6 Prokaryotes

At the end of this chapter students will be able to:

- Outline the taxonomic position of prokaryotes in terms of domains archaea and bacteria and in terms of kingdom monera.
- Explain the phylogenetic position of prokaryotes.
- List the unifying archeal features that distinguish them from bacteria.
- Explain that most Archaea inhabit extreme environments.
- Justify the occurrence of bacteria in the widest range of habitats.
- List the diagnostic features of the major groups of bacteria.
- Justify why cyanobacteria are considered as the most prominent of the photosynthetic bacteria.
- Describe detailed structure and chemical composition of bacterial cell wall and other coverings.
- Compare cell wall differences in Gram-positive and Gram-negative bacteria.
- Explain the great diversity of shapes and sizes found in bacteria.
- Justify the endospore formation in bacteria to withstand unfavorable conditions.
- Explain motility in bacteria.
- Describe structure of bacterial flagellum.
- Describe genomic organization of bacteria.
- Classify bacteria on the basis of methods of obtaining energy and carbon.
- Describe autotrophic and heterotrophic nutrition in bacteria.
- Explain the pigment composition in cyanobacteria.

- Differentiate between the photosynthesis mechanisms in cyanobacteria and other photosynthetic bacteria.
- List the phases in the growth of bacteria.
- Describe different methods of reproduction in bacteria.
- Explain how mutations and genetic recombinations lend variability to bacterial reproduction.
- Describe bacteria as recyclers of nature.
- Outline the ecological and economic importance of bacteria.
- Explain the use of bacteria in research and technology.
- Describe important bacterial diseases in man e.g. cholera, typhoid, tuberculosis, and pneumonia; emphasizing their symptoms, causative bacteria, treatments, and preventative measures.
- Describe important bacterial diseases in plants in terms of spots, blights, soft rots, wilts, and galls; emphasizing their symptoms, causative bacteria, and preventative measures.
- Define the term normal flora.
- List the important bacteria that make the normal bacterial flora residing in the oral cavity, respiratory and urinogenital tracts and large intestine of man.
- Describe the benefits of the bacterial flora of humans.
- List the chemical and physical methods used to control harmful bacteria.

exist between archaea and bacteria are:

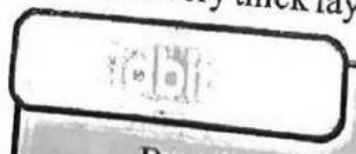
- The plasma membrane of both is made up of lipid bilayers but they contain different kinds of lipids.
- The cell wall in bacteria is made up of carbohydrates-protein complex called peptidoglycan but the cell wall of archaea lacks this complex.
- Archaea has a unique type of ribosomal RNA different from that of bacteria.

Archaea live in both extreme and moderate environments. Those inhabiting extreme condition are called extremophile (lovers of extreme environment) and the other group living in moderate conditions are known as methanogens. The extremophiles are further divided into extreme halophiles and extreme thermophiles. Extreme halophiles live in high-salt environments such as Utah's Great Salt Lake and Dead Sea. The proteins and cell walls of these archaea help to survive in saline conditions. These organisms cannot survive if the salinity drops below certain level. Extreme thermophiles thrive in very hot environments. Some of these organisms live in sulphur-rich volcanic springs as hot as 90°C where most other organisms do not survive because their DNA cannot maintain its double helical structure and many proteins denature at this temperature. Some extreme thermophiles are found forming dense communities in boiling water121°C above an active volcano 150 feet below the surface of Pacific Ocean at Macdonald Seamount.

Methanogens live in strict anaerobic environment. They obtain energy in a unique way by using CO_2 to oxidize hydrogen releasing methane as a waste product. They may be found living in marshes, lake bottoms and intestines of some animals and water thick ice layers in Greenland.

6.4 Bacteria

Bacteria are microscopic organism first seen by Van Leeuwenhoek. Very little was known about them until the work of Louis Pasteur and Robert Koch in the last half of the 19th century. Bacteria occur in a wide range of habitats. They play many ecological roles because of their diverse physiology. Some survive in hot water springs where the water temperature may be as high as 90°C. Others live in Antarctica under a very thick layer of ice.



Bacteria are the most abundant organisms. There are more living bacteria in our mouth than the mammals living on earth.

Introduction

Living world is divided into prokaryotes and eukaryotes. Prokaryotes are characterized by the absence of true nucleus and membrane-bound organelles. Prokaryotes are the simplest, most abundant and ancient organisms living on earth today. They closely resemble the first organisms to evolve on earth. They lived and evolved all alone on earth for over a billion years before the advent of eukaryotes. They had the ability to exploit the harsh conditions prevailing on planet earth.Prokaryotes are too small to be seen without a microscope. Life on earth cannot exist without prokaryotes because they are involved in many essential functions including fixation of atmospheric nitrogen, decomposition of organic matter and photosynthesis which is the source of much of the oxygen in earth atmosphere.

6.1 Taxonomy of Prokaryotes

In five kingdom system of classification of Whittaker, all prokaryotes are placed in kingdom monera, whereas eukaryotes are distributed in four other kingdoms viz, protista, plantae, fungi and animalia.

Prokaryotes cannot easily be classified simply on the basis of their forms. Sufficient information on their biochemical and metabolic characteristics has been gathered which helped in developing a satisfactory classification of prokaryotes. These characteristics are mode of nutrition, motility, form and method of division.

6.2 Phylogeny of Prokaryotes

It is a challenging job to study genetic diversity in prokaryotes due to their large number and difficulty to culture in laboratory. A new technique based on the use of polymerase chain reaction (PCR), has made it possible to study the genome of prokaryotes.

This has revealed that over hundreds of millions of years, prokaryotes acquired genes from distantly related species and they continue to do so even today. New information and research would accumulate and would lead to rise in certain new groups in prokaryoptes. About 6300 species of prokaryotes have been identified and many more will be identified in the days to come.

Prokaryotes in their early life on earth diverged into two main lines of ancestry i.e. archaea and bacteria. Little is known about the evolutionary history of archaea but it is believed that both groups have a common ancestor.

6.3 Archaea

Archaea are distinctive in several ways. Some of the major differences which

6.8 Bacterial Flora of Humans

The assemblage of microorganisms that constantly and consistently inhabit the human body is called human flora. They include bacteria, fungi and other organisms. Some of these organisms are known to perform tasks that are useful for the human body, while most of them produce no known beneficial or harmful effects. The microorganisms which are expected to be present and under normal circumstances do not cause disease are considered as member of the normal flora.

6.8.1 Benefits of normal Bacterial flora

1. Normal flora synthesizes and excretes vitamins in excess of their own needs. These vitamins are absorbed as nutrients by the human body.
2. It prevents colonization of pathogens by competing for attachment sites or for essential nutrients. In this way the normal flora of the human organs inhibits the growth of pathogenic bacteria through competitive exclusion. This is thought to be the most important beneficial effect of normal bacterial flora.
3. Normal flora of bacteria may antagonize other bacteria through production of substances which inhibit or kill non-indigenous bacteria. The intestinal bacteria produce many substances which inhibit or kill other bacteria.
4. Normal flora stimulates the production of natural antibodies inducting immunological response. Such antibodies are lacking in germ-free individuals.

