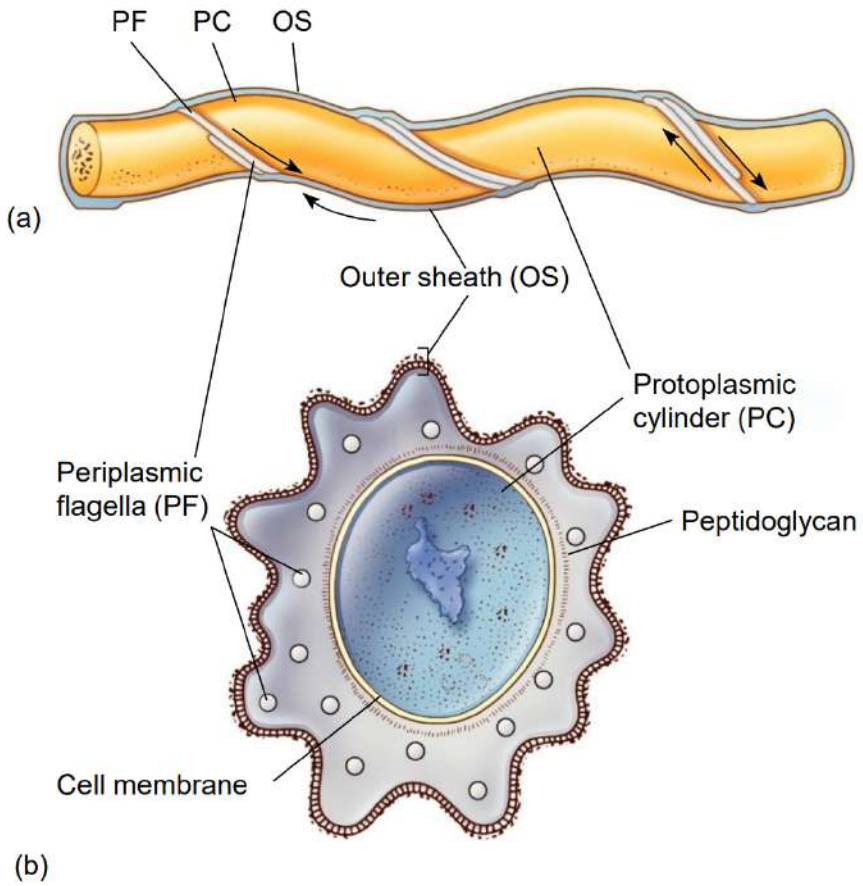
- Guide bacteria in a direction in response to external stimulus:
  - Chemical stimuli – **chemotaxis**; positive and negative
  - Light stimuli – **phototaxis**
- **Signal** sets flagella into motion clockwise or counterclockwise:
  - Counterclockwise – results in smooth linear direction – **run**
  - Clockwise – **tumbles**



Periplasmic Flagella

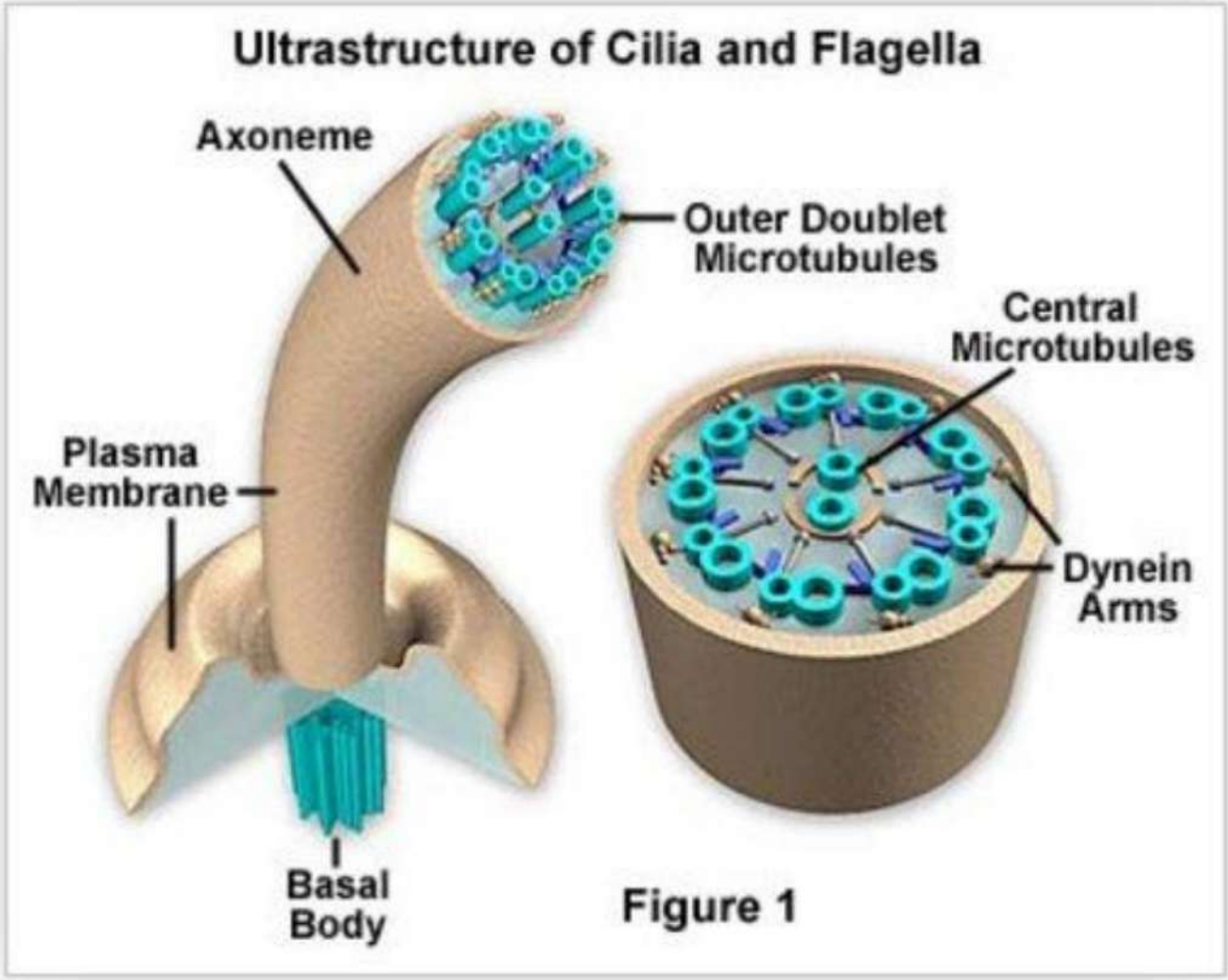
- Internal flagella, enclosed in the space between the outer sheath and the cell wall peptidoglycan

