Unit 2: Bacteria and Viruses

Long Questions - Full (10-Mark Style) Answers

Q1. Comment about the latest classification (taxonomic) status of bacteria.

Over the years, many schemes have been put forward for sorting organisms into kingdoms. The five-kingdom system, put forward by Robert H. Whittaker in 1969, is the one usually taught in biology. This system sorted

Descriptive Questions

organisms in a broad way that reflects their evolutionary history. Under this system, all prokaryotes (organisms without a nucleus) were placed together in one separate kingdom - kingdom Monera.

Why a Separate Classification Was Needed for Prokaryotes

Over the last decade, gene (molecular) studies have pointed out clear weaknesses (flaws) in the five-kingdom system. In 1990, American microbiologist Carl Woese suggested that there are actually two separate groups of prokaryotes - Archaea and Bacteria. He sorted living things into three domains: domain Archaea, domain Bacteria, and domain Eukarya. Under this three-domain system, domain Archaea and domain Bacteria both hold prokaryotes, but they differ in a number of features - e.g., cell membrane fats (lipids), cell wall make-up, and metabolic differences. Gene evidence suggests that Archaea are more closely related to Eukaryotes than to Bacteria.

- Robert H. Whittaker's five kingdoms were: Monera, Protista, Fungi, Plantae, and Animalia. The first holds prokaryotes; the other four hold eukaryotes.

Most biologists now favour swapping the five-kingdom system for a newer one, called the three-domain system, since it lines up better with the evidence gained from gene studies. In this system, bacteria are given their own separate domain - domain Bacteria.

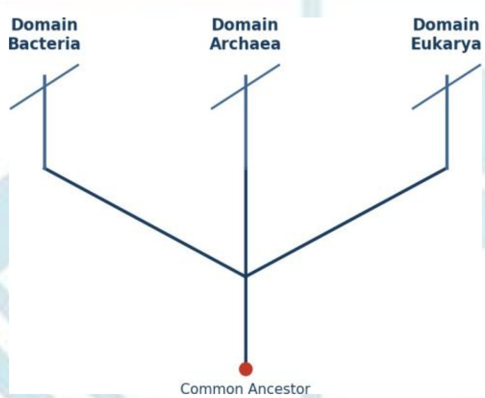

Fig: Evolutionary tree of the three domains, from a common ancestor

Structure of Bacteria

Q2. Write the make-up (composition) of the bacterial cell wall. Compare and contrast the cell wall of Gram-positive and Gram-negative bacteria.

Cell Wall Composition

The cell wall is a stiff (rigid) covering around the plasma membrane of a bacterial cell. Its main building block is a special large molecule (macromolecule), called peptidoglycan or murein. It is made of a long sugar-chain (glycan) strand, cross-linked with short protein (peptide) fragments. Its amount differs in different bacteria. The cell wall also contains fats (lipids), which are linked to the peptidoglycan.

Gram's Staining

Sir Hans Christian Gram devised the technique of Gram's staining. Gram-positive bacteria stain purple because they hold onto (retain) a violet dye (the CV-I complex) in their cell walls. Gram-negative bacteria do not retain the violet dye - they instead retain a pink dye (safranin) - so they show up in their original (pink) colour.

Composition of Cell Wall

The make-up of the cell wall is quite different in Gram-positive and Gram-negative bacteria.

- **Gram-Positive Bacteria:** the cell wall has a thick layer of peptidoglycan and holds less fat (lipid).
- **Gram-Negative Bacteria:** the cell wall has a thin layer of peptidoglycan and holds more fat (lipid). They also have an extra outer membrane made of lipopolysaccharides and lipoproteins. This outer membrane makes Gram-negative bacteria resistant to many antibiotics. It contains a protein called porin, which acts like a tiny channel (pore) for specific molecules. The cell wall of Gram-negative bacteria has more periplasmic space (the gap between the peptidoglycan layer and the cell membrane) than Gram-positive bacteria.

