Anatomy of the Bacterial Cell

By

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Introduction

Bacteria are microscopic single-celled organisms that thrive in diverse environments. They can live within soil, in the ocean and inside the human gut. Humans' relationship with bacteria is complex. Sometimes they lend a helping hand, by curdling milk into yogurt, or helping with our digestion. At other times they are destructive, causing diseases like pneumonia and UTI infections .

Bacterial Cell Components

These can be divided into:

A. Cell envelope and its appendages.

1. **The outer layer or cell envelope** consists of two components: Cell wall and Cytoplasmic or plasma membrane

2. **Cellular appendages:** Capsule, fimbriae, and flagella

B. Cell interior: Those structures and substances that are bounded by the cytoplasmic membrane compose the cell interior and include **cytoplasm**, **cytoplasmic inclusions (mesosomes**, **ribosomes**, **inclusion granules**, **vacuoles) and a single circular chromosome of deoxyribonucleic acid (DNA)**

A. Cell Envelope and its Appendages

1- Cell wall

The cell wall is the layer that lies just outside the plasma membrane. It is strong and relatively rigid, and openly porous.

Functions of the cell wall:

1. It imparts shape and rigidity to the cell.
2. It supports the weak cytoplasmic membrane against the high internal osmotic pressure of the protoplasm.
3. It maintains the characteristic shape of the bacterium.
4. It takes part in cell division.
5. It also functions in interactions (e.g. adhesion) with other bacteria and with mammalian cells.
6. It provides specific protein and carbohydrate receptors for the attachment of some bacterial viruses.

Chemical structure of bacteria cell wall: Chemically the cell wall is composed of mucopeptide **(**peptidoglycan or murein) scaffolding formed by N-acetyl glucosamine and N-acetyl muramic acid molecules alternating in chains, which are crosslinked by peptide bonds (Fig. 1).

