بِسۡمِ اللّٰہِ الرَّحۡمٰنِ الرَّحِیۡمِ

(In the Name of Allah, the Most Compassionate, the Most Merciful.)

Biology

11

Punjab Education, Curriculum, Training and Assessment Authority

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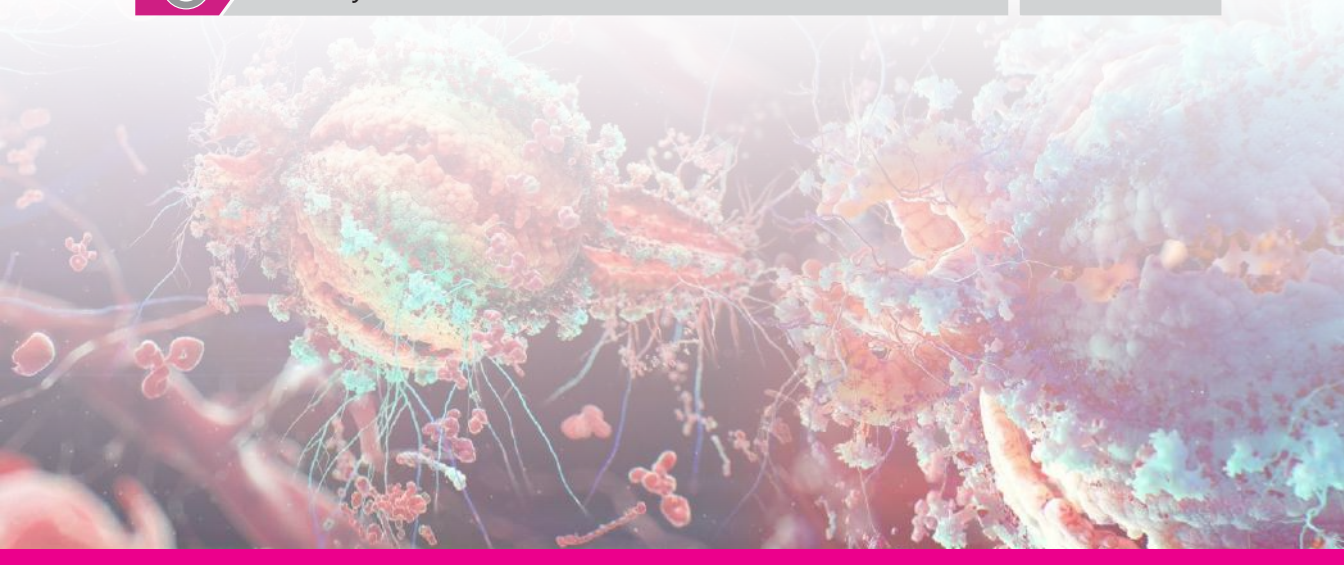

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Chapter 1

BIODIVERSITY & CLASSIFICATION

STUDENTS' LEARNING OUTCOMES

After studying this chapter, the students will be able to:

- Discuss the meaning of the terms species and speciation.
- Describe the classification of organisms into three domains: Archaea, Bacteria and Eukarya.
- Describe the classification of organisms in the Eukarya domain into the taxonomic hierarchy of kingdom, phylum, class, order, family, genus and species.
- Outline the characteristic features of the kingdoms Monera, Protoctista, Fungi, Plantae and Animalia.
- Outline how viruses are classified.
- Define the terms ecosystem and niche.
- Explain the different levels at which biodiversity can be assessed.
- Explain the importance of random sampling in determining the biodiversity of an area.
- Describe and use suitable methods to assess the distribution and abundance of organisms in an area.

Biodiversity and classification are fundamental concepts in biology that provide insight into the vast array of life forms on Earth and their evolutionary relationships. In this chapter, we will study the biodiversity, highlighting the variety of life at genetic, species, and ecosystem levels. We will also explore the principles and methods of biological classification, which scientists use to organize and categorize organisms.

1.1- THREE-DOMAIN SYSTEM OF CLASSIFICATION

According to the five-kingdom classification system, proposed by American ecologists **Rebert Whittaker** in 1969, all organisms were divided into five kingdoms i.e., Monera, Protista, Fungi, Plantae, and Animalia. According to this system, the kingdom Monera included prokaryotes while all the other four kingdoms included eukaryotes. In 1990, American microbiologist **Carl Woese** suggested that there are two separate groups of prokaryotes i.e., Archaea and Bacteria. On the basis, he classified living organisms into three domains i.e., domain Archaea, domain Bacteria and domain Eukarya. According to his three-domain

The evolutionary relationship among organisms is called **phylogeny**. The diagram to show phylogeny, is called phylogenetic or evolutionary tree.