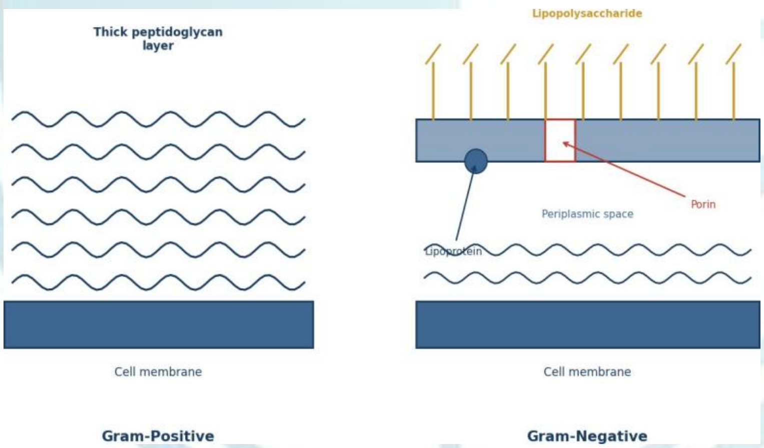

Fig: Cell wall makeup of Gram-positive and Gram-negative bacteria

Characteristics	Gram-Positive	Gram-Negative
Number of major layers	One	Two
Chemical make-up	Peptidoglycan (50% of dry weight in some ce [illegible]	[illegible]
Overall thickness	20-80 nm	8-11 nm
Outer membrane	No	Yes

Periplasmic space	Present in some	Present in all
Permeability	More permeable	Less permeable

Q3. Briefly describe the following bacterial cell structures: (i) Cell membrane (ii) Cytoplasm and genetic material.

(i) Cell Membrane

• **Location:** the cell membrane (plasma membrane) sits just beneath the cell wall. In bacteria that lack a cell wall altogether (e.g., Mycoplasmas and Spiroplasmas), it forms the outermost layer.

• **Lacks sterols:** the bacterial cell membrane does not contain sterols (e.g., cholesterol) in its make-up, unlike eukaryotic membranes.

• **Mesosomes:** at some points, the cell membrane folds inward (invaginates) and forms pouches, tubes, or sheet-like structures (vesicles, tubules, or lamellae) in the cytoplasm. These are known as mesosomes, and take part in DNA copying, cell splitting (division), and act as centres for breathing (respiration).

(ii) Cytoplasm and Genetic Material

• **Composition:** the cytoplasm holds dissolved substances plus large structures such as the nucleoid, ribosomes, and mesosomes.

• **Organelles:** it lacks a cytoskeleton and membrane-bound organelles. Many ribosomes float freely in the cytoplasmic matrix, and some are loosely attached to the plasma membrane. Bacterial ribosomes are smaller than eukaryotic (80S) ribosomes. Each bacterial ribosome sediments at 70S (with a larger 50S and a smaller 30S subunit).

• **Nucleoid and genetic material:** near the centre of the cytoplasm lies an irregular-shaped, dense area - the nucleoid. It holds DNA. A bacterium carries a single, circular, double-stranded DNA molecule. Bacterial DNA does not have histones attached to it. It is sometimes called the chromosome of the bacterium.

• **Plasmids:** some bacteria hold circular, double-stranded pieces of extra (extra-chromosomal) DNA, called plasmids. They can copy themselves (self-replicate) and may replicate before or after cell division. They carry genes that let bacteria resist unfavourable conditions (e.g., antibiotics).

