BACTERIA

- These are unicellular, prokaryotic, microscopic organisms.
- **Leeuwenhoek** discovered them from his teeth scrapings and named them as **animalcules**.
- **Ehrenberg** gave the term bacterium.
- The significance of bacteria was known due to the works of **Louis Pasteur** and **Robert Koch**. They observed the pathogenic nature of bacteria in plants, animals and man.
- **Earnest Haeckel** placed bacteria in the kingdom **Protista**. Some of the scientists placed them in **Schizomycetes** because of their mode of reproduction by fission.
- **Whittaker**, in his five–kingdom classification placed them under kingdom Monera that also includes another group of organisms known as Blue–Green Algae.

Distribution and Habitat

- They are cosmopolitan in distribution. They can withstand extreme cold (**–190°C**) and heat (**75°C**) and drought.
- Some are parasitic on animals, plants and man and some others are saprophytic.
- Some bacteria grow as symbionts in the root nodules of angiosperms (*Rhizobium*).
- *Escherichia coli* is common inhabitant of human intestine.

Size

- The size of most of the bacteria ranges from 0.5 to 1.0μ in breadth and 2.0 to 5.0μ in length.
- The size of bacterium *Epulopiscium fishelsoni* present in the intestine of Brown Surgeon Fish (*Acanthurus nigrofuscus*) is 200 to 500μ. It is a bacillus.
- The recently discovered largest bacterium is *Thiomargarita namibiensis*. It is a coccus.

Shape

- It differs from one bacterium to the other.
- Spherical bacteria are known as **Cocci**. A single spherical bacterium is known as **Monococcus**, two spherical cells as **Diplococcus**, a group of spherical cells as **Tetracoccus**, a chain of spherical cells as **Streptococcus**, a group of spherical cells arranged irregularly in three planes as **Staphylococcus** and spherical cells arranged in cuboid manner as **Sarcina**.
- Bacilli are rod shaped bacteria. They are monobacillus with a single rod like cell, Diplobacillus with two rod like cells and **Streptobacillus** with a chain of rod cells.
- **Vibrios** are comma shaped bacteria.
- **Spirillae** are bacteria with completely coiled body. Flexible spirillae are called as **Spirocheates**.
- Some bacteria are in the form of thread or filament. e.g. *Beggiotoa*.
- Bacteria without definite shape are known as **Pleomorphic** bacteria and the phenomenon is known as Pleomorphism. e.g. *Acetobacter* It occurs in the form of small rods, long rods, ellipsoid or a chain of small rods.

Gram's stain

- **Christian Graham Gram** developed bacterial staining technique. He classified bacteria into **Gram +ve** and **Gram –ve**.
- The bacteria are stained with **C**rystal Violet and later with Iodine. These are transferred to **ethanol** or **acetone**. Some bacteria retain their **purple** colour after ethanol treatment and they are called as **Gram +ve bacteria**. Some bacteria lose the purple colouration and they are called **Gram –ve**.

Structure of Bacterial Cell

- It is prokaryotic cell because it lacks nuclear envelope.

Cell wall

- It is present around the protoplast. It is made of 2 to several layers of **peptidoglycon** (Murein or Mucopeptide).
- **Teichoic acid** is absent in Gram–ve bacteria but present in Gram +ve bacteria.

Functions of Cell wall

- It gives a definite **shape** to the cell.
- It protects the cell from **osmotic lysis** and **toxic substances**.
- Cell wall components contribute for the **pathogenic nature** of bacteria.
- It is the site for the **action of antibiotics**.

Structures present peripheral to the cell wall

- These structures are glycocalyx, flagella and pili.

i) Glycocalyx and S layer

- Glycocalyx is present as a layer outside the cell wall.
- It consists of **polysaccharides** and very rarely **proteins**. It aids in attaching to solid objects of aquatic environments and tissue surfaces of plants and animal hosts.
- If it is in the form of a loose sheath, it is called as **Slime layer**. It protects the cell from loss of water and nutrients.
- If the glycocalyx closely invests the cell wall, it is called as **Capsule**.
- Capsule gives gummy or sticky nature to the cell. It is immunogenic and protects the cell from **dessication**.
- S – layer is made of **proteins** or **glycoproteins** and present around the cell wall of many gram +ve bacteria and some Gram –ve bacteria.
- It protects the bacterial cell from **pH fluctuations**, **osmotic stress**, **enzymes** and **predaceous bacteria** such as *Bdellovibrio bacteriovorous*.
- It also contributes for the **virulence** of the pathogen.