Table: 6.1 Bacterial flora of humans

	Body Part	Human flora
1.	Oral cavity	*Streptococci and lactobacilli.*
2.	Respiratory tract	*Streptococci, corynebacteria, Neisseria sp., Gramnegative rod and cocci.*
3.	Urinogenital tract	*Streptococci, corynebacteria and lactobacilli.*
4.	Large intestine	*Helicobacter sp., Bifidobacteria, Bacteroides sp.,* Lactic acid bacteria, *Clostridia and Methanogens.*

Soft rots are caused by several bacteria, most commonly *Pectobacterium carotovorum* (previously called *Erwinia carotovora*), *Dickeya dadantii* (*previously called Erwinia chrysanthemi*), and certain species of *Pseudomonas*, *Bacillus* and *Clostridium*.

Fig: 6.11 Bacterial soft rot

Fig: 6.12 Bacterial gall

4. Bacterial galls

Crown gall is caused by a soil-inhabiting bacterium, *Agrobacterium tumefaciens*, which occurs worldwide and attacks over 600 plant species in more than 90 plant families. The most obvious symptoms are the galls or growths that usually occur on the twigs, stems, and roots near the base of the plant at the soil line. Gall size can vary from small to large and are usually spongy when young, but then become hard and woody with age.

5. Bacterial blights

Bacterial blights on different plants are known by different names and are caused by different species of bacteria. For example, bacterial blight of bean is caused by *Xanthomonas axonopodis pv. Phaseoli,* bacterial blight of cotton is caused by *X. axonopodis pv. Malvacearum,* Bacterial leaf blight of rice is caused by *X. oryzae pv. Oryzae etc.* it effects the plant through out its growth and leaves, pods, and fruits are affected in the process.

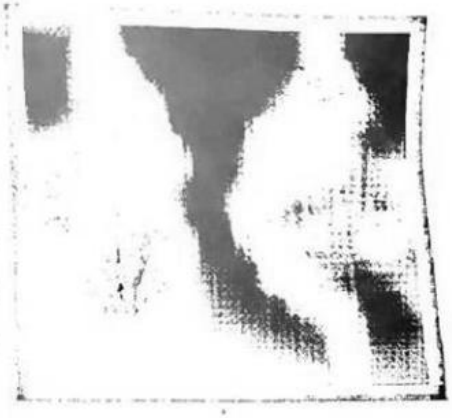


Fig: 6.13 Bacterial blights

Major preventive control of the disease includes crop rotation, use of diseased-free seeds, Insect pest control as they may serve as the carrier of the bacteria.

6.7 Some important bacterial diseases of plants

1. Bacterial leaf spots

This disease is caused by *Pseudomonas* spp. and *Xanthomonas* spp. Its host includes *Chrysanthemum, Delphinium, Heuchera, Hypericum* etc. Disease symptoms include water-soaked lesions on foliage that darken with age. Lesions may be bordered by the leaf venation. Bacteria on the plant surface are easily spread to nearby plants by splashing water from rain and irrigation. Most fungicides are not effective against bacteria. Copper-based products are helpful in limiting populations of surface-borne populations of bacterial pathogens.

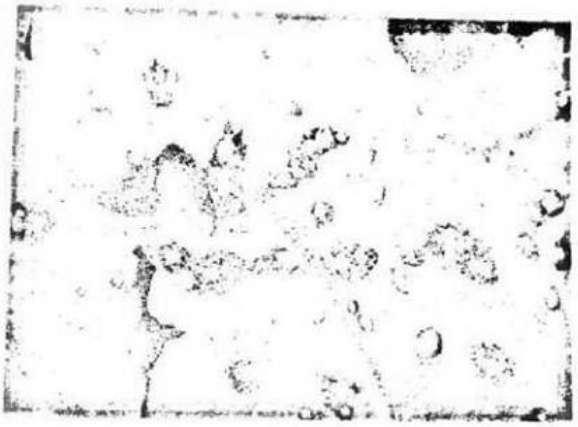


Fig: 6.9 Bacterial Leaf spots

2. Bacterial wilt

Bacterial wilt (BW) is yet another plant disease caused by *Ralstonia solanacearum* that affects pepper, tomato and eggplant. At the early stages of disease, the first visible symptoms of bacterial wilt are usually seen on the foliage of plants. These symptoms consist of wilting of the youngest leaves at the ends of the branches.

Another common symptom that can be associated with bacterial wilt in the field is stunting of plants. Preventive measures of disease are: destroying the infected plants immediately, crop rotation, control of nematodes and use of disinfected farm tools.

Fig: 6.10 Bacterial wilt

3. Bacterial soft rot

Bacterial soft rots damage succulent plant parts such as fruits, tubers, stems and bulbs of plants in nearly every plant family. Soft rot bacteria degrade pectate molecules that bind plant cells together, causing plant structure to eventually fall apart. Woody tissues are not susceptible. Soft rots commonly affect vegetables such as potato, carrot, tomato, cucurbits (e.g., cucumbers, melons, squash, pumpkins), and cruciferous crops (e.g., cabbage, cauliflower)

1. Cholera

Cholera is caused by *Vibrio cholera*, a curved Gram-negative bacterium. It enters the intestinal tract from contaminated water and food. Bacteria secrete a toxin that stimulates the loss of fluid. Massive diarrhea is associated with cholera. Antibiotic such as tetracycline may be used to kill bacteria. In severely dehydrated cases oral rehydrated solution (ORS) is given to restore the normal balance of water and salts. The most important preventive measures include sanitation, personal hygiene and care in food preparation. Immunization against the disease gives protection for about six months.

2. Typhoid fever

Typhoid is caused by a rod-shaped Gram-negative bacterium called *Salmonella typhi.* This bacterium causes disease only in humans and is transmitted by **five Fs**, flies, food, fingers, feces and fomites(an object or substance that serves to transfer infectious organisms from one individual to another).

The symptoms of the disease are ulcers and blood in stools. The patient experiences mounting fever and lethargy. The treatment of typhoid fever is generally successful with antibiotics. Vaccines are available for immunization. Widal and typhidot test is used for diagnosis.

3. Tuberculosis (TB)

Tuberculosis is caused by *Mycobacterium tuberculosis*. It is a contagious disease. Poor quality of life and overcrowding increase the chances of occurrence of tuberculosis. The patient experience chronic cough, chest pain and high fever and expel sputum containing blood. A hard nodule called tubercle is formed in the lungs. The tubercle expands and the lungs slowly deteriorate. Patient must complete full course of medication to control and not allowing bacteria to develop. Immunization to tuberculosis is done by injecting the vaccine called Bacille Calmette Guerin (BCG).

4. Pneumonia

Pneumonia refers to a microbial disease of bronchial tubes and lungs. It is caused by bacteria, viruses and fungi. Over 80 percent of bacterial cases are due to *Streptococcus pneumoniae*. The patient with pneumonia experience high fever, sharp chest pains, difficulty in breathing and rust- coloured sputum. The blood seeps into the alveolar sacs of the lungs and the lung tissues gradually deteriorate. The drug given to pneumonia patient is penicillin with tetracycline and chloramphenicol used for people who are allergic to penicillin.