- Produce cellular motility by contracting and imparting twisting or flexing motion



Difference Between Prokaryotic and Eukaryotic flagella

Prokaryotic flagella	Eukaryotic flagella
They have rotary movement	They have bending movement (Back and forth movement)
Flagella are thin and small	Flagella are thick and large
Do not contains microtubules, "9+0": No central microtubules, only a simple structure.	Contains the microtubules, "9+2": Two central microtubules surrounded by nine outer doublets.
Made up of the protein flagellin	Made up of the protein tubulin
Smaller and simpler structure	The large and complex structure
It is proton driven	It is ATP driven
They consist of three parts basal body, hook, and filament	They consist of two parts basal body and shaft
The basal body contains rings that help in locomotion	The basal body is made up of centriole like structures
For example, Bacteria	For example, Chlamydomonas (green algae)


Ultrastructure of Cilia and Flagella
Axoneme
Outer Doublet Microtubules
Central Microtubules
Plasma Membrane
Dynein Arms
Basal Body
Figure 1

Bacterial Structure and Function

Lecture 6

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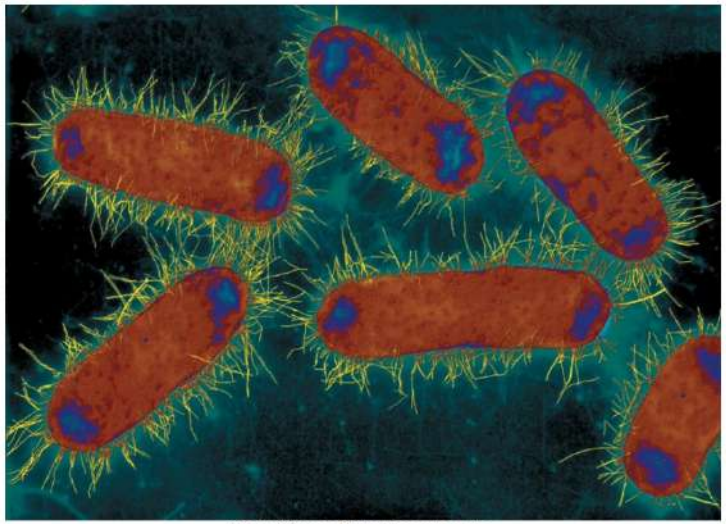
Fimbriae

- Fimbriae are tiny bristle-like fibers arising from the surface of bacterial cells.
- Made up of **Fimbrillin** protein.
- Function crucial for colonization and infection.
- Adhesion to other cells and surfaces



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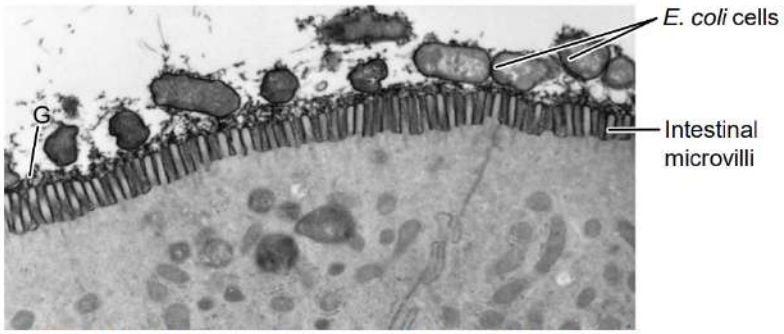
(a)



Dr. S. Knutton from D.R. Lloydand S. Knutton, Infection and Immunity, January 1987, p 86-92. © ASM

