BIOLOGY AND DIVERSITY OF VIRUSES, BACTERIA AND FUNGI (PAPER CODE: BOT 501)

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OBJECTIVES

The main objective of the present lecture is to cover the topic and make it easy to understand and interesting for our students/learners.

BLOCK – II : BACTERIA

Unit – 7 : Ultra Structure, Nutrition and Reproduction of Bacteria

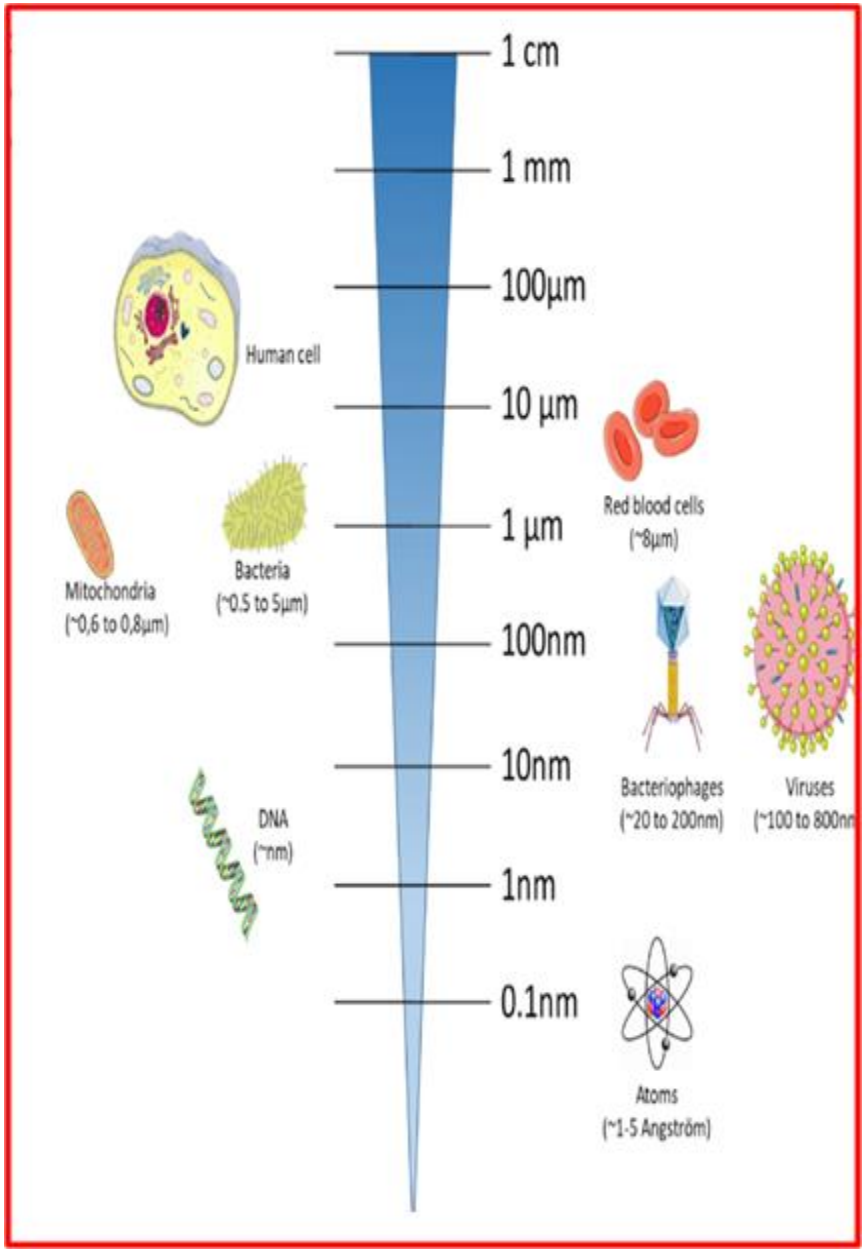
CONTENT

- Morphology of bacteria
  - Size
  - Shapes and arrangement
- Ultrastructure of bacteria
- Locomotion in bacteria
- Nutrition in bacteria
  - Autotrophic
  - Heterotrophic
- Reproduction in bacteria
  - Asexual reproduction
  - Sexual reproduction
- Key points of the lecture
- Terminology
- Assessment Questions
- Bibliography

MORPHOLOGY OF BACTERIA

❑ SIZE:

- ❖ Bacteria are prokaryotic, unicellular microorganisms, which lacking chlorophyll.
- ❖ The cell structure is simpler than that of other organisms as there is no nucleus or membrane bound organelles.
- ❖ Due to the presence of a rigid cell wall, bacteria maintain a definite shape, though they vary as shape, size and structure.
- ❖ In general, bacteria are between 0.2 and 2.0 µm - the average size of most bacteria.
- ❖ *E. coli*, a bacillus of about average size is 1.1 to 1.5 µm wide by 2.0 to 6.0 µm long.
- ❖ Spirochaetes occasionally reach 500 µm in length and the cyanobacterium.
- ❖ *Oscillatoria* is about 7 µm in diameter.
- ❖ The bacterium, *Epulosiscium fishelsoni* , can be seen with the naked eye (600 µm long by 80 µm in diameter).



- One group of bacteria, called the Mycoplasmas, have individuals with size much smaller than these dimensions.
- They measure about 0.25 µ and are the smallest cells known so far. They were formerly known as pleuropneumonia-like organisms (PPLO).
- *Mycoplasma gallicepticum, w*ith a size of approximately 200 to 300 nm are thought to be the world smallest bacteria.
- *Thiomargarita namibiensis* is world's largest bacteria, a gram-negative.
- Proteobacterium found in the ocean sediments off the coast of Namibia.
- Usually it is 0.1—0.3 mm (100—300 µm) across, but bigger cells have been observed up to 0.75 mm (750 µm).
- Research studies have shown their size to play an important role in survival over time.
- Due to their small size, bacteria are able to exploit and thrive in various microenvironments.
- The small size of bacteria is also beneficial for parasitism and oligotrophy.
- Bacteria can continue relying on a range of hosts (large and small) for their nutrition. In addition, they can also live and survive in environments that contain a low concentration of nutrients.
- Bacteria have a high surface area to volume ratio that allows them to take up as many nutrients as possible for survival. In the process, they are able to continue growing and reproducing at a steady rate.

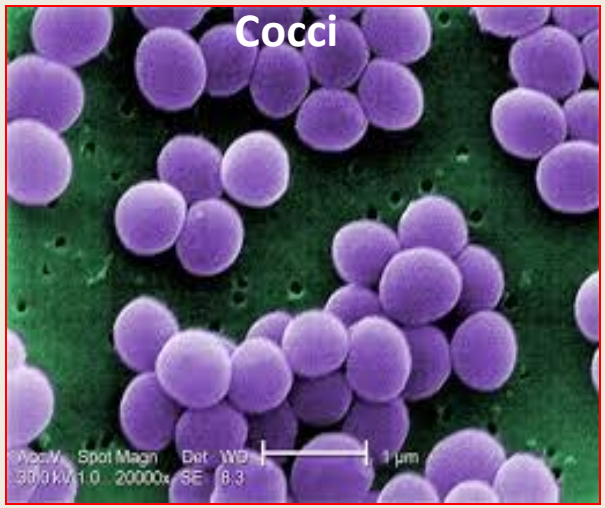
❑ SHAPES AND ARRANGMENT:

❖ Due to the presence of a rigid cell wall, bacteria maintain a definite shape, though they vary as shape size, structure and arrangment.

✓ **Shapes**:

❖ When viewed under light microscope, most bacteria appear in variations of three major shapes:

- **Cocci** (or coccus for a single cell) are round cells, sometimes slightly flattened when they are adjacent to one another.
- **Bacilli** (or bacillus for a single cell) are rod-shaped bacteria.
- **Spirilla** (or spirillum for a single cell) are curved bacteria which can range from a gently curved shape to a corkscrew-like spiral. Many spirilla are rigid and capable of movement. A special group of spirilla known as spirochetes are long, slender, and flexible.



✓ Arrangements:

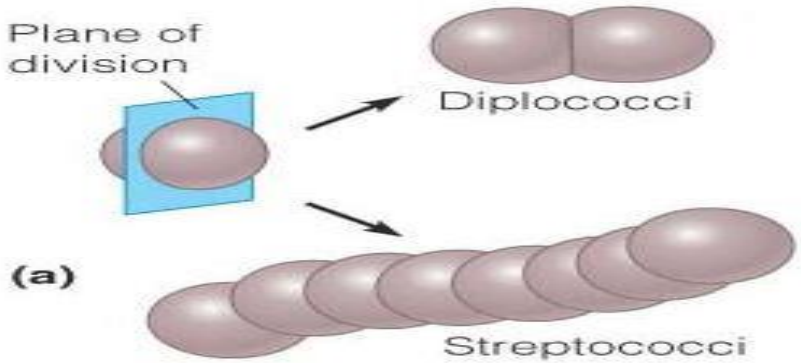
❖ So far as the arrangement is concerned, it may Paired (diplo), Grape-like clusters (staphylo) or Chains (strepto).

➢ Arrangement of Cocci

❖ Cocci bacteria can exist singly, in pairs (as diplococci), in groups of four (as tetrads), in chains (as streptococci), in clusters (as stapylococci), or in cubes consisting of eight cells (as sarcinae). Cocci may be oval, elongated, or flattened on one side. Cocci may remain attached after cell division. These group characteristics are often used to help identify certain cocci.

1. **Diplococci:** The cocci are arranged in pairs. Examples: *Streptococcus pneumoniae, Moraxella catarrhalis, Neisseria gonorrhoeae,* etc.

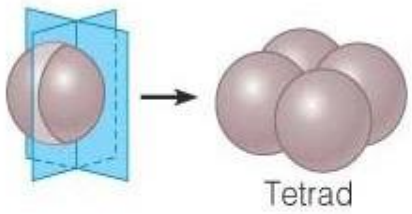
2. **Streptococci:** The cocci are arranged in chains, as the cells divide in one plane. Examples: *Streptococcus pyogenes, Streptococcus agalactiae*

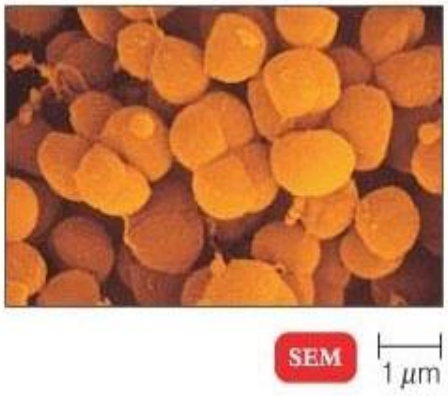


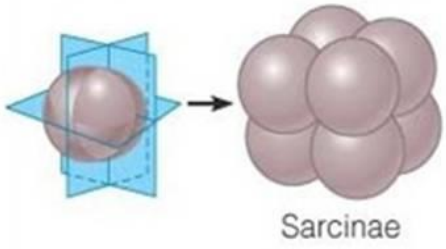
3. **Tetrads:** The cocci are arranged in packets of four cells, as the cells divide in two plains. Following division, the cells remain attached and grow in this attachment. Examples: *Aerococcus, Pediococcus and Tetragenococcus.*

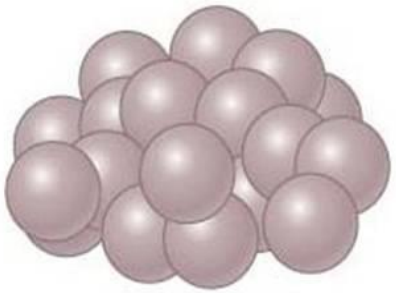
4. **Sarcinae:** The cocci are arranged in a cuboidal manner, as the cells are formed by regular cell divisions in three planes. Cocci that divide in three planes and remain in groups cube like groups of eight. Some of the characteristics associated with these bacteria include being strict anaerobes, Gram-positive bacteria and that measure between 1.5 and 3.0 um. Examples: *Sarcina ventriculi, Sarcina ureae, etc.*

5. **Staphylococci:** The cocci are arranged in grape-like clusters formed by irregular cell divisions in three plain. As members of the family Streptococcaceae, this group of bacteria is characterized by being non-motile, Gram-positive organisms. Examples: *Staphylococcus aureus*









➢ Arrangement of Bacilli

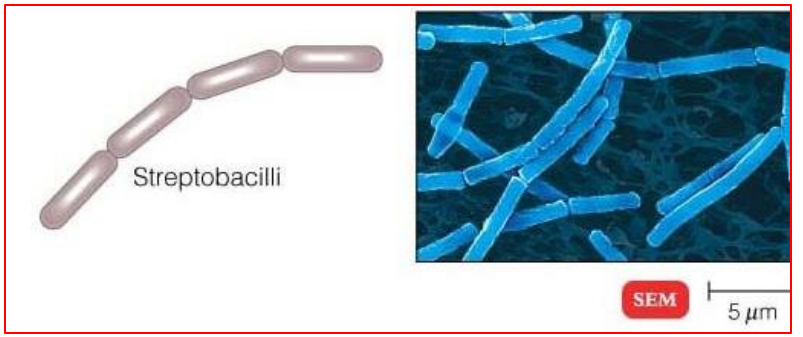
❖ The cylindrical or rod-shaped bacteria are called 'bacillus' (plural: bacilli). These group characteristics are often used to help identify certain bacilli.