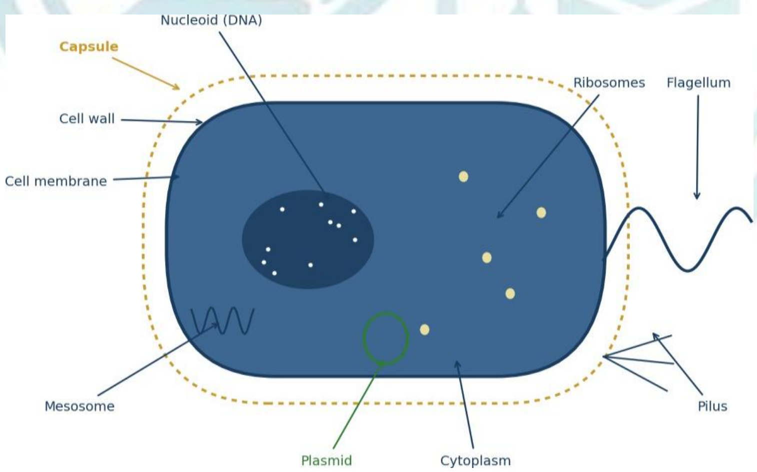

Fig: Structure of a generalized bacterium

Plasmids as Vectors: plasmids also serve as important carriers (vectors) in genetic engineering. They are used to carry chosen genes into bacteria, for cloning or for making specific proteins.

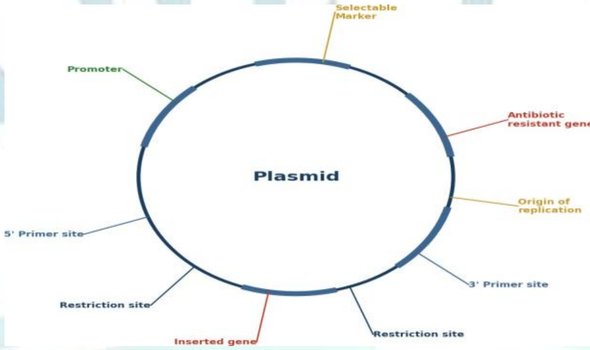

Fig: A plasmid map, showing its main functional regions

Endospore Formation in Bacteria

Q4. State the formation of an endospore in bacteria. / Explain the mechanism of sporulation in bacteria.

Definition: endospores are thick-walled, metabolically inactive (dormant) special "resting" cells, which let bacteria survive long stretches of harsh conditions.

Sporulation: the process by which bacteria make endospores is called sporulation.

Mechanism of Spore Formation

1. **DNA copying and septum formation:** when a bacterium meets unfavourable conditions, it copies (replicates) its DNA. The cell membrane forms a wall-like partition, called a septum, to set apart the new DNA and a small portion of cytoplasm; the cell membrane then surrounds this DNA, cytoplasm, and isolated membrane.
2. **Double membrane formation:** the cell membrane grows again around the new DNA, cytoplasm, and septum. This way, the new DNA ends up surrounded by two membranes.
3. **Formation of new peptidoglycan:** the DNA of the original (vegetative) cell breaks down, and the whole cell begins to lose water (dehydrate). A new peptidoglycan layer forms between the membranes around the separated DNA and cytoplasm.
4. **Spore coat formation and endospore release:** a spore coat also forms around it. The structure matures into an endospore. The vegetative cell then breaks open, and the endospore is set free (released). The endospore stays inactive (dormant) unless good conditions return.
5. **Endospore germination:** once good conditions return, the endospore sprouts (germinates) to give rise to a new, active, growing cell.

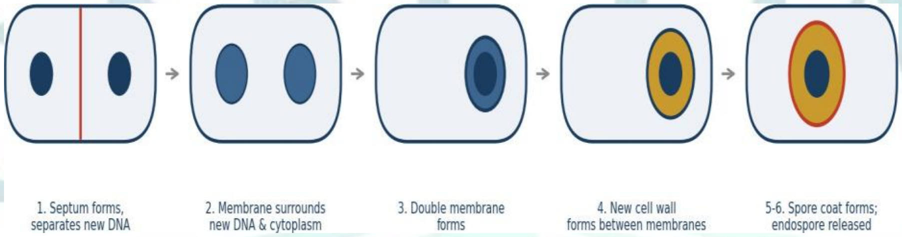

Fig: Process of endospore formation (sporulation) in bacteria

Examples: endospore formation is common in Gram-positive bacteria like Bacillus and Clostridium.

Motility in Bacteria

Q5. Explain different methods of movement (locomotion) in bacteria.

Bacteria use different movement patterns to get around and explore their natural surroundings (habitats). Below are some important ways bacteria move.