6.5 Importance of Bacteria

i. In research technology

Bacteria are used in biotechnology. For example, *Escherichia coli* are used in gene cloning. *Agrobacterium tumefaciens* is used in producing transgenic plants such as Golden Rice which prevents blindness. Golden Rice contains beta-carotene, a precursor of vitamin A needed for normal vision. Bacteria are modified by genetic engineering to produce vitamins, antibiotics, hormones and other products. Humulin, human insulin is produced by using recombinant DNA technology. It also helps in producing disease resistant crop plants.

ii. As nutrient recyclers

Saprophytic bacteria are decomposers. They break down organic compounds like proteins and carbohydrates into simpler compound like CO_2 which is released in the atmosphere for recycling. It is fixed by green plants in photosynthesis. Other nutrients released in the process enter the soil and become available to plants. Bacteria can decompose the dead remains of plants and animals. Because of their cleaning action they are called the scavengers of planet earth. In sewage treatment, the bacteria bring about the break down of organic compounds and convert them into harmless ions such as nitrates and sulphates.

iii. Role in Ecology

Bacteria play important role in ecological interactions. They are involved in symbiotic nitrogen fixation in the roots of leguminous plants. Herbivorous mammals cannot break down cellulose. Bacteria live in their guts and help in the digestion of cellulose by breaking it down. The relationship is called commensalisms. Soil bacteria decompose the organic matter and make the soil fertile. Bacteria also play important role in nitrogen, phosphorus, sulphur and carbon cycles.

iv. Other uses of bacteria

Bacteria are used in the preparation of diary products such as butter, cheese and yoghurt. They are involved in the preparation of antibiotics, vinegar, amino acids and proteins. Bacteria are employed in retting of fibers and making of silage.

v. Spoilage of food

Bacteria spoil the food items. Foods with high protein contents are decomposed by bacteria. Eggs, fish and cooked food and milk are all spoiled by bacterial action.

6.6 Bacterial Diseases in Humans

A relatively small number of bacteria are the cause of many serious diseases of human beings. These diseases are transmitted through air, water, food and through wounds or cracks in the skin. Some of the diseases caused by the bacteria are discussed below.

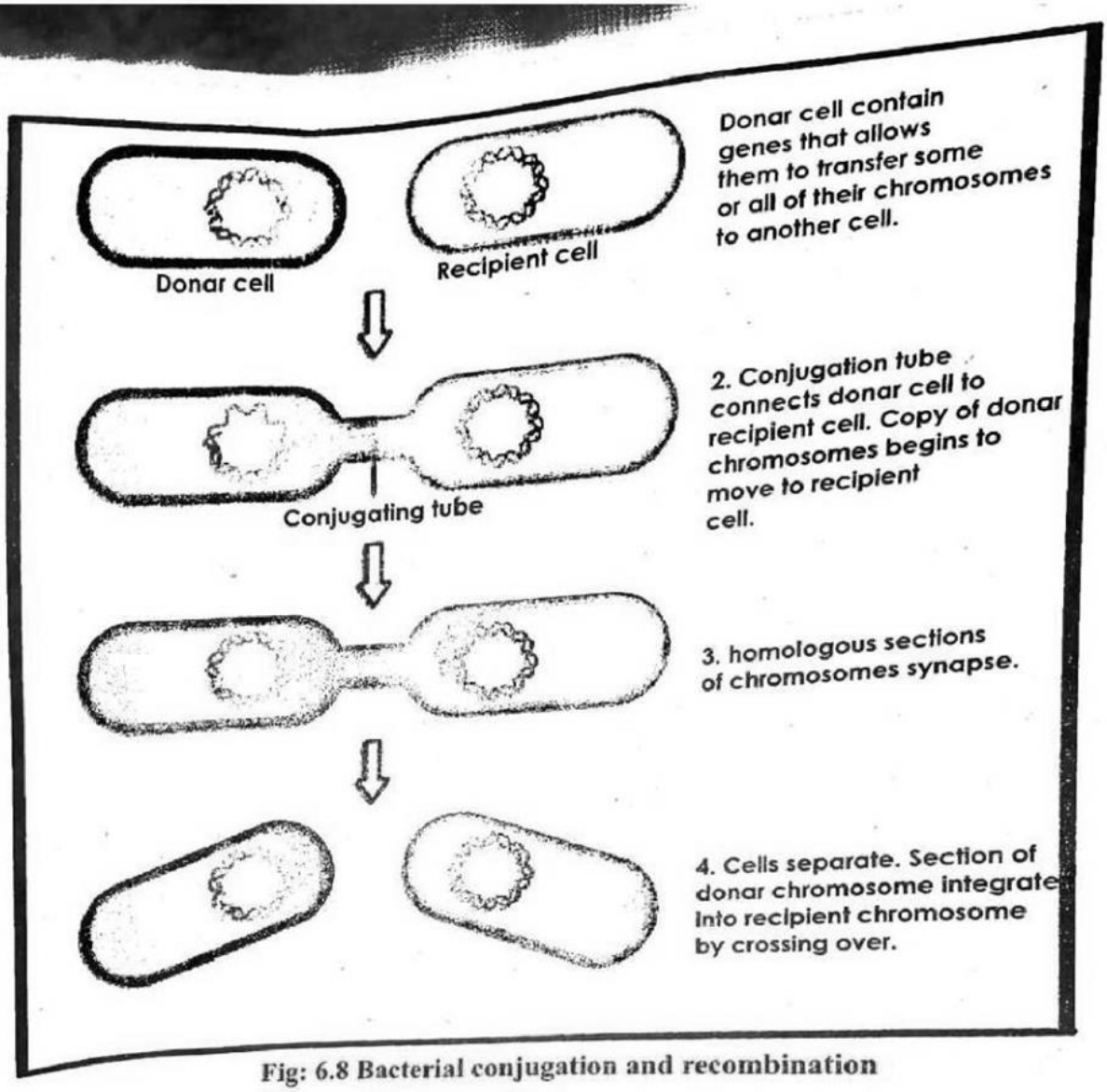


Fig: 6.8 Bacterial conjugation and recombination

Normally *Escherichia coli* can synthesize all amino acids it requires. It was exposed to shortwave radiation and two mutants were isolated. One mutant was unable to synthesize biotin (a vitamin) and amino acid methionine. The other mutant could not synthesize amino acids theronine and leucine. The four chemicals are essential for the growth of bacteria. The two mutants were mixed and cultured in a common medium lacking in all the four compounds. None of the cells would have grown in the absence of essential chemicals, but to the great astonishment of researchers, hundreds of colonies of bacteria developed. This suggests that exchange of genes has occurred between two parental bacteria and new recombinants were formed which did not require the four essential compounds for growth. Later studies made by electron microscope confirmed the close contact and the formation of conjugation tube between the parental cells.

ii. Transduction

Bacterial recombination by transduction was first reported by Lederberg and Zinder in 1952. A piece of DNA is transmitted from a donor cell to a recipient cell through a third party called bacteriophage. The phage attaches itself to the surface of the bacterial cell called donor bacterium and injects its DNA into the cell. The viral DNA directs the formation of protein coats. Sometimes a piece of DNA of donor bacterium may become attached to the DNA of phage, the recombinant DNA is known as prophage. Many phages are assembled in the bacterial cell which bursts and a crop of phages is released completing a lytic cycle. Phages which cause lysis are called virulent phages.