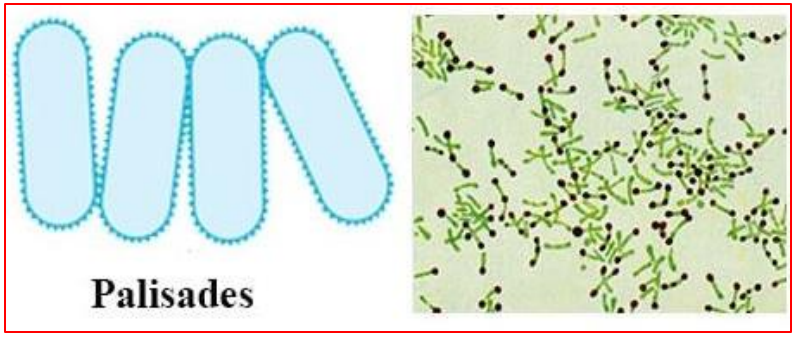
1. **Diplobacilli:** Like Diplococci bacteria, Diplobacilli occur in pairs. Following cell division, the two cells do not separate and continue existing as a pair. Example of Single Rod: *Bacillus cereus* Examples of Diplobacilli: *Coxiella burnetii, Moraxella bovis, Klebsiella rhinoscleromatis,* etc.

2. **Streptobacilli:** The bacilli are arranged in chains, as the cells divide in one plane. Examples: *Streptobacillus moniliformis*

3. **Coccobacilli:** These are so short and stumpy that they appear ovoid. They look like coccus and bacillus. Examples: *Haemophilus influenzae, Gardnerella vaginalis,* and *Chlamydia trachomatis.*

4. **Palisades:** The bacilli bend at the points of division following the cell divisions, resulting in a palisade arrangement resembling a picket fence and angular patterns that look like Chinese letters. Example: *Corynebacterium diphtheriae*





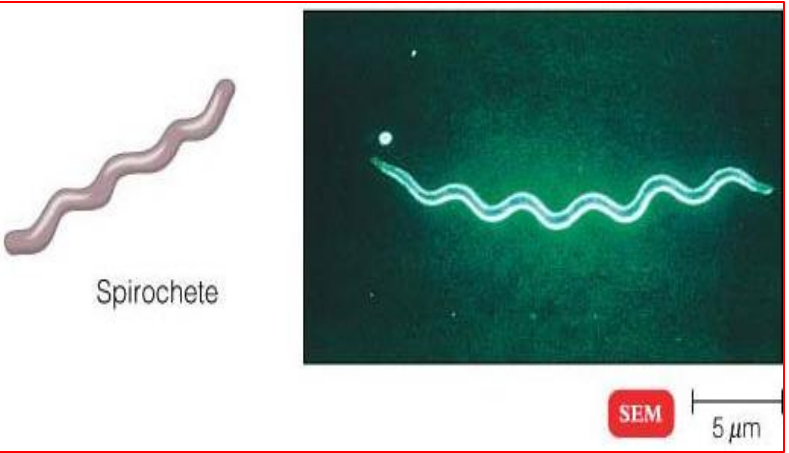
➢ Arrangement of Spiral Bacteria

❖ **Spirilla:** (or spirillum for a single cell) are curved bacteria which can range from a gently curved shape to a corkscrew-like spiral. Many spirilla are rigid and capable of movement. A special group of spirilla known as spirochetes are long, slender, and flexible.

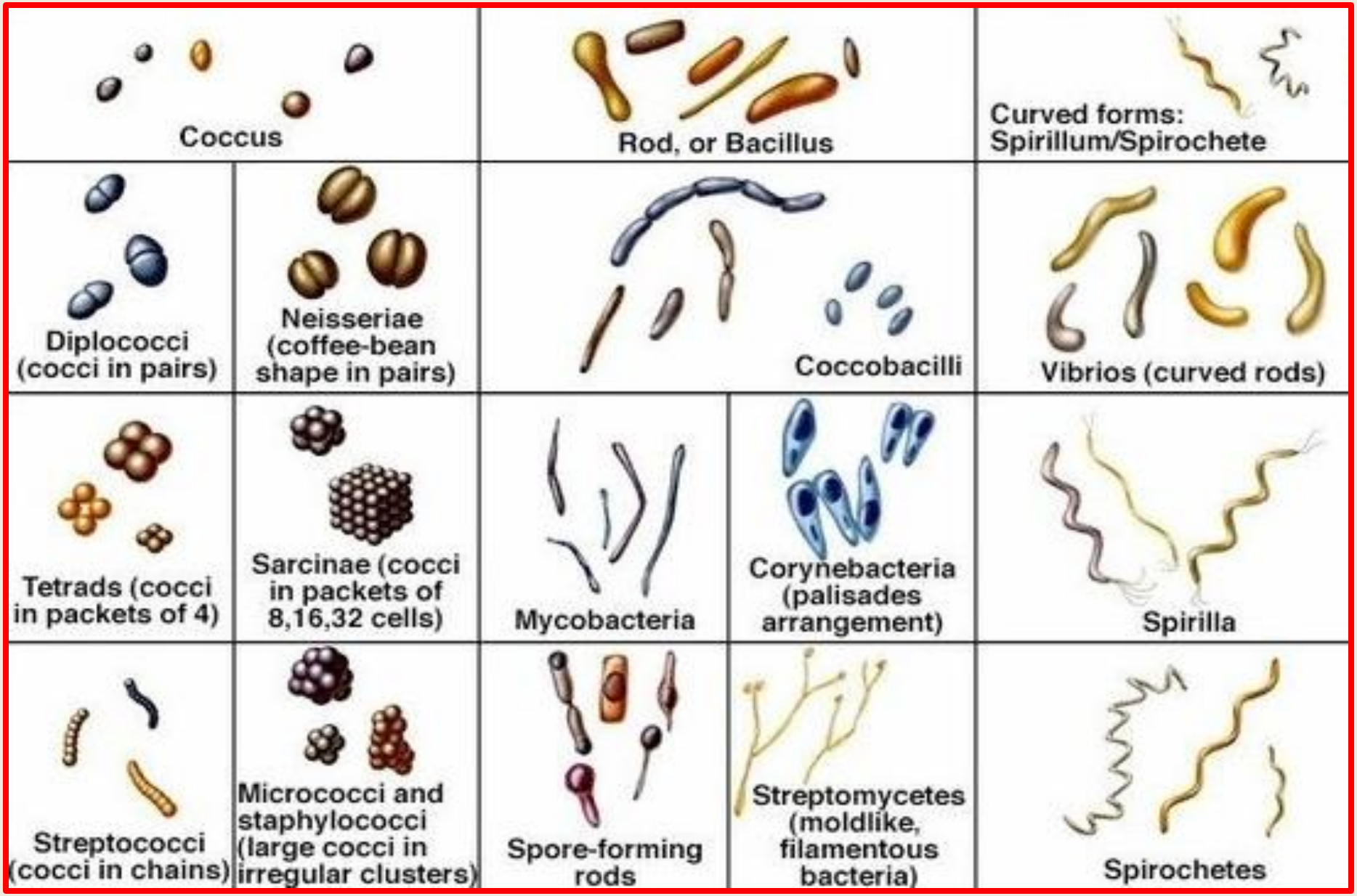
1. **Vibrio:** They are comma-shaped bacteria with less than one complete turn or twist in the cell. Example: *Vibrio cholerae*

2. **Spirilla:** They have rigid spiral structure. Spirillum with many turns can superficially resemble spirochetes. They do not have outer sheath and endoflagella, but have typical bacterial flagella. Example: *Campylobacter jejuni, Helicobacter pylori*, *Spirillum winogradskyi,* etc.

3. **Spirochetes:** They have a helical shape and flexible bodies. Spirochetes move by means of axial filaments, which look like flagella contained beneath a flexible external sheath but lack typical bacterial flagella. The movement involves the use of axial filaments, which is one of the distinguishing features between the bacteria and other types of bacteria. Examples: *Leptospira* species, *Treponema pallidum*, *Borrelia recurrentis*, etc.

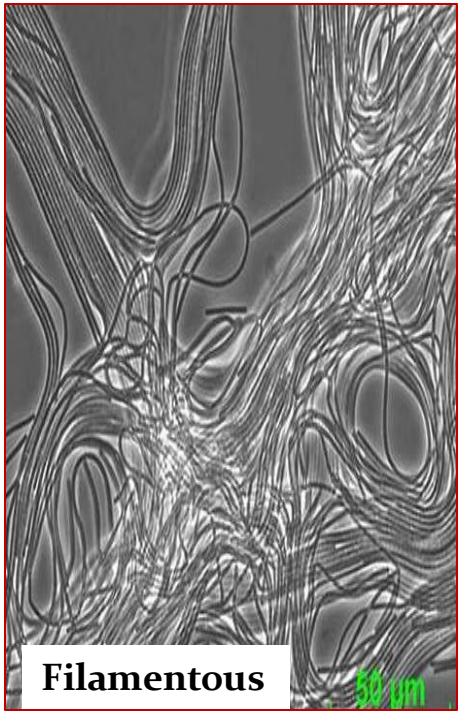


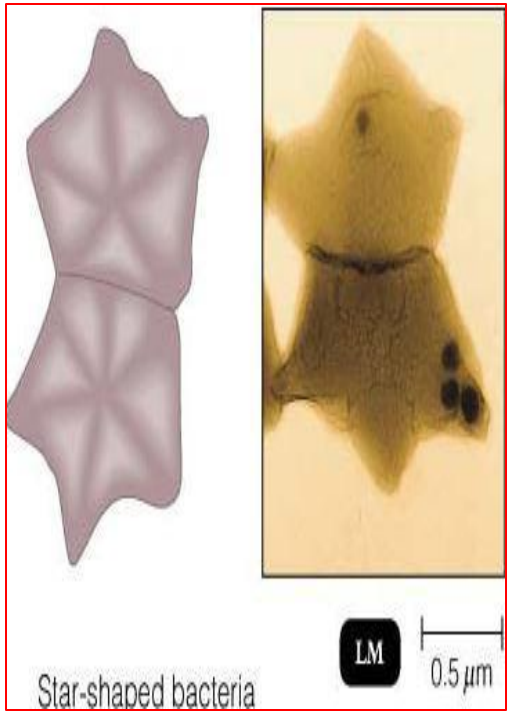
SHAPES AND ARRANGMENT OF BACTERIA

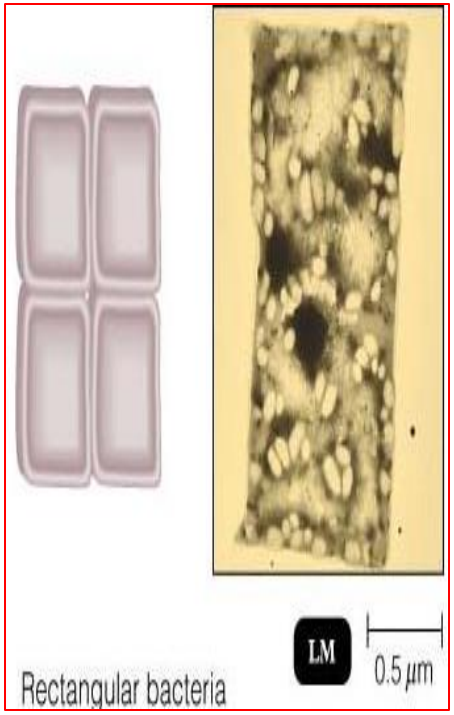


➢ Others Shapes and Arrangements of Bacteria

- **Filamentous Bacteria:** They are very long thin filament-shaped bacteria. Some of them form branching filaments resulting in a network of filaments called 'mycelium'. Example: *Candidatus Savagella*.
- **Star Shaped Bacteria:** Look like stars (star-shaped). Example: *Stella humosa*
- **Rectangular Bacteria:** They are rectangular in shaped. Example: *Haloarcula* spp
- **Pleomorphic Bacteria:** These bacteria do not have any characteristic shape unlike all others described above. They can change their shape. In pure cultures, they can be observed to have different shapes. Examples: *Mycoplasma pneumoniae, M. genitalium,* etc.







ULTRA STRUTURE OF BACTERIA

- Like other living plant cell, bacterial cell comprises a cell wall and protoplast.

❑ Slime layer/ Capsule:

- Slime layer is a gelatinous layer present on the outer surface of cell wall, composed of polysaccharides and polypeptide chain of amino acids.
- When its constituents are only polysaccharides which form a viscous layer, it is called slime layer, but when nitrogenous substances (i.e., amino acids) are also present along with polysaccharides, then it is called capsule.
- The capsulated cells are drought resistant. Association of polysaccharides with others makes it antigenetically important (used in serology).
- Mucopolysaccharieds help bacteria to remain in body without damage. Mucopolysaccharides have virulence (bacteria genetically capable of producing capsule if are pathogenic).
- If capsule is removed the cells will die. It means that for survival capsule is must.
- Mucopolysaccharides are sometimes associated with Ca^{2+}, Mg^{2+} ions for holding higher amount of water. The capsule is removed by chelating polysaccharides like EDTA or EDTA + NaCl in which cells after shaking, shed off capsule.
- In *Streptococci*, *Staphylococci* mucilage capsule is present only when cells are dividing rapidly.
- Slime/ Capsule protects cells from lysozyme activity.