ii) Flagella

- These are slender, elongated coiled structures that arise from basal granule of protoplasm and involved in locomotion.
- These are usually present in bacilli, vibrios and spirillae.
- These are absent in Cocci and some bacilli.
- These are 1 to many in number.
- **Atrichous** bacteria do not have flagella.
- **Monotrichous** bacteria have a single flagellum on only one side of the cell.
- **Lophotrichous** bacteria have a tuft of flagella at only one end of the cell.
- **Amphitrichous** bacteria have flagella at both the ends of cell.
- **Peritrichous** bacteria have flagella all over the body.
- Bacterial flagella lack **9 + 2** structure. They have **three** long coiled filaments made of protein called as **flagellin**.
- Flagellum **rotates around** the axis during movement of the bacterium.

iii) Pili of fimbriae:

- These are short, straight, slender and rigid appendages of bacteria.
- These help in adhering to other surfaces organisms.
- These are usually present in **Gram –ve** bacteria. A **Gram +ve** bacterium known as *Corynebacterium renale* also has pili.
- These are around **1000** in number and made of a protein known as pilin.
- Sex pili are larger than normal pili and present in **F^+ strain** bacteria.
- These are **helical tubules** with a hollow core. These are few in number.

- They help in conjugation for binding to the F^- strain and establishing conjugation canal.

Protoplast

- It is demarcated into three regions known as Cell membrane, Cytoplasm and Nucleoid.

i) Cell membrane

- It is lipoproteinaceous differentially permeable membrane present around the protoplasm.
- It helps in maintaining the turgor and osmoregulation.
- In Gram +ve bacteria, it is invaginated into protoplasm to form globular finger like structures known as **Mesosomes**.
- Mesosomes take part in the formation of daughter cells during binary fission, replication of chromosome and the distribution of daughter chromosomes into daughter cells and increase in absorption of nutrients.

ii) Cytoplasm

- It consists of ribosomes, chromatophores, reserve food materials and other organic and inorganic substances.
- The ribosomes are of **70 S** type and occur as groups known as **Polysomes** or **Polyribosomes**.
- **Chromatophores** are groups of membrane bound tubular or flattened or spherical vesicles. They have chlorophylls, proteins and lipids.
- Reserve food material is present in the form of **glycogen** or **poly β – hydroxy butyrate granules**.
- **Gas vacuoles** with organic inclusion bodies are seen in **purple** and **green** photosynthetic bacteria and some other aquatic forms. These are aggregates of a number of small, hollow cylindrical vesicles. These are **not permeable to water** but **permeable to gases**. These help the bacteria to **float on** or near the surface of water.

iii) Nucleoid

- It is the region of bacterial protoplasm with its only circular chromosome made of only double stranded DNA.
- Extrachromosomal DNA rings seen in some bacteria are known as **Plasmids or Episomes**. These have genes for **fertility factor**, **antibiotic resistance**, **new pathogenic abilities**, **metabolic pathways** and **tumour inducing abilities**.
- Plasmids occur either freely or in integrated form with the main chromosomes.
- They can replicate themselves irrespective of replication of main chromosome.
- Plasmids are of 1. F-plasmids 2. R-plasmids 3. Col plasmids

Nutrition

- Based on the carbon source utilised, bacteria are classified into **Autotrophs** and **Heterotrophs**.
- **Autotrophic** bacteria derive their carbon from either **CO_2** or **Carbonates**.
- **Heterotrophic** bacteria obtain their carbon from **organic substances** like **glucose** and **aminoacids**.

Photoautotrophic bacteria have chlorophyll, obtain their carbon from CO_2 and utilise the sunlight as energy source. e.g. Purlple Sulphur Bacteria (*Chromatium*), Green Sulphur Bacteria (*Chlorobium*).

- **Photoheterotrophic** bacteria obtain energy from sunlight and carbon from organic sources. e.g. Purple Non–Sulphur bacteria (*Rhodospirillum*, *Rhodopseudomonas* and *Rhodomicrobium*).
- **Chemoautotrophic** bacteria obtain their energy from the oxidation of inorganic substances and carbon from CO_2. These are Hydrogen bacteria that oxidise hydrogen in the presence of oxygen (*Hydrogenomonas*), Sulphur bacteria that oxidise elemental sulphur into Sulphuric acid (*Thiobacillus thio–oxidans*) and H_2S into elemental sulphur (*Beggiotoa*), Iron bacteria that oxidise Ferrous iron to Ferric iron (*Ferrobacillus*) and nitrifying bacteria that oxidise NH_3 into Nitrites (*Nitrosomonas*) and Nitrites into Nitrates (*Nitrobacter*).
- **Chemoheterotrophs** derive both carbon and energy from organic substances such as Glucose and aminoacids. These are symbionts, saprophytes and parasites.