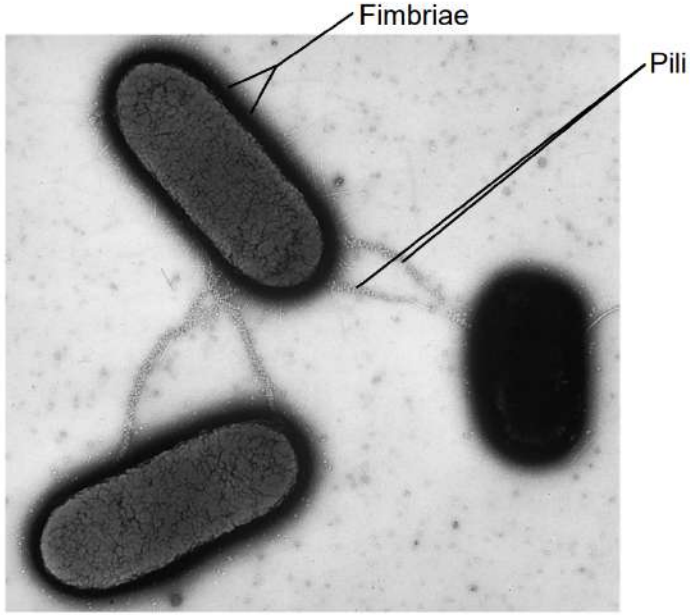
(b)

Pili

- Rigid tubular structure made of **pilin** protein
- Found only in gram-negative cells
- Two basic function of pili:

✓ gene transfer called **conjugation**

✓ and attachment.

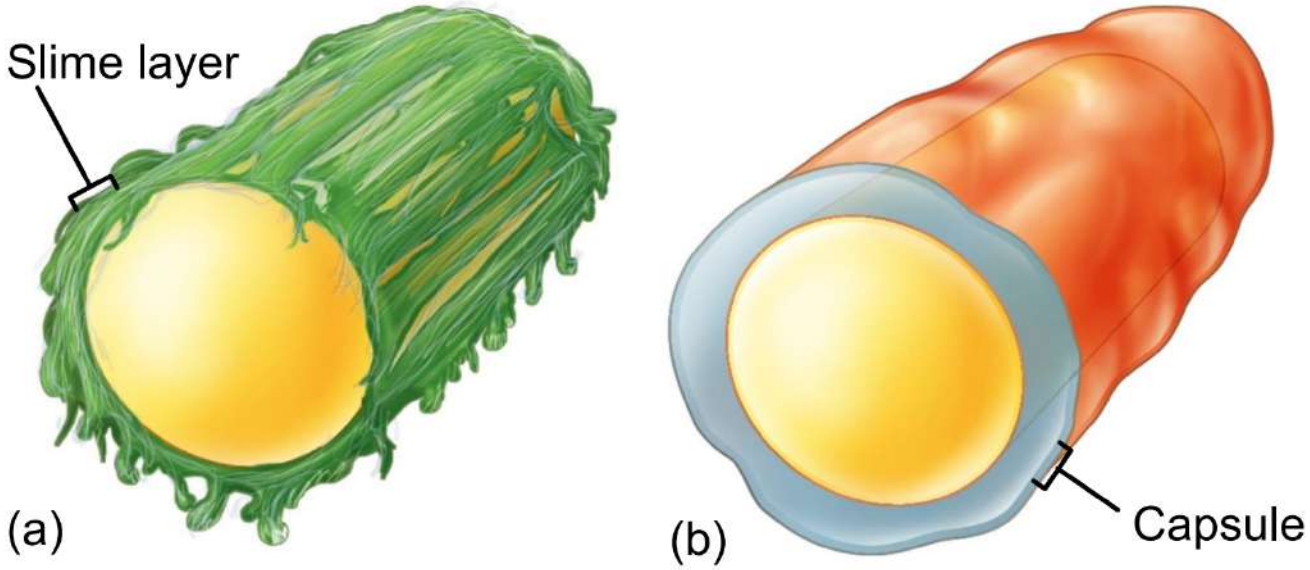


FIMBRIAE VERSUS PILI

FIMBRIAE	PILI
Tiny, bristle-like fibers arising from bacterial cells	Hair-like microfibers on the surface of bacteria
Occur in both Gram-positive and Gram-negative bacteria	Occur in Gram-negative bacteria
Around 200-400 fimbriae occur per bacterial cell	Only 1-10 pili occur per bacterial cell
Made up of fimbrillin protein	Made up of pilin protein
Genes responsible for the formation occur in the bacterial chromosome	Genes in the plasmids are responsible for the formation
Shorter	Longer
Thin	Thick
Attach the bacterium to the substrate	Aid in bacterial conjugation

Glycocalyx

- It's the outer or surface layer that lines the cell membrane.
- Glycocalyx is made up of proteoglycans, glycosaminoglycans, glycoproteins, and associated plasma proteins.
- Two form of Glycocalyx:
  1. **Slime layer** - loosely organized and attached
  2. **Capsule** - highly organized, tightly attached, are found on many pathogenic bacteria



Examples:

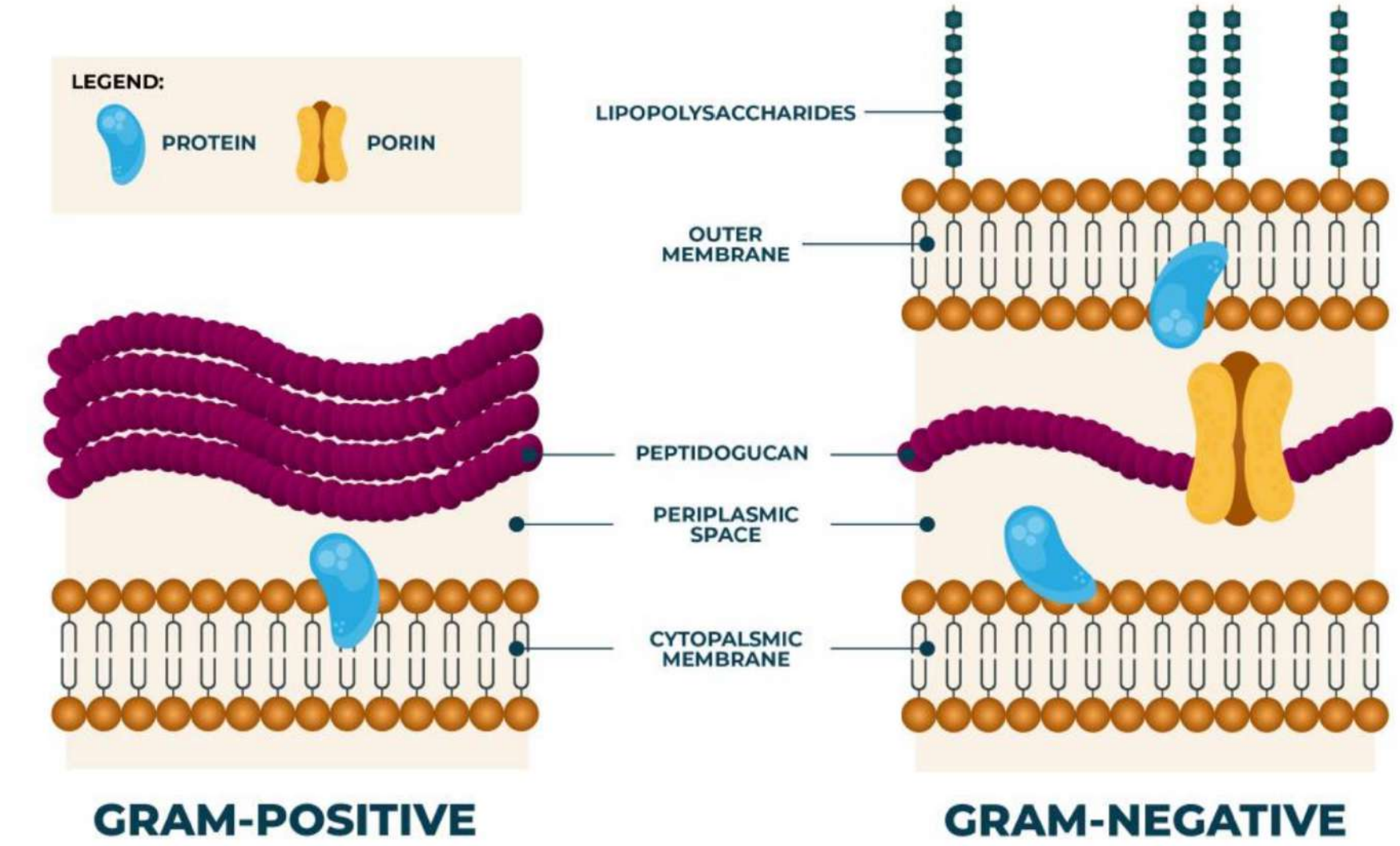
- Bacterial cells that have a glycocalyx layer surrounding their cell surface, which may be a sugar coat surrounding the cell wall (such as a bacterial capsule) or a slime layer.
- Human cells also exhibit a glycocalyx; examples are vascular endothelial cells and cells of the digestive system.

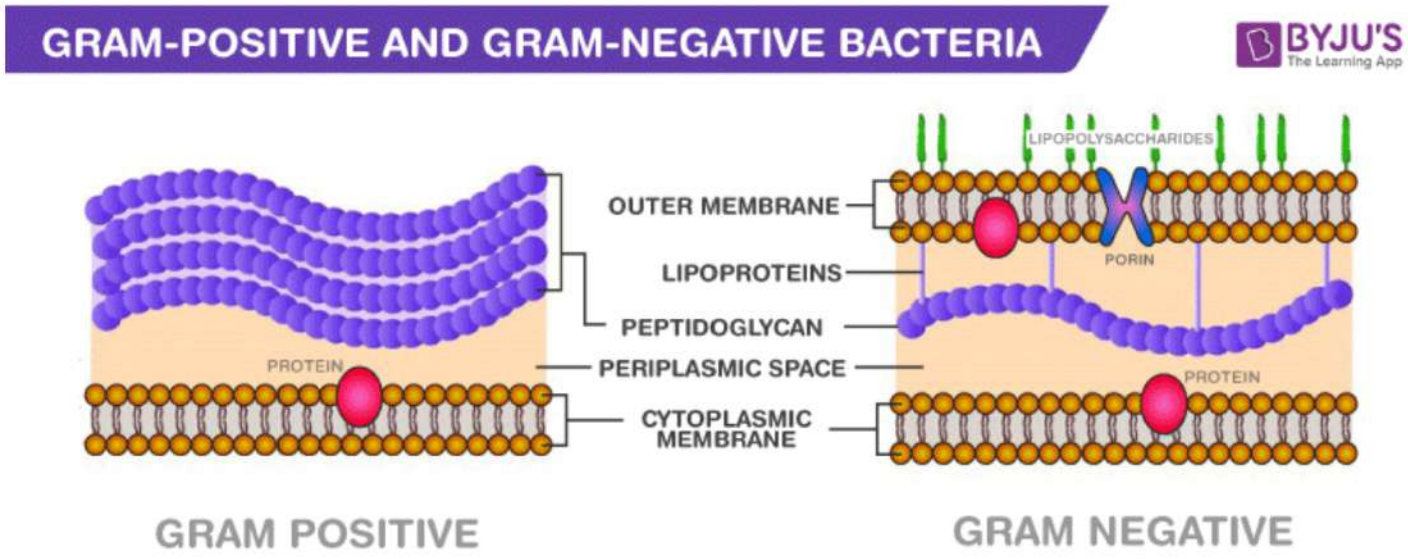
- Functions of glycocalyx of a cell include the following:

✓ Cell recognition
✓ Cell adhesion
✓ Protection from dehydration, from WBCs attacks, and protect the bacterial cell by preventing immune cells from attaching to it and destroying it through phagocytosis
✓ Permeability barrier

The Cell Envelope

- External covering outside the cytoplasm
- Composed of two basic layers:
  - ✓ Cell wall
  - ✓ Cell membrane
- Maintains cell integrity
- Two different groups of bacteria demonstrated by **Gram stain**:
  - **Gram-positive bacteria**: thick cell wall composed primarily of peptidoglycan and cell membrane
  - **Gram-negative bacteria**: outer cell membrane, thin peptidoglycan layer, and cell membrane


LEGEND:
PROTEIN
PORIN
LIPOPOLYSACCHARIDES
OUTER MEMBRANE
PEPTIDOGUCAN
PERIPLASMIC SPACE
CYTOPALSMIC MEMBRANE
GRAM-POSITIVE
GRAM-NEGATIVE

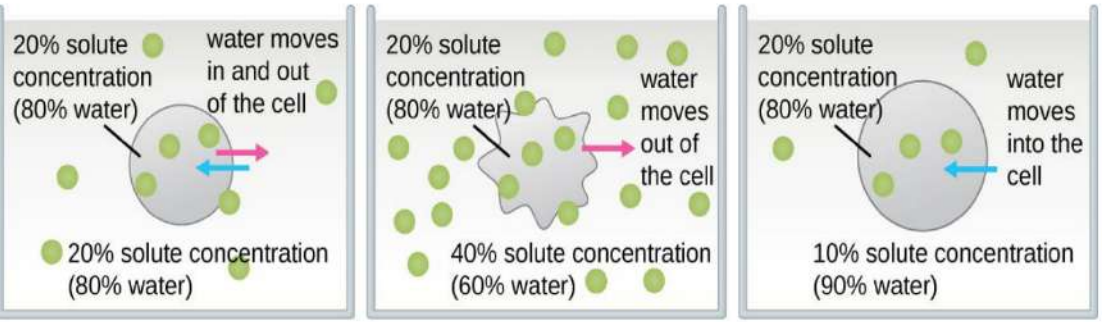


- Bacteria can be gram-positive or gram-negative depending upon the staining methods.
- **Christian Gram** distinguished the two types of bacteria based on the difference in their cell wall structures.
- The gram-positive bacteria retain the **crystal violet dye**, which is because of their thick layer of peptidoglycan in the cell wall.

Structure of Cell Walls

- Determines cell shape, prevents **lysis** due to changing osmotic pressures

Cells lack a cell wall

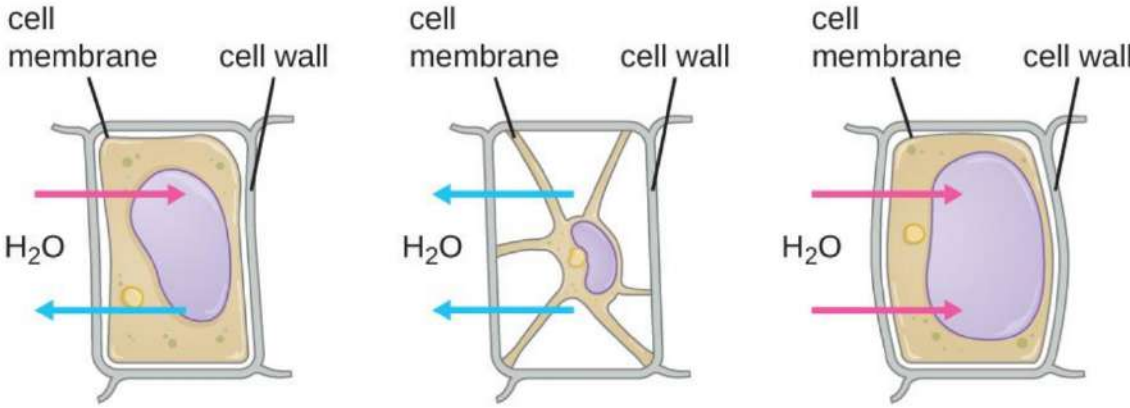


a **Isotonic solution**
A solution that has the *same* solute concentration as another solution. There is no net movement of water particles, and the overall concentration on both sides of the cell membrane remains constant.

b **Hypertonic solution**
A solution that has a *higher* solute concentration than another solution. Water particles will move out of the cell, causing crenation.

c **Hypotonic solution**
A solution that has a *lower* solute concentration than another solution. Water particles will move into the cell, causing the cell to expand and eventually lyse.