- **a. Flagellar movement:** locomotion powered by flagella is called flagellar movement; it may be swimming or swarming. Counter-clockwise rotation of the flagellum pushes the cell forward with the flagellum trailing behind.
  - **Swimming:** the movement of individual bacteria in a liquid setting. They swim using their flagella - most rod-shaped (bacilli) and spiral (spirilla) bacteria move this way.
  - **Swarming:** the coordinated movement of a group/population of bacteria together. Flagellar movement lets bacteria travel through liquid surroundings (media).
- **b. Twitching or crawling:** used to move over surfaces. It is powered (mediated) by pili, which grip the nearby solid surface and pull back (retract). This way, the bacterial cell is pulled forward.
- **c. Gliding:** in gliding, bacteria release a slimy substance, which helps them glide smoothly over solid surfaces. It is similar to twitching.
- **d. Sliding:** movement caused by the expansion created by the pushing force of dividing cells.
- **e. Brownian movement:** some bacteria (e.g., Streptococcus) that lack flagella or pili move because of the random, uncontrolled jostling of particles present in the surrounding fluid - this is called Brownian movement.
- **f. Movement by axial filament:** some bacteria (e.g., spirochaetes) have a changed (modified) flagellum, known as the axial filament.

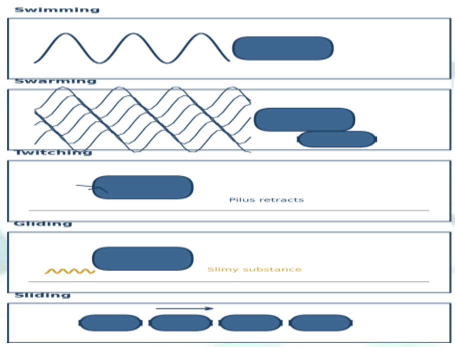

Fig: Five bacterial motility patterns - swimming, swarming, twitching, gliding, and sliding

It is anchored at one end and runs lengthwise (length-wise) through the periplasmic space (the gap between the cell membrane and outer membrane). It is made of two sets of flagella-like threads (fibrils), anchored at the two ends (poles) of the cell. It helps spirochaetes bend (flex), swim, creep, and spin.

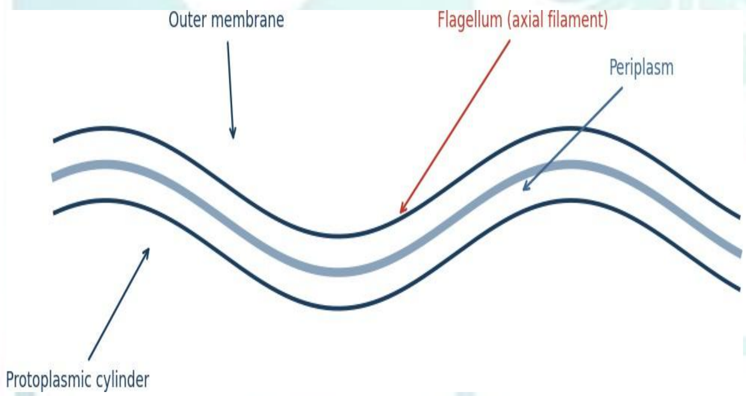

Fig: Axial filament in a spirochaete

Flagella

Q6. Explain the structure of the bacterial flagellum. Classify bacteria on the basis of flagella.

Structure of the Flagellum

- The flagellum of bacteria is entirely different in structure from the flagellum of eukaryotes. Bacterial flagella are not built on the 9+2 pattern of microtubules; instead, they are made of a protein called flagellin.
- The bacterial flagellum is made up of a basal body, a hook, and a filament.
- **i. Basal body:** sits just beneath the cell membrane. It consists of rotating rings (one pair in Gram-positive bacteria, and two pairs in Gram-negative bacteria). The rings anchor the flagellum within the cell membrane and cell wall.
- **ii. Hook:** a curved structure that connects the basal body with the filament.
- **iii. Filament:** an elongated, thread-like structure, made of flagellin protein sub-units arranged in a helical (spiral) fashion.