- Saprophytes grow on dead decaying organic matter (**Bacillus**).
- Parasites grow in or on other living organisms and cause diseases in them (*Xanthomonas*, *Salmonella*). *Bdellovibrio bacteriovorous* is parasitic on other parasitic bacteria.
- Symbiotic bacteria grow in other organisms in mutual beneficial association (*Rhizobium* of root leguminous root nodules).

Reproduction

- Bacteria reproduce asexually and sexually.

I. Asexual reproduction

- Asexual reproduction takes place by binary fission and endospore formation.

1. Binary Fission

- It is the most common type of reproduction occurs in favourable conditions.
- The cell slightly elongates and the DNA is replicated into two daughter DNA molecules.
- In the mean time the plasma membrane invaginates at the middle of the cell at mesosomal area and advances towards the centre to divide the protoplasm into two units.
- Later a furrow appears at the centre of the cell and deepens in **centripetal** manner to divide the cell into two daughter cells.
- The bacterium undergoes binary fission once in every **18 – 20** minutes.

2. Endospores

- These are formed in unfavourable conditions (dry and nutrient deficiency) in bacteria like **Bacillus** and **Clostridium**.
- Usually a single endospore is formed in a cell. Sometimes two endospores are formed.
- It is **spherical** or **oval** in shape. It consists of DNA, small amount of RNA and large amount of organic acids (**dipicolinic acids**).
- Its protoplasmic content is surrounded from periphery towards the centre by a delicate **Spore Wall**, thick layered **Cortex** and several **protein** layered **Spore Coat**.
- In some cases a thin delicate covering exosporium is present around the Spore coat.
- Endospore is terminal, subterminal or central in position.
- Endospores are liberated after their maturation from the parental cell wall and dispersed through wind.
- They are dormant for months and years. Under suitable environmental conditions, they germinate and give rise bacterial cells.

II. Sexual Reproduction

- True sexual reproduction is absent in bacteria.
- They show genetic recombination that occurs by means of **transformation**, **conjugation** and **transduction**.

1. Transformation

- It is absorption of naked DNA molecule by a bacterium from its surroundings and its incorporation into its DNA to change into a new heritable form.
- **Griffith** discovered it in *Streptococcus pneumoniae*.
- It is seen in **soil** and **marine** bacteria belonging to Gram +ve and Gram –ve such as *Streptococcus*, *Bacillus*, *Azotobacter* and *Pseudomonas*.
- The naked DNA of the surroundings is bound to the **cell wall** of receipient bacterium with the help of **DNA binding protein** of bacterium.
- **Endonucleases** cleave the bound DNA into small segments.
- One strand of each DNA fragment is hydrolysed by the **exonucleases**. The other strand is associated with **small competence proteins** moves into the protoplasm through plasma membrane.

- The **competence specific proteins** are associated with the undegraded single strand, and integrate it the homologous portion of host DNA.

2. Conjugation

- It is transfer of genetic material due to cell–to–cell contact.
- **Lederberg** and **Tatum** discovered it in *Escherichia coli.*
- It is of the following two types.

i) $F^+ \times F^-$

- E. coli has two strains known as F^+ (donor) and F^- (Recipient) strains. F^+ strain has a plasmid for fertility and sex pili. F^- stain lacks these two.
- The F plasmid replicates and forms two daughter plasmids.
- The F^+ strain adheres to F^- strain with the help of **sex pili** and establishes conjugation canal through which the F plasmid is incorporated into the F^- strain to transform the F^- to F^+ strain.

ii) HFr × F^- mating

- **HFr** means High Frequency recombination strain. In this the F plasmid is integrated into the main chromosome.
- The HFr strain adheres to the F^- strain and establishes conjugation canal.
- The HFr chromosome is opened at the point of insertion of plasmid.
- The main part of the replicated chromosome and rarely a part of the plasmid present at rear end enters into the F^- strain and exchanges the genetic material.
- In this the F^- cannot be converted to F^+ because there is no complete entry of plasmid part.

iii) Transduction

- It is transfer of genetic material from one bacterium to another bacterium through bacteriophage.
- **Lederberg** and **Zinder** discovered it in *Salmonella typhimurium*.
- It takes place during lytic and lysogenic cycles of bacteriophages during which a part of bacterial chromosome is not degraded is transferred.

Economic Importance

- Some bacteria are beneficial to mankind and some other bacteria cause diseases in man, animals and plants. Hence they are considered as **Friends and Foes** of man.