❑Cell wall:

- ❖ In the electron micrograph the cell wall is seen as thin, sharply defined enveloped around the protoplast.
- ❖ It range in thickness around 0.02µ. The cell wall is tough though flexible.
- ❖ The inert and somwhat rigid cell wall limits the volume occupied by the protoplast and thus gives rigidity and shape to the bacterial cell.
- ❖ It show granular and lacks microfibrils.

(a) Structure of cell wall: The bacterial cell wall is composed by 4 layers. Of these two are of higher electron density

- ❖ The outer layer (L_4) is wavy. Within it is the lighter layer of low electron density (L_3). Next comes the inner dense or darker layer (L_2), is considered to be mucopeptide followed by the innermost layer of low electron density (L_1).

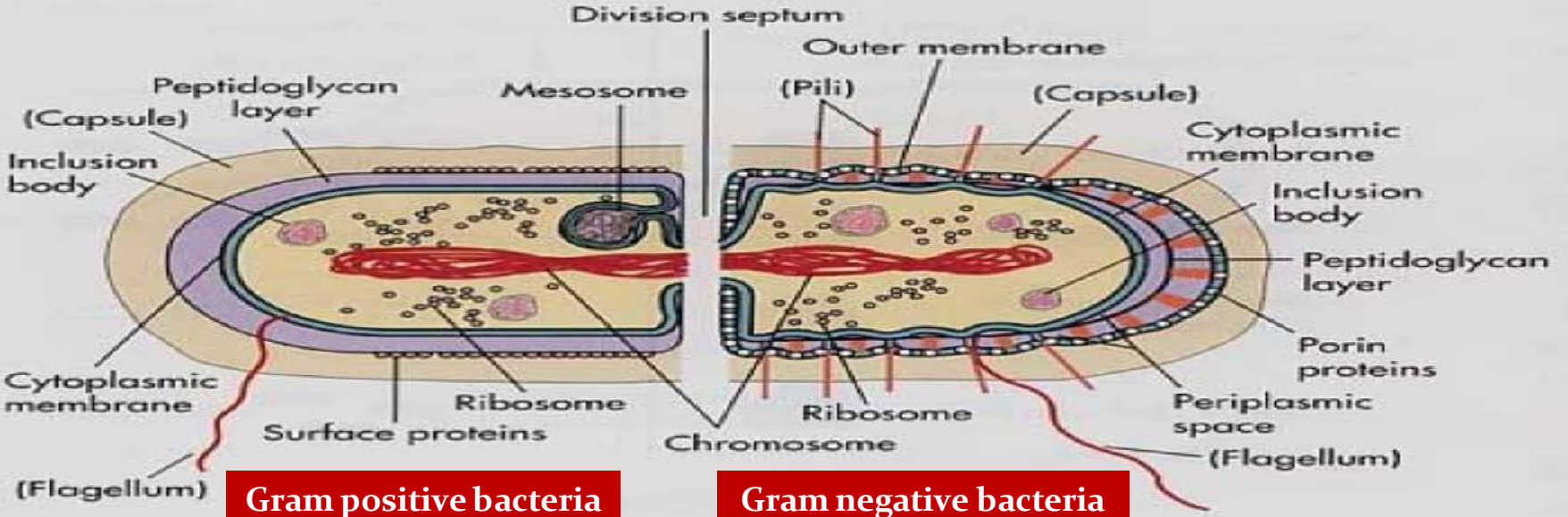
(b) Chemical composition of cell wall: The three main constituents of cell wall are: (i) N-acetyl glucosamine (NAG), (ii) N-acetyl muramic acid (NAM), and (iii) a peptide chain of four or five amino acids. These together form a polymer called peptidoglycan or mucopeptide.

- ❖ The NAG and NAM molecules which are arranged alternatively, run in one direction and the peptide chain run crosswise. The rigidity of bacterial cell wall is due to the presence of this polymer. Besides above mentioned three constituents, some other chemicals such as teichoic acid, protein polysaccharides, lipoproteins. Lipopolysaccharides are also deposited on it.

❖ The Gram stain, developed in 1884 by Hans Christian Gram, characterizes bacteria based on the structural characteristics of their cell walls as; Gram positive and gram negative. The thick layers of peptidoglycan in the "gram-positive" cell wall stain purple, while the thin "gram-negative" cell wall appears pink. A comparison between Gram-positive and Gram-negative bacteria is given:

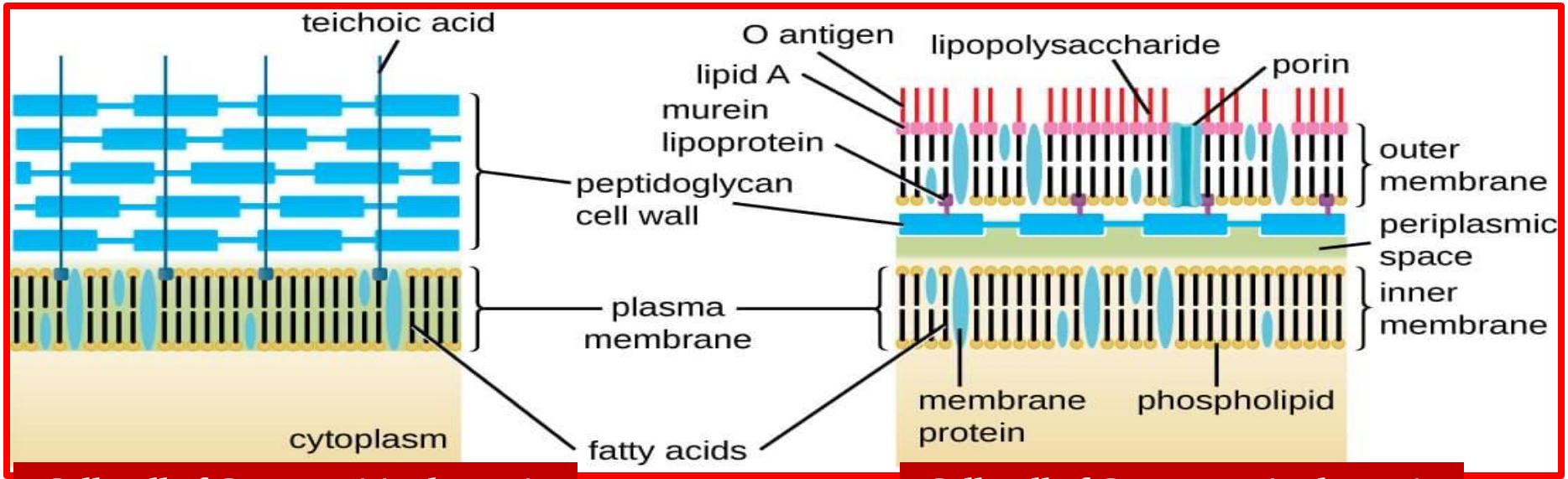
Characteristics	Gram-positive bacteria	Gram-negative bacteria
Cell wall structure	Single layered and 150-200A° thick	Triple layered and 75-120A° thick
Outer membrane	Absent	Present
Periplasmic space	Present in some	Present in all
Chemical composition	Peptidoglycans accounts about 80% of the cell wall and the rest are polysaccharides, teichoic acid present, low in lipid (1-4%), highly responsive to triphenylmethane, resistant to alkalies and insoluble in 1% KOH solution.	Peptidoglycans accounts only 3-12% of the cell wall. Mainly composed of lipoproteins and lipid polysaccharides, teichoic acid absent. High in lipid (11-22%), little response to triphenyl methane, show sensitivity to alkalies and soluble in 1% KOH solution.
Rigidity	Highly rigid due to high proportion of peptidoglycans	Elastic due to plastic nature of lipoprotein-polysaccharide mixture.
Susceptibility	High susceptibility	Low susceptibility
Nutritional requirement	Relatively complex in many species	Relatively simple
Permeability	More penetrable	Less penetrable

ULTRA STRUTURE OF BACTERIA



Gram positive bacteria

Gram negative bacteria



Cell wall of Gram positive bacteria

Cell wall of Gram negative bacteria

❑Protoplast:

❖ A living, slightly viscous stuff called protoplast is differentiated into:

(a) Cytoplasmic membrane: Inner to cell wall, a semipermeable cytoplasmic membrane is present which is about 75 A^o thick. Chemically it is composed of a double layer of phospholipid molecules. Proteins are found embedded in the lipid bilayers. The cytoplasmic membrane has many folded structures called mesosomes which are associated with number of activities like seat for protein synthesis, respiratory function, multiplication of chromosomal DNA, and DNA. Plasma membrane contains special receptor molecules that help bacteria detect and respond to chemicals in their surroundings. It also controls the entry of organic and inorganic molecules.

(b) Cytoplasm: Bacterial cytoplasm is a complex mixture of carbohydrates, proteins, lipids, minerals, nucleic acids and water. It stores organic material in the form of glycogen, rolutin and poly-β-hydroxy butyrate. Besides fluid portion and storage particles, the bacterial cytoplasm also contain chromatic or nuclear area and some other inclusions. The bacterial cell is devoid cell organelles but the photosynthetic bacteria have chromatophores in their cytoplasm.

Ribosomes are the sites of protein synthesis and suspended freely in cytoplasm. Their number varies from 10,000 to 15,000 in a cell. Bacterial ribosmoes are 70s type (50s and 30s subunits) consists of two subunits. Mesosomes are complex localized infoldings of the cytoplasmic membrane and higher in bacteria which show high respiratory activity, such as nitrifying bacteria. It has been suggested that mesosomes serves to accommodate more centres of respiration. But the absence of enzymes like ATPase, dehydrogenase and cytochrome in mesosome indicates that they are not the sites of respiration. They probably participate in the formation of transverse septum during cell division.

(c) The nuclear apparatus:

- The bacterial nucleus devoid of nuclear membrane, nucleolus, chromonemata and nuclear sap, such structure is called nucleoid or genophore.
- The DNA molecule (may be double or single) is approximately 1,000 µm long, usually forming ring like structure or sometimes remain diffused throughout the cytoplasm of the cell. The Bacterial DNA is devoid of histones and referred as bacterial chromosome.
- Bacterial cells also contain some extrachromosomal heredity determinants which are either independent of bacterial chromosomes or are intergrated with them called plasmid.
- Extranuclear materials called as episome are present which may be linear, circular, covalent coiled circular. Lederberg (1952) gave the term plasmid to those extragenophoral genetic materials. The replication of plasmid seems self controlled. They contain different non-essential characters.
- Based on host properties, the plasmids are classified into different types as:
    - F-factor for fertility
    - Col-factor for colicinogeny
    - R-factor for resistance
    - Tumor inducing plasmid (*Agrobacterium*)
    - Degradative plasmid (*Pseudomonas*)
    - Pathogenicity to mammals
    - Penicillase plasmid (*Staphylococcus*)
    - Mercury resistance
    - Cryptic plasmids
- Two important genes are associated with plasmids *ori* (origin of replicon) and *tra* (transfer).

LOCOMOTION IN BACTERIA

- Some bacteria are self motile. They are swim through the liquid in which they live. They can't crawl over dry surface or fly through the air. Motility is universal among the spirilla, common among the bacilli but lacking or rare in cocci forms.

- The organ of the locomotion is small whips or hair like appendages called flagella.

❑ Flagellation

- The flagella are distributed over the surface of the bacterial cell in a characteristic manner. Their number, position and arrangement varies with the species. On the basis of the flagellation and arrangement the bacterial cell can be classified as;

(a) Polar flagellation: This type of flagellation is restricted to a rather homogenous group of bacilli and spirilla. They are all gram negative. These are the following type;