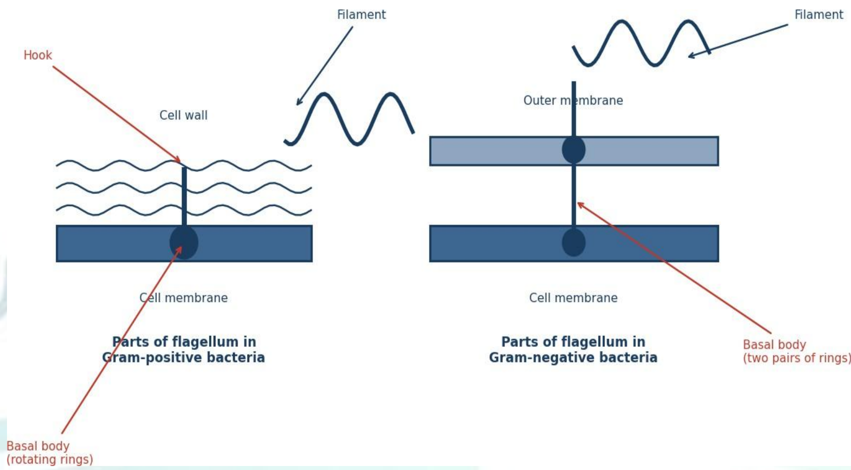

Fig: Structure of bacterial flagella in Gram-positive and Gram-negative bacteria

Pili in Bacteria: some bacteria have pili (singular: pilus). These are straight (non-helical), thread-like extensions, and are smaller and thinner than flagella. Pili are used to attach bacteria to different surfaces. They also take part in the mating process (conjugation) between cells.

Classifying Bacteria by Flagella

The main (primary) job of flagella is to give bacteria the power of movement (locomotion). Many kinds of bacteria have flagella, which let them move. Their secondary job is to detect and respond to chemical signals (chemotaxis).

1. **Atrichous:** bacteria that do not have any flagella.
2. **Monotrichous:** bacteria with a single flagellum at one pole (end).
3. **Lophotrichous:** bacteria with a tuft (bundle) of flagella at one pole.
4. **Amphitrichous:** bacteria with a tuft of flagella at each of the two poles.
5. **Peritrichous:** bacteria with flagella surrounding the whole cell.

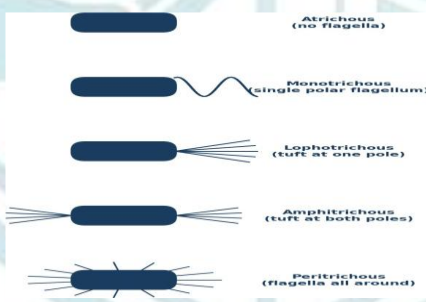

Fig: Different arrangements of bacterial flagella

Bacteria; Ecology and Diversity

Q7. Elaborate on the major groups of domain Bacteria.

Margulis and Schwartz put forward a useful classification system for all prokaryotes. They sorted bacteria into 16 phyla. Below is a look at the important groups within domain Bacteria.

1. Omnibacteria

• Stiff (rigid), rod-shaped, heterotrophic (feeding on organic matter), Gram-negative bacteria.

• Many important disease-causing bacteria (pathogens) belong to this group. Most of them have flagella.

• They do not produce spores. They are usually aerobic (need oxygen).

• Examples: Escherichia coli and vibrios.

2. Cyanobacteria

• These are photosynthetic bacteria. They played the single most important part in Earth's history for raising the level of free oxygen in the atmosphere.

• They contain chlorophyll-a and helper (accessory) pigments like carotenoids, plus blue and red phycobilins.

• Many cyanobacteria fix atmospheric nitrogen in special cells called heterocysts. They are common in soil, in the form of mats; sea-floor sediment mats are dominated by cyanobacteria. Cyanobacteria found within lichens occur on rock surfaces.

