CHAPTER 6

PROKARYOTES

Number of allotted teaching periods: 14

Major Concepts:

6.1 Taxonomy of Prokaryotes (2 Periods)

6.2 Archaea (1 Period)

6.3 Bacteria: Ecology and Diversity (3 Periods)

6.4 Structure; Shape and Size of Bacteria (2 Periods)

6.5 Modes of Nutrition in Bacteria (2 Periods)

6.6 Growth and Reproduction in Bacteria (1 Period)

6.7 Importance of Bacteria (1 Period)

6.8 The Bacterial Flora of Human (1 Period)

6.9 Control of Harmful Bacteria (1 Period)

As we have seen in section 1.4 that all cells can be grouped into two broad categories: prokaryotic cells and eukaryotic cells. All prokaryotes have a simple structure than eukaryotes. All prokaryotes lack a membrane bound nucleus. They have no membrane bound organelles or microtubules and their flagella are simple, compared to eukaryotes.

6.1 TAXONOMY OF PROKARYOTES

In 1969 American biologist **Robert H. Whittaker** proposed five-kingdom system that incorporated the basic prokaryotic-eukaryotic distinction which has been modified by **Lynn Marguis** and **Karlene V. Schwarts** in 1988. They assigned a separate kingdom **Monera** for all the prokaryotes.

Phylogenetic Position of Prokaryotes

In biology, phylogenetics (Greek: *phyle*, tribe, race and *genetikos*, relative to birth, from *genesis*, birth) is the study of evolutionary relatedness among various groups of organisms (e.g., species, populations). Phylogeny (or phylogenesis) is the origin and evolution of a set of organisms, usually a set of species.

The term "bacteria" was traditionally applied to all microscopic, single-celled prokaryotes. However, molecular systematics showed prokaryotic life to consist of two separate domains, originally called **Eubacteria** and **Archaebacteria**, but now called **Bacteria** and **Archaea** that evolved independently from an ancient common ancestor. These two domains, along with **Eukarya**, are the basis of the **three-domain system**, which is currently the most widely used classification system in bacteriology.

A major step forward in the study of bacteria was the recognition in 1977 by **Carl Woese** that archaea have a separate line of evolutionary descent from bacteria. This new phylogenetic taxonomy was based on his discovery that the genes encoding ribosomal RNA are ancient and distributed over all lineages of life with little or no lateral gene transfer. Therefore rRNA are commonly recommended as molecular clocks for reconstructing phylogenies, and divided prokaryotes into two evolutionary domains as part of the three-domain system, **eubacteria**, **archaea** and **eukaryotes**.

The ancestors of modern bacteria were single-celled microorganisms that were the first forms of life to develop on Earth, about 4 billion years ago. For about 3 billion years, all organisms were microscopic, and bacteria and archaea were the dominant forms of life.

Gene sequences can be used to reconstruct the bacterial phylogeny, and these studies indicate that bacteria diverged first from the archaeal/eukaryotic lineage. The most recent common ancestor of bacteria and archaea was probably a hyperthermophile that lived about 2.5 billion to 3.2 billion years ago.

6.2 ARCHAEA

The microorganisms Archaea were originally called archaebacteria (GK; *archaios*, ancient). They are prokaryotic cells that are found in extreme environments thought to be similar to those of the Earth. Further investigations have revealed that these unusual microorganisms are different enough from bacteria to be incorporated into their own domain, archaea.

Unifying Features of Archaea

The unifying features of archaea are: (1) The plasma membranes of archaea contain unusual lipids that allow them to function at high temperatures. (2) Lipids of archaea contain glycerol linked to branched chain hydrocarbons in contrast to lipids of bacteria that contain glycerol linked to fatty acids. (3) The cell walls of archaea do not contain peptidoglycan. In some archaea the cell wall is largely composed of polysaccharides and in others, the wall is pure protein. In a few there is no cell wall.(4) Methanogenesis the ability to form methane, is one type of metabolism that is performed only by some archaea. (5) Most archaea are autotrophs and use molecular hydrogen and reduced elemental sulphur, carbon dioxide and water. (6) There is no photosynthetic archaea. (7) The most fundamental difference between archaea and eubacteria is in their nucleic acid e.g. rRNA. For instance, near nucleotide number 910 (out of 1500) in one type of rRNA researchers have found the following difference.

Eubactera: AAACUCAAA Archaea: AAACUUAAAG

Researchers have **identified** about a dozen of these molecular "signatures" short rRNA sequences that distinguish eubacteria from archaea. Interestingly in a number of cases, including the one above, the sequence in archaea is identical to that of eukaryotes.

Table 6.1 Differences Between Eubacteria and Archaea

Main Features	Eubacteria	Archaea
rRNA sequences	Many unique to Eubacteria	Many match eukaryotic ones
RNA polymerase	Relatively small and simple	Complex similar to eukaryotic
Introns (noncoding parts of genes)	Absent	Present in some genes
Antibiotic sensitivity (to streptomycin, chloramphenicol)	Inhibited	Not inhibited
Peptidoglycan in cell wall	Present	Absent
Membrane lipids	Carbon chains unbranched	Carbon chains branched

Most Archaea Inhabit Extreme Environments

Many of the extreme environments to which the modern archaea are adapted resemble conditions that were common to primitive Earth but somewhat rare today. Archaea includes (a) Methogens, (b) Halophiles, (c) Thermoacidophiles.

The **methogens** (*methano*, methane, *gen*, producer) are found in anaerobic environments in swamps, marshes and in the intestinal tracts of human and other animals where they produce methane from hydrogen gas and carbon dioxide coupled to the formation of ATP. This methane, is also called **biogas** e.g., *Methanobacterium formicom.* The **halophiles** (*halo*, salt, *philes*, lover) grow where nothing else can live, such as on fish and meat that have been heavily salted to keep most bacteria away. The halophiles require high salt concentrations for growth e.g. *Holobacterium halobium*. The **thermoacidophiles** (heat and acid lovers) are isolated from extremely hot, acidic environments such as hot springs, geysers, submarine thermal vent and around volcanoes e.g., *Pyrulobus fumarii*.

6.3 BACTERIA: Ecology and Diversity

The kingdom Prokaryotae is made up of organisms commonly known as bacteria. The study of bacteria is called **bacteriology** and is an important branch of microbiology. The Dutch scientist **Anton van Leeuwenhoek** first discovered bacteria in 1674, using a single-lens microscope of his own design. He called them "animalcules" and published his observations in a long series of letters to the Royal Society. **Christian Gottfried Ehrenberg** introduced the name bacterium in 1882. It is derived from the Greek word *bacterion-a*, meaning "small stuff".

Occurrence of Bacteria in the Widest Range of Habitats

Eubacteria a huge group of prokaryotes is found just everywhere and upon which nearly all other forms of life depend. Here we will discuss some of the structural features that help eubacteria thrive in a great variety of environments.

Bacteria having **flagella** can move toward more favourable places or away from less favourable one. **Pili** help bacteria stick to each other and to surfaces such as rocks in flowing streams or to the lining of human intestine. Bacteria form **endospores**. Under harsh conditions the outer cell may disintegrate, but the endospore survives all sorts of trauma, including lack of water and nutrients, extreme heat or cold and most poisons. When the environment becomes more hospitable, the endospore absorbs water and resume growth.

Some endospores can remain dormant for centuries. Not even boiling water kills most of these resistant cells. The mass of **branching cell chains** or **filaments** is a structural feature unique to the eubacterial group called **actinomycetes**. These bacteria are very common in soil, where they break down organic substances. The filaments enable the organism to bridge dry gaps between soil particles.

