



The Bacterial Cell Wall

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Cell Envelope: Cell Wall

- A rigid cell wall surrounds all eubacterial cells except mycoplasmas
- The structure and function of the bacterial wall is distinctive- it constitutes a hallmark of the prokaryotes
- Unlike the capsule, which is dispensable for survival outside the body of the host, the wall has vital functions.

Cell Wall: Function

- It protects the cell from mechanical disruption and from being burst by osmotic pressure (the cell interior is hypertonic relative to the environment)
- The wall also provides a barrier against certain toxic chemical and biological agents
- Being rigid, it is responsible for the shape of the cell

Cell Wall

Functions

- Providing attachment sites for bacteriophage - teichoic acids
- Providing a rigid platform for surface appendages - flagella, fimbriae, and pili

The Cell Wall

Bacteria may be conveniently divided into two further groups, depending upon their ability to retain a crystal violet-iodine dye complex when cells are treated with acetone or alcohol. This reaction is referred to as the Gram reaction: named after Christian Gram, who developed the staining protocol in 1884.

Gram Stain

The diagram features the text "Gram Stain" at the top, where each letter is a different color (G: pink, r: orange, a: yellow, m: green, S: blue, t: purple, a: red, i: orange, n: yellow). Below this, a blue arrow points down to "Gram Positive" and a pink arrow points down to "Gram Negative".

Gram Positive

Gram Negative

Bacterial Cell Wall

G +ve
Cell wall



Peptidoglycan

Plasma membrane

G -ve
Cell wall



Outer membrane

Peptidoglycan

Periplasmic space

Plasma membrane

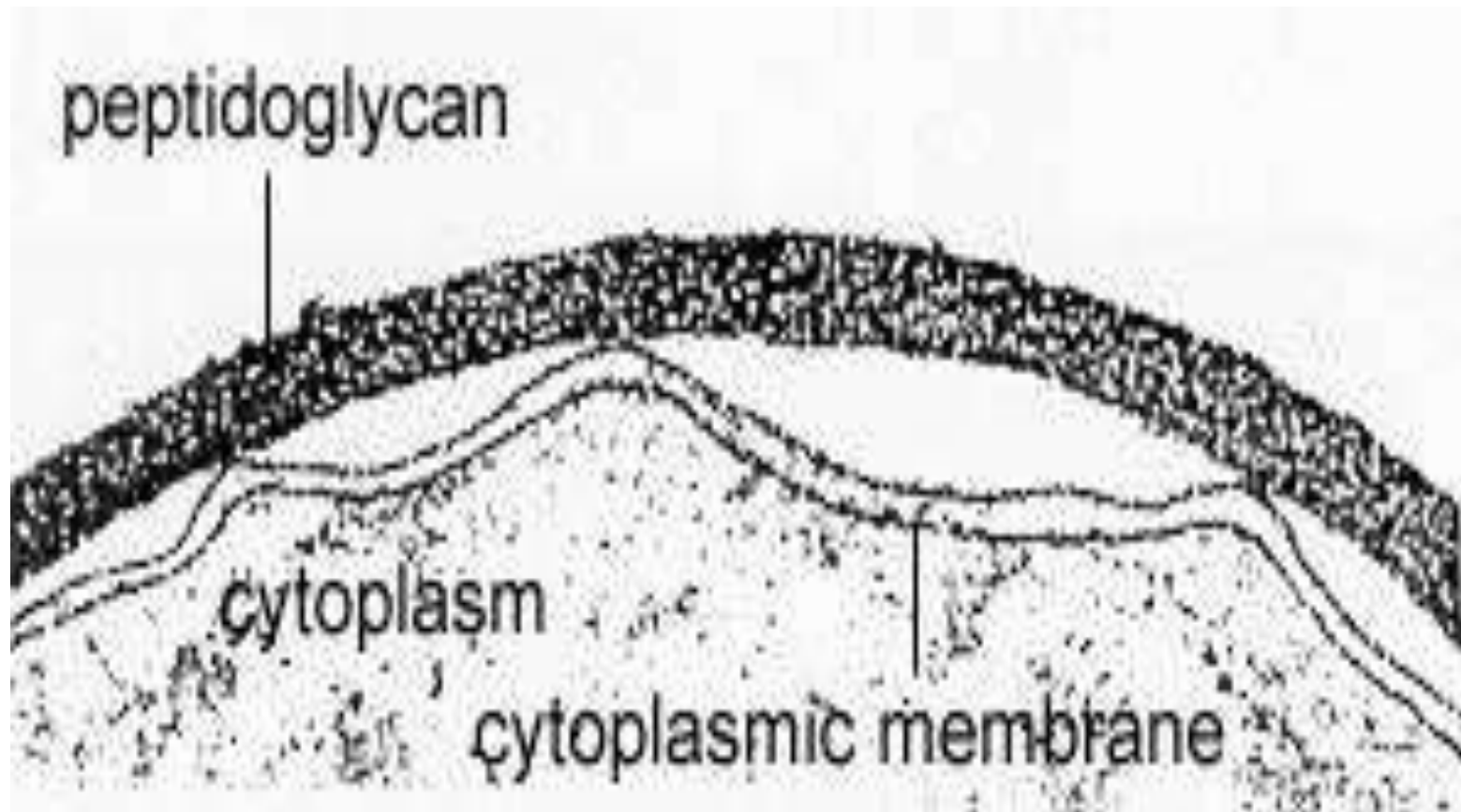
The **cell wall of Gram-positive** bacteria is composed of:

- Peptidoglycan; may be up to 40 layers of this polymer
- teichoic and teichuronic acids - surface antigens

The **cell wall of Gram-negative** bacteria is complex and consists of:

- a periplasmic space – enzymes
- An inner membrane - one or two layers of peptidoglycan beyond the periplasm
- Outer membrane (LPS) – external to peptidoglycan
- Braun's lipoproteins – anchoring outer membrane to inner
- Porins - through which some molecules may pass easily.

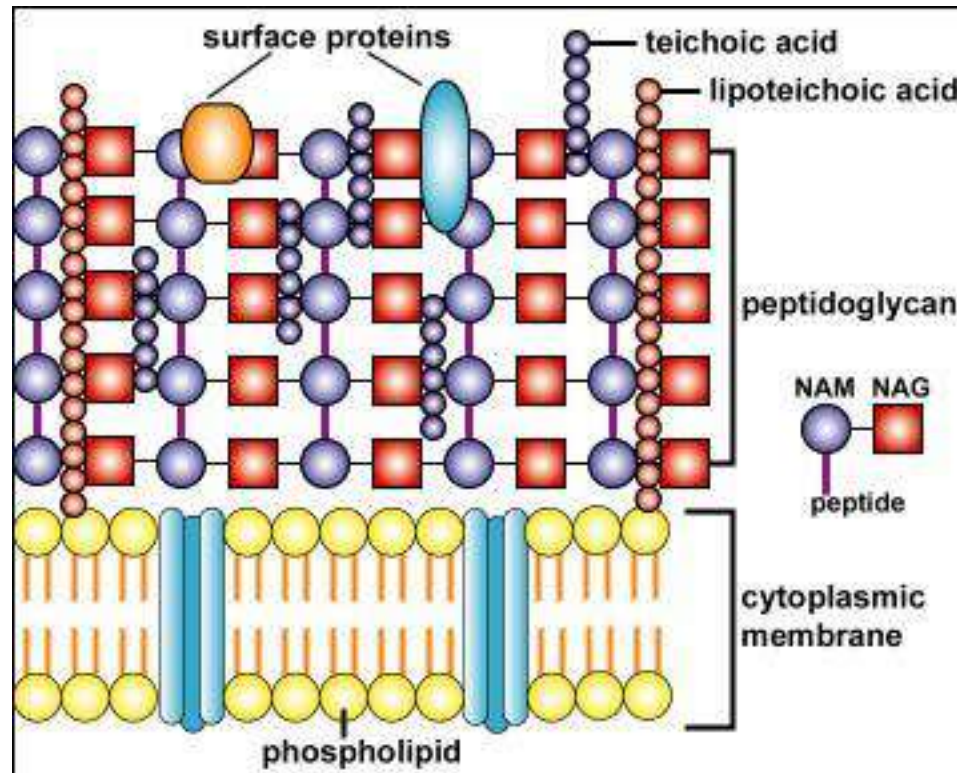
Gram-Positive Cell Wall



Gram Positive Cell Wall:

- The Gram-positive cell wall contains two major components
 - **peptidoglycan** and
 - **teichoic acids**
 - there are also additional carbohydrates and proteins depending on the species of organism
- The Gram positive cell wall is much thicker than that of Gram negative cells

Structure of a Gram-Positive Cell Wall



Peptidoglycan

- **single macromolecule**
- **highly cross-linked**
- **surrounds cell**
- **provides rigidity**

Gram Positive Cell Wall: Peptidoglycan

- The chief component of the Gram positive cell wall is **murein**, a peptidoglycan, which is found nowhere except in eubacteria
- Murein consists of a linear glycan chain (1:4 linkages) of two alternating sugars:
 - N-acetylglucosamine (NAG)
 - N-acetylmuramic acid (NAM)