3. Mycoplasmas and Spiroplasmas

• These groups differ from all other bacteria in that they lack cell walls, and so are resistant to penicillin and other antibiotics that work by blocking (inhibiting) cell-wall growth.

• Some Mycoplasmas cause diseases in mammals, e.g., certain kinds of pneumonia in humans. Spiroplasmas cause serious plant diseases, e.g., the deadly (lethal) yellowing disease of coconuts.

4. Spirochaetes

• Long, spiral-shaped (spirilla) bacteria with Gram-negative cell walls. They may have 2 to more than 100 flagella.

• Treponema are important spirochaetes; they cause syphilis (a deadly, sexually transmitted disease).

5. Pseudomonas

• Straight or curved Gram-negative rods with one or many flagella at one end, found in soil and water. They can break down organic compounds with ease.

• Some are autotrophic (make their own food), but many are plant disease-causers (pathogens); some take part in denitrification. Pseudomonas aeruginosa occurs in soil, water, and raw vegetables, and although usually harmless, can cause serious infections in people with weak immunity.

6. Actinomycetes

• These have thread-like (filamentous) growth forms. They produce spores that resist unfavourable conditions.

• Some actinomycetes are nitrogen fixers and are found in the root swellings (nodules) of many flowering plants. Some are responsible for dental plaque, in which tooth enamel is destroyed.

• Mycobacterium leprae (a member of this group) causes leprosy, and Mycobacterium tuberculosis causes tuberculosis. Many antibiotics, e.g., tetracycline, chloramphenicol, erythromycin, and neomycin, were first obtained from actinomycetes.

7. Nitrogen-Fixing Aerobic Bacteria

- This group includes bacteria of great economic value. They are Gram-negative, and most have flagella.
- Azotobacter is a member of this group; found in soil and water, it converts atmospheric nitrogen into nitrates.

8. Chemosynthetic Bacteria (Chemoautotrophs)

- These bacteria get energy from the oxidation (chemical breakdown) of inorganic compounds of nitrogen, sulphur, and iron, and use this energy to build their own food.
- Nitrosomonas and Nitrobacter belong to this group. They oxidize nitrogen compounds (NH3) to gain energy; the NH3 is, in turn, changed to nitrite and nitrate. This way, they play a vital part in the nitrogen cycle.

Importance of Bacteria

Q8. Briefly describe the economic and ecological importance of bacteria.

Among the great variety of bacteria, many are useful both ecologically and economically.

a. Ecologically Important Bacteria

- **1. Recyclers of nature:** bacteria take part in almost all biogeochemical cycles, in which essential elements move back and forth between organisms and the environment.
  - Nitrifying bacteria (Nitrosomonas, Nitrobacter, and Azotobacter) and denitrifying bacteria (Pseudomonas) play a significant part in completing the nitrogen cycle.
  - Decomposer bacteria break down dead organic matter and play a key part in the carbon-hydrogen-oxygen cycle. Photosynthetic bacteria, e.g., cyanobacteria, help raise the level of free oxygen in Earth's atmosphere.
- **2. Environmental cleaners:** many bacteria can break down organic compounds with ease. Such bacteria are used to remove or break down pollutants (bioremediation) from the environment.
  - For example, bacteria are used to break down city sewage into harmless products. Some bacteria can digest the hydrocarbons found in petroleum, and are used to clean up oil spills. Bacteria are also used for the bioremediation of toxic industrial waste.

b. Economically Important Bacteria

- **1. Makers of useful products:**
  - **Fermented food:** many bacteria, e.g., Lactobacillus, working with yeasts and moulds, have been used for thousands of years to make fermented foods such as cheese, pickles, soy sauce, vinegar, wine, and yogurt.
  - **Pharmaceutical and agrochemical industry:** bacteria are highly important for producing key chemicals in the drug-making and farm-chemical industries. Some bacteria are used to make antibiotics.
  - **Commercial preparation** of animal skins to make leather goods also relies on the use of bacteria.
- **2. As biopesticides:** bacteria are used in place of chemical pesticides for biological pest control. This commonly involves Bacillus thuringiensis, a Gram-positive, soil-dwelling bacterium. These biopesticides are eco-friendly and have little to no effect on humans, wildlife, pollinators, and most other helpful insects.