Table:6.2 The Major Phylogenetic Groups of Bacteria

GROUP	CHARACTERISTICS OF THE GROUP	REPRESENTATIVE GENERA OF THE GROUP
Aquificales	Extremely thermophilic bacteria, the oldest branch of the bacterial domain.	*Aquifex*
Thermotogales	Extremely thermophilic bacteria.	*Thermotoga*
Green nonsulfur bacteria	Most bacteria in this group are photosynthetic, some are thermophilic.	*Chioroflexus* *Thermomicrobium*
Deinococci	The Dinococcus subgroup are Gram-positive bacteria that are resistant to radiation. The Thermus subgroup are Gram-negative thermophilic bacteria.	*Deinococcus* *Thermus*
Proteobacteria (purple bacteria)	Includes a phenotypically diverse group of Gram-negative bacteria. Some are phototrophic but do not produce oxygen during photosynthesis, some are chemotrophic and some members are capable of nitrogen fixation.	*Escherichia* *Salmonella*
Gram-positive bacteria	This group includes endospore-forming bacteria, lactic acid bacteria, anaerobic and aerobic cocci, mycoplasmas, filamentous actinomycetes, etc.	*Staphylococcus* *Clostridium, Bacillus* *Mycoplasma*
Cyanobacteria	Phototrophic bacteria that produce oxygen during photosynthesis.	*Nostoc, Anabaena* *Oscillatoria*
Chlamydiae	Bacteria that lack peptidoglycan and contain a protein cell wall; live as obligate intracellular parasites of animal cells.	*Chlamydia*
Planctomycetes	Gram-negative bacteria that divide by budding.	*Planctomyces*
Bacteroides and relatives	Gram-negative, rod-shaped bacteria. It includes fermentative anaerobes and respiring aerobes.	*Bacteroides* *Flavobacterium*
Green sulfur bacteria	Green phototrophic bacteria that do not produce oxygen during photosynthesis.	*Chlorobium*
Spirochetes	Gram-negative helical or spiral-shaped cells with a distinctive corkscrew motility.	*Spirochaeta* *Leptospira, Borrelia*

Diagnostic Features of the Major Groups of Bacteria

Historically, bacteria have been subdivided taxonomically into groups based on their cell wall types (Gram –positive or Gram-negative), presence of endospore, metabolism, growth and nutritional characteristics, physiological characteristics and other criteria. The table 6.2 shows the diagnostic features of the twelve major groups of bacteria.

CYANOBACTERIA - The Most Prominent Photosynthetic Bacteria

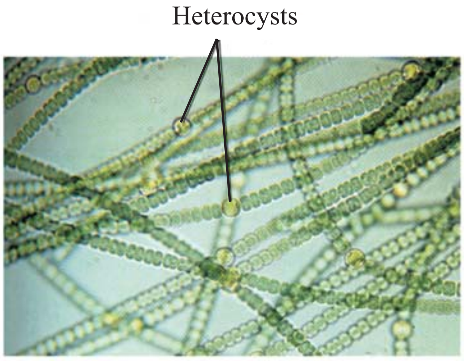
Cyanobacteria (Gk. *kyanoa*, blue and *bacterion*, rod) are Gram-negative. The **habitat** of cyanobacteria is any damp place, salt water, fresh water, in moist soil, on damp rock tree trunks, hot springs (with temperature up to 85°C). The **mode of life** may be epiphytic or symbiotic. They are symbiotic with a number of organisms, such as liverworts, ferns and even at times invertebrates like corals. In association with fungi they form lichens. It is presumed that cyanobacteria were the first colonizers of land during the course of evolution. The **forms of life** are that they (a) may be unicellular and solitary (b) in the form of colonies (c) in the form of filaments attached end to end.

The **prokaryotic features** of cynobacteria are: (a) nuclear membrane is absent (b) the chromosomes do not have protein combined with DNA (c) membrane bound organelles are absent. **Cell wall** contains muramic acid, which is found only in prokaryotes. The cell wall is often surrounded by mucilaginous sheath. The **genetic material** is a circular strand of DNA. Many **ribosomes** are present in the cytoplasm.

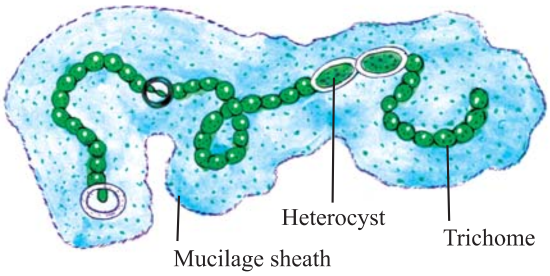
Photosynthesis takes place in the extensive system of membrane, which is located in the outer zone of the cytoplasm. Oxygen is released during photosynthesis. Cyanobacteria use phycobilins as accessory pigment. Phycocyanin a blue pigment is their predominant phycobilins. They are believed to be responsible for first introducing oxygen into the primitive atmosphere.

Sexual reproduction is absent in cyanobacteria. Asexual reproduction takes place by: (a) Cell division e.g. unicellular form. (b) Fragmentations is the breaking of the body of the organism into small pieces of fragments. It takes place at weak points next to **heterocyst** forming **hormogonia**. (c) Certain cells of the filament, may become enlarged. The walls become thick. They contain reserve food and DNA. These are the resting stages called **akinetes**. After resting stage, the wall of the akinete ruptures and a short filament of cells is released. (d) Spore formation is not common. Sometimes the heterocyst forms **endospores**. The nuclear material divides and then the cytoplasm of the heterocyst divides within the parent cell wall and many spores called endospores are formed. Each spore forms a new *Nostoc* filament.

About one third of cyanobacteria are able to fix atmospheric nitrogen. In most cases **nitrogen fixation** occurs in **heterocycts**, which are thick walled without nuclei. In Pakistan cyanobacteria e.g. *Nostoc*, *Anabaena* are purposely cultivated to increase the soil fertility, because of nitrogen fixation by these organisms.



Anabaena



Nostoc

Fig. 6.1 Cyanobacteria

6.4 STRUCTURE: Shape and Size of Bacteria

A typical bacterium consists of cell wall, cell membrane, cytoplasm, genetic material, and specialised structures outside the cell wall.

The **cell wall** is the outermost component common to all bacteria. Cell wall is absent in *Mycoplasma* species, which are bounded by cell membrane. Some bacteria have surface feature external to the cell wall such as capsule, flagella and pili.

The cell wall is a multilayered structure located external to the cytoplasmic membrane. It is composed of an inner layer of **peptidoglycan** and an outer membrane that varies in thickness and chemical composition depending upon the bacterial type. The peptidoglycan provides structural support and maintains the characteristic shape of the cell.

Peptidoglycan is a complex interwoven network and surrounds the entire cell and is composed of a singly covalently linked macromolecule. It is found only in bacterial cell wall. The term peptidoglycan is derived from the peptide and sugars (glycan) that make up the molecule. Synonyms for peptidoglycan are **murein** and mucopeptide.

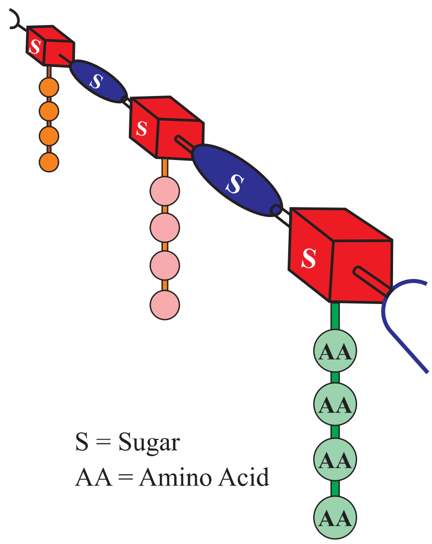


Fig: 6.2 Peptidoglycan

The **capsule** is a gelatinous layer covering the entire bacterium. It is composed of polysaccharide, except in the *Anthrax bacillus*, which has a capsule of polymerized D-glutamic acid. The sugar components of the polysaccharide vary from one species of bacteria to another. The capsule may play a role in the adherence of bacteria to human tissues.