PEPTIDES

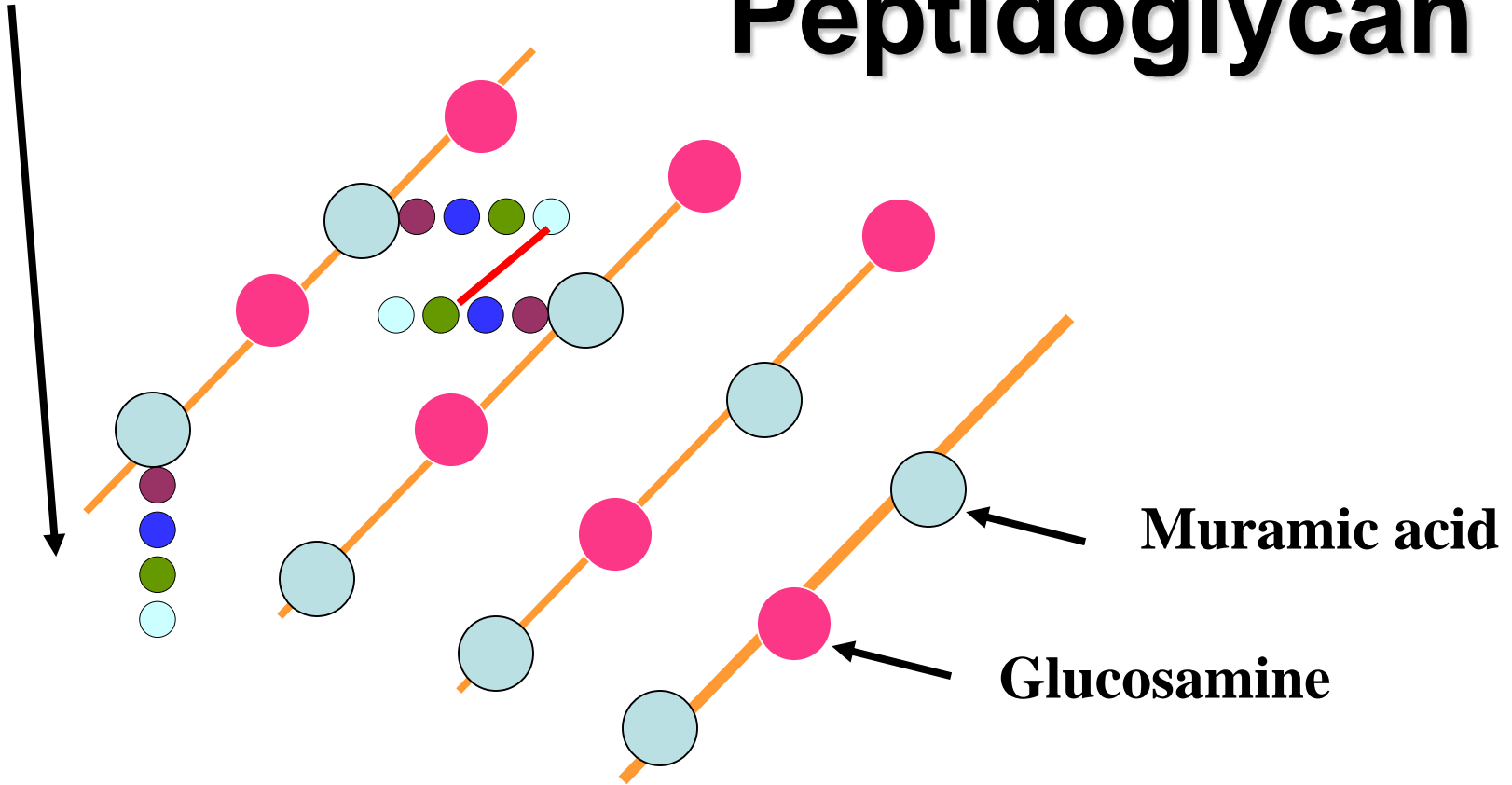
There are two types of peptide chains:

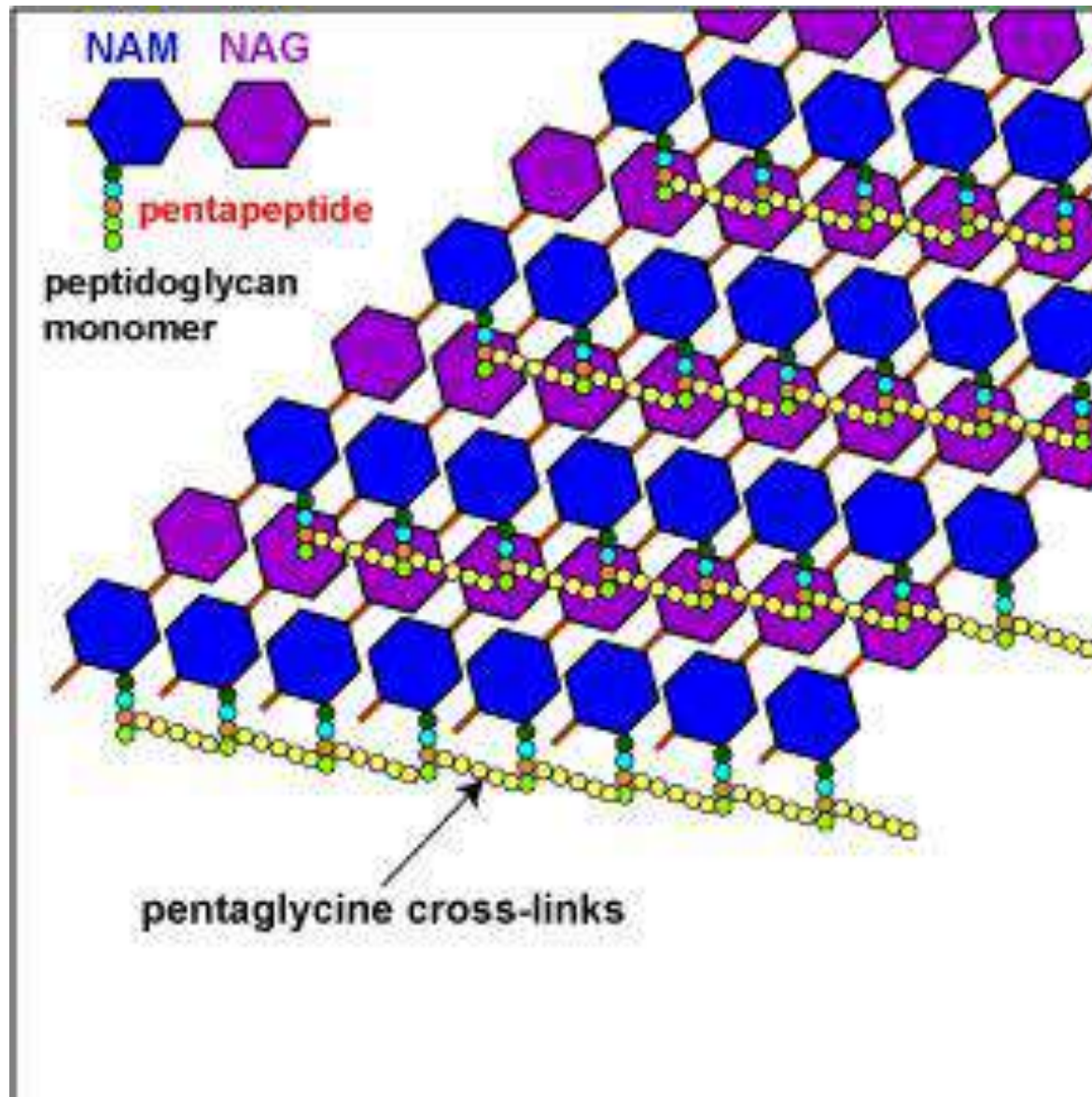
1. A tetra peptide side chain linked to N-acetyl-muramic acid and containing the common amino acids L-alanine and L-lysine and the unusual amino acids D-glutamic acid, D-alanine and meso-diaminopimelic acid (DAP).
2. A penta-glycine bridge in Gram –positive bacteria, such as *Staphylococcus aureus*, linking the linear peptide / polysaccharide chains to form a 2-D network.

NOTE: Muramic acid, D-amino acids, and diaminopimelic acid are not synthesized by mammals

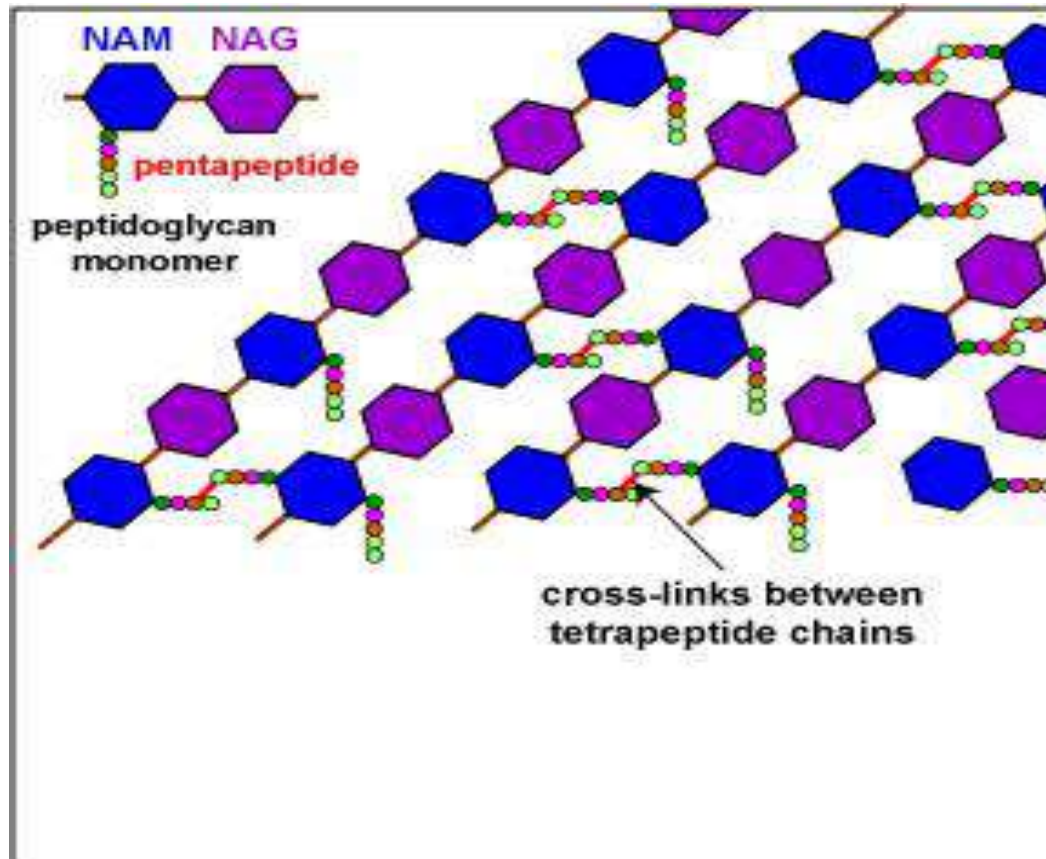
- L-alanine
- D-glutamic acid
- L-lysine/Diaminopimelic acid
- D-alanine

Peptidoglycan





In many Gram-negative bacteria the tetra peptide side chains are cross linked directly via a covalent peptide bond between the carboxyl- group of the terminal D-alanine and amino- group of L-lysine or meso-diaminopimelic acid without the involvement of a separate penta-glycine bridge.