Cells have cell wall



a **Isotonic solution**
No net movement of water particles. Cell membrane is attached to cell wall.

b **Hypertonic solution**
Water particles move out of the cell. Cell membrane shrinks and detaches from cell wall (plasmolysis).

c **Hypotonic solution**
Water particles move into the cell. Cell wall counteracts osmotic pressure to prevent swelling and lysis.

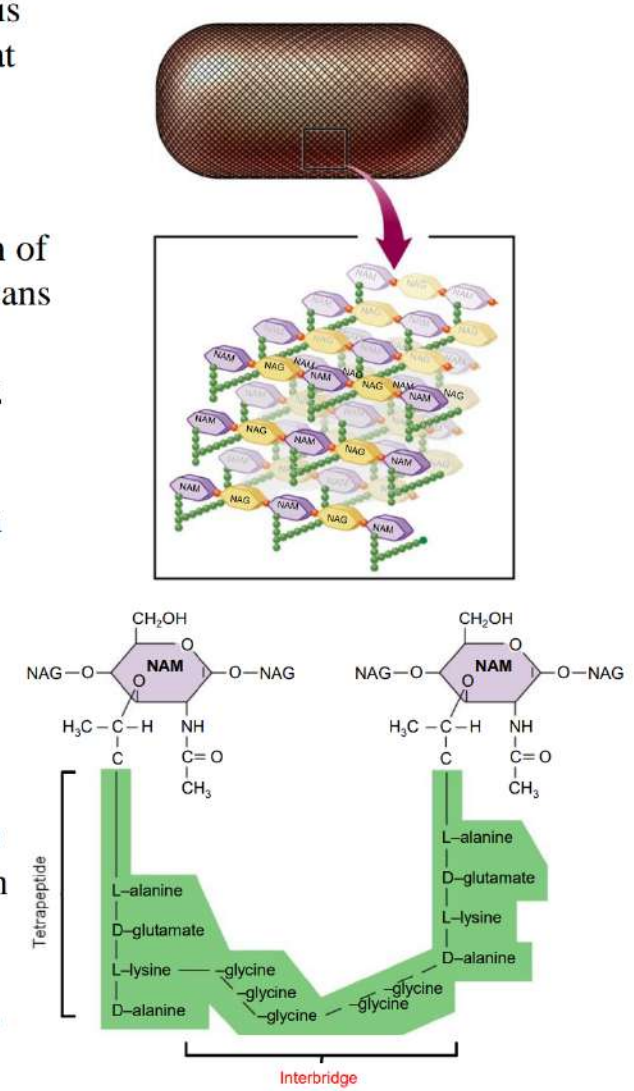
Structure of Cell Walls

- **Peptidoglycan** is the primary component:
  - Unique macromolecule composed of a repeating framework of long glycan chains cross-linked by short peptide fragments

(a) The peptidoglycan of a cell wall is a huge, 3-dimensional lattice work that is actually one giant molecule to surround and support the cell.

(b) This shows the molecular pattern of peptidoglycan. It has alternating glycans (**NAG** and **NAM**) bound together in long strands. The **NAG** stands for ***N*-acetyl glucosamine**, and the **NAM** stands for ***N*-acetyl muramic acid**. Adjacent muramic acid molecules on parallel chains are bound by a cross-linkage of peptides (green spheres)

(c) An enlarged view of the links between the NAM molecules. Tetrapeptide chains branching off the muramic acids connect by amino acid Interbridges. The amino acids in the interbridge can vary or may be lacking entirely. This linkage that provides rigid yet flexible support to the cell.



Gram-Positive Cell Wall

- 20-80 nm thick peptidoglycan.
- Includes **teichoic acid** and **lipoteichoic acid**:
- Function in:

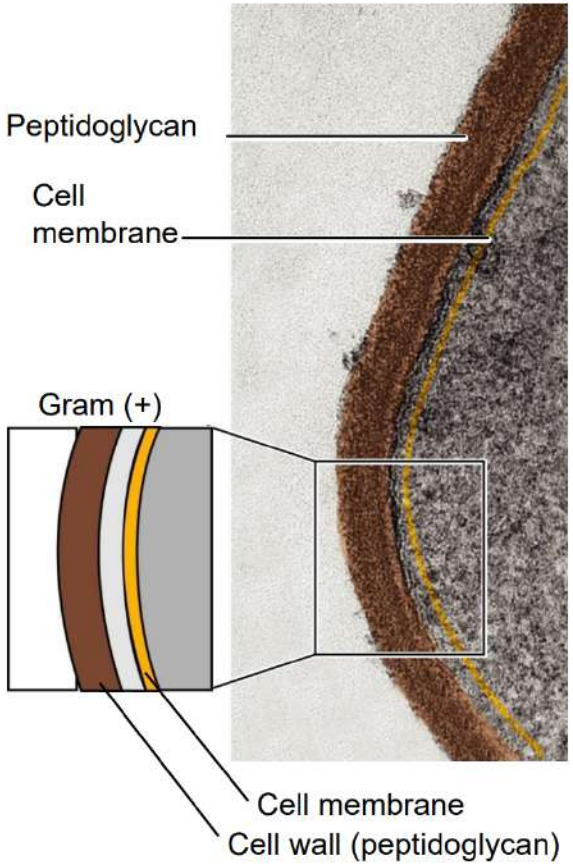
✓ Cell wall maintenance.