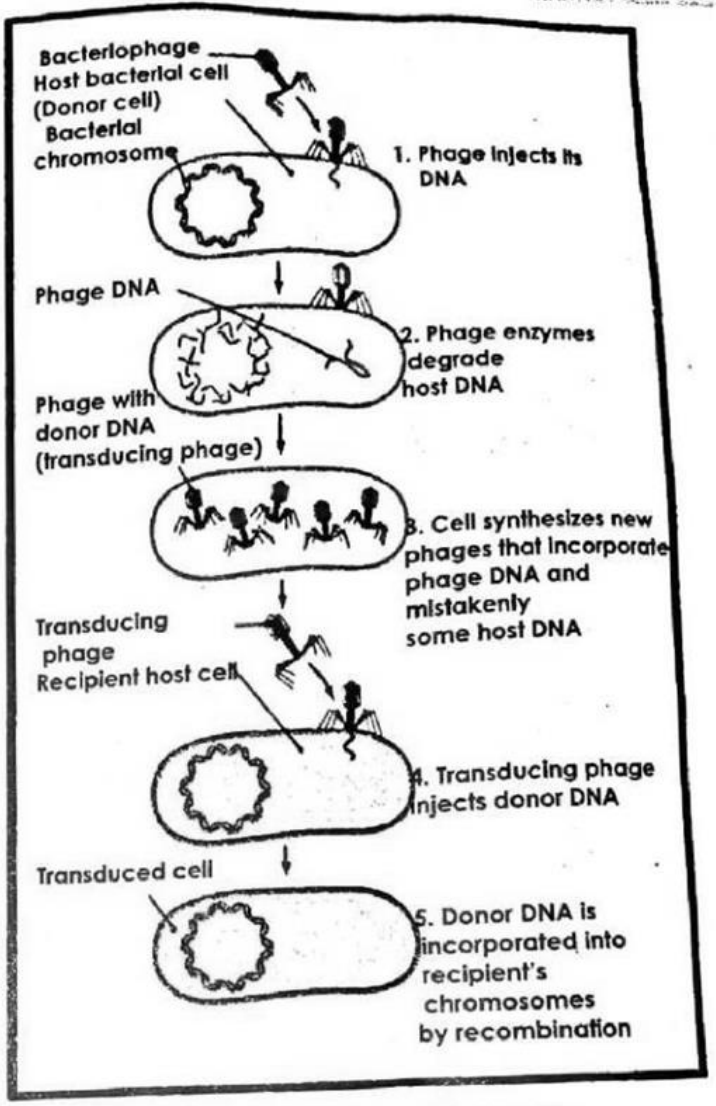


Fig: 6.7 Transduction in bacteria

Newly formed phage now attacks a new bacterium, inserts its DNA into the bacterium which is now called recipient bacterium. The lysogenic life cycle starts. The phage is called temperate phage. The recipient bacterium at this stage contains three types of DNA i.e DNA of its own, DNA of donor bacterium and DNA of phage. Now recipient cell's chromosome becomes a combination of DNA derived from both the bacterial cells i.e the recipient and the donor cells. With the division of recipient bacterium . all three types of DNA also replicate. In some daughter bacteria, some genes of donor DNA also express themselves donor and recipient bacteria. In this way, the genetic material of donor bacterium is carried to the recipient through a bacteriophage completing the process of transduction.

ii. Conjugation

Conjugation is a recombination process in which living bacteria come into direct contact and the donor cell transfers DNA to the recipient cell. The DNA transfer is one way. The process was studied in 1946 by Lederberg and Tatum in ***Escherichia coli.***

In 1928 Fredrich Griffith, an German microbiologist, injected live R-type cell into the body of a healthy mouse, the mouse remained alive and showed no symptoms of pneumonia. Then S-type live cells were injected into the body of another mouse, the mouse suffered from pneumonia and died. Heat-killed S-type cells were injected into the body of a healthy mouse, the mouse remained alive.

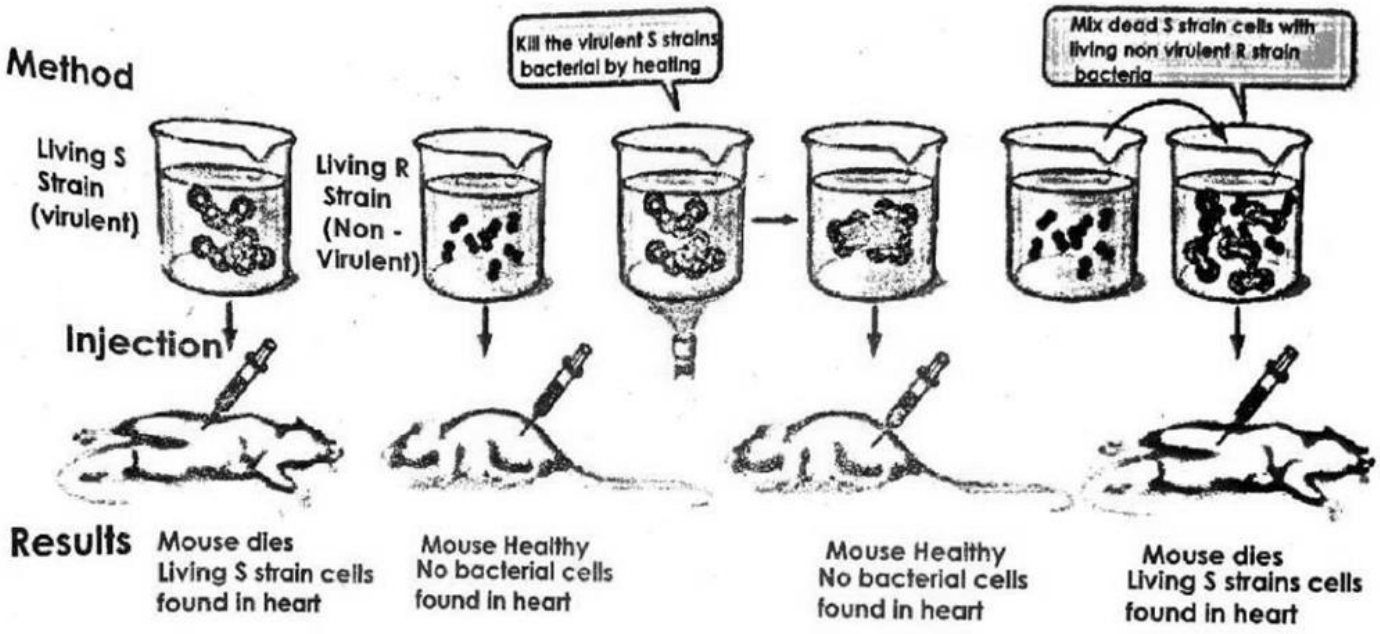


Fig: 6.6 Experiment showing transformation principle in bacteria

These results were all according to the expectations of the researchers. But what happened next puzzled Griffth and his associates. A mixture of heat killed S - type and live R-type was injected into the body of a healthy mouse, the mouse died from pneumonia. The autopsy revealed the presence of many living S-type cells in the dead body of the mouse. He concluded that the head-killed S-type cells released some substances which changed some of the R-type non-virulent cells into S-type virulent cells. The live R-type non-virulent bacteria were transformed into live S-type virulent bacteria.

Later Avery and his co-worker in 1944 isolated and identified the transforming substance as DNA. It is now known that during transforming a small fragment of DNA is released by donor bacteria and it is taken by the recipient where it replaces a similar piece of DNA.

Mutation and genetic recombination in bacteria

The genetic variation in bacteria is achieved either by mutation or genetic recombination. Mutation is a major source of variation in bacteria but additional diversity arises from genetic recombination. After a few round of binary fission, most of the offspring are genetically identical to the parent cell. The genetic diversity leads to fast evolution. Genetically better individuals survive and reproduce more prolifically than less fit individuals.