Q9. Explain the use of bacteria in research and technology.

Determining the Function of Genes and Enzymes

Bacteria grow quickly, and scientists can work with (manipulate) them very easily. Because of this, bacteria are used in the fields of molecular biology, genetics, and biochemistry. Scientists cause mutations in bacterial DNA and examine the resulting changes in traits (characteristics). This way, they work out the job (function) of genes and enzymes in bacteria. This knowledge is then applied to study the same genes and enzymes in more complex organisms.

Human Genes in Bacteria

Scientists also insert human genes into bacterial plasmids to produce medically useful (therapeutic) proteins, e.g., insulin, growth hormones, or antibodies.

Normal Flora

Q10. Define normal flora. State the benefits which we get from normal bacterial flora.

Definition

The mixture of organisms regularly found at any body location (anatomical site) is referred to as the normal flora.

Description

In a healthy animal, the internal tissues, e.g., blood, brain, muscle, etc., are normally free of microorganisms. On the other hand, the surface tissues, e.g., skin and mucous membranes, are constantly in touch with the environment and become home to (colonized by) certain microbial species. The normal flora of humans is made up of bacteria, a few fungi and protists, and some methane-making (methanogenic) archaea. Bacteria are the most common and obvious microbial part of the normal flora.

Benefits to Normal Flora

The relationships between humans and their normal flora are mutually beneficial (mutualistic). In the human body, the normal flora gets nutrients, a stable setting, and constant warmth (temperature), protection, and transport.

Benefits to Humans

In the same way, the body also gets many benefits from normal bacteria. For example:

1. **Synthesis of vitamins:** bacteria in the gut (alimentary canal) produce vitamins. They release vitamins that are more than they themselves need. From the gut, these vitamins are absorbed and spread through the body. For example, gut (enteric) bacteria release Vitamin K and Vitamin B12, and lactic-acid bacteria produce certain B-vitamins.
2. **Prevent colonization by pathogens:** the bacteria of the normal flora compete with disease-causers (pathogens) for spots to attach to and for nutrients. So, pathogens have less chance of entering body tissues.
3. **Inhibit or kill pathogens:** the gut bacteria produce a range of substances that block (inhibit) or kill disease-causing bacteria.
4. **Boosts the production of cross-reactive antibodies:** since the normal flora behaves like foreign markers (antigens), it triggers an immune response. Small amounts of antibodies made against the normal flora are known to also react against certain disease-causers (cross-react with pathogens), and thereby help prevent infection or invasion.

Virus

Q11. Explain the structure and shapes of viruses.

Structure of Virus

Viruses are extremely small infectious agents and can only be seen under an electron microscope.

Size: they range in size from 20 nm (parvovirus) to 250 nm (poxviruses). They are 10 to 1000 times smaller than most bacteria - that is why they can pass through the pores of filter paper.

Genome: the central core of a virus is its genome. It is made up of nucleic acid (either DNA or RNA).

Capsid and Capsomeres

The core is surrounded by a protein coat, called the capsid. It gives a definite shape to the virus. The capsid is made up of protein sub-units, called capsomeres. The number and kind of capsomeres are unique to a particular virus.

- Herpes virus contains 162 capsomeres in its capsid (causes cold sores, chickenpox, etc.).
- Adenovirus contains 252 capsomeres in its capsid (causes the common cold).

Nucleocapsid: the central core and capsid together are called the nucleocapsid.

Fig: Diversity in virus shapes - helical, icosahedral, complex, enveloped, and non-enveloped

Envelope: a lipid-rich membrane, taken from the host cell.

Enveloped viruses: in some animal viruses, the nucleocapsid is covered by another membrane, called the envelope.

Naked viruses: viruses without an envelope are known as naked viruses.

General Appearance

There is great variety in how viruses look.