Cell Walls of Gram-Positive and Gram Negative Bacteria

The structure, chemical composition and thickness of the cell wall differ in Gram-positive and Gram-negative bacteria. (1) The peptidoglycan layer is much thicker in Gram-positive than in Gram-negative bacteria. Some Gram-positive bacteria also have fibre of teichoic acid that protrude outside the peptidoglycan, whereas Gram-negative bacteria do not have it. (2) In contrast, the Gram-negative have a complex outer layer consisting of lipopolysaccharide, lipoprotein and phospholipid. Lying between the outer

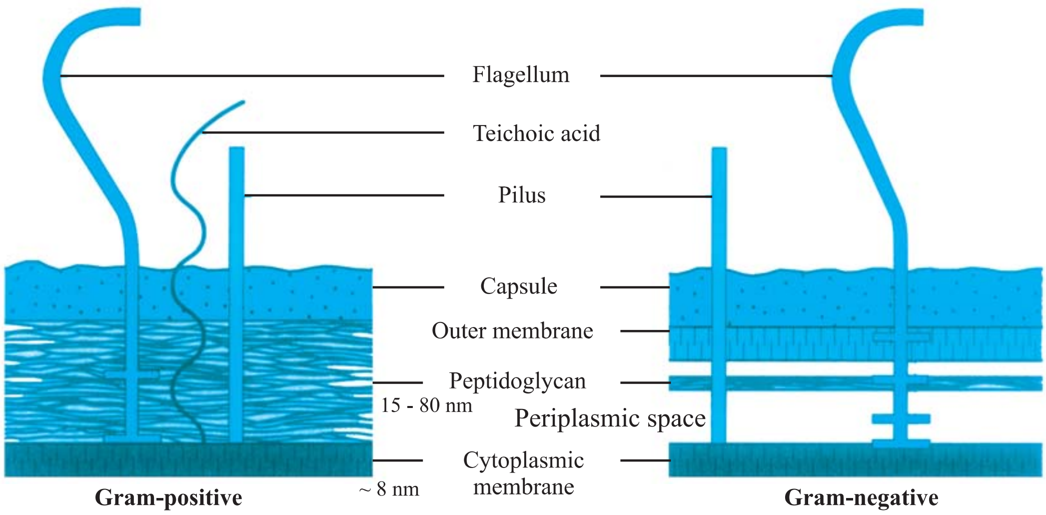


Fig: 6.3 Cell Wall of Bacteria

membrane layer and the cytoplasmic membrane in Gram-negative bacteria is the, which is the site,in some species of enzymes called β-lactamases that degrade penicillins and other β-lactum drugs.

Diversity of Shapes and Sizes in Bacteria

Bacteria have three main shapes: spherical, rod shaped and spiral.

Spherical: A **coccus** (*kokus*) is a spherical bacterium **Cocci** (*koksi*) generally appears in groups: (1) the groups consisting of two cells are called *diplococci*, (2) in the long chain called *streptococci*, (3) in irregular clumps that look like bunches of grapes called *staphylococci*, (4) **Cocci** may form packet of 4 cells called tetrad and (5) packet of eight cells called octate or sarcina. The example of cocci are: *Streptococcus pneumoniae*, *Neisseria meningitidis*.

Rod shaped: Bacilli are straight or rod shaped organisms. They are found in: (1) pairs, called *Diplobacillus*, (2) very short and *ovoid*, called *Coccobacilli*, (3) curved into a form resembling comma called *Vibrio*, (4) look like stack of coin called palisade. The examples of rod shaped bacteria are *Escherichia coli*, *Pseudomonas*.

Spiral: Spirochetes are spiral bacteria usually occur singly, seldom form colonies. They are thin walled flexible spiral rods. Relatively spirochetes are large and flexible e.g. *Treponema pallidum*.

Size of Bacteria: Bacteria range in size about 0.1 to 600μm over a single dimension.

Endospore Formation in Bactera

A single bacterium forms a single spore by a process called **sporulation**. The spore contains bacterial DNA, a small amount of cytoplasm, ribosomes, peptidoglycan, very little water and most importantly, a thick, keratin like coat. As the spore develops within the vegetative cell, so it has been named as **endospore**.

During germination the cell takes up water and enlarges. At the same time the wall disintergrates and a vegetative cell emerges. Endospore formation is not a means of reproduction since there is no increase in cell number during the spore cycle.

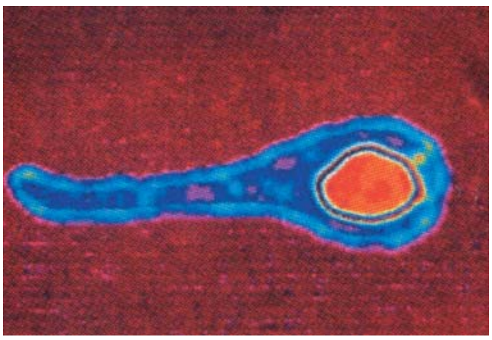


Fig: 6.4 Endospore

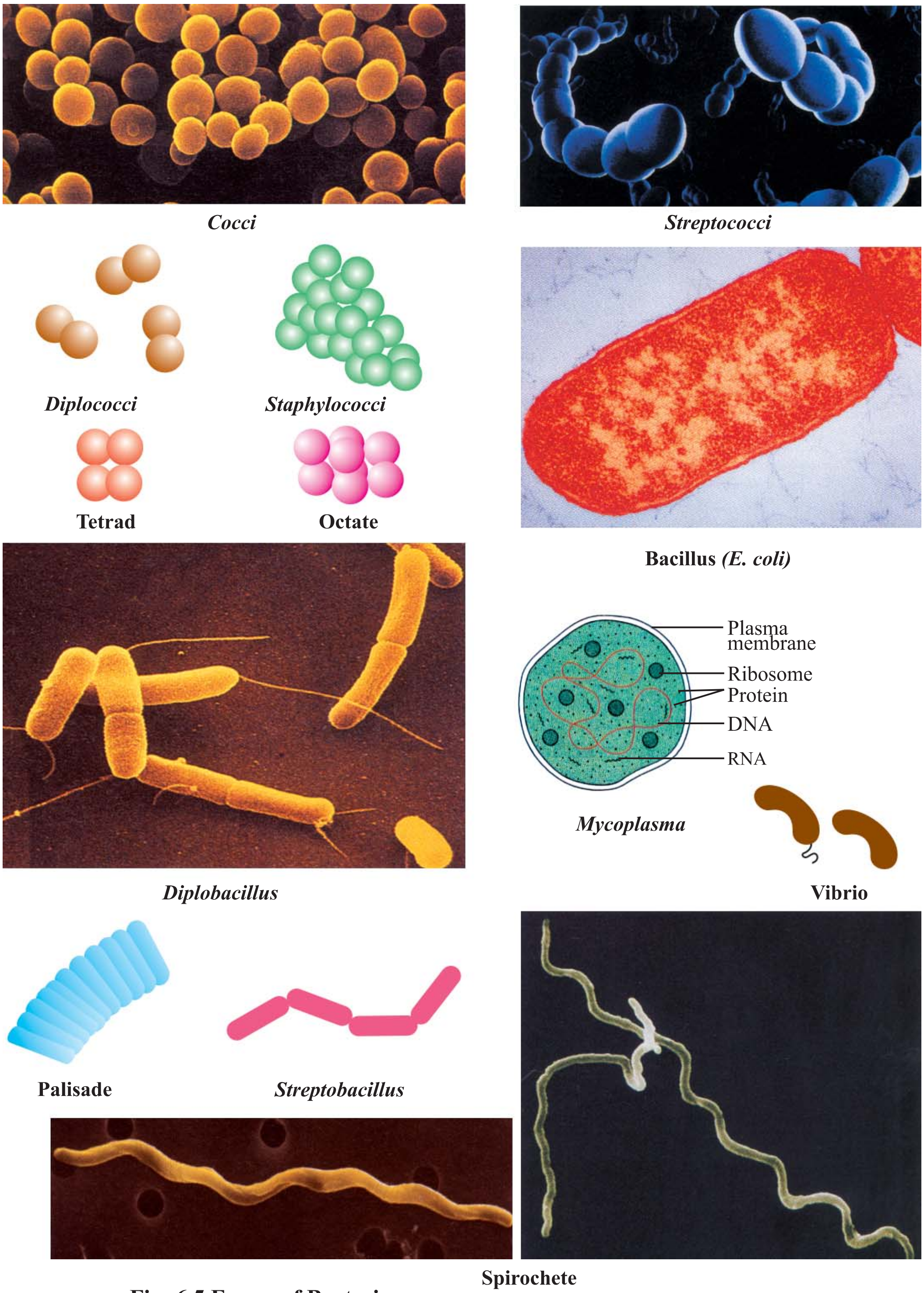
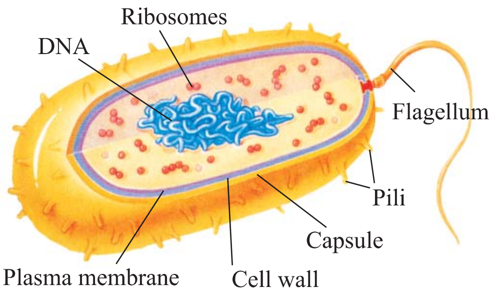


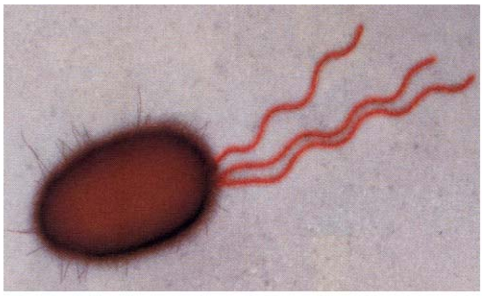
Fig: 6.5 Forms of Bacteria

Motility in Bacteria

Motile bacteria can move using flagella, bacterial gliding, twitching motility or changes of buoyancy. A unique group of bacteria, the spirochetes, have structures similar to flagella, They have a distinctive helical body that twists about as it moves. In twitching motility, bacteria use their pili as a grappling hook, repeatedly extending it, anchoring it and then retracting it with remarkable force.