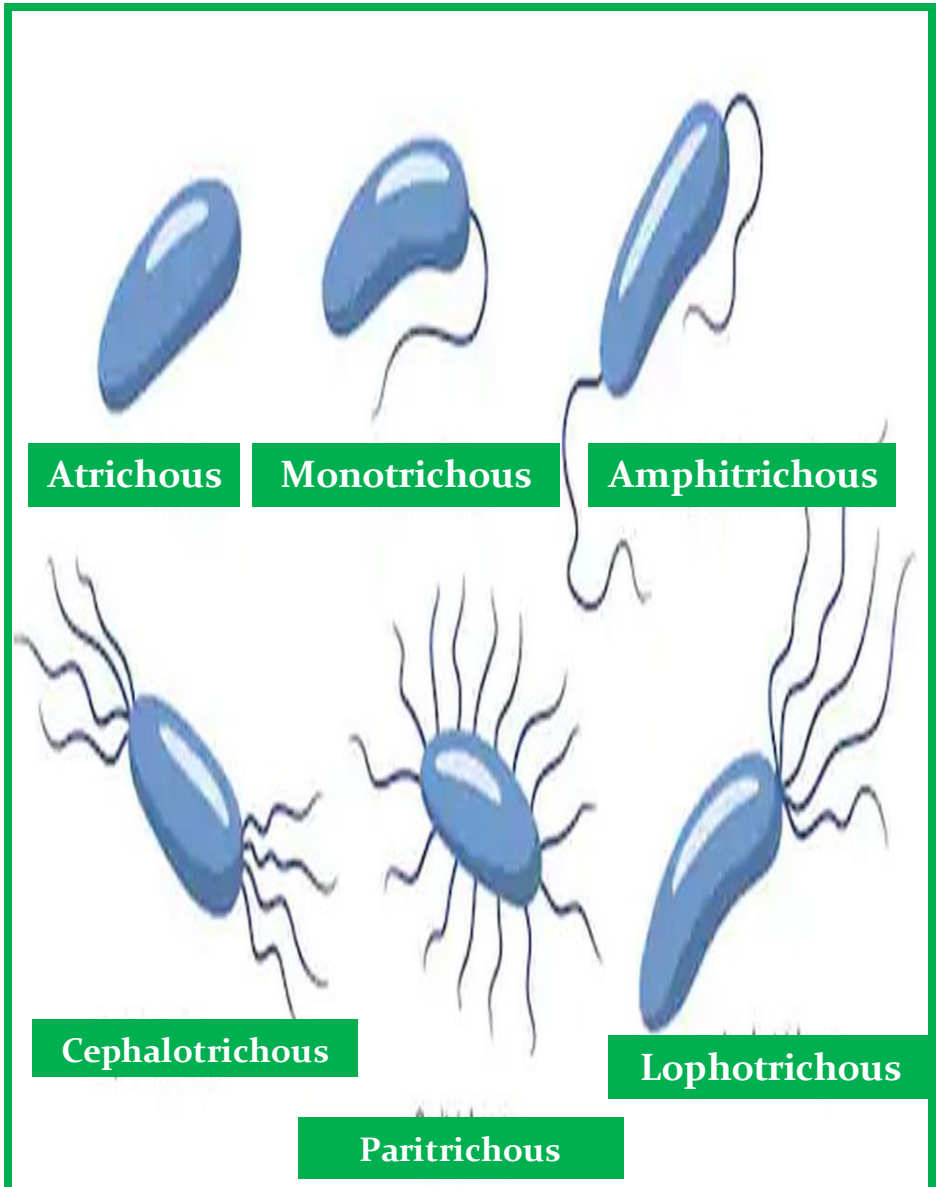
- **Monotrichous:** One flagella at one end, e.g. *Vibrio chlolerae, Pseudomonas*
- **Amphitrichous:** One flagella at each end, e.g. *Nitosomonas, Spirillum*
- **Cephalotrichous:** Two or more flagella at one end only, e.g. *Pseudomonas fluorescens*
- **Lophotrichous:** Tufts of flagella at both the ends, e.g. *Spirillum volutans*

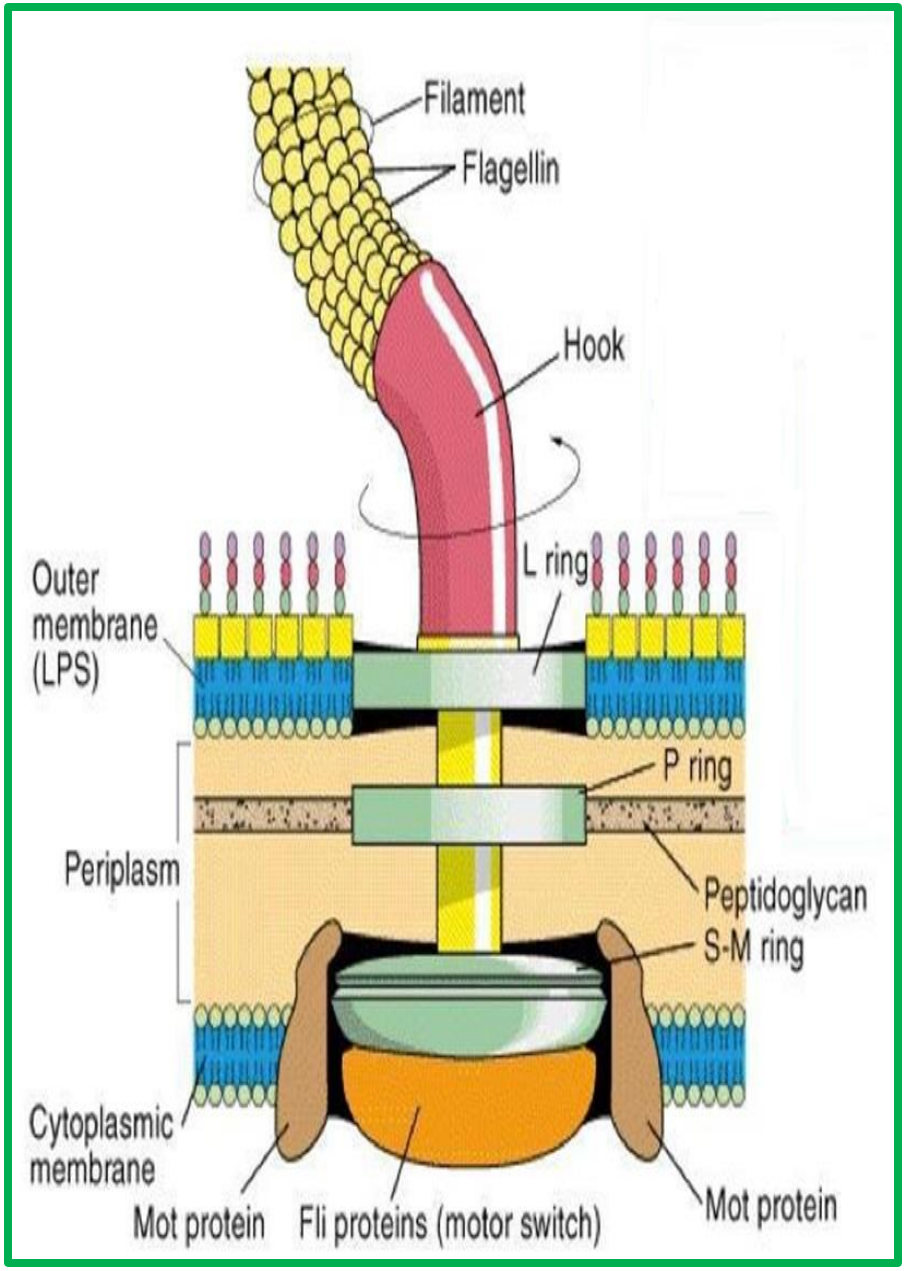
(b) Non-polar flagellation: In this case flagella distributed uniformly all over the body surface.

- **Peritrichous:** Flagella distributed evenly all over the body, e.g., *Proteus vulgaris*

- **Atrichous:** Bacteia which lack flagella, e.g., *Lactobacillus*

ARRANGMENT AND STRUCTURE OF FLAGELLA





❑ Structure of Flagellum

- ❖ Flagella in bacteria has special significance (a) a hook is always present and is never straight (b) eukaryotic flagella has 9+2 arrangements of microtubules with association to each other have protein attachments called spokes.

- ❖ Laterals of peripheral tubules are made of protein dinein; but in prokaryotes like bacteria flagella organization is simple. Flagellum is made up of contractile protein called flagellin. There are polymers of this attached laterally/longitudinally by special bondage with the result that there may be 5-6 subunits arranged in spirals creating hollow in centre.

- ❖ Basal body structure in both eukaryotes and prokaryotes are different. In prokaryotes the basal subunits has only 4 discs. Through hook flagellum passes and whole structure is joined by a flagellin rod.

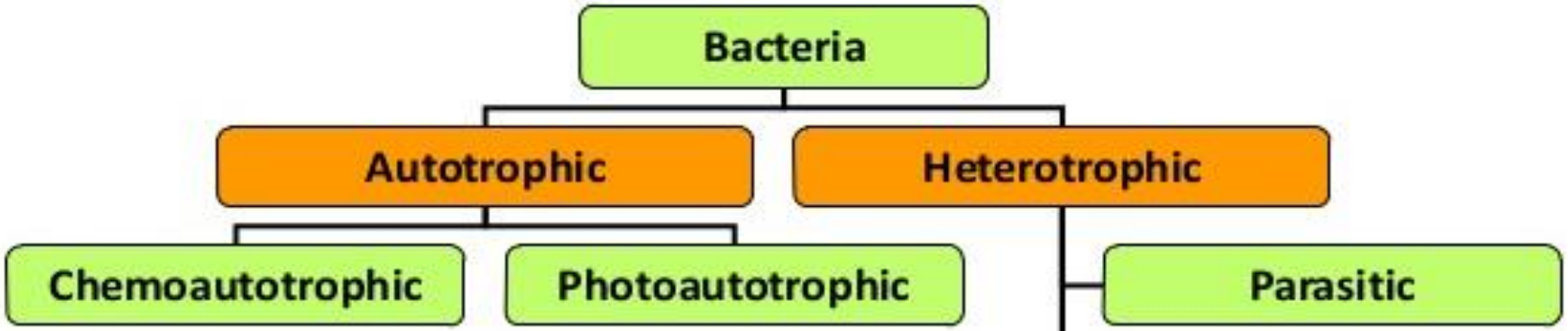
- ❖ A sort of lever system is provided by these rings. A fixed position of rod L, P, S have a hollow centre through which rod passes and act as bearings of movement of flagella. Periplasmic space provides the force for rotation by ionic strength and the source of motion is not ATP.

- ❖ In gram negative bacterium peptidoglycan layer is very small and only 2 rings are available and hook is not as rigid. If bacterium is present in water, the resistance to the cell is very large. Thus for movement very high force is required, usually the movement is anticlockwise. With this movement the cell is pushed forward. This rotation is not constant. After sometime the cell either stops or flagella changes its direction to clockwise movement.

- ❖ Thus the movement of bacteria is zig-zag or Brownian movement. Rotation of flagella is unique. Motion is controlled by ionic balance in periplasmic space.

NUTRITION IN BACTERIA

Nutrition



- Autotrophs
  - They are able to synthesize their own organic food from inorganic substances.
  - Can use CO_2 as a sole carbon source (Carbon fixation)
- Heterotrophs
  - They are unable to manufacture their own organic food and hence are dependent on external source.
  - Cannot use CO_2 as a carbon source

NUTRITION IN BACTERIA

- Most of the bacteria do not contain chlorophyll. They are unable to synthesize their own food, but a small group of bacteria are capable of synthesizing their own food.
- So, nutrition in bacteria is both autotrophic and heterotrophic.

Autotrophic bacteria:

- The bacteria which synthesis their own food (organic compound) necessary for structure and metabolism from the simple inorganic compound, is called autotrophic. They are further divided into 2 types, photosynthetic and chemosynthetic according to the energy utilization. Thus the former called photosynthetic autotrophs and the later non- photosynthetic autotrophs.

✓ **Photosynthetic Bacteria:** They can prepare their food by using solar energy in the presence of photosynthetic pigment bacteriochlorophyll and chlorobium chlorophyll. Photosynthesis in bacteria differs from other green plants because there is no release of oxygen in photosynthesis. Such photosynthesis is called anoxygenic photosynthesis. It is of following types:

Green sulphur bacteria	:	The photosynthetic pigment is chlorobium chlorophyll and sulphur is by- product. e.g: *Chlorobium*
Purple sulphur bacteria	:	The photosynthetic pigment is bacteriochlorophyll and sulphur is by- product. e.g: *Chromatium*
Non-sulphur bacteria	:	The photosynthetic pigment bacteriochlorophyll and sulphur is not a by-product. e.g: *Rhodopseudomonas*

✓ **Chemosynthetic Bacteria:** These bacteria prepare their food by using chemical energy in the absence of photosynthetic pigment. They get energy for food synthesis by the oxidation of certain inorganic substances such as ammonia, nitrites, nitrate, ferrous iron, hydrogen sulphides and a number of metalic or non matelic materials avialable in the environment. The bacteria absorb inorganic molecules of the substance into the body where the chemical reaction takes place . In this reaction the chemical bonds are broken and energy is resleased. This energy is used by the bacteria and this process is called chemosynthesis. It is following types:

- **Sulphur bacteria:** They use chemical energy while there is oxidation of sulphur compound. E.g: *Thiobacillus*

$$2H_2S \text{ or } S_2 + O_2 \text{=======} \rightarrow 2S + 2H_2O + \text{energy}$$

- **Iron bacteria:** They use chemical energy while there is oxidation compound (Fe^{2+} to Fe^{3+}). E.g: *Leptothrix, Ferobacillus, Cladothrix*

$$4FeCO_3 + O_2 + 6H_2O \text{=======} \rightarrow 4Fe(OH)_3 + 4CO_2 + \text{Energy}$$

- **Hydrogen bacteria:** They use chemical energy while there is oxidation of molecular hydrogen. E.g: *Pseudomonas, Hydrogenomonas, Bacillus pectotrophus.*

$$H_2 + \tfrac{1}{2} O_2 \text{=====} \rightarrow H_2O + \text{Energy}$$

- **Nitrifying bacteria:** They use chemical energy while there is oxidation of nitrogen compound. E.g: *Nitrosomonas, Nitrobacter*

$$2NO_2 + O_2 \text{=========} \rightarrow 2NO_3 + \text{Energy}$$

Difference between chemosynthesis and photosynthesis

Parameters	Chemosynthesis	Photosynthesis
Amount of energy	The amount of energy available in the chemosynthesis is much less as compare with photosynthesis	The amount of energy available in the photosynthesis is much more as compare with chemosynthesis
Gain of energy	There is no gain of energy from outside the planet	There is distinct gain of energy from the outside the planet.
Energy input	No light is involve in the process	It take place in the present of sun light
Type of energy	Reaction are all exothermic	The reactions are endothermic
	Energy required for the process is obtained by the oxidation of certain inorganic substances available in the environment	Solar energy trapped by the pigment is used in the process
Pigments	No pigments are required	Bacteriochlorophyll, chlorobium chlorophyll
Bacteria	Purple sulphur bacteria and green sulphur bacteria. E.g., Pseudomonas, Thiobacillus	Sulphur bacteria, iron bacteria, nitrifying bacteria, hydrogen bacteria. E.g., Rhodospirillum, Chlorobium
Example	$H_2S + CO_2$ ======➔$(CH_2O) + S + H2O$ (in the presence of sun light, pigment)	$4FeCO_3 + O_2 + 6H_2O$=======➔$Fe(OH)_3 + 4CO_2$ + Energy