1. Beneficial activities

i) Bio–geo–chemical cycles

- **Saprophytic bacteria** decompose the dead bodies of plants and animals and convert them to minerals by humification and mineralisation.
- The plants absorb these minerals.
- In this way they not only help in recycling of materials but also clean the environment. That is why bacteria are described as Scavengers of Nature.

ii) Agriculture

- Bacteria help in maintaining and increasing soil fertility.
- Ammonifying bacteria such as *Bacillus* liberate ammonia from nitrogenous organic substances such as Nucleic acids, Proteins and Aminoacids.
- Among nitrifying bacteria, **Nitrosomonas** converts ammonia into nitrite and **Nitrobacter** converts nitrite into nitrate.
- Photosynthetic bacteria (*Chlorobacterium, Rhodospirillum, Rhodomicrobium*), non–symbiotic bacteria (*Azotobacter, Azospirillum, Clostridium*) and symbiotic bacterium **Rhizobium** are Nitrogen fixing bacteria. They convert the Nitrogen of atmosphere into **ammonia** and increase soil fertility.
- **Bacillus thuringiensis** is used as **bioinsecticide** to eradicate larvae of disease causing insects.

iii. Industry

Industry in which the bacterium is employed	Bacterium/a
1. Tanning industry	Some bacteria
2. Retting of Sunhemp and Flax fibre	Clostridium butyricum, C.felcinium
3. Tobacco curing	*Bacillus megatherium*
4. Tea curing	*Micrococcus*
5. Milk fermentation	*Lactobacillus*
6. Gobar gas (methane gas) production	*Methanococcus, Methanobacillus*
7. Acetone, Butanol	*Clostridium acetobutylicum*
8. Vinegar (Acetic acid)	*Acetobacter aceti, A.pasteurianum*
9. Lactic acid	*Lactobacillus delbruckii*
10. Propionic acid	Propionibacterium propionum
11. Ethanol	*Zymomonas mobilis, Thermoanaerobacter ethanolicus*

iv. Medicine

- *Corynebacterium glutamicum* produces an essential amino acid **Lysine**.
- **Diphtheria** and **Pneumonia** vaccines are produced by employing bacteria.
- Several antibiotics are produced by using bacteria such as *Streptomyces, Bacillus species.*

Antibiotic/s	Bacterium
Streptomycin,	Streptomyces griseus
Cycloheximide	*S. venezuelae*
Chloramphenicol	*S. fradiae*
Neomycin	*S. kanamyceticus*
Kanamycin	*S. nodosus*
Amphoterican	*S. rimosus*
Oxytetracycline	*Bacillus polymyxa*
Polymyxin B	*B. licheniformis*
Bacitracin	

v. Biotechnology

- Genetically engineered *E. coli* is used for the production of human insulin known as humulin. It is also used to crack various secrets of biochemistry, molecular biology, genetics and physiology.
- Bacteria such as **Brevibacterium** are used as Single Cell Proteins.
- Plasmid of *Agrobacterium tumefaciens* is used as vector in plant genetic engineering.
- *Bdellovibrio bacteriovorous* purifies the water of Ganges by parasitising on harmful bacteria.

2. Harmful activities

i. Spoilage of Food materials

- *Achromobacter, Pseudomonas, Ptoteus, Flavobacterium, Micrococcus, Clostridium, Salmonella, Staphylococcus* etc. grow on different food stuffs and render them useless for consumption.
- *Clostridium botulinum* releases a potential toxin known as botulin. It is responsible for the disease Botulism or Food poisoning.

ii. Denitrification

- Some bacteria like *Thiobacillus denitrificans* liberates molecular nitrogen from inorganic nitrogenous substances such as nitrates, nitrites and decrease soil fertility.

iii. Plant diseases

- About **170** species of bacteria cause diseases in plants.

Plant disease	Bacterium
1. Blight of Rice	Xanthomonas oryzae
2. Angular leaf spot of cotton	*X. malvacearum*
3. Citrus canker	*X. axonopodis citri*
4. Wilt of Solanaceae members	*Pseudomonas solanacearum*
5. Crown galls of apple and pear	*Agrobacterium tumefaciens*
6. Fire blight of apple	*Erwinia amylovora*

iv. Human diseases

Disease	Bacterium
Dysentry	Bacillus dysentry
Diphtheria	*Corynebacterium diphtheriae*
Cholera	*Vibrio cholerae*
Typhoid	*Salmonella typhi*
Pneumonia	*Diplococcus pneumoniae*
Tuberculosis	*Mycobacterium tuberculosis*
Leprosy	*M. leprae*
Plague	*Pasteurella pestis*
Gonorrhoea	*Neisseria gonorrhoea*
Tetanus	*Clostridium tetani*
Syphilis	*Treponema pallidum*

v. Animal diseases

Disease	Bacterium
Anthrax of sheep	Bacillus anthracis
Tuberculosis of dogs, cattle etc.	*Mycobacterium tuberculosis*
Actinomycosis of cattle	*Mycobacterium bovis*
Vibriosis	*Vibrio tetus*