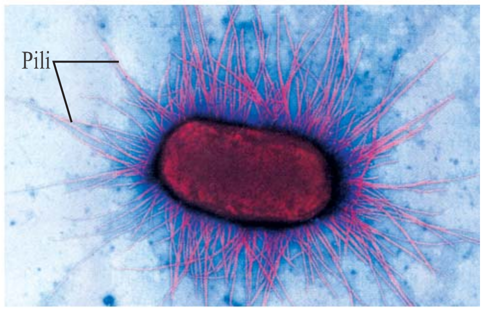


(a) Monotrichous



(c) Lophotrichous

(b) Amphitrichous



(d) Peritrichous

Fig: 6.6 Location of Flagella in Bacteria

Bacterial species differ in the number and arrangement of flagella on their surface; some have a single flagellum i.e. **monotrichous**, a flagellum at each end i.e **amphitrichous**, clusters of flagella at the poles of the cell i.e. **lophotrichous**, while others have flagella distributed over the entire surface of the cell i.e. **peritrichous**. Many bacteria (such as *E. coli*) have two distinct modes of movement: forward movement (swimming) and tumbling. The tumbling allows them to reorient and make their movement a three-dimensional random walk.

Motile bacteria are attracted or repelled by certain stimuli in behaviors called **taxes**: these include chemotaxis, phototaxis and magnetotaxis. Several species move inside host cells by usurping the cytoskeleton, which is normally used to move organelles inside the cell.

Structure of Bacterial Flagellum

Many bacteria have fine thread like outgrowth called flagella (singular: *flagellum*). It is composed of a single protein **flagellin**, arranged in interwined chains, which are noncontractile protein, and lacks microtubules. Flagella are about twenty nanometers diameter and up to 20 micrometers in length. Bacterial flagella consists of three parts: a basal body, a hook and a filament (fig. 6.7). The **basal body** originates just beneath the cell membrane. It is a complex structure that produces rotatory motion. The **hook** connects the basal body to the filament. The **filament** is a hollow structure which consists of several protein chains twisted into a helical structure. The 360° rotation of the flagellum causes the cell to spin and move forward.

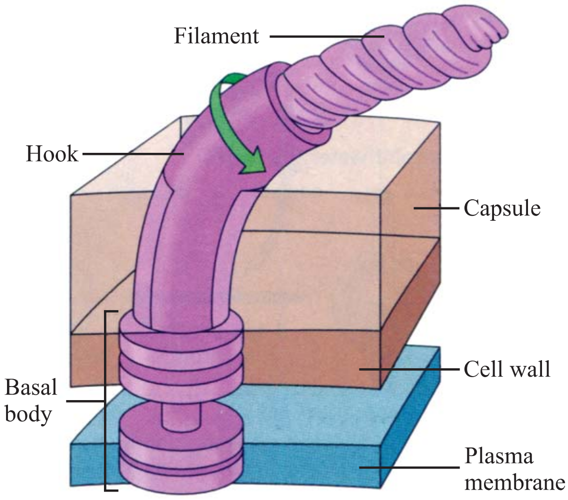


Fig: 6.7 Structure of Bacterial Flagellum

Genomic Organization in Bacteria

The genetic material of a typical bacterium, *Escherichia coli*, consists of a single circular DNA molecule and is composed of approximately 5 × 106 base pairs. This amount of genetic information can code for about 2000 protein.

Most bacteria have a single circular chromosome that can range in size from only 160,000 base pairs in the endosymbiotic bacteria *Candidatus Carsonella ruddii* to 12,200,000 base pairs in the soil-dwelling bacteria *Sorangium cellulosum*. Spirochetes of the genus *Borrelia* are a notable exception to this arrangement, they contain a single linear chromosome. Apart from bacterial chromosome many bacteria have accessory rings of DNA called **plasmids**. To date, 8 complete bacterial genomes have been sequenced.

6.5 MODES OF NUTRITION IN BACTERIA

Bacteria can be classified on the basis of method of obtaining energy and carbon. Carbon metabolism in bacteria is either **heterotrophic**, where organic carbon compounds are used as carbon sources, or **autotrophic**, meaning that cellular carbon is obtained by fixing carbon dioxide.

Autotrophic Nutrition in Bacteria

Autotrophy means self nourishing organisms. An autotrophic organism can obtain all the carbon it needs from CO_2 that is present in the atmosphere and that dissolves readily in water. There are two major groups of autotrophs: photosynthetic and chemoautotrophic.

Photosynthetic Bacteria: The photosynthetic bacteria contain unique type of chlorophyll called bacteriochlorophyll. The chlorophyll is incorporated in the membrane of their mesosomes, or dispersed in the cytoplasm. Like green plants, the photosynthetic bacteria use the energy of sunlight to make carbohydrates from CO_2.

$$2H_2S + O_2 \xrightarrow[\text{Chlorophyll}]{\text{Light}} (CH_2O)_n + H_2O + 2S$$

The examples of photosynthetic bacteria are Green sulphur bacteria, purple sulphur bacteria, purple non-sulphur bacteria. They use hydrogen sulfide (H_2S) instead of water.

Chemoautotrophic Bacteria: Certain colourless bacteria make carbohydrates from inorganic substance. They do not use light energy. They oxidize inorganic substance. The energy produced by this oxidation is then used to make carbohydrates. Sulphur bacteria oxidize sulphur to produce energy.

$$2H_2S + O_2 \longrightarrow 2S + H_2O + \text{Energy}$$

The energy thus produced is used by bacteria to make carbohydrate $(CH_2O)_n$.

$$2H_2S + CO_2 \xrightarrow{\text{Energy}} (CH_2O)_n + H_2O + 2S$$

The examples of chemoautotrophic bacteria are Nitrifying bacteria, Sulphur bacteria.

Heterotrophic Nutrition in Bacteria

Heterotrophic Bacteria cannot synthesize their organic compounds from simple inorganic compounds, so they depend on the organic compounds present in the environment. There are two types of heterotrophic bacteria: (a) Saprotroph bacteria (b) Parasitic bacteria.

Saprotroph Bacteria contain extensive enzyme system that break down the complex substances of humus to simpler compounds. The bacteria then absorb the simpler compounds, for example many soil bacteria. eg., *Pseudomonas*, *Azobacter*.

Parasitic Bacteria obtain their food from the host. Parasitic bacteria include pathogenic (disease causing) bacteria e.g. *Streptococcus pneumoniae*.

Respiration in Bacteria

Respiration may be aerobic or anaerobic, accordingly bacteria are known as **aerobic bacteria** e.g *Pseudomonas* and **anaerobic bacteria** e.g *Spirochaeta*. Some are **facultative bacteria** e.g *E.coli* which grow either in the presence or absence of oxygen. The bacteria which require a low concentration of oxygen for growth are known as **microaerophilic** e.g *Campylobacter*.

Pigment Composition and Photosynthesis Mechanism in Cyanobacteria

Cyanobacteria contain a blue pigment called **phycocyanin** and a red pigment called **phycoerythrin**. The simplest mixture of chlorophyll and blue green pigment in some species produces the blue green colour that gives the entire group its common name. But those species that contain red pigments, appear red, purple brown or even black.

Cyanobacteria release oxygen during photosynthesis, which takes place in the extensive system of membrane. It is located in the outer zone of the cytoplasm. Their photosynthetic system closely resembles that of eukaryotes because they have chlorophyll "a" and photosystem II. They use water as an electron donor and generate oxygen during photosynthesis. Cyanobacteria use **phycobilins** as accessory pigments. Photosynthetic pigments and electron transport chain components are located in thylakoid membrane linked with particles called **phycobilisomes**. Phycocyanin (a blue pigment) is their predominant phycobilin and CO_2 in them is assimilated through Calvin cycle. Whereas in photosynthetic bacteria as we have already seen bacteriochlorophyll is located in mesosome and use light energy to make carbohydrates from carbon dioxide.