❑ Heterotrophic bacteria:

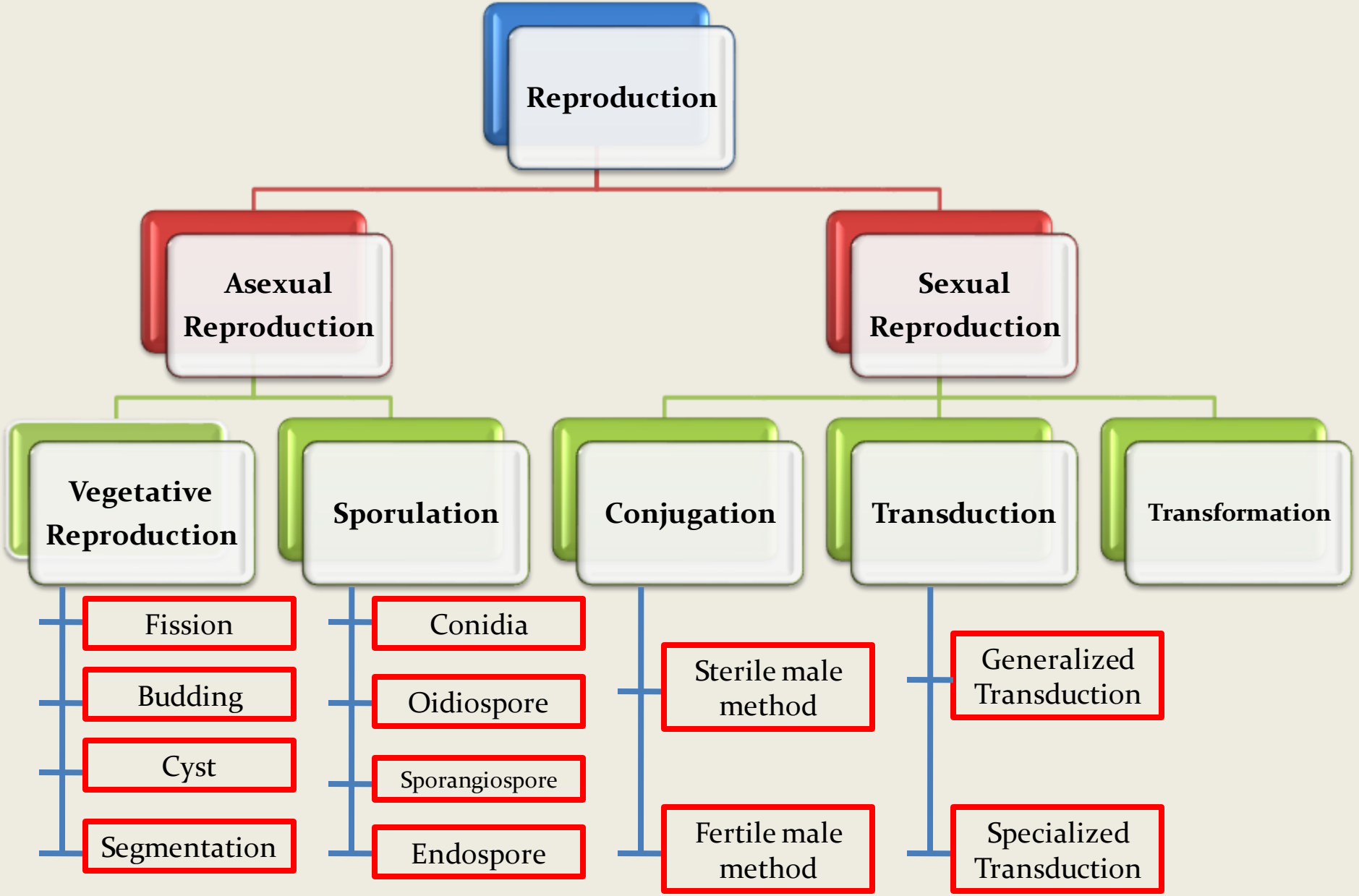
❖ The heterotrophic bacteria which form the majority cannot synthesized organic compounds from the simple inorganic substances. Lacking the pigment they can not capture the solar energy which is essential for the synthesis the substances they need as food. Thus these type of bacteria live where the organic food is readily available either from living organism.

✓ **Saprophytic bacteria:** They grow in dead, decaying organic material and live by digesting and absorbing them. These bacteria gradually break down complex organic compounds into simpler products. For doing so they secreting the enzymes. The break down of carbohydrate is called fermentation (e.g., Lactic acid bacteria). The break down of protein material called putrefaction (nitrifying bacteria).

✓ **Parasitic bacteria:** Parasitic bacteria live on and within other organisms (host) and they obtain their nutrition from the host. They live on or within the organisms both plants and animals. If the parasitic bacteria cause diseases and are harmful for their host they are called pathogenic. If the parasitic bacteria cannot cause diseases and are harmless for their host they are called non-pathogenic. e.g.: *Vibrio cholerae*, *Diplococcus pneumoniae*. Many diseases including plant and animal including the man are caused by the pathogenic bacteria.

✓ **Symbiotic bacteria:** Symbiotic bacteria live in close association with other living organisms so that they both are benefited to each other, neither of them is harmed. e.g.: Rhizobium. Certain plants establish a symbiotic relationship with bacteria, enabling them to produce nodules that facilitate the conversion of atmospheric nitrogen to ammonia. It appears that not only must the plant have a need for nitrogen fixing bacteria, but they must also be able to synthesize cytokinins which promote the production of root nodules, required for nitrogen fixation.

REPRODUCTION IN BACTERIA



REPRODUCTION IN BACTERIA

❖ Asexual reproduction is characteristic of all bacteria. Sexual reproduction was long through to be absent but investigation with the help of electron microscope have clearly demonstrated the exchange of genetic material in some species of bacteria.

❑ **Asexual reproduction:** It take place by two methods: (i) Vegetative, (ii) Sporulation

➢ **Vegetative reproduction:** It take place by the following methods.

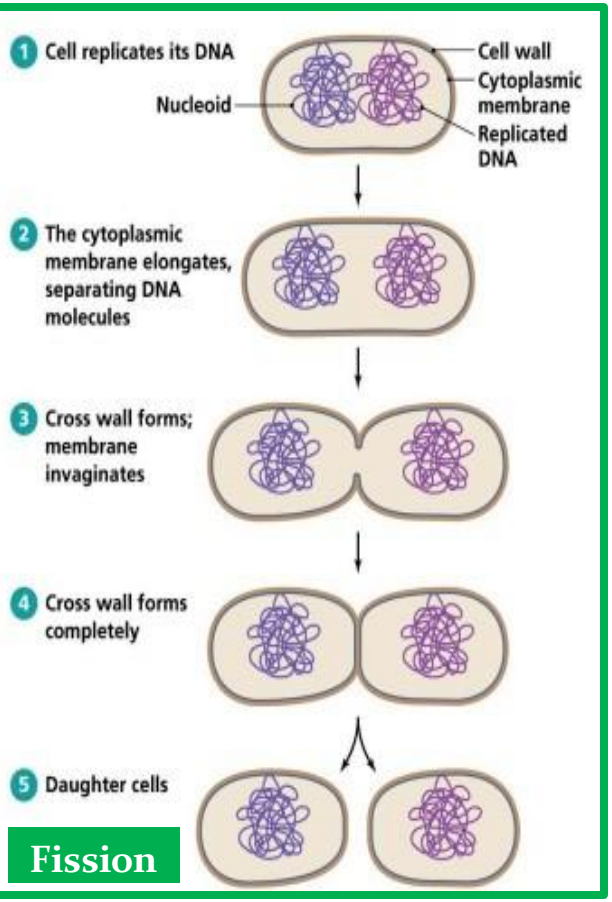
✓ **Binary Fission:** The most common way by which the bacteria reproduce itself is the Binary Process. It is a process by which a single bacterial cell simply divides into two in half an hour time. The various events of binary fission are as follows:

- The nucleoid gradually become elongated in size and form dumbel-shaped structure.
- They still remain attached to the plasma membrane with the help of mesosome.
- The duplication of DNA and mesosome takes place and get separate from each other.
- The daughter mesosomes and nucleoids migrate towards the opposite poles.
- The plasma membrane invaginates at the center and the parent cell is divided into two identical cells.

✓ **Budding:** In this case, a small protuberance, called bud, develops at one end of the cell. Genome replication follows, and one copy of the genome gets into the bud. Then the bud enlarges, eventually become a daughter cell and finally gets separated from the parent cell. It is comparatively rare process observed in few bacteria like *Rhodopseudomonas*, *Hyphomicrobium*, *Pedomicrobium, Hyphomonas* etc. Hyphomicrobeales, commonly called the budding bacteria, a branch strand of cell wall material may be initiated prior to the separation of a bud.

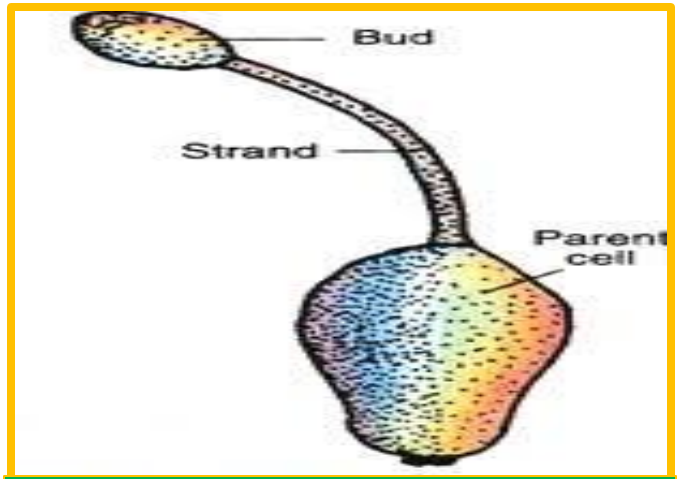
- ✓ **Cysts:** In certain bacteria the entire protoplast of the cell recedes from the cell wall and becomes rounded. A thick wall is then secreted around it to form resistant structure somewhat similar to the endospore. It is called the cyst. These are formed in certain species of *Azobacter*. Under suitable environment conditions the cyst germinate to produce the new bacterium.

- ✓ **Segmentation:** In some other species of bacteria reproduce vegetative called segmentation. In this case the protoplast of the bacterium cell at some stage , divides to form very tiny body called gonidia. The cell wall ruptured and the librated tiny gonidia grow into new bacterium cell under suitable conditions

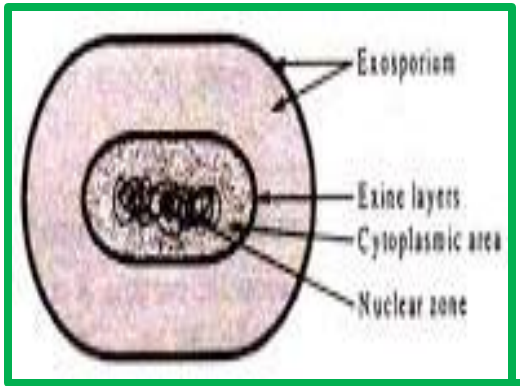


Fission


Budding



Budding in Hyphomicrobiales



Cyst

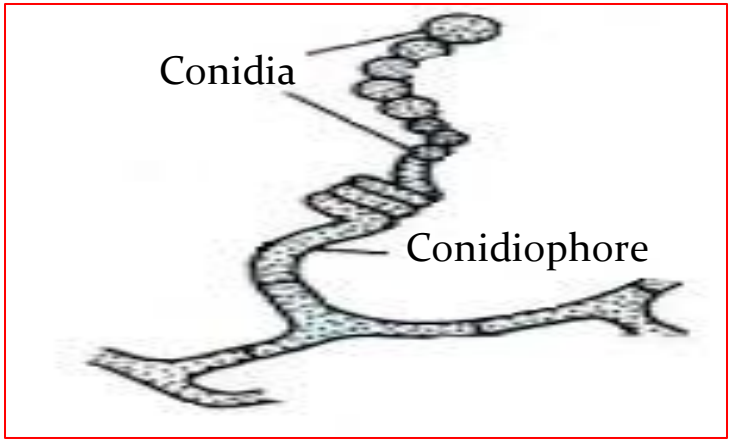

Segmentation

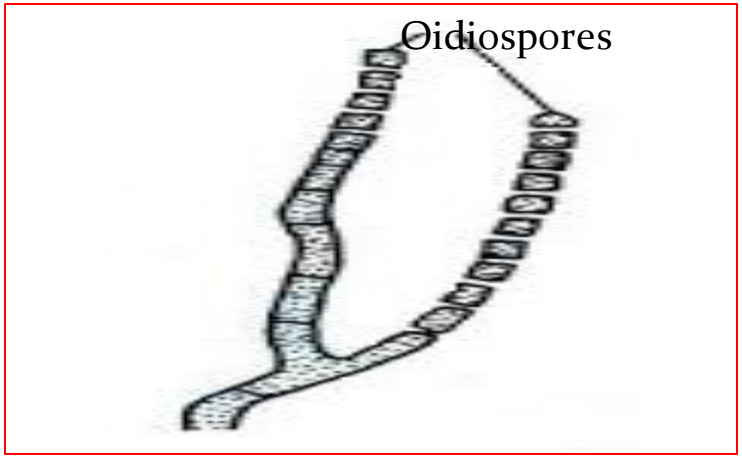
- **Sporulation:** Some bacteria produce non motile spores which are of the following types:

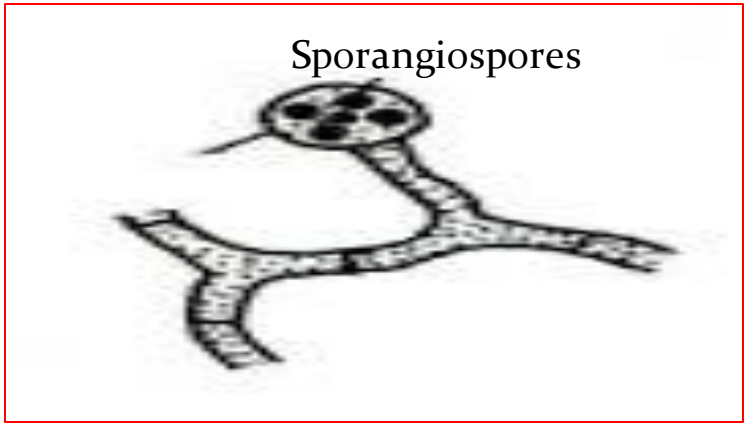
- ✓ **Conidia:** Many filamentous bacteria (e.g., Streptomyces) form chains of small, spherical spore-like conidia at the tips of the filaments. A conidium develops by the formation of a transverse wall at the tip of the filament. The filament bearing conidia are known as conidiophores. After liberation each conidium gives rise to a new filamentous bacterium, provided conditions for germination are favourable.

- ✓ **Oidiospores:** In an another member Actinomyces he hypha insead of obstructing spore in succession at the free end, undergodes additional separation through its lnght to form numerous small reproductive units known as oidiospores. Each oidiospores on germination produces, a filamentous bacterium.

- ✓ **Sporangiospores:** In some branching bacteria sporangia like structure may developed at the end of certain hyphae. The protoplast of the sporangia may divided to form tiny sporangiospores. On libration of these spores germinate under suitable condition, each producing a filamentous bacterium.

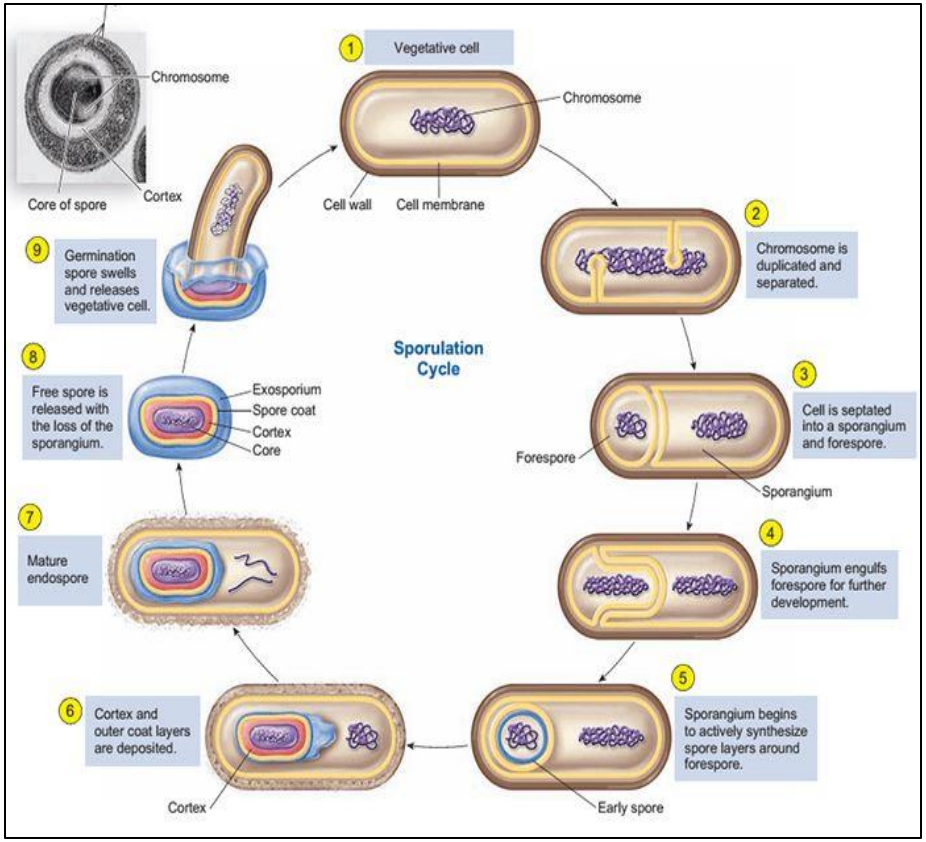


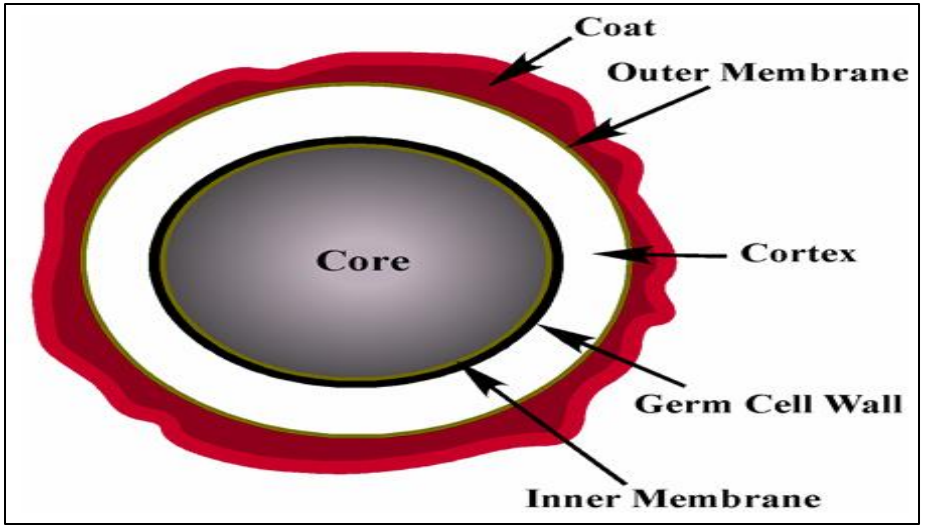




✓Endospore

- ❖During the unfavorable condition, eubacteria have the ability to become endospores.
- ❖In this state, the bacteria can tolerate exceedingly high and low temperatures, acidic and basic conditions, and large amounts of radiation.
- ❖Endospores are extremely hard to kill. Surprisingly, they can be boiled for hours and still survive.
- ❖Endospores can only be made by Gram-positive bacteria.
- ❖Within the endospore remains the bacterial DNA, but the cytoplasm has a decreased water concentration.
- ❖This is thought to help in protecting against high heat. The bacteria will take on a tough coating composed of calcium and dipicolinic acid, creating a dense and impregnable barrier to stabilize the DNA within the cell. DNA repair enzymes are also still active, aiding in the resistance of the endospore.





✓ Endospore formation:

- These are specialized structures produced for the cells tiding over unfavourable conditions to the extent that they are heat resistant even at 80°C for 10 minutes (during pasteurization). They can withstand draught and can survive for years (200 years). They can survive in radiation also and can withstand acid treatments (conc. H_2SO_4).

- Their presence is very widely distributed among various groups of bacteria and almost all those bacteria which show endospores are gram positive except one *Archebacterium*.

- These spores are formed in both aerobic and anaerobic forms. Spore formation is observed under conditions of restricted growth starting with accumulation of protein rich content in spore forming region. Numerous metabolic conversions occurs during spore formation sometimes at the expense of PHBA and as well as polysaccharide during anaerobic. During first hour protein of specific nature is formed the reserve food gets depleted. Dipicolenic acid is synthesized which is not usually associated and accumulated. These 2 diamino pimalic acid and Ca^{2+} acts as chelate and makes upto 10-15% of dry weight.

- Equal division starts from periphery of the plasma membrane. Two cells are specifically formed, one small and other large. As soon as it occurs, the large cell starts engulfing the smaller one so that the spore becomes embedded in the original cell. It is at this stage that spore coat is laid down. Spore coat becomes double walled structures with DPA accumulated in cortex region. Outer spore envelope is formed by mother cell and is formed of polysaccharide which may remain as such or additionally a exosporium may be laid in *B. cerius* which is also formed of mother cell. This exosporium remains as loose, discrete structure in mature spore. As mature one is getting investing by cortical region much of the water is lost. This state is reached in 7-8 hours which results in completion of endospore formation.

❑ **Sexual reproduction:** The following points highlight the methods of sexual Reproduction (Para Sexuality) in Bacteria, i.e., Conjugation, Transformation and Transduction.

➢ **Conjugation:** It was first discovered in *Escherichia coli* by Lederberg and Tatum (1946). They found that two different types of auxotroph (nutritional mutants) grown together on minimal medium produced an occasional prototroph (wild type).

❖ Cell contact was required for this change. Anderson (1957) observed conjugation between two such bacteria under electron microscope. Conjugation was later reported in a number of other bacteria. Bacteria showing conjugation are dimorphic, i.e., they have two types of cells, male (F^+) or donor and female (F-) or recipient.

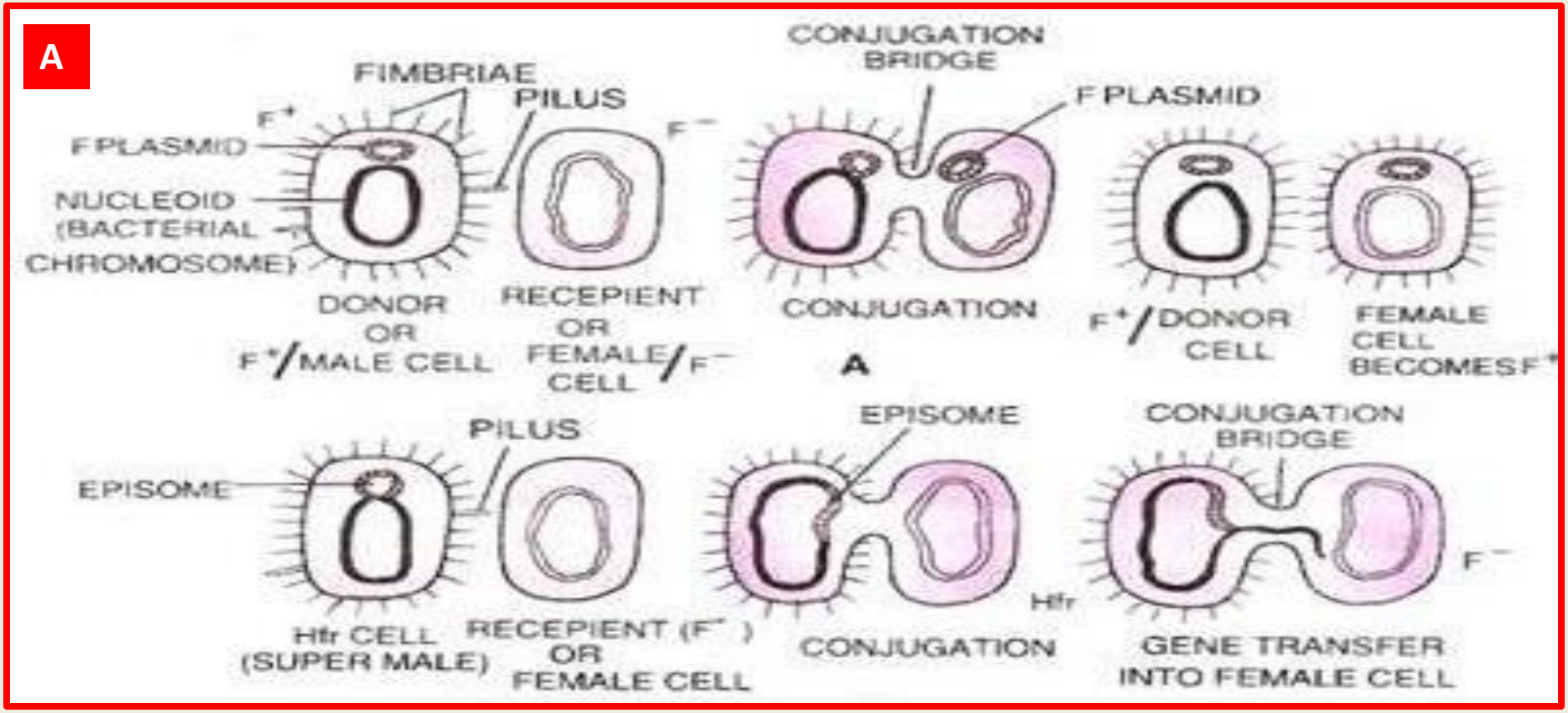
❖ The male or donor cell possesses 1-4 sex pili on the surface and fertility factor (transfer factor, sex factor) in its plasmid. Fertility factor contains genes for producing sex pili and other characters needed for gene transfer.