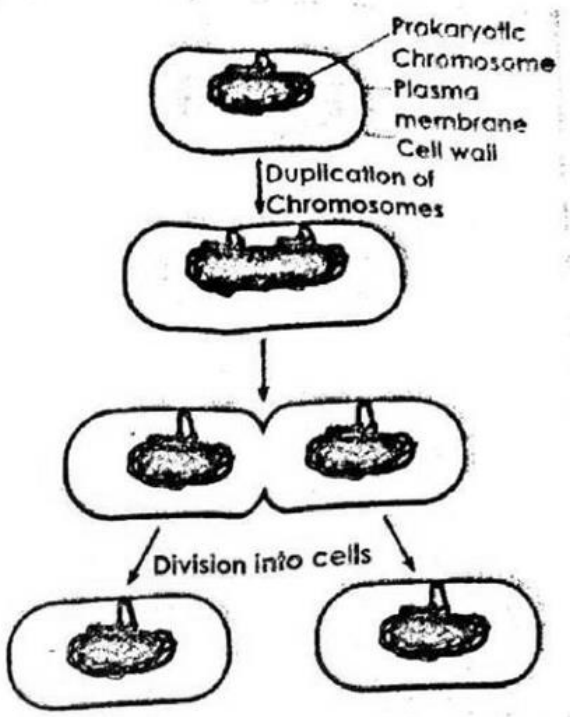


Fig: 6.5 Asexual reproduction in Bacteria

Mutation changes the bacterial chromosome by altering the DNA of the cell. In most cases, mutation involves a disruption of the nitrogen base sequence in DNA or the loss of a significant piece of chromosome.

In bacterial recombination the cells do not fuse and only a portion of DNA from the donor cell is transferred to the recipient cell. A fragment of the recipient DNA is replaced by donor DNA.

b. Sexual reproduction

In bacteria, sexual reproduction occurs by genetic recombination which is a primitive type of sexual reproduction. In genetic recombination, DNA from two different sources combine. The cells do not fuse, only a piece of DNA of donor cell is inserted in the recipient cell. In recipient cell, the DNA portion of the donor cell orients itself in such a way that the homologous genes come close to one another. A fragment of the DNA of the recipient is knocked off and DNA of donor is integrated into it. The recipient cell is now called a recombinant cell. There are three methods of bacterial recombination i.e transformation, transduction and conjugation.

i. Transformation

Streptococcus pneumonia has two strains, one causes pneumonia but the other is unable to do so. The cells of the virulent strain are capsulated from smooth colonies and are called S-types. The non-virulent strain is non-capsulated, forms rough colonies and is called R-type.

The lag phase is followed by a period of fast growth called log phase. It represents an active stage of growth. The mass of cells increases and reproduction follows it. As each generation time passes, the number of bacteria doubles. In humans, the disease symptoms develop during the

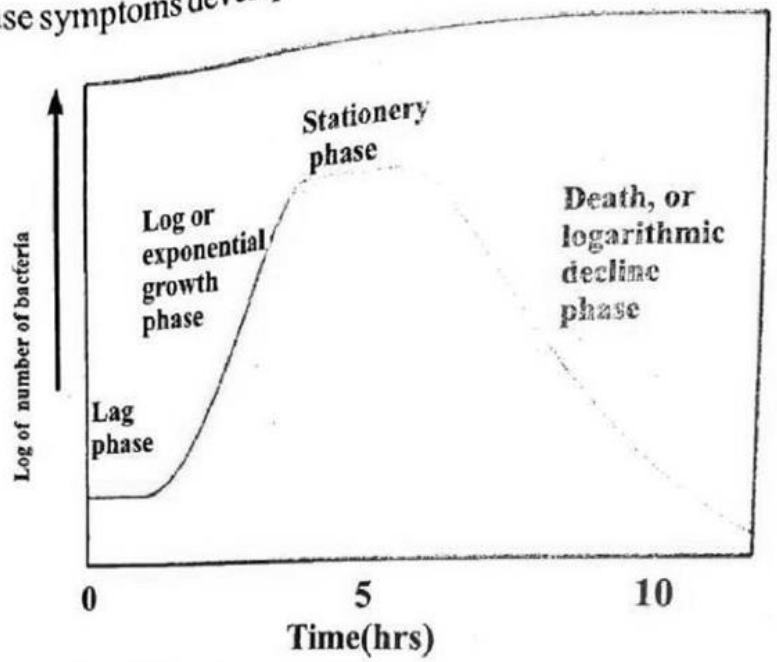


Fig: 6.4 Growth curve for bacterial population

log phase because the bacterial production attains such a high level which damages the tissues. Later on, the growth slows down because of the shortage of nutrients and is called as stationary phase. Later the number of dying cells exceeds the number of new cells formed. The population declines and it is called decline phase. The decline phase occurs because of the exhaustion of nutrients and the accumulation of toxic wastes.

6.4.8 Reproduction in bacteria

Most common method of reproduction in bacteria is asexual reproduction, but they can also reproduce sexually by genetic recombination which is primitive types of sexual reproduction.

a. Asexual reproduction

Asexual reproduction in bacteria takes place by binary fission. The cell and the cell membrane grows twice to its size, accumulates nutrients, chromosome replicates and the cell membrane grows inward at the middle of the cell. Usually a mesosome is attached to the cytoplasmic membrane at the location of inward growth. When the nuclear material is equally distributed, the cell wall thickens and grows inward to separate the dividing cell. In this type of division, no mitotic structure is formed.

Another type of relationship is commensalism in which one partner is benefitted while the other is neither benefitted nor harmed. *Rhizobium radiciola* develops a symbiotic association with roots of leguminous plants. It forms nodules on the roots, fix atmospheric nitrogen and supply nitrogenous compounds to the plant and gets food and shelter in return from the plant.

6.4.6 Comparison of Photosynthesis in Bacteria and Cyanobacteria

The process of photosynthesis in photoautotrophic bacteria is different from cyanobacteria. In photosynthetic bacteria, oxygen is not released as by product whereas the cyanobacteria release oxygen during photosynthesis. The source of hydrogen in bacteria is hydrogen sulphide where as cyanobacteria, like plants, get hydrogen from water.

Photoautotroph bacteria have photosystem I but lack photosystem II. In bacteria cyclic electrons flow is the sole means of generating ATP and NADPH both. Bacteria possess bacteriochlorophyll "a" whereas the pigment complex in cyanobacteria consists of chlorophyll "a", phycocyanin, allophycocyanin and phycoerythrin.

6.4.7 Growth in Bacteria

In case of bacteria, growth means the increase in the total population rather than increase in the size of organism. Bacteria grow very fast and their growth is affected by temperature, availability of nutrients, pH and ionic concentration. Under favorable conditions, a bacterium divides after every 20 minutes.

The number of cells doubles at the end of each division. It is called exponential growth and the interval between two successive divisions is called generation time. It is different for different species of bacteria.

Phases of growth

In a typical growth curve of bacterium, four distinct phases of the curve are recognized. The lag phase covers the first few hours when there appears no growth. During this period, the bacteria become accustomed to their new environment.

tidbit

The generation time for *Escherichia coli* is 20 minutes. If the division goes unchecked, after 36 hours there would be enough bacteria to cover the face of the earth.