6.6 GROWTH AND REPRODUCTION IN BACTERIA

Bacteria reproduce by binary fission. Because one cell gives rise to two progeny cells, bacteria are set to undergo exponential growth (Logarithmic growth).

Number of cells:	1	2	4	8	16
Exponential	2^0	2^1	2^2	2^3	2^4

Thus one bacterium will produce 16 bacteria after four generation.

Phases of Growth

The curve in graph is known as a logarithmic or exponential curve. Such growth curves can be converted to straight lines by plotting the logarithms of growth against time. The growth cycle of bacteria has four major phases.

Lag Phase-No Growth: During the lag phase the bacteria are adapting to their new environment and growth has not yet achieved its maximum rate. The bacteria for example may be synthesising new enzymes to digest the particular spectrum of nutrients available in the new medium.

Log Phase-Rapid Growth Period: The log phase is the phase when growth is proceeding at its maximum rate, closely approaching a logarithmic increase in numbers when the growth curve would be a straight line.

Stationary Phase-Bacterial Rate of Death and Reproduction is Equal: Eventually growth of the colony begins to slow down and it starts to enter the stationary phase where growth rate is zero, and there is much greater competition for resources. Rate of production of new cells is slower and may cease altogether. Any increase in the number of cells is offset by the death of other cells, so that the number of living cells remains constant. This phase is a result of several factors, including exhaustion of essential nutrients, accumulation of toxic waste products of metabolism and possibly, if the bacteria are aerobic, depletion of oxygen.

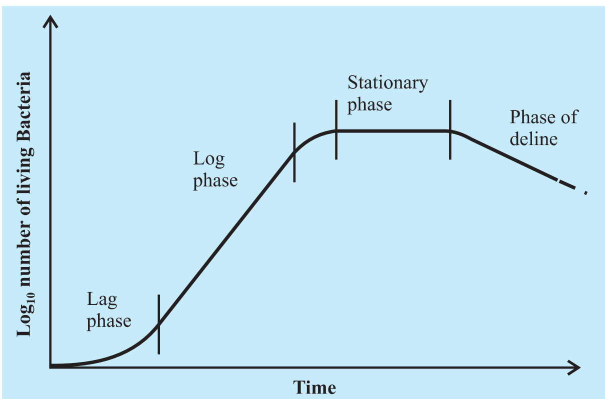


Fig: 6.8 Typical Growth of Curve of a Bacterial Population

Death Phase-Bacteria Start Dying: During the final phase, the death phase or phase of decline, the death rate increases and cells stop multiplying.

Reproduction in Bacteria

The two types of reproduction in bacteria are asexual reproduction and sexual reproduction.

Asexual Reproduction: Bacterial reproduction is mostly asexual. Bacteria reproduce asexually by cell splitting called fission. As the bacteria are divided into two so it is called **binary fission**. There is no mitosis in bacteria. First DNA is replicated. Then the two chromosomes move apart into separate nuclear region. The plasma membrane pushes inward to form a central transverse septum (partition wall). Next the cell wall grows inward within the transverse septum and eventually divides the cell into two. The interval time until the completion of next division is known as **generation time**. Under favourable condition i.e. when there is sufficient amount of water and nutrients and temperature is suitable, bacteria can divide rapidly. It takes 20 minutes to daughter cells to grow and start dividing again.

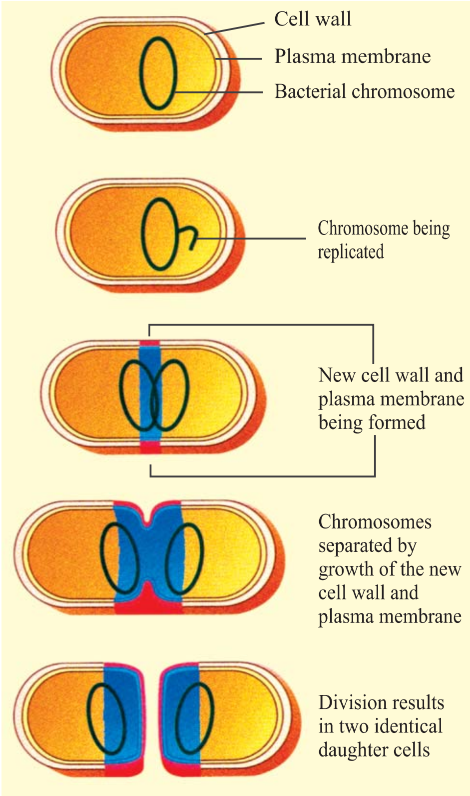


Fig: 6.9 Binary Fission in Bacteria

Sexual Reproduction: The sexual reproduction in bacteria is the genetic recombination i.e. DNA of two bacteria combine to give rise to a new type of bacteria called **recombinant**. The genetic recombination in bacteria occurs by conjugation, transduction and transformation.

Science Titbits

The doubling (generation) time of bacteria ranges from as little as 20 minutes for *Escherichia* coli to more than 24 hours for *Mycobacterium tuberculosis*. The doubling time varies not only with the species but also with the amount of nutrients, the temperature, the pH and the environmental factors.

Conjugation

Indirect proof of genetic recombination in bacteria was proved indirectly by **J. Lederberg** and **E.L. Tatum** (1946) and they were awarded Nobel Prize for this and other research works.

Experiment of Lederberg and Tatum

They took wild type of *Escherichia coli* bacteria. The bacteria were grown on minimal medium containing inorganic salts, glucose and from these materials **wild type** *Escherichia coli* can synthesize all substances necessary for growth and reproduction.

Irradiation with X-rays on these wild type bacteria caused mutation. Two types of nutritional **mutants** were taken out of many.

One strain called Y-10 required amino acid threonine, leucine and vitamin thiamine in the minimal medium for growth. Another strain called Y-24 required amino acids phenylalanine, cysteine and vitamin biotin in the minimal medium for growth.

The mixed cultures of strain Y-10 and Y-24 were grown in nutrition medium containing all the four amino acids and the two vitamins. Three types of bacteria were obtained (a) one were like parent Y-10 (b) another were like the parent Y-24 and (c) third group were like the wild type, as it could grow in the minimal medium.

From this experiment it was concluded that the offspring of the two mutant types were wild type and it is only possible when actual genetic recombination takes place.

Direct Proof of Genetic Recombination

With the invention of electron microscope, the direct proof of genetic recombination was obtained. Mixture of the two mutants was observed using electron microscope. The mutants are easily distinguished by their structure. The bacterium that will give the DNA is called **donor** and the bacterium that will receive the DNA is called the **recipient**.

Fig: 6.10 Sexual reproduction in Bacteria by forming conjugation bridge

Method of Gene Transfer in Bacteria

Bacterial conjugation involves a plasmid that can be transferred during the conjugation process. In some instances, however a part of bacterial chromosomal genes are also transferred. Not all plasmids are involved in bacterial conjugation. Only one type of plasmid, the 'F' (fertility) plasmid, also called the F-factor takes part in conjugation. It forms pilus. The pilus forms the conjugation bridge, connecting the donor and the recipient bacterial cells. The F-plasmid replicates and transfers a copy to the recipient cell.

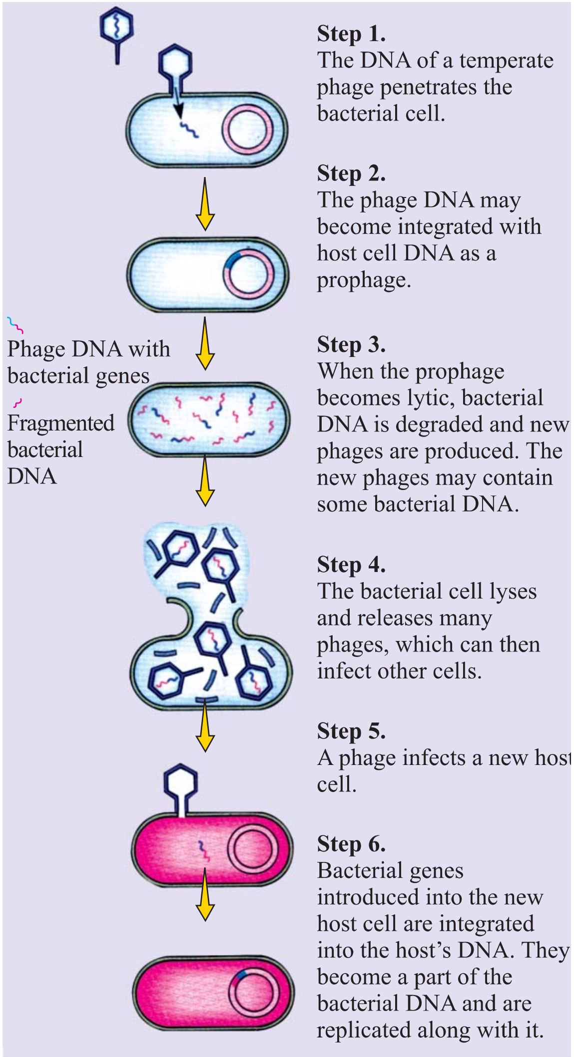


Fig: 6.11 Generalized transduction by a bacteriophage

Transduction

The transfer of genetic material from one bacterium to another bacterium through the third party-the virus, is called transduction.