✓ Enlargement during cell division.

✓ Move cations across the cell envelope. sodium-potassium pump

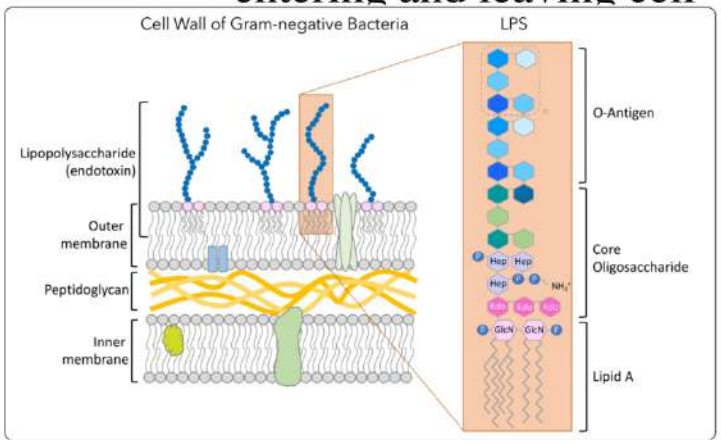
✓ Stimulate a specific immune response.

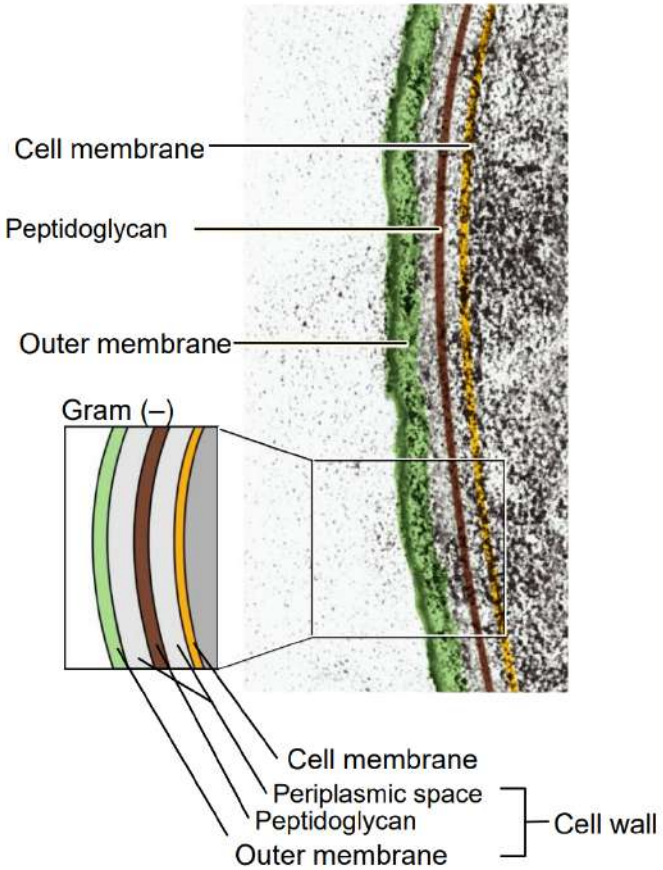
– Some cells have a **periplasmic space,** between the cell membrane and cell wall