Gram Positive Cell Wall: Teichoic Acid

- Some teichoic acid is covalently linked to:
 - NAM residues of the murein or
 - a glycolipid in the underlying cell to form **lipoteichoic acid**
 - plays a role in anchoring the wall to the cell
- Teichoic acids are found only in Gram positive cells and constitute the major antigenic determinants of the cell surface

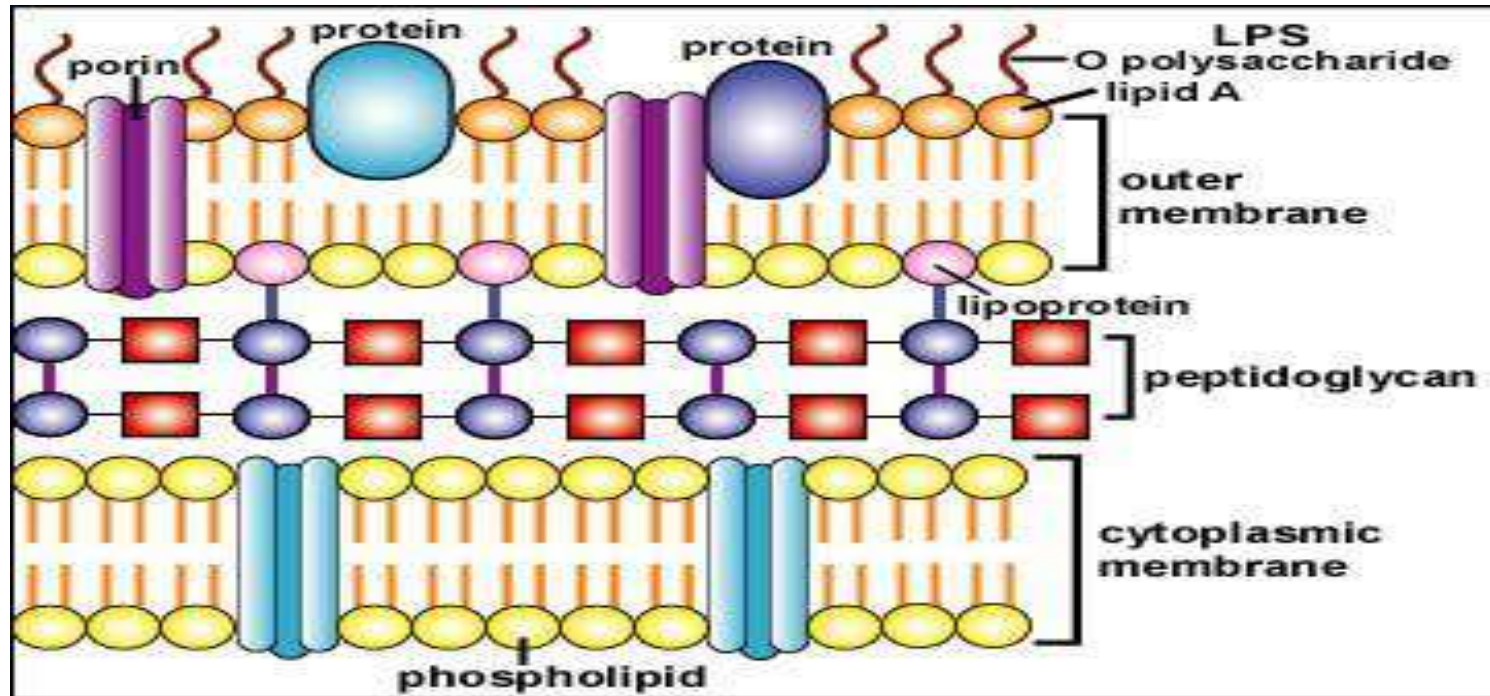
Gram Positive Cell Envelope

- **Teichoic acid**
 - **Polymer**
 - **phosphorus**
 - **ribitol or glycerol backbone**
 -
- **Teichuronic acid**
 - **polymer**
 - **no phosphorus**
 - **glucuronic acid backbone**

Gram Negative Cell Wall:

- The Gram negative cell wall, except for the presence of a limited amount of murein, has little chemical resemblance to cell walls of Gram positive bacteria
- The architecture of the Gram negative cell wall is fundamentally different