The source of hydrogen is hydrogen sulphide instead of water. Sulphur is released in the process instead of oxygen.

$$CO_2 + H_2S \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} (C_6H_{12}O_6) + S$$

Some other photoautotrophic bacteria are purple sulphur bacteria, suluphur bacteria and non-sulphur bacteria.

ii. Chemoautotrophs

These bacteria do not use sunlight as a source of energy. They derive the energy by the oxidation of inorganic substances such as hydrogen sulphide, ammonia, nitrates, nitrites and iron compounds. Such a process of food formation is called chemosynthesis.

b. Heterotrophic bacteria

These bacteria are unable to prepare their own food. These organisms obtain energy from organic compounds prepared by other organisms. There are three types of heterotrophic bacteria i.e. saprophytic bacteria, parasitic bacteria and symbiotic bacteria.

I. Saprophytic bacteria

Saprophytic bacteria, commonly known as saprobes, feed exclusively on dead organic matter which is derived from plants and animals remains. These bacteria possess a powerful enzyme system which helps in the break down of complex organic compounds to simpler substance. They utilize the energy released in the process. The chemicals thus released become available to other organisms. The saprobes are called recyclers of nutrients. As they clean the earth by their action, they are also called the scavengers of earth.

ii. Parasitic bacteria

The parasitic bacteria do not possess the enzyme system for the breakdown of organic matter of their live hosts which include humans, plants and animals. Many parasitic bacteria cause diseases and are called pathogens.

iii. Symbiotic bacteria

"Symbiosis" means living together. Symbiotic bacteria develop a nutritional relationship with other organisms. The relationship may be beneficial to both partners and is called mutualism.

Endospore may develop near the end or in the centre of the cell. It contains little water. The cell membrane grows in to seal off the developing spore. It is further protected by thick layers of peptidoglycan. When the external environment is favourable the protective layers break down and the spore is released which acts as a vegetative cell. Endospore formation is not a reproductive process as a vegetative cell forms a single endospore which later on produces one vegetative cell.

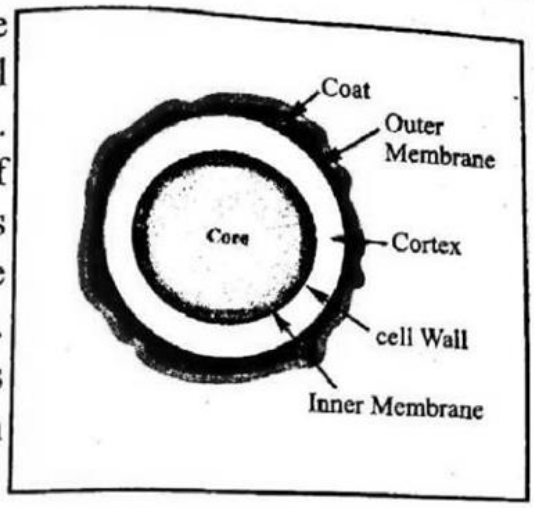


Fig: 6.3 Structure of Endospore

Tidbit

Live spores have been recovered from the intestines of Egyptian mummies. Archaeologists found the endopores alive from 7518 years old sediments of Minnesota's Elk Lake.

6.4.5 Mode of nutrition in bacteria

Bacteria, like other organisms, require food for growth and other vital activities. They need carbon and energy for their nutrition. Bacteria are divided into two groups on the basis of their nutritional approach i.e. autotrophs and heterotrophs.

a. Autotrophic bacteria

Autotrophic bacteria synthesize their food from simple carbon sources. They use inorganic carbon compound such as carbon dioxide and ions like carbonates, nitrates and sulphates. Energy needed for the synthesis of food comes from sun and chemical reactions occur in cytoplasm.

The autotrophic bacteria are further divided into two groups namely photoautotrophs and chemoautotrophs.

i. Photoautotophs

Photoautotrophic bacteria possess chlorophyll and can manufacture their food. The source of energy is sunlight which they capture through chlorophyll. The chlorophyll is not contained in chloroplasts but it dispersed in the infolded region of cell membrane in cytoplasm.

b. Bacilli (singular: bacillus)

Bacilli are rod-shaped bacteria. Most rods occurs singly but some form pairs and are called diplobacilli, others forming chains are known as streptobacilli. *Salmonella typhi* causing typhoid and *Clostridium tetani* causing tetanus are bacilli bacteria.

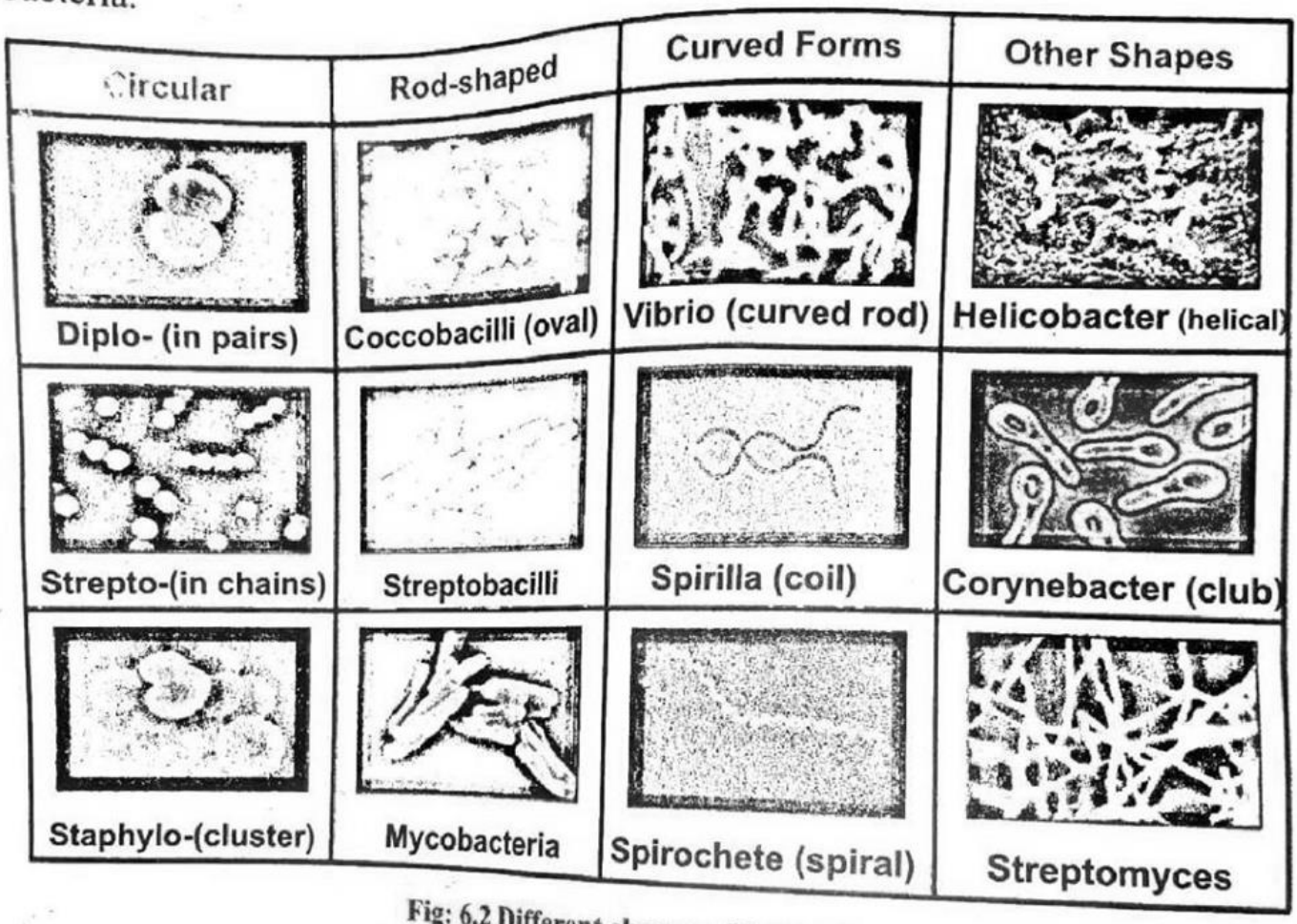


Fig: 6.2 Different shapes of bacteria

c. Spirilla (singular: spirillum)

They are corkscrew-shaped bacteria. They are motile and flagella are attached at the ends. Spirilla never form clusters or colonies. Some spirilla have less than one complete twist, look like commas and are called vibrios.