- **Animal and plant viruses:** may be polyhedron-shaped (having many sides) or helical (spiral).
- **Bacterial viruses (bacteriophages):** may be cube-shaped (cubical), icosahedral (having 20 faces), helical, or complex (a many-sided head plus a rod-shaped tail).

Q12. Explain the structure of a model bacteriophage.

Bacteriophages are a varied group of viruses that attack bacteria. They are among the most complex viruses known. The best-known phages of Escherichia coli are the T-phages; there are many varieties of T-phages.

Structure of a T4 Phage

A T4 phage consists of a head and a tail.

- **i. Head:** the head is an elongated, pyramid-shaped (with two triangles sharing a common base), hexagonal (six-sided), prism-shaped structure. Its capsid is made of proteins, while its core holds a long, double-stranded DNA molecule. A straight tail is attached to the head.
- **ii. Tail:** the tail is also made of an inner core and outer sheath, both built of different proteins. A neck joins the sheath to the head, and an end plate is present on the other side of the sheath. Six tail fibres are attached to the end plate. They help the phage attach to the bacterial wall. These structures are also made of proteins.

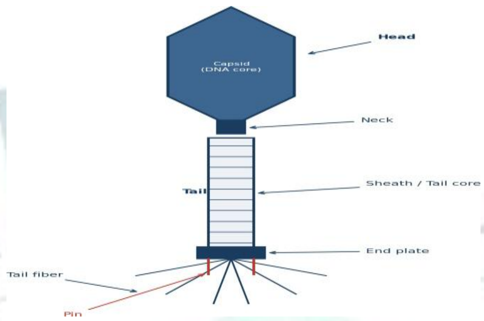

Fig: Structure of a T4 bacteriophage

Q13. Explain the structure of HIV.

Structure of HIV

Human Immunodeficiency Virus (HIV) belongs to the group called retroviruses - a special group of animal viruses. Retroviruses contain RNA, along with a capsid.

Envelope: these structures are surrounded by a lipid-rich envelope. The envelope also carries glycoprotein spikes, which help the virus recognize and bind to its target. HIV particles are spherical in form and are about 100 nm in diameter.

Reverse Transcriptase

The most distinguishing feature of retroviruses is the presence of a specific enzyme, reverse transcriptase. This enzyme drives (catalyses) the process of reverse transcription, in which a single strand of RNA is transcribed backward into a strand of DNA. The enzyme then uses this DNA strand to complete a full double helix of DNA.

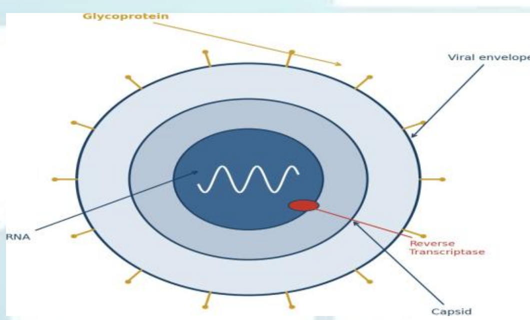

Fig: Structure of HIV

Q14. How did HIV possibly get entry into humans? Relate its discovery with AIDS.

Possible Origin of HIV

Experts have concluded that HIV originated in the jungles of Africa, among wild chimps. Evidence suggests that a form of this virus entered the human species by way of monkey bites or by eating monkey meat and organs (brains).

AIDS

HIV is responsible for the disease AIDS (Acquired Immunodeficiency Syndrome). AIDS weakens the immune system of the patient. The disease is deadly (fatal) because no one can survive without an immune system to defend against other viral and bacterial infections (opportunistic infections).

Discovery

The disease was first reported in 1981, and the patients were found to be homosexual men. Later on, AIDS was also discovered in non-homosexual patients who had received blood or blood products from other AIDS patients.

In 1984, it was discovered that the agent causing AIDS was a virus. In 1986, the virus causing AIDS was given the name Human Immunodeficiency Virus (HIV). It is a host-specific virus - it can multiply in monkeys but does not cause AIDS in them, because HIV attaches to human cells using a specific binding factor known as the CD4 receptor, which is not present in monkeys.