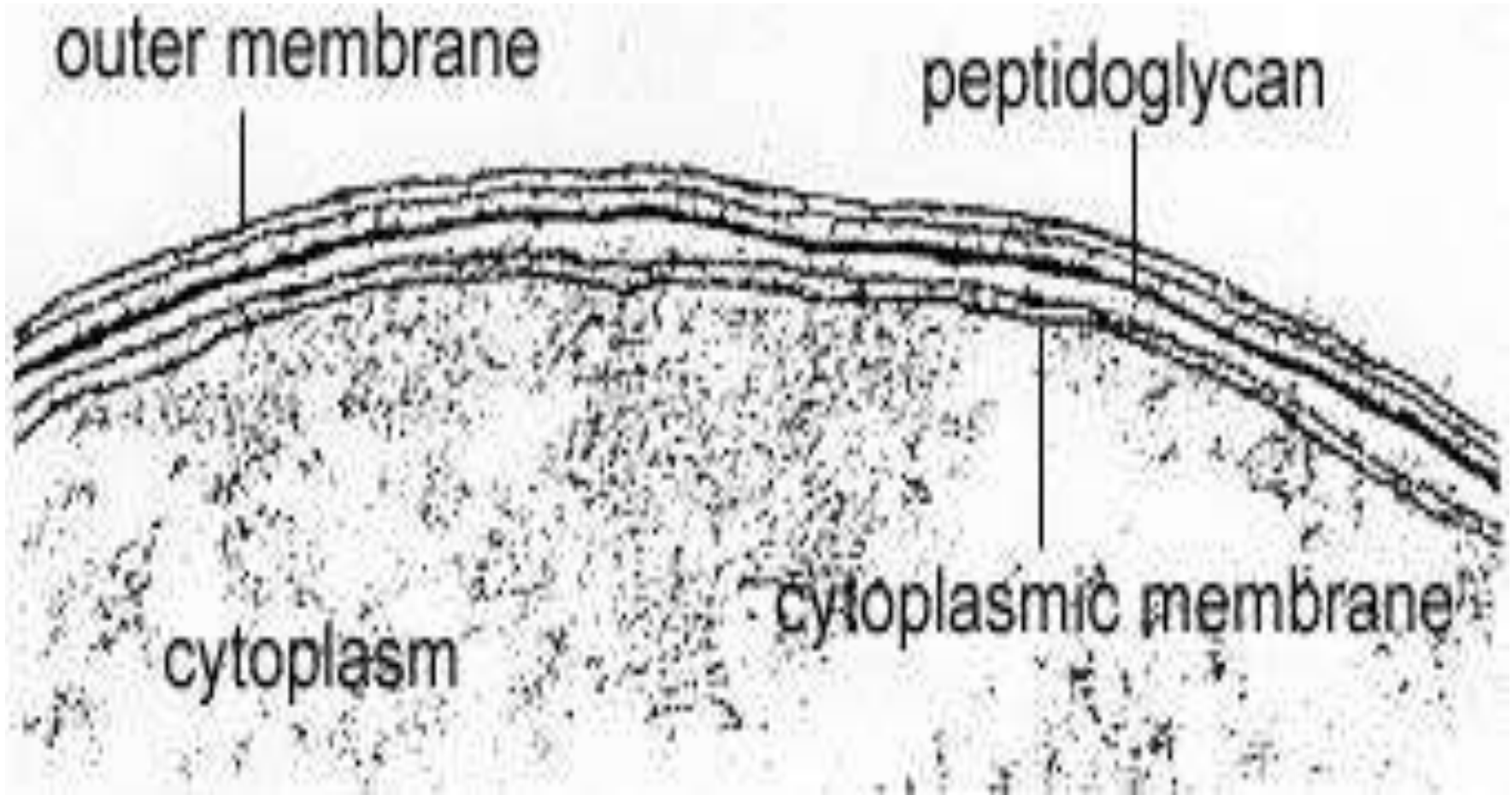
Gram-Negative Cell Wall



The Gram-negative cell wall is composed of:

- periplasmic space
- peptidoglycan (thin layer)
- Braun's lipoproteins
- Lipopolysaccharides
- Porins

Gram-Negative Cell Wall



Gram Negative Cell Wall: Periplasm

- The proteins in solution in the periplasm consist of:
 - enzymes with hydrolytic functions (such as alkaline phosphatase)
 - antibiotic-inactivating enzymes
 - various binding proteins with roles in chemotaxis and in the active transport of solutes into the cell
- Oligosaccharides secreted into the periplasm create an osmotic pressure buffer

Gram Negative Peptidoglycan

- Only one or two layers
- No pentaglycine bond
- Lesser cross-linking
- Braun's lipoproteins
 - binds peptidoglycan layer to outer membrane

Outer Membrane

- major permeability barrier consisting of
 - lipopolysaccharide
 - phospholipids
 - Proteins
 - Porins

Gram Negative Cell Wall: Outer Membrane

- In the outer membrane, the inner leaflet consists of ordinary phospholipids, but the outer leaflet consists of a special molecule called **lipopolysaccharide (LPS)**
- LPS is extremely toxic to humans and other animals and is called **endotoxin**
- Even minute amounts of LPS can produce fever and shock (**Gram-negative shock, or endotoxic shock**)

Outer Membrane: Endotoxin (LPS)