6.4.4 Endospores

Some Gram-positive bacteria produce highly resistant structures called endospores. The spores remain alive for many years under extremely harsh conditions with regarded to temperature, radiations and water shortage prevailing on earth in its early days.

e. Cell membrane

Cell membrane lies inner to the cell wall. It is thin, delicate, flexible and selectively permeable. Chemically it resembles the membrane of eukaryotic cells with the exception that it contains different kinds of lipids. Cell membrane invaginates into cytoplasm to form pocket-like structure called mesosome. They help in cell division and replication of DNA.

f. Cytoplasm

Cytoplasm lies inside the cell membrane. It is a gelatinous mass of proteins, carbohydrates, lipids, nucleic acids, salts and inorganic ions dissolved in water. It is thick, semi-transparent and elastic and lacks membrane-bounded organelles,. The semi fluid jelly-like portion of cytoplasm enclosed by the cell membrane is called cytosol

g. Ribosomes

Ribosomes are RNA-protein bodies found freely dispersed within the cytoplasm. They are associated with the synthesis of proteins. They are smaller in size than the ribosomes of eukaryotic cells.

h. Genomic organization

The genome of bacteria is different from a eukaryotic genome and possesses less DNA. It consists of a single circular chromosome containing few-proteins than a linear chromosome of eukaryote. A membrane-bounded nucleus is missing here. The chromosome is located in a specific region of cytoplasm called nucleoid. In addition to its single circular chromosome, the cell also possesses extra chromosomal DNA rings of small size called plasmids. Plasmids carry a fewer genes than the normal bacterial chromosome and replicate separately independent of the normal chromosome.

6.4.3 Size and Shape of bacteria

Most bacteria are about 2 to 10 micrometer in length and 0.2 to 2 micrometer to in diameter. The shape of the bacterial cell is controlled by its rigid cell wall. They appear in three different forms.

a. Cocci (singular: coccus)

Cocci are spherical bacteria and are non-motile because they lack flagella. When these bacteria remain together in pairs after division, they are called diplococci. Those which form chains of diplococci are called streptococci.

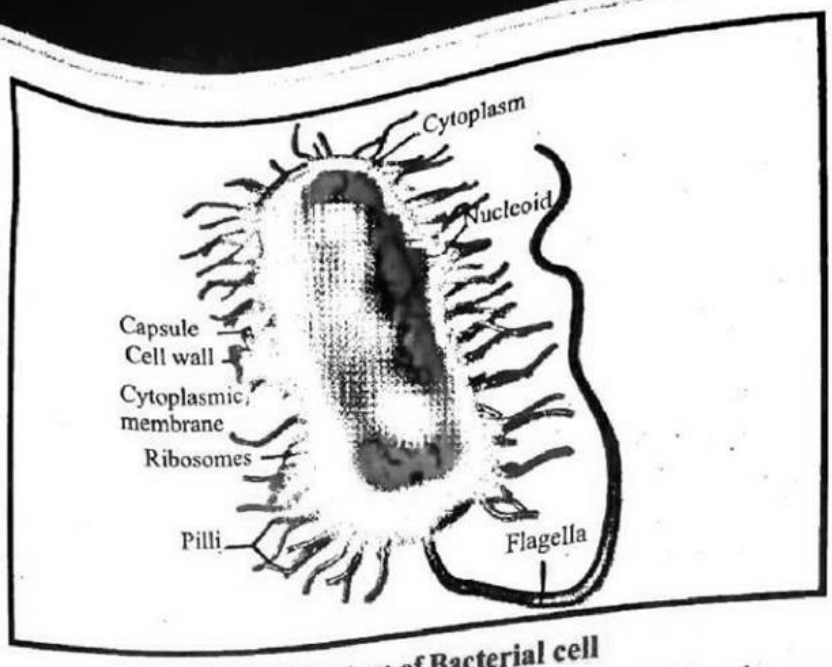


Fig: 6.1 Structure of Bacterial cell

Gram-negative bacteria have a thinner layer of peptidoglycan and lose the dye easily when rinsed with alcohol. Cell walls in Gram-negative bacteria are more complex; the thin peptidoglycan layer is covered externally by a layer of lipopolysaccharides. Gram-negative bacteria are more resistant than Gram-positive bacteria because the outer layer of lipopolysaccharides impedes the entry of antibiotics.

c. Flagella

Many species of bacteria possess thin hair-like appendages which help them in motility. Flagella are anchored in the cell wall and spin like a propeller, pulling the cell through water. A flagellum is composed of three parts i.e. a basal apparatus associated with the cytoplasmic membrane and cell wall; a short curved hook and a helical filament. The hook and the filament are made up of a protein called flagellin.

The flagella may vary in number and placement. A monotrichous bacterium possesses a single flagellum. A lophotrichous organism has a group of two or more flagella inserted at one pole of the cell. An amphitrichous bacterium is characterized by groups of flagella inserted at both end of the cell. In peritrichous bacterium flagella are dispersed on the entire surface of the cell. Some bacteria lack flagella and are called as atrichious.

d. Pilli

Pilli are small filamentous appendages scattered all over the surface of bacterial cell. They play no part in motility. Pilli are smaller than flagella in size. They are made up of protein called pillin. Pilli help the bacteria to attach to various surfaces but in some cases they are involved in the transfer of genetic material from one to another bacterium.

Mycoplasma is the only genus of bacteria known to lack cell walls.

5. Cyanobacteria

It is speculated that the first cell evolved fed on organic matter in the environment. But the shortage of organic material seems to diverge the attention of these organisms towards getting the energy from inorganic sources. The evolution of pigment in the cells made it possible to capture energy from sunlight and to store it in chemical bonds. The oxygen-producing bacteria like cyanobacteria took up this task. Cyanobacteria play important role in the evolution of life as their photosynthetic activity gradually oxygenated the atmosphere and the oceans about two billion years ago.

It was the beginning of great transition that changed the conditions on earth permanently. The level of oxygen was raised from 1% to the current level of 21%. With the increase of oxygen, the amount of ozone also increased in the upper layers of the atmosphere. The thick layer of ozone acted as a screen protecting the proteins and nucleic acids from destruction by ultraviolet radiation from sun. It encouraged the other autotrophs to appear and survive on earth. Some members of this group like Nostoc are involved the fixation of atmospheric nitrogen.