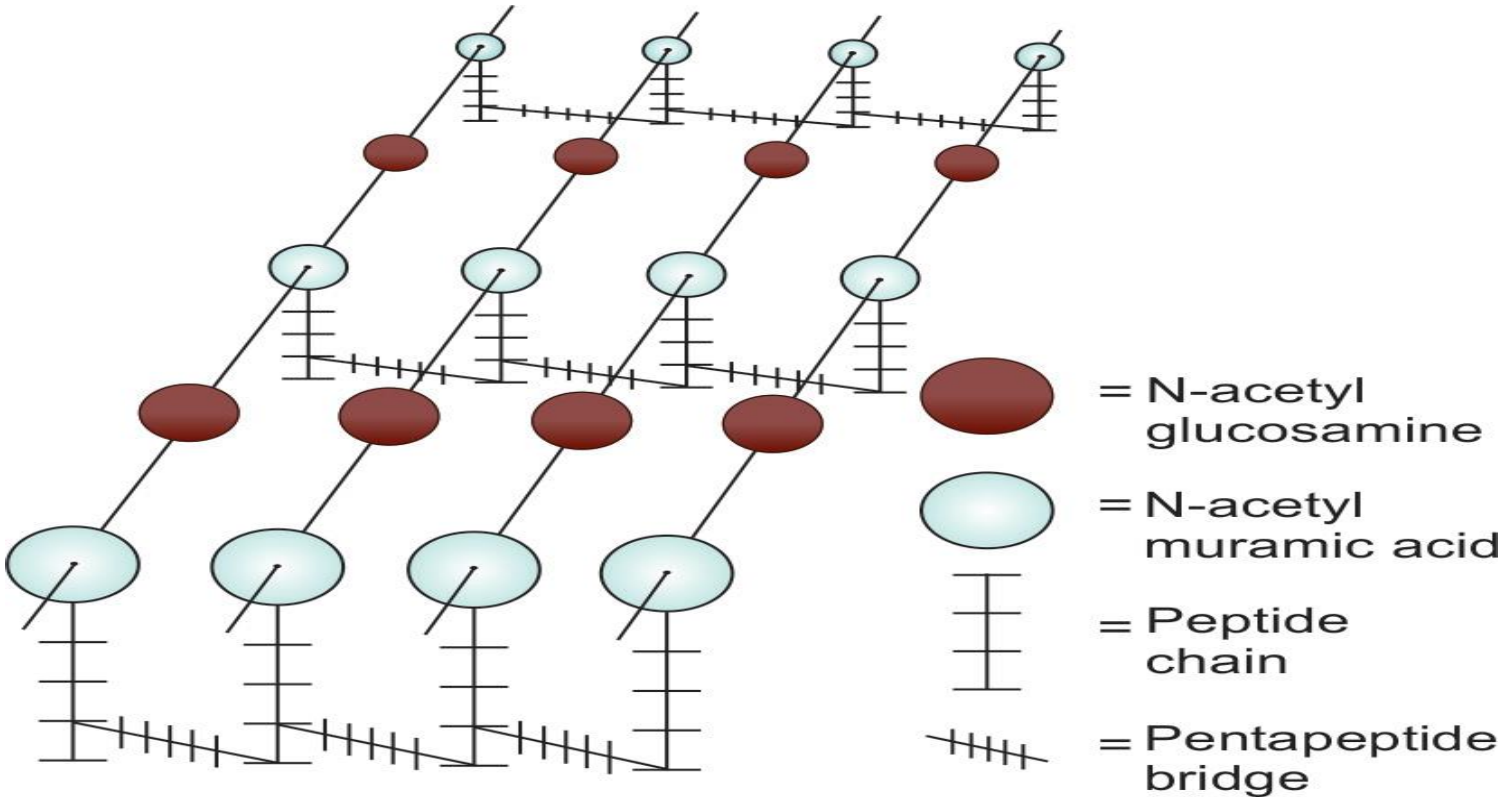


Fig1: Chemical structure of bacterial cell wall

Difference between cell wall of gram-positive and gram-negative bacteria

In general, the walls of the gram-positive bacteria have simpler chemical nature than those of gram negative bacteria (Table 1).