Transformation

When bacteria die or when they are reproducing very rapidly, they release fragments of their DNA into their immediate environment. Transformation is the absorption of DNA into a cell. As a result the cell is transformed into a new type of cell. These cells are called **transformed cells**.

Bacterial cells that release DNA fragment are called **donor cells**. If one of the released DNA fragment contacts a cell of a species of bacteria that is capable of transformation, the DNA fragment may bound to the recipient and take inside.

Mutations and Genetic Recombinations in Bacteria

Bacteria, as asexual organisms, inherit identical copies of their parent's genes (i.e., they are clonal). However, all bacteria can evolve by selection on changes to their genetic material DNA caused by genetic recombination or mutations. Mutations come from errors made during the replication of DNA or from exposure to mutagens.

Mutation rates vary widely among different species of bacteria and even among different clones of a single species of bacteria. Genetic changes in bacterial genomes come from either random mutation during replication or "stress-directed mutation", where genes involved in a particular growth-limiting process have an increased mutation rate.

Skills: Performing and Recording

- **Draw a graph to present the time taken in each phase of bacterial growth and the number of bacteria.**

Phases of growth *(Escherichia coli)*		
Phase	Time taken in phases of growth.	Number of Bacteria
Lag phase	10 minutes	1
Log Phase	180 minutes	1000
Stationary phase	180 to 360 minutes	3000
Death Phase	360 to 1800 minutes	300

6.7 IMPORTANCE OF BACTERIA

Bacteria are useful as recyclers of nature and they have also ecological importance.

BACTERIA: Recyclers of Nature

Bacteria are vital in recycling nutrients. Many important steps in nutrient cycles depend on bacteria. e.g. nitrogen cycle. Nitrogen fixing bacilli bacteria, genus *Rhizobium*, that live in root nodule of legume convert nitrogen gas to ammonium. Saprotrophic soil bacteria, forming ammonia, decompose the nitrogenous wastes of animals and plants. Chemosynthetic bacteria *Nitrosomonas* and *Nitrobacter* then oxidise ammonia to nitrate, a process called **nitrification**. **Denitrifying** bacteria converts nitrates into nitrogen gas and the process is called **denitrification**. Bacteria recycle both organic matters and inorganic substances e.g. minerals, water, ammonia, carbon dioxide etc. Carbon dioxide is produced by fermentation, which is released in the atmosphere. The green plants fix this carbon.

Ecological Importance of Bacteria

Bacteria and fungi are the only organisms that decompose dead animals and plants. The organic matter of dead organisms is converted into **humus**. It contains nutrients and increases soil fertility for the growth of plants. It also increases the water retaining capacity of the soil.

Economic Importance of Bacteria

Bacteria are both beneficial as well as harmful. Here we will discuss these two aspects of bacteria.

Harmful Bacteria

Parasitic Bacteria attack plants and cause various diseases e.g., fire blight in apple, ring diseases in potatoes, crown gall etc., many human diseases are caused by bacteria e.g. tuberculosis, diphtheria, tetanus, cholera, leprosy, typhoid fever, meningitis, sore throat, whooping cough (pertusis) etc. Bacteria produce acids, which convert wine to vinegar. Bacteria cause decay of wood, leather, fabrics etc. Bacteria spoil the food materials by decomposition.

Beneficial Bacteria

Help in Digestion: Some bacteria in the large and small intestine help to emulsify fats taken as food and thereby promote the digestion and absorption of fats by the host. In cattle, bacteria help in digestion by decomposing cellulose and starch.

Synthesis of Vitamins: Some bacteria can synthesize vitamin K and vitamin B. These bacteria e.g. *Escherichia coli* are grown in culture and produce vitamin B_{12} for commercial purposes.

Bacteria in Industry: Bacteria are widely used in many industrial processes. It is easier and cheaper to use cultured bacteria than to produce the substances by synthetic process. Bacteria are used in the manufacturing of acetic acid (vinegar), acetone, lactic acid, butanol (alcohol), several vitamins, curing cheese and flavouring of tobacco. Bacteria are also used in coffee and leather (tanning) industries.

Bacteria in Food Industry: Dairy products such as yogurt (yoghurt, yoghourt), cheese, butter etc. are produced with the help of bacteria.

Bacteria as Food: The large number of bacterial cells moving with the partially digested plant material through the alimentary canal undergoes digestion too. When they do, they provide the animal with most of its amino acids and vitamins.

Antibiotics: Most of the antibiotics are obtained from various species of actinomycetes group, e.g., Streptomycin, Auromycin, Teramycin etc.

Biogas: Bacteria decompose sawages, garbages, dungs, stool and during the process produce methane gas. It is used as fuel. Biogas plants are used in villages. Biogas is 54-70% methane, whereas the natural gas is about 80% methane.

A Single Cell Protein: A relatively new food source is "single cell protein". Its production began in the late 1960. The term refers to protein obtained from the large scale growth of microorganisms such as bacteria, yeast and other fungi and algae. The protein may be used for human consumption or animals.

Use of Bacteria in Research

Microorganisms e.g.,bacteria, yeast, *Neurospora* etc have been extensively used in research. We owe to bacteria for many of the biological achievement for the benefit of human being. For example 1n 1952 Alfered D. Hershey and Martha Chase used T2 bacteriophage and bacteria to prove that DNA is the hereditary material.

Use of Bacteria in Technology

Biotechnology Products: Free-living organisms in the environment that have a foreign gene inserted into them are called transgenic organisms. Bacteria are used to clone a gene or to mass-produce a product. These products include hormones and similar types of proteins or vaccines e.g., insulin, growth hormones, clotting factor VII for haemophilia etc.

Protection and Enhancement of Plants: Genetically engineered bacteria can be used to promote the health of plants. For example, bacteria that normally live on plants and encourage the formation of ice crystals have been changed from frost-plus to frost- minus bacteria.

Bioremediation: Naturally occurring bacteria that eat oil can be genetically engineered to clean up beaches after oil spills.

Science Titbits

Escherichia coli has been used to produce protein products of recombinant DNA technology, such as insulin, human growth hormone, etc. Genetic engineers often use a plasmid vector to introduce new genes into plant cells. The plasmid they use is from soil bacterium *Agrobacterioum tumefaciens*. *Saccharomyces ceresvisiae* (yeast) has been used to produce hepatitis B vaccine, alpha and gamma interferoms.

Science, Technology and Society Connections

List some biotechnologies utilizing bacteria.

Chemical Production: Organic chemicals are often synthesized by using bacteria to carry out the synthesis. Today it is possible to manipulate the genes that code for these enzymes. For example genetically engineered bacteria are used to produce phenylalanine.

Mineral Processing: Genetic engineering may enhance the ability of bacteria to extract copper, uranium and gold from low-grade sources.

Important Bacterial Diseases In Man

Bacteria cause many diseases in man such as pneumonia, anthrax, tetanus, botulism, diptheria, meningitis, gonorrhea, whooping cough, pneumonia, plague, urinary tract infection, typhoid fever, gastritis, peptic ulcer, cholera, tuberculosis, syphilis, etc. Here we will discuss only cholera, typhoid, tuberculosis and pneumonia.

Science Titbits

The plague, or “Black Death” which killed 100 million people during the mid-fourteenth century, is caused by highly infections bacteria, *Yersinia pestis*, spread by the fleas carried by infected rats. In 1994, an outbreak of plague occurred in India for the first time in 30 years. Tuberculosis, a bacterial disease has killed millions of peoples in the past and also thousand of people all over the world including Pakistan. *Streptococcus pneumoniae*, causes pneumonia has killed a large number of people in the past.