6.4.2 Structure of bacteria

a. Capsule

Many species of bacteria possess a tight protective covering around the cell called capsule. It is a very sticky, gelatinous structure made up of polysaccharides and proteins. These bacteria are called capsulated bacteria. The capsule prevents dehydration of bacterial cell. A capsule which is less tightly bound to the cell is commonly called glycocalyx.

b. Cell wall

The cell wall protects the cell and also gives it a definite shape. It is made up of peptidoglycan which is a carbohydrate-protein complex. The wall is laid in many layers and it makes the cell wall rigid. Based on the variations in the chemical constituents of cell wall, Hans Christian Gram, a Danish physician, developed a staining technique in 1884. He divided bacteria in two groups i.e. Gram-positive and Gram-negative bacteria. Gram-positive bacteria which are stained blue-purple with crystal violet dye, possess thick walls of peptidoglycan; they retain the dye when the cells are washed with an organic solvent like alcohol.

6.4.1 Classification of bacteria

The classification of bacteria is based on the morphology, mode of nutrition, biochemical and genetic characteristics. Major groups of bacteria are:

1. Proteobacteria

This is a large group of Gram-negative bacteria and includes photoautotrophs, chemoautotrophs and heterotrophs. Some proteobacteria are aerobic while others are anaerobic. It is divided into five sub-groups.

a. Alpha-proteobacteria

Many species of this subgroup are associated with eukaryotic hosts such as symbiotic association of *Rhizobium* species with the roots of leguminous plants for the fixation of atmospheric nitrogen.

b. Beta-proteobacteria

It is a nutritionally diverse group. The bacteria are involved in nitrogen recycling oxidizing ammonium , producing nitrites as a waste product.

c. Gamma-proteobacteria

The group includes sulphur bacteria which obtain energy by oxidizing H_2S instead of water.

d. Delta-proteobacteria

This subgroup includes the slime-secreting myxobacteria. When the soil is dry or food is scarce, they aggregate into fruit bodies releasing resistant myxospores. The members of the subgroup may get attached to other bacteria.

e. Epsilon proteobacteria

Most species included in this sub-group are pathogenic and cause diseases in humans and animals.

2. Chlamydias

They are parasitic Gram-negative bacteria and cause some common diseases of humans.

3. Spirochetes

These helical heterotrophs move in spiral course through their environment by means of rotating internal filaments. Many are free-living but others are notorious parasites of human race.

4. Gram-positive bacteria

This group contains both solitary and colonial forms. Actinomycetes, which is a subgroup of Gram-positive bacteria cause tuberculosis and leprosy. Most actinomycetes are free-living and decompose the organic matter in soil. Species of Streptomyces are cultured as a source of many antibiotics including streptomycin.

6.9 Control of Harmful Bacteria

Although the disease producing nature of bacteria become known 100 years after their discovery largely because of the research of Louis Pasteur and Robert Koch, however the early civilization used some crude techniques such as salting, smoking, picking, drying and exposure of food and clothing to sunlight to control microbial growth. Today microbial growth is controlled by physical and chemical methods.

a. Physical method

I. Heat treatment

Heat kills the microbes by denaturing their enzymes and other proteins. Autoclave chambers used for sterilization of surgical instruments.

Pasteurization is a process to prevent the spoilage of beverages such as juices, milk etc. A more effective method of pasteurization of milk is through ultra high temperature (UHT) in which milk is treated at 140°C for 3 seconds and then cooled suddenly in a vacuum chamber. Milk treated by UHT can be stored at room temperature for several months.

Incineration is dry heat treatment of sterilization of disposable items such as paper cups, dressing etc. the contaminated items are placed in an oven at 170°C for 2 hours to kill microbes.

ii. Filtration

Filtration is the removal of microbes by passage of a liquid or gas through a screen like material with pores. It is \used to sterilize heat sensitive material like vaccines, enzymes, antibiotics etc.

iii. Low temperature treatment

Refrigeration at temperature 0°C to 7°C reduces activities of microbes; they cannot reproduce or produce toxins. It is called bacteriostatic effect.

iv. Desiccation

Water is extracted from the contaminated material. In the absence of water, bacteria cannot grow or reproduce.

v. Osmotic pressure treatment

The high concentration of salt or sugar in food increase its osmotic pressure and creates a hypertonic environment which helps in controlling the growth of microbes.

vi. Radiation

Three types of radiation i.e ionizing radiation, ultraviolet light and microwave radiation are used to kill microbes.

EXERCISE ?

A. Choose the correct answer for the following questions.

1. The first forms of life on Earth were thought to be:
   a. protista
   b. prokaryotes
   c. insects
   d. dinosaurs

2. Dead sea are home to which of the following groups of organisms?
   a. Halophiles
   b. Thermophiles
   c. Halophytes
   d. Phytoplanktons

3. *Rhizobium* belongs to which of the following subgroup of proteobacteria?
   a. Alpha- proteobacteria
   b. Delta-proteobacteria
   c. Gamma- proteobacteria
   d. Epsilon proteobacteria

4. The first organisms that oxygenated the atmosphere were:
   a. cyanobacteria
   b. phototrophic organisms
   c. anaerobic organisms
   d. saprophytes

5. One of the feature of prokaryotic genome which makes it different from the eukaryotic genome is :
   a. it is made up of DNA only
   b. it is made up of RNA only
   c. it is made up of larger ribosome
   d. it is made up of smaller ribosomes

6. Organisms most likely to be found in extreme environments are:
   a. fungi
   b. algae
   c. viruses
   d. archaea

7. Peptidoglycan is a characteristic of the walls of :
   a. eukaryotic cells
   b. bacterial prokaryotic cells
   c. archaean prokaryotic cells
   d. bacterial and archaean prokaryotic cells.

8. The lipopolysaccharide layer (LPS) is a characteristic of the wall of :
   a. archaean cells
   b. Gram-negative bacteria
   c. bacterial prokaryotic cells
   d. eukaryotic cells

EXERCISE ?

9. An extra-chromosomal DNA ring in bacteria is called
   a. Nucleoid b. Plasmid
   c. Pili d. Mesosome

10. In photoautotrophic bacteria the source of hydrogen in photosynthesis is
   a. H_2O b. H_2S
   c. H_2O_2 d. H_2SO_4

11. In bacteria fastest growth occurs in the phase called
   a. Log phase b. Lag phase
   c. Stationary phase d. Decline.phase

10. The reproduction in which the genetic material is transmitted from a donor to a recipient bacterium through a phage is called
   a. Transformation b. Conjugation
   c. Binary fission d. Transduction

B. Write short answers of the following questions.

1. Why has monera become obsolete?
2. What is a domain? Why is this term coined?
3. What is the role of prokaryotes in supporting life on earth?
4. What are main differences between archaea and bacteria?
5. What are plasmids and what are their importance?
6. What is the function of endospores?
7. What do you mean by genetic recombination?
8. Why are the bacteria called nutrient recyclers?
9. Discuss the role of radiation in controlling bacterial growth.

C. Write answers of the following questions.

1. Give an account of the structure of a bacterium.
2. Discuss various methods of sexual reproduction of a bacteria.
3. Describe the mode of nutrition in bacteria.
4. Give an account of bacterial diseases of plants.
5. Describe the normal flora of some important organs of humans and also discuss its benefits

b. Chemical Methods

Different groups of chemicals are used for disinfecting various products.

i. Phenolics are effectively used against Gram-positive bacteria in nurseries but their excessive use in infants is harmful.
ii. Among halogens, chlorine is used to disinfect drinking water and pools. Tincture iodine is one of many antiseptics used.
iii. Formaldehyde (formalin) is widely used to preserve biological specimens. It inactivates bacteria in vaccines. Glutaraldehyde is less irritating but more effective than formalin. It is used to disinfect hospital instrument.
iv. Ethylene oxide kills all microbes and endospores but requires 4-18 hours exposure.