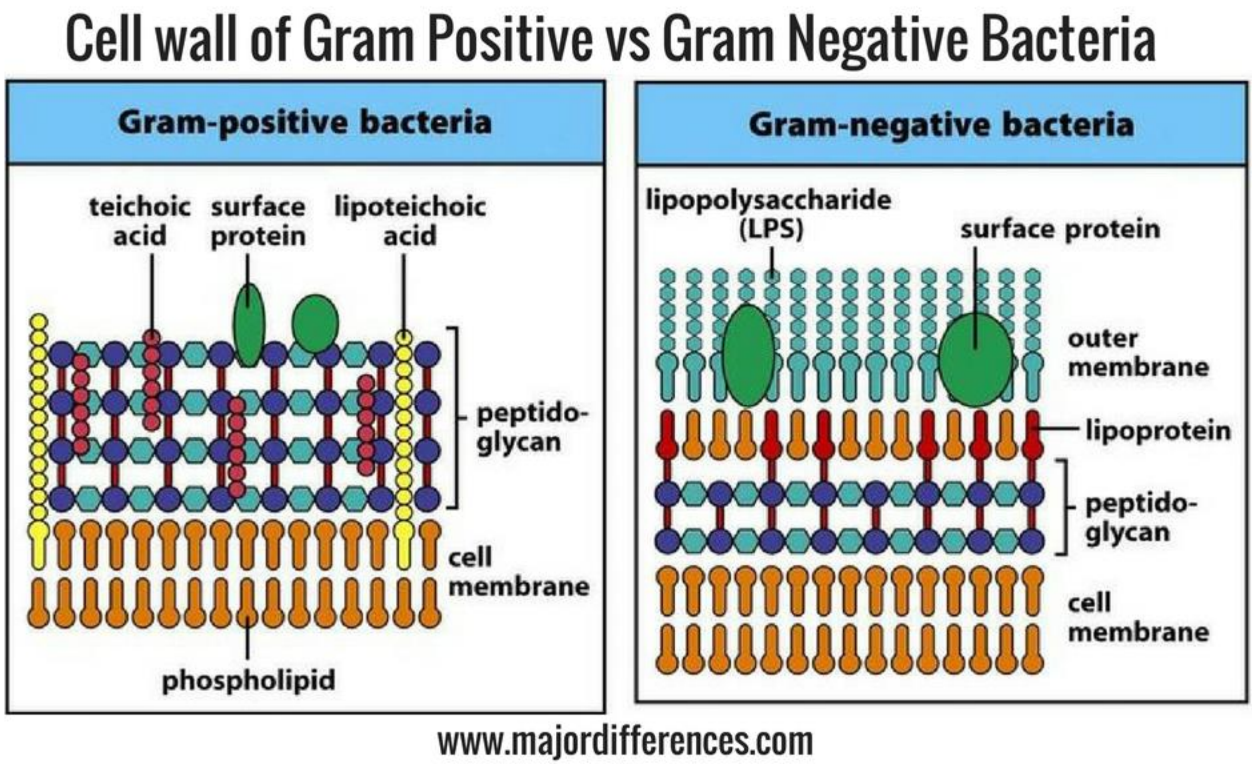


Table 4.1	Some Comparative Characteristics of Gram-Positive and Gram-Negative Bacteria	
Characteristic	**Gram-Positive**	**Gram-Negative**
		
Gram Reaction	Retain crystal violet dye and stain blue or purple	Can be decolorized to accept counterstain (safranin) and stain pink or red
Peptidoglycan Layer	Thick (multilayered)	Thin (single-layered)
Teichoic Acids	Present in many	Absent
Periplasmic Space	Absent	Present
Outer Membrane	Absent	Present
Lipopolysaccharide (LPS) Content	Virtually none	High
Lipid and Lipoprotein Content	Low (acid-fast bacteria have lipids linked to peptidoglycan)	High (because of presence of outer membrane)
Flagellar Structure	2 rings in basal body	4 rings in basal body
Toxins Produced	Exotoxins	Endotoxins and exotoxins
Resistance to Physical Disruption	High	Low
Cell Wall Disruption by Lysozyme	High	Low (requires pretreatment to destabilize outer membrane)
Susceptibility to Penicillin and Sulfonamide	High	Low
Susceptibility to Streptomycin, Chloramphenicol, and Tetracycline	Low	High
Inhibition by Basic Dyes	High	Low
Susceptibility to Anionic Detergents	High	Low
Resistance to Sodium Azide	High	Low
Resistance to Drying	High	Low

- **Gram-positive bacterial cell wall**

The gram-positive bacterial cell wall is composed mostly of several layers of peptidoglycan.

Peptidoglycans: It is thicker and stronger than that of gram-negative bacteria.

Teichoic acid: In addition, the cell walls of gram positive bacteria contain teichoic acids.

- **Gram-negative bacterial cell wall**

The gram-negative bacterial cell wall is structurally quite different from that of gram-positive cells. It consists of **peptidoglycan**, **lipoprotein**, **outer membrane**, **and lipopolysaccharide**.

i. **Peptidoglycan layer:** Peptidoglycan layer is a single-unit thick of gram-negative bacteria. It is bonded to lipoproteins covalently in the outer membrane and plasma membrane and is in the **periplasm**, a gel-like fluid between the outer membrane and plasma membrane. The **periplasm** contains a high concentration of degradative enzymes and transport proteins.

ii. **Lipopoprotein:** Lipopoprotein, or murein lipoproteins seemingly attach (both covalently and non covalently) to the peptidoglycan by their protein portion, and to the outer membrane by their lipid component.

iii. **Outer membrane:** External to the peptidoglycan, and attached to it by lipoproteins is the outer membrane. It is a bilayered structure. Its inner leaflet is composed of phospholipid while in phospholipids, the outer leaflet are replaced by lipopolysaccharide (LPS) molecules.

Functions

a. **A protective barrier**.

b. **Porins** or **transmembrane proteins:** Function in the selective transport of nutrients into the cell.

c. **Lipopolysaccharide (LPS)** Lipopolysaccharide (LPS) consists of three components:

i. **Lipid A:** It is the lipid portion of LPS and is embedded in the top layer of the outer membrane. When gram-negative bacteria die, they release lipid A, which functions as an **endotoxin**. All the toxicity of the endotoxin is due to lipid A which is responsible for the endotoxic activities, that is, pyrogenicity, lethal effect, tissue necrosis, anticomplementary activity, B cell mitogenicity, immunoadjuvant property and antitumor activity.

ii. **The core polysaccharide** its role is to provide stability.

iii. **O-polysaccharide:** It extends outward from the core polysaccharide and is composed of sugar molecules. Polysaccharide represents a major surface antigen of the bacterial cell. It is known as **O-antigen**.