- LPS consists of:
 - **lipid A** (a phospholipid containing glucosamine rather than glycerol)- this is the toxic component of the endotoxin
 - a **core polysaccharide** (containing some unusual carbohydrate residues and fairly constant in structure among related species of bacteria)
 - **O-antigen** polysaccharide side chains- the major surface antigen of Gram-negative cells

LIPOPOLYSACCHARIDE

Four segments can be differentiated within the lipopolysaccharides:

1. **Lipid A** – a phospholipid consisting of two molecules of glucosamine which carry three fatty acids anchoring the LPS in the lipid bilayer.
2. **R-core:**
 - **Inner core** - 3 molecules of 2-keto-3-deoxyoctonate (KDO) and two heptose both linked to phosphoethanolamine.
 - **Outer core** - pentasaccharide of glucose, galactose and GNAc.
3. **O-side chain** (also known as **O-antigen**), consisting of unusual sugars such as mannose, rhamnose, abequose, fucose, colitose and others.

Lipopolysaccharides

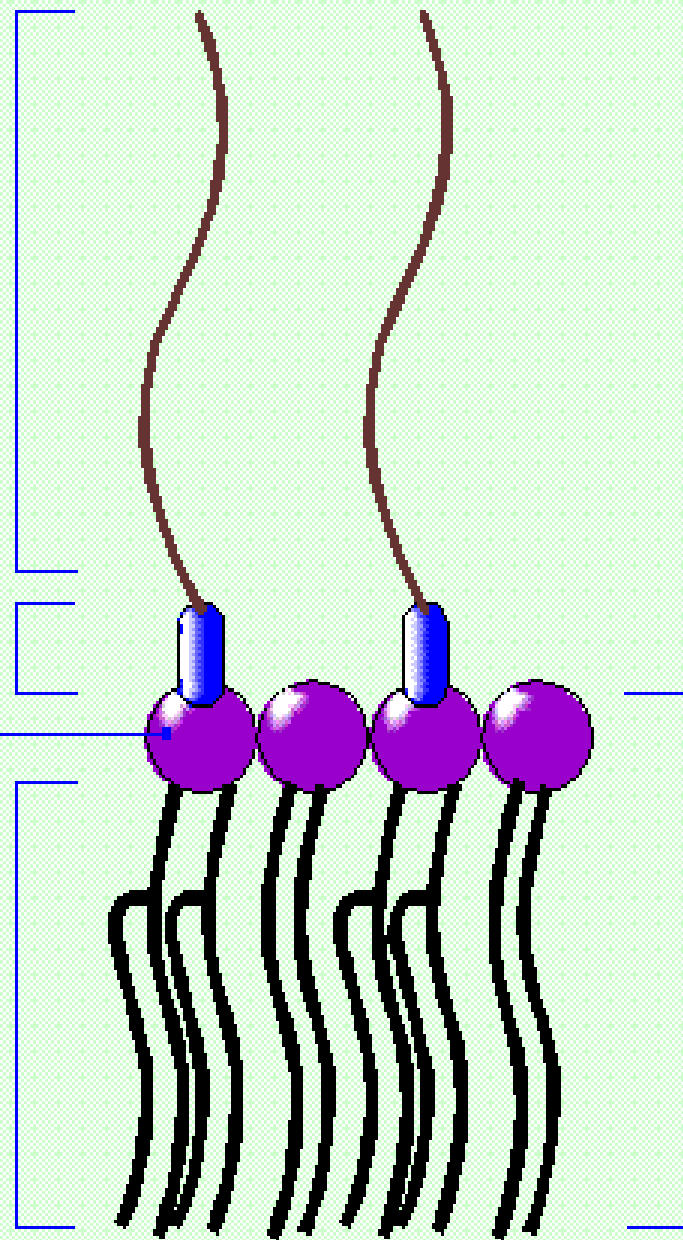
O - antigen

Core polysaccharide

Polyglucosamine - (P)

Fatty acids

Lipid A



Gram Negative Cell Wall: Outer Membrane

- LPS in the outer membrane results in a barrier that blocks the passage of virtually every organic molecule into the cell
- The Gram negative cell must make provision for the rapid entry of nutrients
 - Special proteins, called **porins** or **matrix proteins**, form pores through the outer membrane
 - **porins** allow hydrophilic molecules of <800 MW to diffuse into the periplasm

Gram positive versus Gram negative wall

<u>Characteristic</u>	<u>Gram positive</u>	<u>Gram negative</u>
Peptidoglycan	Thick	Thin
Tetra peptide	Most have lysine	All have DAP
Cross-linkage	Generally pentapeptide	Direct bond
Teichoic/teichuronic acids	+	-
Lipoproteins	-	+
Lipopolysaccharide	-	+
Outer membrane	-	+
Periplasmic space	-	+
Polysaccharide	+	+
Protein	+ or -	+