Science, Technology and Society Connections

Narrate how bacterial diseases have affected human societies in the past.

Cholera

Symptoms: Watery diarrhoea in large volume is the hallmark of cholera.

Causative Agent: Cholera is caused by the bacteria *Vibrio cholerae*.

Treatment: It consists of prompt, adequate replacement of water and electrolytes, either orally or intravenously. Antibiotics such as tetracycline are not necessary, but they do shorten the duration of symptoms and reduce the time of excretion of the organisms.

Prevention: It is achieved mainly by public health measures that ensure a clean water supply. The vaccine composed of killed organisms has limited usefulness. A live vaccine is available in certain countries. The uses of tetracycline for prevention are effective. Prompt detection of carriers is important in limiting outbreaks.

Science, Technology and Society Connections

Relate the causes of food poisoning and the sanitation condtions in restaurants.

Typhoid

Symptoms: In typhoid and other enteric (pertaining to intestine) fever infection begins in the small intestine. The onset of illness is slow, with fever and constipation. High fever, delirium, tender abdomen and enlarged spleen occur. "Rosy spots" i.e. rose coloured macules on the abdomen, are associated with typhoid fever but occur rarely.

Causative Agent: It is caused by bacteria *Salmonella typhi*.

Treatment: Antibiotics should be used in patients who are chronic carriers of *S.typhi*.

Prevention: It is prevented mainly by public health and personal hygiene measures. Hand washing prior to food handling, pasteurisation of milk, and proper cooking of poultry, eggs and meat are all-important. Vaccines are available for the prevention of typhoid.

Tuberculosis

There are different types of tuberculosis e.g. meningeal TB, miliary TB, bone TB, skin TB, abdominal TB etc. Here we will discuss only pulmonary TB.

Symptoms: Mild fever lasts for 7-14 days and mild dry cough. Bluish red raised tender cutaneous lesions on the shins and less commonly on the thighs may occur in primary tuberculosis. In secondary tuberculosis there is low-grade intermittent fever usually in the evening, night sweats, weight loss, anorexia, malaise and weakness, dry hacking cough with blood stained sputum, dull ache in the chest due to pleurisy etc.

Causative Agent: *Mycobacterium tuberculosis*.

Treatment: Multiple-drug therapy is used to prevent the emergence of drug resistant mutants during the long 6 to 9 month duration of treatment or DOTS (directly observed treatment short course) of only two months duration.

Prevention: Prevention of the spread of the organism depends largely on the prompt identification and adequate treatment of patients who are coughing up the organism. The use of masks and other respiratory isolation procedures to prevent spread to medical personnel is also important. A vaccine containing a strain of live *Mycobacterium bovis* (Bacillus Calmette-Guerin or BCG) can be used to induce partial resistance to tuberculosis.

Pneumonia

Symptoms: Pneumonia often begins with sudden chill, cough and pleuritic pain. Sputum is red brown “rusty” colour.

Causative Agent: *Streptococcus pneumoniae.*

Treatment: Most pneumococci are susceptible to penicillins and erythromycin.

Prevention is better than cure, so the measure to prevent any epidemic are : Massive programs of immunization for vaccine preventable diseases e.g. tuberculosis, hepatitis B, polio etc must be launched. Detection of cases at the earliest and to treat them properly is the goal. Complete quarantine of persons or domestic animals, which have been exposed to communicable diseases. Supply of safe drinking water. Control of vector disease e.g. mosquitoes, house flies at larval stages and adult stage. To educate people for improving hygiene practices like washing of hands. If any communicable disease occurs it should be notified immediately e.g. pneumonia, polio etc.

Science, Technology and Society Connections

Suggest how can we stop any epidemic to occur in future?

Important Bacterial Diseases In Plants

The important bacterial plant diseases are leaf spots, blights, soft rots, wilts and galls.

Leaf spot

Symptoms: The most common symptoms of plant diseases are discrete or spreading type lesion on leaf blade. It is caused by bacterial pathogens through the action of toxins they produce.

Cause: It is cause by *Xanthomonas campestris* on tomato and pepper. *Pseudomonas syringae* on tobacco, *Aplanobacter sepedanium* causes ring disease of potato

Prevention: Prevention of contact between the pathogen and the host, use of disease free seeds.

Blight

Symptoms: When the necrotic symptoms develop very rapidly damage the plant cell wall structure, and effect organ or shoot or even the whole plant soon gets killed. The symptom is termed blight. In some cases blight symptoms appear initially at or near the leaf tip, often at the margin then spread downwards and inwards drying up the leaf and the whole plant may get blighted soon e.g. maize, rice and oat etc.

Cause: *Xanthomonas oryzae* cause blight disease in rice, *Eriwinia anylovora* causes fire blight of pears and apples

Prevention: Disease free seeds, suitable location and removal of diseased plant by physical method.

Soft Rot

Symptoms: When the cells of plant tissue die because of the action of pathogen, produce pectolytic and cellulolytic, rot type symptoms. Rotting may affect any organ of plant including flowers and fruits. When the pathogen produces peptolytic enzyme, plant cell soon separates from one another because of maceration and the affected host tissue loses its coherence and leakage of water takes place from the effected cells, which are killed soon. The necrotised tissue becomes wet to touch and soft inconsistency hence termed soft rot. Such rot is of fast spreading nature and damage plant organs very rapidly.

Cause: *Erwinia atroseptica* in potato, *Corynebacterium* causes ear rot of wheat.

Prevention: Removal of diseased plants by physical method.

Wilting

Symptoms: Interference with the upward transport of water with dissolved nutrients from roots through the stem into the leaves leads to loses of turgidity in the leaf blade, which becomes limp. Such loss of turgidity in the leaf blade increased with time and ultimately leads to wilting of leaf and drying.

Cause: *Pseudomonas solanacaerum* causes wilt disease of potato. *Xanthomonas campestris* causes important wilt diseases.

Prevention: Selection of disease free seeds, selecting proper dates for planting and suitable location and allowing proper spacing between the plants.

Galls

Symptoms: These are localised outgrowth mostly small but may be very large in some diseases.

Cause: *Rhizobium leguminosarum* causes small galls called **root nodule** in legumes. *Pseudomonas savastonoi* cause a small gall in olive plant known as olive knot. *Agrobacterium tumifaciens* causes large galls in many plants. *Xanthomonas campestris* causes galls on cotton.

Prevention: Crop rotation, removal of disease plants and use of disease free seeds.

Fig. 6.12 Root nodules: The bacteria live in these nodules of legumes

Fig. 6.13 Crown gall disease on a tobacco plant caused by *Agrobacterium*

6.8 THE BACTERIAL FLORA OF HUMANS

There are approximately ten times as many bacterial cells as human cells in the human body, with large numbers of bacteria on the skin and in the digestive tract. Normal flora is the term used to describe the various bacteria (and fungi) that are permanent residents of certain body parts, especially the skin, oropharynx, colon and vagina.

Table 6.3 Some of the Member of Normal Location

Members of the Normal Flora	Anatomic Location
Clostridium species	Colon
Escherichia coli and other coliforms	Colon, vagina, outer urethra
Lactobacillus species	Mouth, colon, vagina
Staphylococcus aureus	Nose, skin
Enterococcus faecalis	Colon
Viridans streptococci	Mouth, nasopharynx

Benefits of the Bacterial Flora to Humans

The members of some normal flora play a role in the maintenance of health and the causation of disease in three significant ways: They can cause disease, especially in having an impaired immune system and weak, feeble individuals. Although these organisms are nonpathogens in their usual location, they can be pathogens in other parts of the body. They constitute a protective host defence mechanism. The nonpathogenic resident bacteria occupy attachment sites on the skin and mucosa that can interfere with colonization by pathogenic bacteria. The ability of members of the normal flora to limit the growth of pathogens is called **colonization resistance**. If the normal flora is suppressed, pathogens may grow and cause diseases.

They may serve a nutritional function. The intestinal bacteria produce several B vitamins and vitamin K. Poorly nourished people who are treated with oral antibiotics can suffer vitamin deficiencies as a result of the reduction in the normal flora. However since germ-free animals are well nourished, the normal flora is not essential for proper nutrition.