Enzymes that attack cell walls

i. **Lysozyme:** The enzyme **lysozyme**, which is found in animal secretions (tears, saliva, nasal secretions) as well as in egg white, is a natural body defense substance which lyses bacteria of many species.

ii. **Autolysins:** Bacteria themselves possess enzymes, called **autolysins**, able to hydrolyse their own cell wall substances.

2- Cytoplasmic (plasma) membrane

Structure: The cytoplasmic (plasma) membrane limits the bacterial protoplast. It is thin (5–10 nm thick), elastic and can only be seen with electron microscope. It is a typical **'unit membrane'**, composed of phospholipids and proteins. Chemically, the membrane consists of lipoprotein with small amounts of carbohydrate. With the exception of ***Mycoplasma,*** bacterial cytoplasmic membrane lacks sterols.

Functions of cytoplasmic membrane:

i. Semipermeable membrane: Controlling the inflow and outflow of metabolites to and from the protoplasm.

ii. Housing enzymes: Involved in outer membrane synthesis, cell wall synthesis, and in the assembly and secretion of extracytoplasmic and extracellular substances.

iii. Housing many sensory and chemotaxis proteins

iv. Generation of chemical energy (i.e. ATP)

v. Cell motility

vi. Mediation of chromosomal segregation during replication

b. Cellular Appendages

I. Bacterial capsule or slime layer

Structure: Many bacteria synthesize large amount of extracellular polymer in their natural environments. When the polymer forms a condensed, well-defined layer closely surrounding the cell, it is called the **capsule** as in the *Pneumococcus*. If the polymer is easily washed off and does not appear to be associated with the cell in any definite fashion, it is referred to as a **slime layer** as in leuconostoc. A **glycocalyx** is a network of polysaccharide extending from the surface of bacteria and other cells. Capsules too thin to be seen under the light microscope are called **microcapsules**.

❖**Composition of capsules and slime layers:**

Capsules and slime layers usually are composed of polysaccharide (for example, *Pneumococcus*) or of polypeptide in some bacteria (for example, ***Bacillus***

anthracis and ***Yersinia pestis***). Some bacteria may have both a capsule and a slime layer (for example, ***Streptococcus salivarius*)**. Bacteria secreting large amounts of slime produce mucoid growth on agar.

Capsulated bacteria: ***Streptococcus pneumoniae,*** several groups of streptococci, ***Neisseria meningitidis***, ***Klebsiella***, ***Haemophilus influenzae***, ***Yersinia*** and ***Bacillus.***

❖ Functions of capsule

i. **Virulence factor:** Capsules often act as an virulence factor by protecting the bacterium from ingestion by phagocytosis and non capsulate mutant of these bacteria are non virurlent.

ii. **Protection of the cell wall:** In protecting the cell wall attack by various kinds of antibacterial agents.

iii. Identification and typing of bacteria.

II. Flagella

Structure: They are long, hollow, helical filaments, usually several times the length of the cell. They are 3–20 μm long and are of uniform diameter (0.01–0.013 μm) and terminate in a square tip. It originates in the bacterial protoplasm and is extruded through the cell wall. Flagella consists of largely or entirely a protein, **flagellin**. Flagella are highly antigenic and flagellar antigens induce specific antibodies in high titers. Flagellar antibodies are not protective but are useful in serodiagnosis.