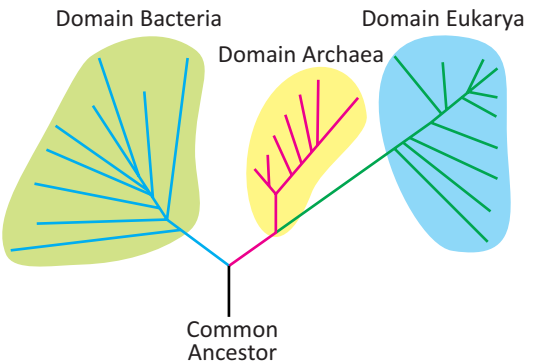


Figure 1.1: Evolutionary tree of the three domains

system, domain Archaea and domain Bacteria contain prokaryotes but they differ in a number of features.

Now biologists believe that Archaea and Bacteria evolved independently from some common ancestor. Molecular evidence suggests that archaea are more closely related to eukaryotes than to bacteria. In other words, Eukarya evolved from Archaea, after archaea split off from the Bacteria (Figure 1.1).

Domain Archaea

In the five-kingdom system, this domain was included in kingdom Monera. The name Archaea comes from the Greek *archaios* ("ancient"). They are prokaryotes which diverged from bacteria in very ancient times. Individual archaeans range from 0.1 µm to over 15 µm in diameter. Some form aggregates or filaments up to 200 µm in length. They occur in various shapes, such as spherical, rod-shape, spiral, lobed, or rectangular. Archaea reproduce asexually by binary or multiple fission, fragmentation, or budding. Mitosis and meiosis do not occur in archaea.

Archaea were initially classified as a group of bacteria, and were called archaebacteria.

How are Archaea unique?

Cell Membrane:

Their cell membrane contains lipids with ether-linkage between glycerol and fatty acid chains. The fatty acid chains are branched. That's why their cell membranes are more resistant to extreme conditions.

On the other hand, bacteria and Eukarya have membrane lipids with fatty acids attached to glycerol by ester linkages. The fatty acid chains are unbranched.

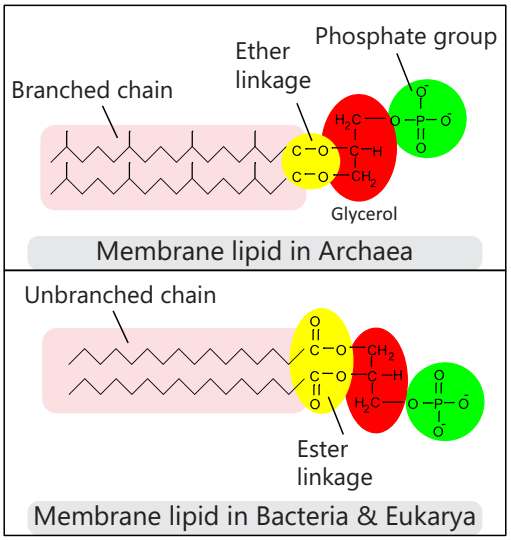


Figure 1.2: Difference in membrane lipids of Archaea and other organisms

Cell Wall Composition:

The cell walls of archaea lack cellulose and peptidoglycan. Instead, they contain distinct polysaccharides and proteins. Some archaea have pseudopeptidoglycan.

On the other hand, bacterial cell walls contain peptidoglycan, a polymer consisting of sugars and amino acids that provides structural support. In Eukarya, the cell walls, if present, are composed of cellulose (in plants) or chitin (in fungi).

Genetic Differences:

Archaea share several genetic sequences and regulatory features with eukaryotes, highlighting their closer evolutionary relationship.

Significance of Archaea

The archaeans which live in high acidity and alkalinity are a source of enzymes that can function under harsh conditions. For example, the enzymes of DNA replication have been extracted from such archaeans. These enzymes can work best at high temperatures and allow rapid cloning of DNA in laboratory. Similarly, the methanogen archaeans are a vital part of sewage treatment. They carry out anaerobic digestion and produce biogas. Acidophillic Archaea are used to extract metals such as gold, cobalt and copper from ores in mineral processing.

Metabolism:

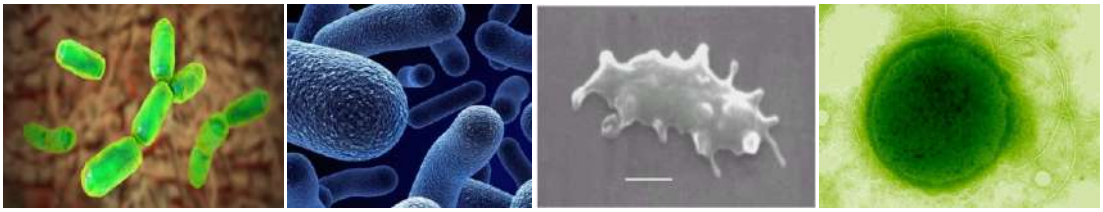
Archaea have unique metabolic processes like methanogenesis (production of methane), which is not found in bacteria or Eukarya.