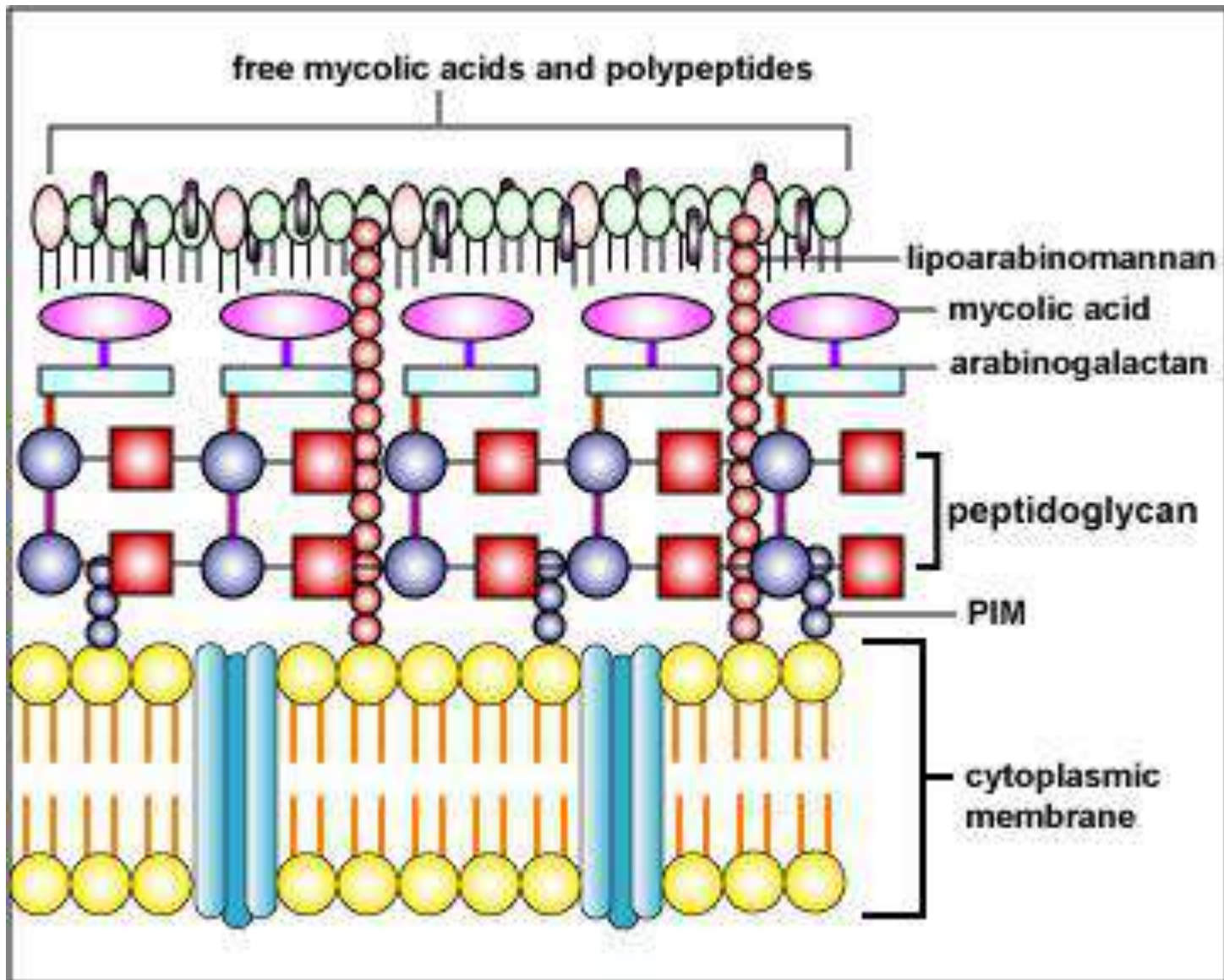
**Acid fast and related bacteria
(mycobacteria, nocardia and corynebacteria)**

Acid Fast Cell Wall

The cell wall of acid-fast bacteria consists of:

- **peptidoglycan layer linked to arabinogalactan**
- **arabinogalactan (D-arabinose and D-galactose) and mycolic acid layers**
- **mycolic acid layer is overlaid with a layer of polypeptides and free mycolic acids.**
- **Other glycolipids include lipoarabinomannan and phosphatidylinositol mannosides (PIM).**

Structure of an Acid-Fast Cell Wall



Wall-less forms

Wall-less bacteria that don't replicate:

- **Result from action of:**
 - **enzymes lytic for cell wall**
 - **antibiotics inhibiting peptidoglycan biosynthesis**
- **non-viable**
- **spheroplasts (with outer membrane) from Gram negative bacteria**
- **protoplasts (no outer membrane) from Gram positive bacteria**

Wall-less bacteria that replicate : L-forms

Naturally occurring wall-less bacteria: Mycoplasmas (viable, replicate)

S-LAYER

- **Some bacteria (e.g. *Bacillus anthracis*) may be covered by a regular arrangement of proteins called as S-layer.**
- **S-layer is attached to the outermost portion of their cell wall.**
- **composed of either a single protein or glycoproteins, depending upon the species.**
- **protect bacteria from harmful enzymes, changes in pH, and the predatory bacterium.**
- **can function as an adhesin.**
- **may contribute to virulence by protecting the bacterium against complement attack and phagocytosis**