Critical Thinking

Although many bacteria can cause dangerous diseases in general, bacteria make life on earth possible. Why?

6.9 CONTROL OF HARMFUL BACTRERIA

Chemical Methods to Control Bacteria

Antiseptics, disinfectants and chemotherapeutic agents are used as chemical methods for microbial control.

Antiseptics: The chemical substances used on living tissues that inhibit the growth of microorganisms are called antiseptics.

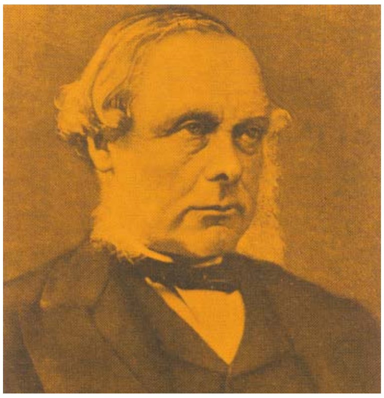


Fig: 6.14 Joseph Lister the first person to use antiseptic.

Disinfectants: Oxidizing and reducing agents are important chemical agents for disinfection e.g. Halogens and phenols, hydrogen peroxide, potassium permanganate, alcohol and formaldehyde etc. These chemicals inhibit the growth of vegetative cells and are used on nonliving material.

Chemotherapeutic Agents: These chemicals and antibiotics destroy the natural defence and stop the growth of bacteria and other microbes in the living tissue e.g. sulphonamide, tetracycline, penicillin etc.

Science, Technology and Society Connections

Justify why it is important to disinfect articles of food and utensils before use?

Physical Methods to Control Bacteria

Sterilization Process: It is the process in which physical agents like steam, dry heat, gas, filtration and radiation are used to control bacteria. Sterilization is destructive to all life forms. This process is used to sterilize surgical apparatus. It is also used to preserve food items on large-scale e.g. milk, meat etc.

High Temperature: It is usually used in microbiological labs for control of microbes. Both dry heat and moist heat are effective. Moist heat causes coagulation of proteins and kills the microbes. Dry heat causes oxidation of chemical constituents of microbes and kills them.

Radiations: Certain electromagnetic radiations below 300 nm are effective in killing of microorganisms. Gamma rays are in general use for sterilization process.

Membrane Filter: Heat sensitive compounds like antibiotics, seras, etc can be sterilized by means of membrane filters.

Pasteurization: It is the process to kill microorganisms by heating at temperature enough to kill nonspore forming bacteria e.g. milk is pasteurised by heating at 71°C for 15 seconds and at 62°C for 32 minutes. It does not change the taste of the milk. **Louis Pasteur** introduced pasterization. It minimizes the infector for typhoid and tuberculosis.

Low Temperature: Food can be preserved for several days by keeping it at a temperature between 10° – 15°C e.g. milk, vegetables, cheese and meat.

Freezing: Food can be frozen at –10°C to -18°C for several weeks to several months e.g. meat, vegetables.

Drying: The removal of water is called dehydration. Food is dehydrated so that in dry condition bacteria may not grow e.g. dried milk and dried meat.

Preservatives: Adding preservatives inhibit the growth of bacteria. Acid is added to lower the pH. The contents of salt are increased so that water in the food is not enough for bacterial growth. Some chemicals like potassium metabisulphite are added. Pickles, candies, jam and breads are preserved by such methods.

Skills: Initiating and Planning

- Acquire some basic microbiological and safety techniques.

Exercise

SECTION I : MULTIPLE CHOICE QUESTIONS

Select the correct answer

1. Cyanobacteria

   A) are poisoned by oxygen B) are not widely distributed

   C) have chlorophyll D) have chloroplast

2. Cyanobacteria, unlike other types of bacteria that photosynthesise, do

   A) not give off oxygen B) give off oxygen

   C) not have chlorophyll D) not have a cell wall

3. Pili are made up of pilin, which is

   A) carbohydrates B) lipids

   C) protein D) triglycerides

4. Most pathogenic bacteria cause disease by

   A) directly destroying individual cells of the host

   B) depriving the host of their nutrients

   C) producing toxins

   D) depriving the host of oxygen

5. Chemosynthetic bacteria

   A) are autotrophic

   B) use the sun rays

   C) oxidize inorganic compounds to acquire energy

   D) both A and C are correct

6. A bacterium with flagella all around is

   A) monotrichous B) lophotrichous

   C) amphitrichous D) peritrichous

7. Conjugation is facilitated by

   A) capsule B) pili

   C) flagella D) both pili and flagella

8. Bacterial membrane differ from eukaryotic membrane in

   A) lacking proteins B) lacking lipids

   C) lacking polysaccharide D) lacking cholesterol

9. Bacterial membrane also contains enzymes for

A) respiration B) photosynthesis

C) protein synthesis D) secretion

10. Facultative anaerobes

A) require a constant supply of oxygen

B) are killed in an oxygenated environement

C) do not always need oxygen

D) are photosynthetic

11. Ancient cyanobacteria found in fossil stromatolites, were very important in the history of life because they

A) were probably the first living things to exist on Earth

B) produced oxygen in the atmosphere

C) are the oldest known archaea

D) extracted heat from the atmosphere, cooling Earth.

12. The bacteria that cause tetanus can be killed only by prolonged heating at temperatures considerably above boiling. This suggests that tetanus bacteria

A) are endotoxin B) are autotrophic

C) produce endospore D) have peptidoglycan

SECTION II : SHORT QUESTIONS

1. Write the pigment composition of cyanobacteria.
2. Do you know the differences between bacteria and archea?
3. What are the morphological forms of bacteria?
4. Give the functions of following in bacteria.

(i)	ribosomes	(ii)	cell membrane	(iii)	nucleoid
(iv)	plasmid	(v)	mesosomes	(vi)	slime capsule
(vii)	flagella	(viii)	cell wall	(ix)	pili

5. How the mechanism of photosynthesis in cyanobacteria is similar and different from that of plants?
6. Draw and label structure of flagellum.
7. How chemosynthetic bacteria are autotrophic in nature?
8. Which chemical methods are, used to control microbes?
9. Give physical methods to control microbes?
10. Name any two bacteria that cause diseases in plants.
11. Name any five diseases caused by bacteria in man.
12. Define the term normal flora.
13. What is chemical composition of cell wall of bacteria?
14. Distinguish between:

    Lysosome and mesosome, Peptidoglycan and muramic acid, Gram positive and Gram negative bacteria, Lytic and lysogenic bacteria, Pathogenic and non-pathogenic bacteria, Autotrophy and heterotrophy, Photosynthetic and chemosynthetic bacteria, Mutation and mutant, Chromosome and a bacteriophage, Bacteria and mitochondria, Prokaryotes and eukaryotes, Cyanobacteria and bacteria.

15. What are plasmids?
16. How do bacteria survive under unfavorable conditions?
17. List five ways in which bacteria are beneficial to man?
18. Why cyanobacteria are considered as the most prominent of the photosynthetic bacteria?
19. What are the benefits of bacterial flora to human?

SECTION III : EXTENSIVE QUESTIONS

1. Discuss taxonomic and phylogenic position of Prokaryotes.
2. Justify occurrence of bacteria in widest range of habitats.
3. Distinguish between conjugation, transformation, transduction in bacteria? What does each accomplish?

4. Describe shape, size, and structure of bacteria
5. Give an account of economic importance of bacteria.
6. Give a detail account of Archaea.
7. Explain the use of bacteria in research and technology.
8. Bacteria exhibit unmatched diversity in methods of obtaining nutrition. Explain?
9. How might life on earth be different if bacteria had not evolved?
10. How prokaryotes are important for biosphere and human society?

ANSWER MCQS

1. C 2. B 3. C 4. C 5. D 6. D 7. B 8. D 9. A 10. C
11. B 12. C

SUPPLEMENTARY READING MATERIAL

1. Jawetz. E and Levinson W. Medical Microbiology and Immunology. Sixth Edition Lange Madical Books/McDraw-Hill 2001.
2. Audesirk G. and Audesirk T. Biology Life on Earth. Prentice Hall, Upper Saddle River, New Jersy. 1996.
3. Sinha A.K. Fundamentals of Plant Pathology, Kalyani Publishers. New Delhi. 2001.

USEFUL WEBSITES

1) biology.about.com/library/weekly/aa030101a.html
2) biology.about.com/library/weekly/aa022201a.html
3) http://www.accessescellence.org/AB/BC/