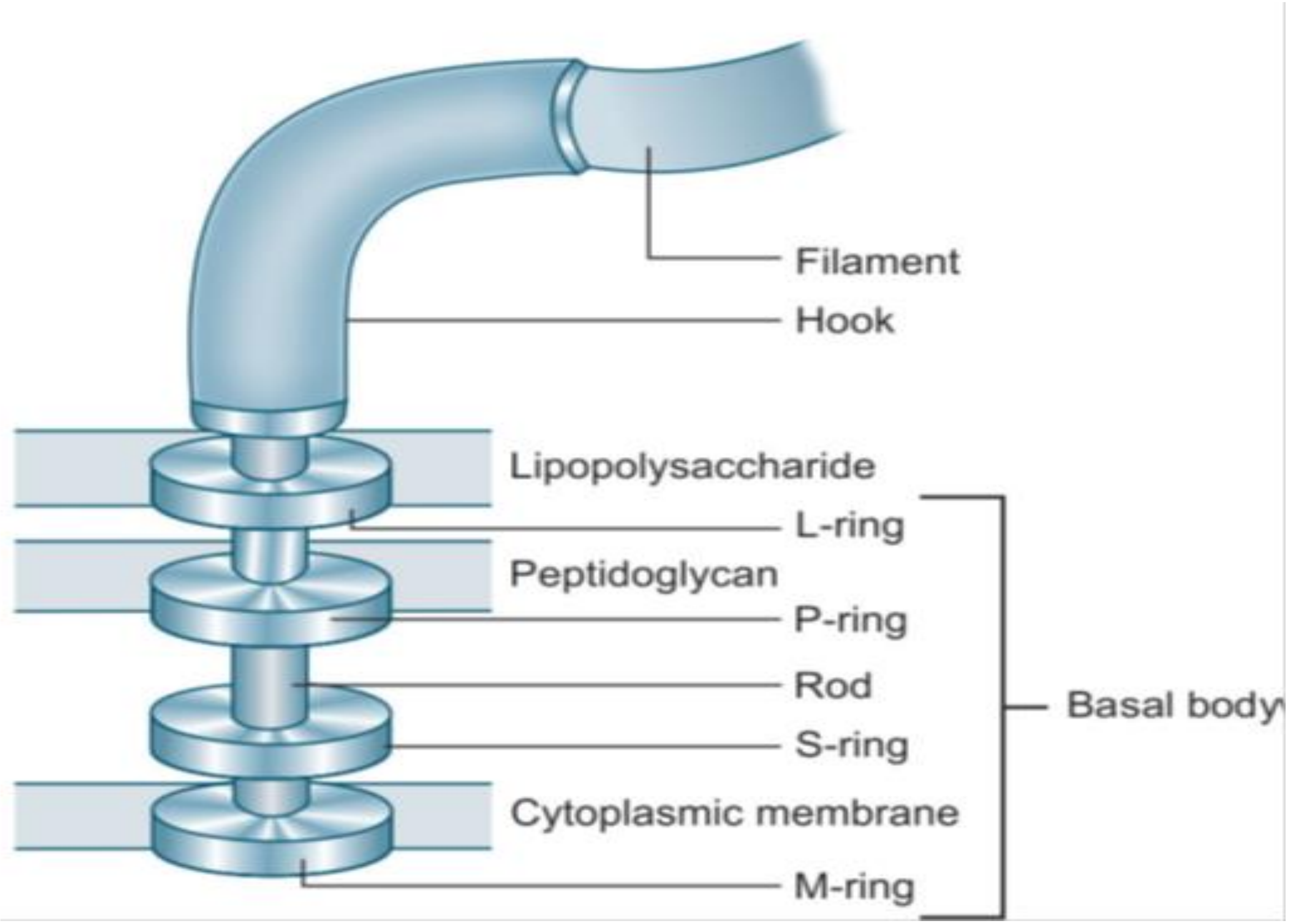


Fig. 3: The structure of bacterial flagellum

Arrangement/Types

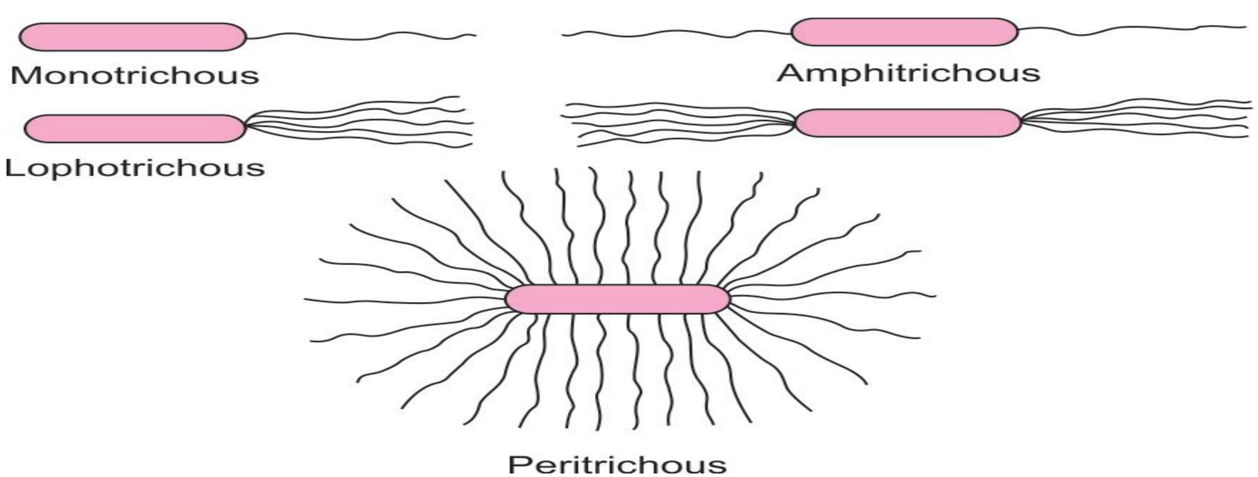
There are four types of flagella arrangement:

i. **Monotrichous:** Single polar flagellum (e.g. Cholera vibrio)

ii. **Amphitrichous:** Single flagellum at both ends, e.g. ***Alkaligenes faecalis***.

iii. **Lophotrichous:** Tuft of flagella at one or both ends, e.g. Spirilla.

iv. **Peritrichous:** Flagella surrounding the cell (e.g. Typhoid bacilli).



III. Fimbria or pili

Structure and synthesis: Many gram-negative bacteria have short, fine, hair-like surface appendages called fimbriae or pili. They are shorter and thinner than flagella and emerge from the cell wall. They originate in the cytoplasmic membrane and are composed of structural protein subunits termed pilins like flagella. Fimbriae are antigenic.

Functions of pilli

Two classes can be distinguished **ordinary (common) pili** and **sex pili**.

A. Ordinary (common) pili: Fimbriae probably function as organs of adhesions.

B. Sex pili: Sex pili are appear to be involved in the transfer of DNA during conjugation. They are found on ‘male’ bacteria.

B. Cell Interior

1. Cytoplasm