❖ Sex pili are 1- 4 narrow protoplasmic outgrowths. Both sex pili and fertility factor are absent in female or recipient cells.

❖ If these two types of cells happen to come nearer, a piles of male cell establishes a protoplasmic bridge or conjugation tube with the female cell. It takes 6-8 minutes. Gene exchange can occur by two methods;

✓ **Sterile Male Method (F^+ x F^- → F^- becomes F^+):** The plasmid having fertility factor replicates. A copy of it gets transferred to the recipient cell through the conjugation tube. The recipient cell also becomes donor. The phenomenon of reversibility of sex is called sexduction.

Conjugation in bacterial cells



Conjugation in bacterial: A: Sexduction (Sterile male method) B: Fertile Male Method

- ✓ **Fertile Male Method (Hfr x F^- $\rightarrow F^-$ remains F^-):** The F^+ plasmid or fertility factor of the donor cell gets integrated to bacterial chromosome or DNA. The attachable plasmid is known as episome.

- ❖ The point at which plasmid gets integrated to bacterial chromosome differs in different strains. Integration is possible because certain nucleotide sequences present in bacterial chromosome are compatible with sequences in plasmid DNA.

- ❖ The donor cell having fertility factor integrated to its chromosome is called Hfr (high frequency of recombination), meta male or super male because it has a recombination frequency of 1000 times more as compared to normal F^+.

- ❖ Non-integrated F^+ plasmids disintegrate in her cells. The integrated F^+ factor breaks the bacterial chromosome at one end of its attachment. The bacterial chromosome now undergoes replication.

- ❖ A copy of the freed end of bacterial chromosome (end distal to F^+ factor, also called zero end) passes into the recipient cell through the conjugation tube. Fertility factor is the last to do so.

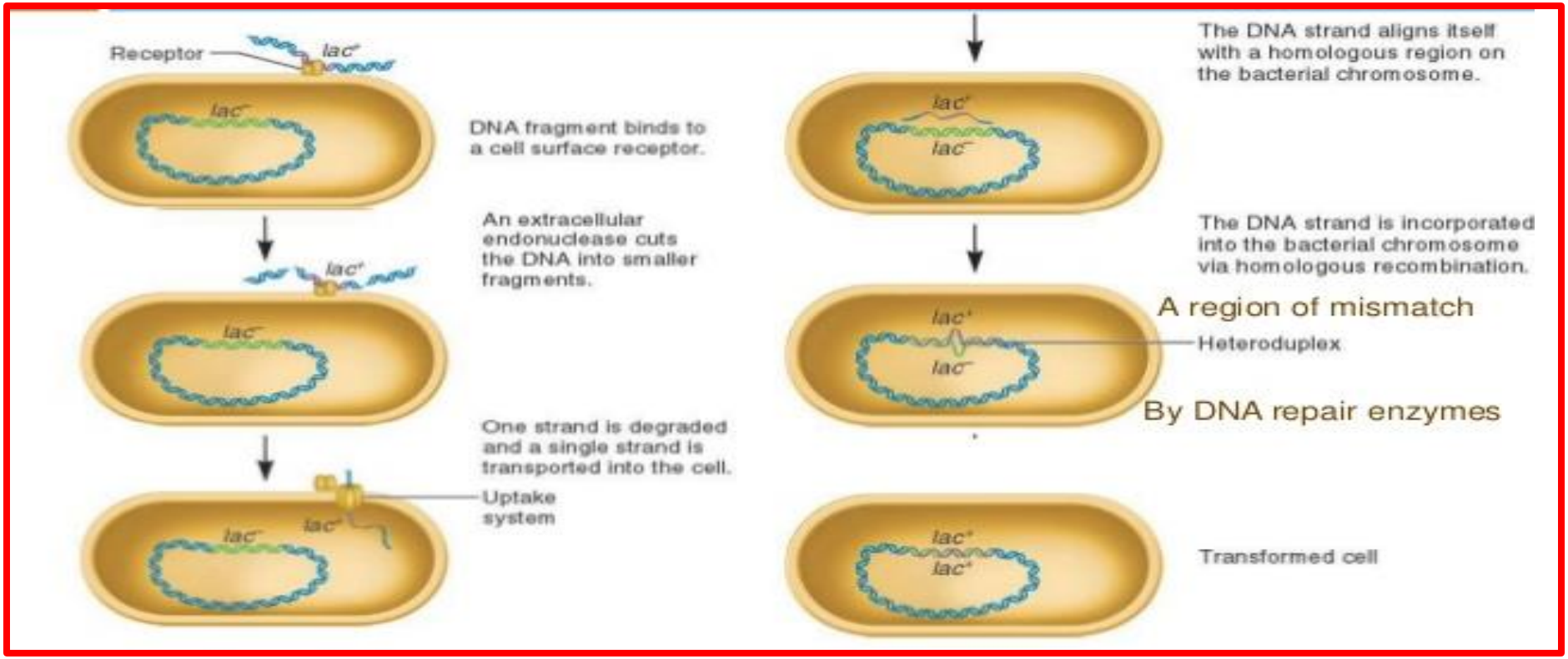
- ❖ Generally whole of bacterial chromosome does not pass into recipient cell. F^+ factor is very rarely transferred as conjugation is maintained for a brief period. Only a few genes are transferred, one in seven minutes, two in nine minutes, three in ten minutes, four in eleven minutes, etc..

- ❖ Conjugation produces an incompletely diploid “zygote” known as merozygote or partial zygote. The new genes may replace the genes present in the recipient cells (those of the recipient cells disintegrate) or get added to them.

- **Transformation:** It is the absorption of DNA segment from the surrounding medium by a living bacterium. The phenomenon was discovered by Griffith in 1928. Its mechanism was worked out by Avery (1944).

- In transformation, a bacterium takes in DNA from its environment, often DNA that's been shed by other bacteria. If the DNA is in the form of a circular DNA called a plasmid, it can be copied in the receiving cell and passed on to its descendants.

- Receptivity for transformation is present for a brief period when the cells have reached the end period of active growth. At this time they develop specific receptor sites in the wall. Normally E. coli does not pick up foreign DNA but it can do so in the presence of calcium chloride.



- **Transduction:** It is the transfer of foreign genes by means of viruses. Transduction was first discovered by Zinder and his teacher Lederberg (1952) in Salmonella typhimurium.

- Such a virus is never virulent. It passes over the gene of the previous host to the new host. Transducing viruses may carry the same genes (restricted transduction) or different genes (generalized transduction) at different times.

- The genetic recombination in which genetic material is transferred by phage virus between two bacteria is called transduction. It has two forms:

- **Generalized transduction:** It occurs in lytic cycle of phage virus. DNA of phages virus enter into *E. coli* bacteria. This DNA replicates and develops many new DNA and capsids.

- The DNA of bacteria is broken. Some pieces of DNA also enter into capsid of virus. Bacteria burst and release new phage viruses. Now this phage enters into recipient bacteria and transfer DNA of donor bacteria into the DNA of recipient bacteria.

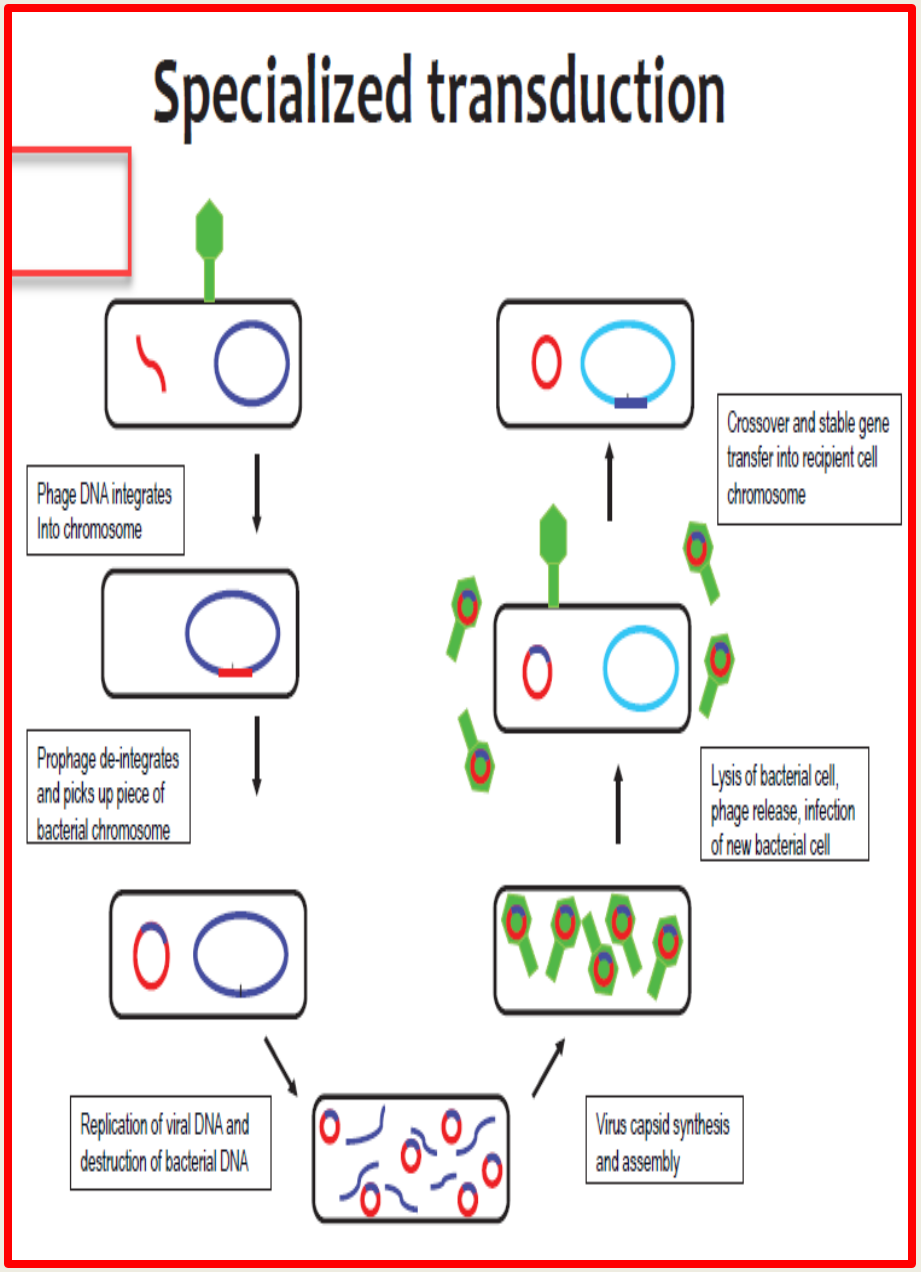
- Bacterial endonucleases enzymes destroy the phage virus. Now these bacteria incorporate genes of donor bacteria and replicates.

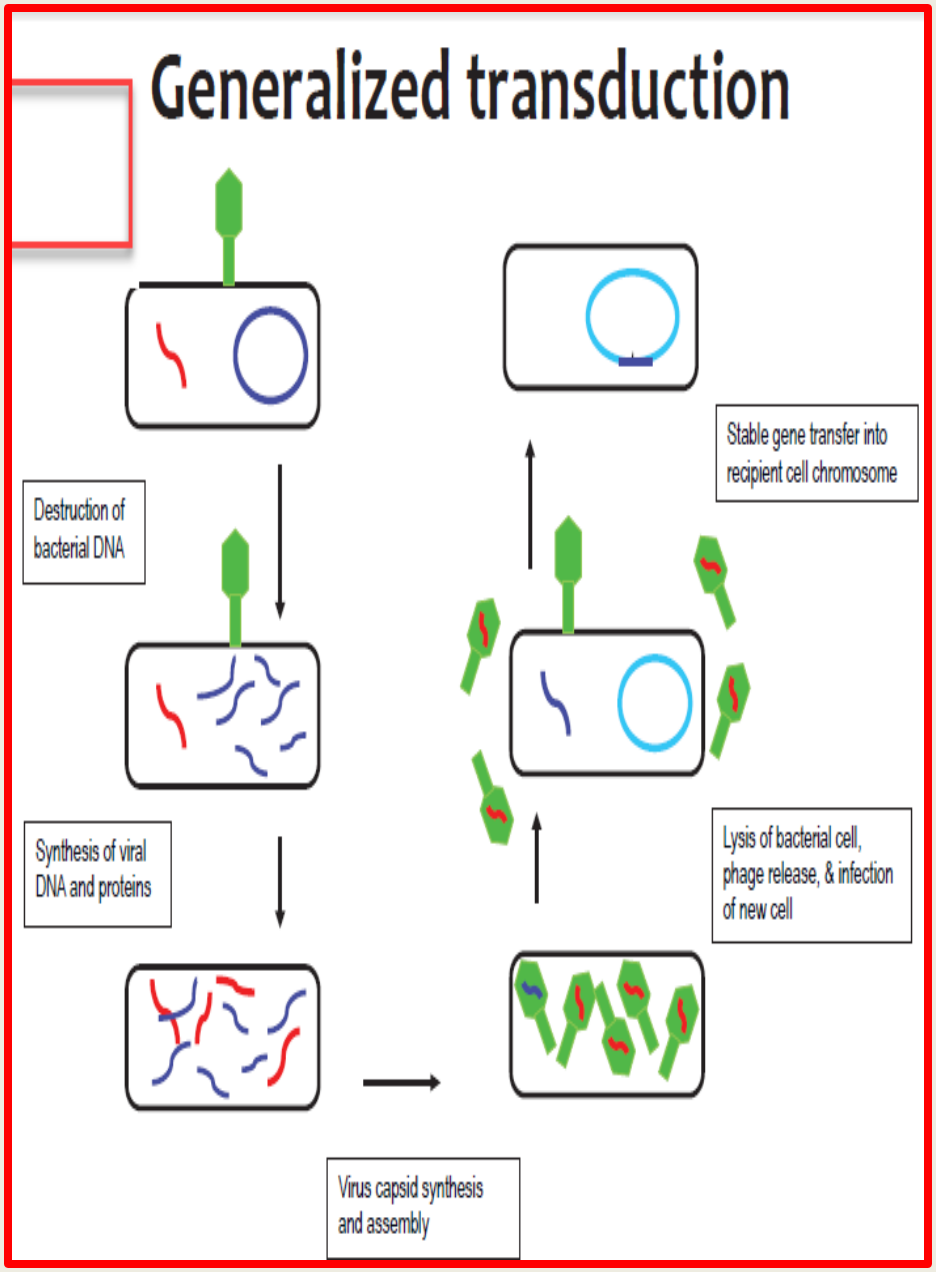
- **Specialized transduction:** It occurs in Lysogenic cycle of phage virus. In this cycle viral DNA incorporate into bacterial DNA as prophage.