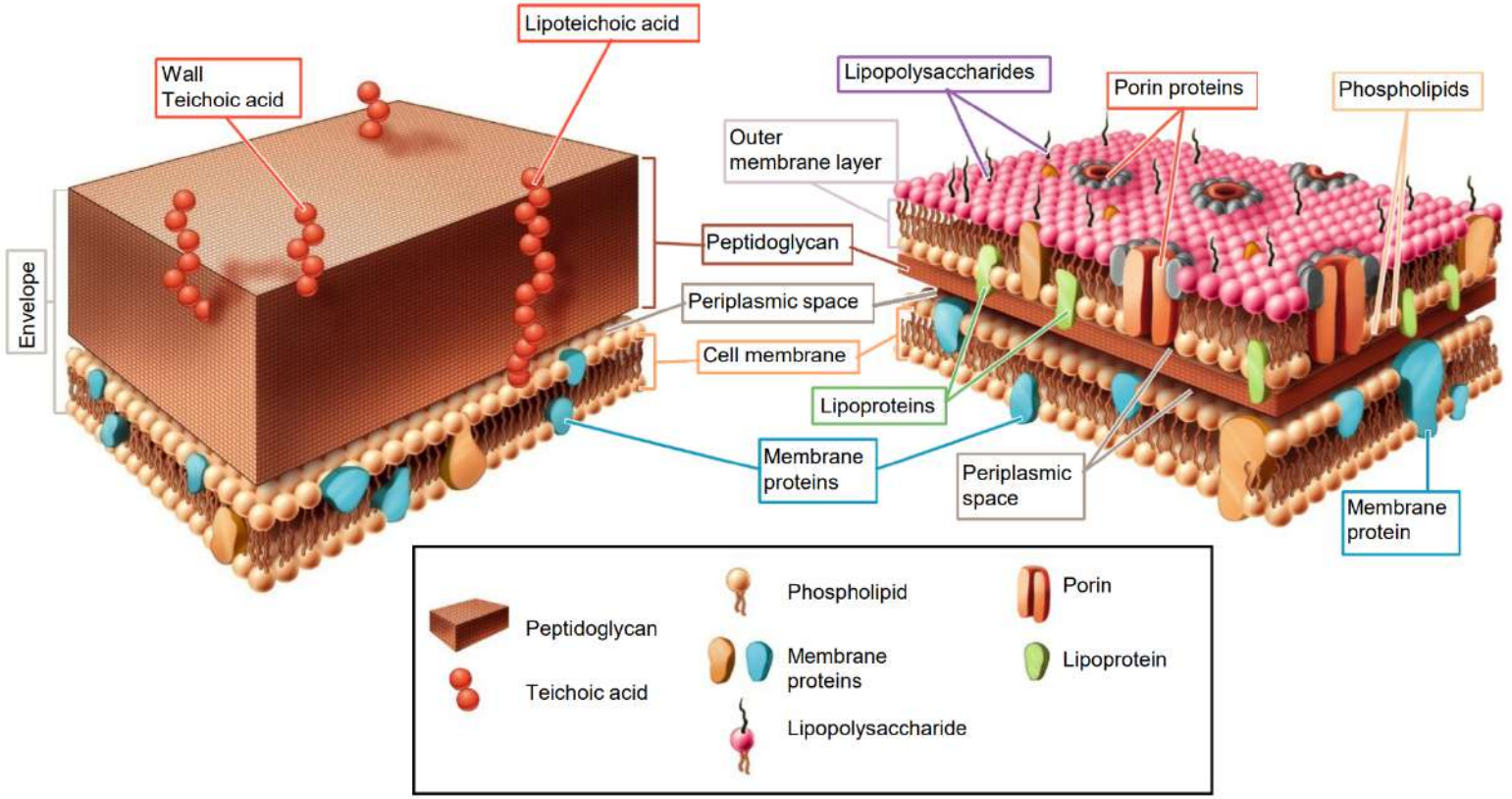
Gram-Negative Cell Wall

- Inner and outer membranes and **periplasmic space** between them contains a thin peptidoglycan layer
- Outer membrane contains **lipopolysaccharides (LPS)**
  - Lipid portion (endotoxin) may become toxic when released during infections
  - May function as receptors and blocking immune response
  - Contain **porin** proteins in upper layer – regulate molecules entering and leaving cell





Structures of Gram-Positive and Gram-Negative Bacterial Cell Walls



Comparison of Gram-Positive and Gram-Negative Cell Walls

TABLE 4.1 Comparison of Gram-Positive and Gram-Negative Cell Walls

Characteristic	Gram-Positive	Gram-Negative
Number of major layers	One	Two
Chemical composition	Peptidoglycan Teichoic acid Lipoteichoic acid Mycolic acids and polysaccharides*	Lipopolysaccharide (LPS) Lipoprotein Peptidoglycan Porin proteins
Overall thickness	Thicker (20–80 nm)	Thinner (8–11 nm)
Outer membrane	No	Yes
Periplasmic space	Narrow	Extensive
Permeability to molecules	More penetrable	Less penetrable

*In some cells.

Cell Walls with some exceptions

➢ Some bacterial groups lack typical cell wall structure, i.e., *Mycobacterium tuberculosis* and *Nocardia*

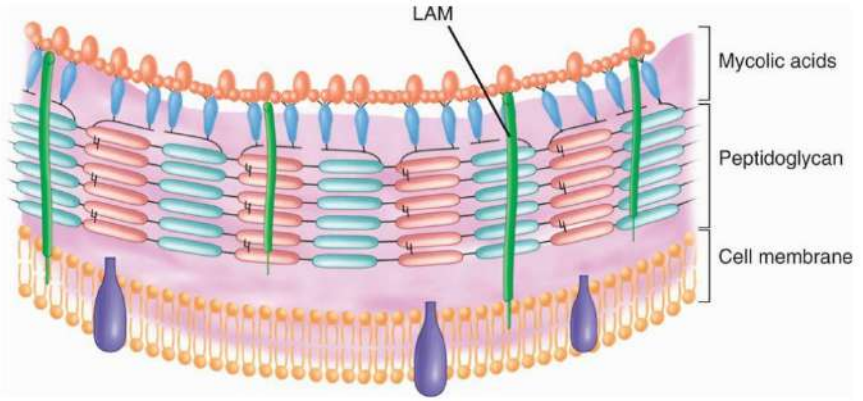
- Gram-positive cell wall
- The cell wall structure with lipid mycolic acid is characteristics:

- Thick, waxy mycolic acid layer forms the outermost part of the cell wall,

- Creating a barrier that is hydrophobic and resists penetration by many molecules, including antibiotics and immune system components.

- Inside this layer is a network of **peptidoglycan** and **arabinogalactan**, and the structure is anchored to the inner cell membrane.

- Structure with **mycolic acid**
  - Pathogenicity and high degree of resistance to certain chemicals and dyes
  - Basis for **acid-fast stain** used for diagnosis of infections caused by these microorganisms



- Some have no cell wall, i.e., *Mycoplasma*
  - The smallest free-living organisms.
  - Cell wall is stabilized by sterols
  - Pleomorphic