The cytoplasm of the bacterial cell is a viscous watery solution or soft gel, containing a variety of organic or inorganic solutes, and numerous ribosomes and polysomes. The cytoplasm of bacteria differs from that of the higher eukaryotic organisms in not containing an endoplasmic reticulum or membrane-bearing microsomes, mitochondria, lysosomes and in showing signs of internal mobility. The cytoplasm stains uniformly with basic dyes in young cultures.

2. Ribosomes

The ribosomes are the location for all bacterial protein synthesis. Bacterial ribosomes are slightly smaller (10–20 nm) than eukaryotic ribosomes and they have a sedimentation rate of 70S (S or Svedberg unit), being composed of a 30S and 50S subunit.

Types of RNA: Ribosomes are composed of different proteins associated with three types of ribonucleic acid (RNA):

i. **Messenger (m) RNA:** These molecules are translated during protein synthesis.

ii. **Ribosomal RNA (rRNA)**

iii. **Transfer RNA (tRNA):** Specifically transfers the genetic information carried in the mRNA into functional proteins.

3. Mesosomes (Chondroids): These are convoluted or multilaminated membranous bodies formed as invaginations of the plasma membrane into the cytoplasm.

4. Intracytoplasmic Inclusions: These are not permanent or essential structures. These bodies are usually sources of storage of energy. They consist of volutin (polyphosphate), lipid, glycogen, starch or sulfur.