- It remains peacefully there. But sometime, it becomes lytic. It comes out of bacterial DNA. Some part of bacterial DNA remain attach with it.

- Viral DNA with a piece of bacterial DNA replicates and develops new capsids. Bacteria burst. Virus infects other bacteria and transfer genes of donor.

Transduction in bacterial cells





KEY POINTS OF THE LECTURE

- Bacteria are prokaryotic, unicellular microorganisms, which lacking chlorophyll.
- The cell structure is simpler than that of other organisms as there is no nucleus or membrane bound organelles.
- Due to the presence of a rigid cell wall, bacteria maintain a definite shape, though they vary as shape, size and structure.
- In general, bacteria are between 0.2 and 2.0 µm - the average size of most bacteria.
- *E. coli*, a bacillus of about average size is 1.1 to 1.5 µm wide by 2.0 to 6.0 µm long.
- *Mycoplasma gallicepticum,* with a size of approximately 200 to 300 nm are thought to be the world smallest bacteria.
- *Thiomargarita namibiensis* is world's largest bacteria, a gram-negative.
- Cocci, Bacilli and Spirilla are the major shapes of bacteria.
- So far as the arrangement is concerned, it may Paired (diplo), Grape-like clusters (staphylo) or Chains (strepto).
- Filamentous, star shaped, rectangular and pleomorphic are some other shapes and arrangement of bacteria.
- Like other living plant cell, bacterial cell comprises a cell wall and protoplast.

KEY POINTS OF THE LECTURE

- Slime layer is a gelatinous layer present on the outer surface of cell wall, composed of polysaccharides and polypeptide chain of amino acids.
- When its constituents are only polysaccharides which form a viscous layer, it is called slime layer, but when nitrogenous substances (i.e., amino acids) are also present along with polysaccharides, then it is called capsule.
- The bacterial cell wall is composed by 4 layers (L1 to L4), cellulose are commonly absent.
- The three main constituents of cell wall are: (i) N-acetyl glucosamine (NAG), (ii) N-acetyl muramic acid (NAM), and (iii) a peptide chain of four or five amino acids. These together form a polymer called peptidoglycan or mucopeptide.
- The Gram stain, developed in 1884 by Hans Christian Gram, characterizes bacteria based on the structural characteristics of their cell walls as; Gram positive and gram negative. The thick layers of peptidoglycan in the "gram-positive" cell wall stain purple, while the thin "gram-negative" cell wall appears pink.
- Inner to cell wall, a semipermeable cytoplasmic membrane is present which is about 75 A^{o} thick. Plasma membrane contains special receptor molecules that help bacteria detect and respond to chemicals in their surroundings. It also controls the entry of organic and inorganic molecules.
- Bacterial cytoplasm is a complex mixture of carbohydrates, proteins, lipids, minerals, nucleic acids and water.
- The bacterial nucleus devoid of nuclear membrane, nucleolus, chromonemata and nuclear sap, such structure is called nucleoid or genophore.

KEY POINTS OF THE LECTURE

- Bacterial cells also contain some extrachromosomal heredity determinants which are either independent of bacterial chromosomes or are intergrated with them called plasmid.
- The organ of the locomotion is small whips or hair like appendages called flagella.
- Bacterial flagella may be polar or non polar.
- Nutrition in bacteria is both autotrophic and heterotrophic.
- The bacteria which synthesis their own food (organic compound) necessary for structure and metabolism from the simple inorganic compound is called autotrophic.
- Photosynthetic bacteria can prepare their food by using solar energy in the presence of photosynthetic pigment bacteriochlorophyll and chlorobium chlorophyll.
- Chemosynthetic bacteria prepare their food by using chemical energy in the absence of photosynthetic pigment.
- The heterotrophic bacteria which form the majority cannot synthesized organic compounds from the simple inorganic substances.
- Saprophytic bacteria grow in dead, decaying organic material and live by digesting and absorbing them.
- Parasitic bacteria live on and within other organisms (host) and they obtain their nutrition from the host.

KEY POINTS OF THE LECTURE

- Parasitic bacteria may be pathogenic or non pathogenic to the host organism.
- Symbiotic bacteria live in close association with other living organisms so that they both are benefited to each other, neither of them is harmed.
- Asexual reproduction is characteristic of all bacteria.
- The most common way by which the bacteria reproduce itself is the Binary Process.
- Budding, cyst, segmentation is the another method of vegetative reproduction.
- Sporulation in bacteria is take place by the conidia, oidiospore, sporangiospore and endospore.
- Endospore prodution take place in the unfavorable conditions.
- Sexual reproduction in bacteria is take place by the conjugation, transformation and transduction.
- In transformation, a bacterium takes up a piece of DNA floating in its environment. Transformation was discovered by Griffith in 1928.
- In transduction, DNA is accidentally moved from one bacterium to another by a virus. Transduction was first discovered by Zinder and Lederberg (1952) in *Salmonella typhimurium*.
- In conjugation, DNA is transferred between bacteria through a tube between cells. Conjugation was first discovered in *Escherichia coli* by Lederberg and Tatum (1946).

TERMINOLOGY

- **Acellular:** not made of cells
- **Adenosine triphosphate (ATP):** energy currency of the cell; a nucleotide derivative that safely stores chemical energy in its two high-energy phosphate bonds
- **Bacillus:** (bacilli) rod-shaped prokaryotic cell
- **Bacteria:** (singular: bacterium) any of various unicellular prokaryotic microorganisms typically (but not always) having cell wells that contain peptidoglycan
- **Bacteriochlorophylls:** green, purple, or blue pigments of bacteria; they are similar to chlorophyll of plants
- **Bacteriology:** the study of bacteria
- **Bacteriophage:** virus that infects bacteria
- **Binary fission:** predominant form of bacterial reproduction in which one cell divides into two daughter cells of equal size, which separate, each offspring receiving a complete copy of the parental genome.
- **Biofilm:** complex ecosystem of bacteria embedded in a matrix
- **Biosynthesis:** replication of viral genome and other protein components
- **Budding:** unequal reproductive division in which a smaller cell detaches from the parent cell
- **Cell envelope:** the combination of external cellular structures (e.g., plasma membrane, cell wall, outer membrane, glycocalyces) that collectively contain the cytoplasm and internal structures of a cell
- **Cell membrane:** lipid bilayer with embedded proteins and carbohydrates that defines the boundary of the cell (also called the cytoplasmic membrane or plasma membrane)
- **Cell morphology:** cell shape, structure, and arrangement, as viewed microscopically
- **Cell theory:** the theory that all organisms are composed of cells.

TERMINOLOGY

- **Cell wall:** a structure in the cell envelope of some cells that helps the cell maintain its shape and withstand changes in osmotic pressure
- **Cellulose:** a structural polysaccharide composed of glucose monomers linked together in a linear chain by glycosidic bonds
- **Chlorophyll:** a type of photosynthetic pigment found in some prokaryotic and eukaryotic cells
- **Chloroplast:** organelle found in plant and algal cells in which photosynthesis occurs
- **Chromosome:** discrete DNA structure within a cell that controls cellular activities
- **Conidia:** asexual fungal spores not enclosed in a sac; produced in a chain at the end of specialized hyphae called conidiophores
- **Conjugation:** mechanism of horizontal gene transfer in bacteria in which DNA is directly transferred from one bacterial cell to another by a conjugation pilus
- **Conjugation pilus (sex pilus):** hollow tube composed of protein encoded by the conjugation plasmid that brings two bacterial cells into contact with each other for the process of conjugation
- **Deoxyribonucleic acid (DNA):** double-stranded nucleic acid composed of deoxyribonucleotides that serves as the genetic material of the cell
- **Disaccharide:** one of two monosaccharides linked together by a glycosidic bond
- **Disease:** any condition in which the normal structure or function of the body is damaged or impaired
- **F^- (recipient) cell:** *E. coli* cell lacking the F plasmid and thus incapable of forming a conjugation pilus but capable of receiving the F plasmid during conjugation
- **F pilus (F pili):** specialized type of pilus that aids in DNA transfer between cells; conjugation pilus of *E. coli*

TERMINOLOGY

- **F plasmid (fertility factor):** bacterial plasmid in *E. coli* containing genes encoding the ability to conjugate, including genes encoding the formation of the conjugation pilus
- **F' plasmid:** integrated F plasmid imprecisely excised from the chromosome; carries with it some chromosomal DNA adjacent to the integration site
- **F^+ (donor) cell:** *E. coli* cell containing the F plasmid, capable of forming a conjugation pilus
- **Flagella:** long, rigid, spiral structures used by prokaryotic cells for motility in aqueous environments; composed of a filament made of flagellin, a hook, and motor (basal body) that are attached to the cell envelope
- **Genes:** segments of DNA molecules that code for proteins or stable RNA molecules
- **Genome:** entire genetic content of a cell
- **Glycogen:** highly branched storage polysaccharide in animal cells and bacteria
- **Glycolipid:** complex lipid that contains a carbohydrate moiety
- **Gram stain procedure:** a differential staining technique that distinguishes bacteria based upon their cell wall structure
- **Gram stain procedure:** a differential staining technique that distinguishes bacteria based upon their cell wall structure
- **Lipid bilayer:** biological membranes composed of two layers of phospholipid molecules with the nonpolar tails associating to form a hydrophobic barrier between the polar heads; also called unit membrane
- **Lysogenic cycle:** life cycle of some phages in which the genome of the infecting phage is integrated into the bacterial chromosome and replicated during bacterial reproduction until it excises and enters a lytic phase of the life cycle
- **Lytic cycle:** infection process that leads to the lysis of host cells

TERMINOLOGY

- **Mycelium:** vegetative network of branched, tubular hyphae
- **Nucleus:** a membrane-bound structure of eukaryotic cells that houses the DNA genome
- **Pathogen:** a disease-causing microorganism
- **Photosynthesis:** process whereby phototrophic organisms convert solar energy into chemical energy that can then be used to build carbohydrates
- **Photosynthetic pigment:** pigment molecule used by a cell to absorb solar energy; each one appears the color of light that it transmits or reflects
- **Plasmid:** small, circular, double-stranded DNA molecule that is typically independent from the bacterial chromosome
- **Pleomorphic:** able to change shape
- **Prokaryote:** an organism whose cell structure does not include a membrane-bound nucleus
- **Prokaryotic cell:** a cell lacking a nucleus bound by a complex nuclear membrane
- **Saprophytes:** Organism grow on dead and decying substances.
- **Sex pilus:** specialized type of pilus that aids in DNA transfer between some prokaryotic cells
- **S-layer:** cell envelope layer composed of protein covering the cell walls of some bacteria and archaea; in some archaea, may function as the cell wall
- **Slime layer:** a type of glycocalyx with unorganized layers of polysaccharides that aid bacterial adherence to surfaces
- **Spores:** specialized cells that may be used for reproduction or may be specialized to withstand harsh conditions
- **Sporulation:** the process by which a vegetative cell produces a dormant endospore

SOME QUESTIONS RELATED TO THE LECTURE

- **Question 1:** Write a note on sizes of bacteria.
- **Question 2:** Define the various shapes of bacteria in detail.
- **Question 3:** What do you understand by the arrangement of bacterial cell? Explain.
- **Question 4:** Write a detail note on the cell wall of bacteria.
- **Question 5:** Write a comparative note on gram positive and gram negative bacterial cell wall.
- **Question 6:** Write a detail note on the protoplast of bacteria.
- **Question 7:** What is autotrophic bacteria? Explain in detail.
- **Question 8:** What do you understand by heterotrophic bacteria?
- **Question 9:** Write a short note on the vegetative mode of reproduction in bacteria.
- **Question 10:** What do you understand by the sporulation in bacteria?
- **Question 11:** Discuss the conjugation mode of reproduction in bacteria.
- **Question 12:** Write a note on transmission in bacteria.
- **Question 13:** What do you understand by transduction in bacteria?

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