5. Bacterial Nucleus

The genetic material of a bacterial cell is contained in a single, long molecule of double-stranded deoxyribonucleic acid (DNA) which can be extracted in the form of a closed circular thread about 1 mm (1000 μm) long. The bacterial chromosome is haploid and replicates by simple fission instead of by mitosis as in higher cells.

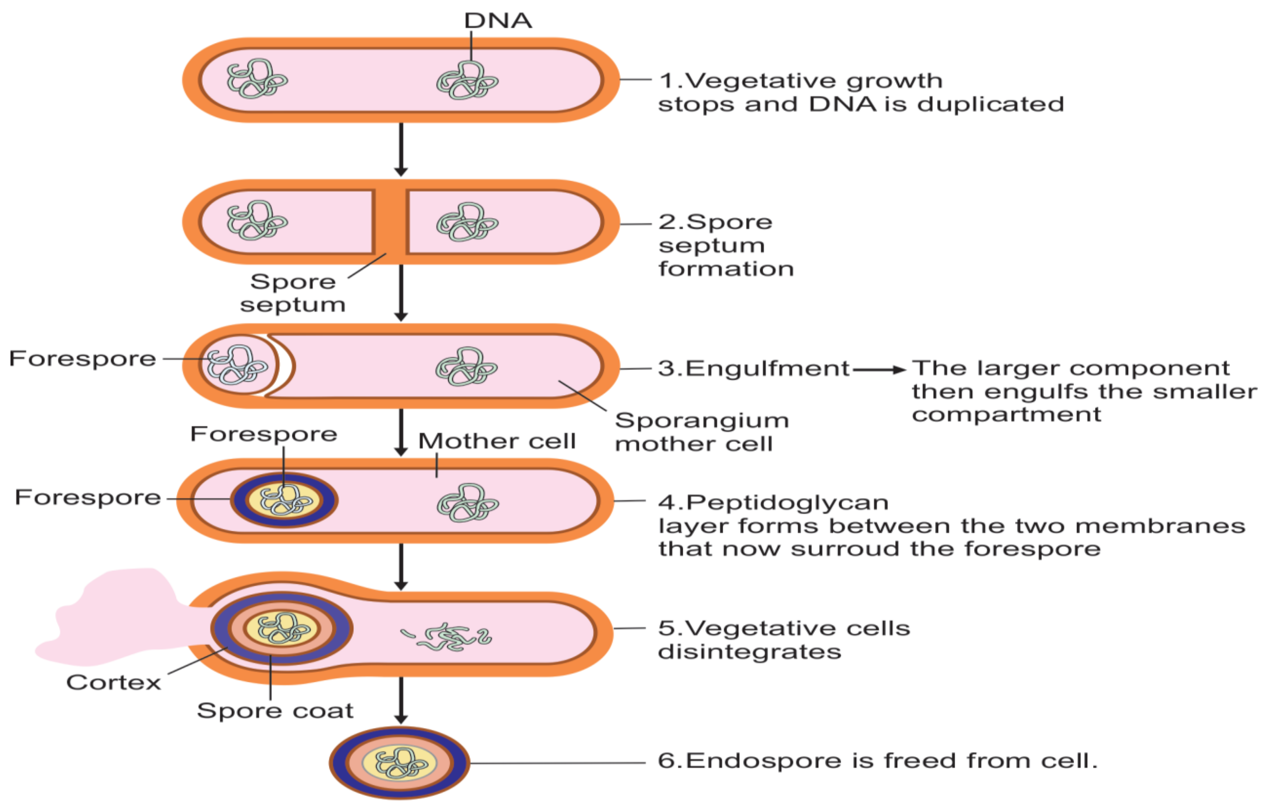
6. Plasmids

Bacteria may possess extranuclear genetic elements in the cytoplasm consisting of DNA termed **plasmids** or **episomes**.

Functions of plasmids: Plasmids are not essential for host growth and reproduction they inhibit, but may **confer on it certain properties** such as drug resistance, and toxigencity which may constitute a survival advantage.

7. Bacterial Spore

A number of gram-positive bacteria, such as those of the genera ***Clostridium*** and ***Bacillus*** can form a special resistant dormant structure called an **endospore**



Fig(5): The stages of endospore formation