On the other hand, bacteria exhibit metabolic pathways, including photosynthesis, nitrogen fixation, and fermentation. In Eukarya, the metabolic processes are often more complex and include cellular respiration, photosynthesis (in plants and algae), and various forms of fermentation.

Major Groups of Archaea

The major groups of Archaea include Methanogens (produce methane as a metabolic by-product), Halobacteria (live in extremely saline environments), Thermococci (found in hot environments), and Thaumarchaeota (involved in nitrogen cycle).

In humans, intestinal gas is largely the result of the metabolism of methanogens.



Methanogens Halobacteria Thermoplasmata Thermococci

Figure 1.3: Major groups of Archaea

Domain Bacteria

In the five-kingdom system, this domain was included in kingdom Monera. They are the true bacteria. They possess several distinct characteristics that differentiate them from other domains i.e., Archaea and Eukarya. Here are the general characteristics of the domain Bacteria:

1. Cell Structure: Like archaea, bacterial possess prokaryotic cell i.e., lack a true nucleus and membrane-bound organelles.

2. Cell Wall Composition: Bacteria have a cell wall composed of peptidoglycan, a unique polymer that provides structural support and shape.

3. Genetic Material: Like Archaea bacteria possess a single, circular chromosome composed of DNA, located in the nucleoid region.
4. Plasmids: Most bacteria have small, circular DNA molecules that can be transferred between bacteria, aiding in genetic diversity and adaptation.
5. Reproduction: Bacteria primarily reproduce asexually through binary fission, a process where a single cell divides into two identical daughter cells.
6. Nutritional Modes : Include autotrophs (self-feeding, e.g., photosynthetic bacteria) and heterotrophs (feeding on organic matter, e.g., decomposers).
7. Morphology : Bacteria exhibit a variety of shapes, such as cocci (spherical), bacilli (rod-shaped), spirilla (spiral-shaped), and vibrios (comma-shaped).
8. Arrangement: Cells may be found singly, in pairs (diplococci), chains (streptococci), clusters (staphylococci), or other arrangements based on species-specific characteristics.
9. Flagella: Many bacteria have one or more flagella, whip-like structures that enable movement.
10. Pili and Fimbriae: These are hair-like structures in some bacteria. They help in attachment to surfaces and in exchange of genetic material with other bacteria.
11. Respiration: Bacteria can be obligate aerobes, obligate anaerobes, facultative anaerobes, microaerophiles, or aerotolerant anaerobes. Some bacteria perform fermentation to produce energy in the absence of oxygen.
12. Extremophiles: Some bacteria thrive in extreme conditions, such as high temperatures (thermophiles), high salinity (halophiles), and low pH (acidophiles).
13. Pathogenicity: Some bacteria cause diseases in humans, animals, and plants, producing toxins or other virulence factors.
14. Symbiosis Many bacteria live in symbiotic relationships with other organisms, including mutualism (both benefit) and commensalism (one benefits, the other is not harmed).

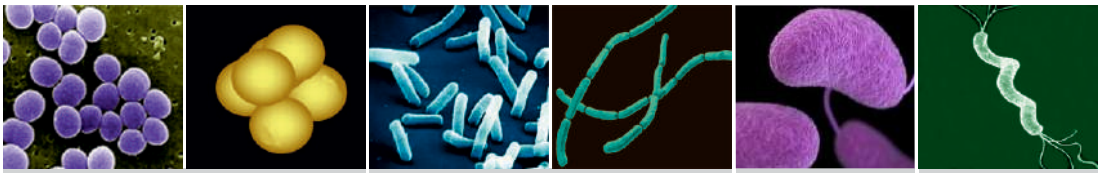


Figure 1.4: Different forms of Bacteria

Major Groups of Bacteria

The domain Bacteria is divided into numerous groups. For example;

- Proteobacteria e.g., *Escherichia coli*, *Rhizobium*, *Helicobacter pylori*.
- Firmicutes e.g., *Bacillus subtilis*, *Lactobacillus*, *Clostridium botulinum*.

- Actinobacteria e.g., *Streptomyces*, *Mycobacterium tuberculosis*
- Cyanobacteria e.g., *Anabaena*, *Spirulina*.
- Spirochaetes e.g., *Treponema pallidum*,
- Acidobacteria e.g., *Acidobacterium*.
- Aquificae e.g., *Aquifex pyrophilus*.

Domain Eukarya

The domain Eukarya encompasses all organisms with eukaryotic cells, which are fundamentally different from the prokaryotic cells of Bacteria and Archaea. Here are the general characteristics of the domain Eukarya that justify its classification as a separate domain:

1. Cell Structure: They possess eukaryotic cells - with true nucleus enclosed by a nuclear membrane. Cells have membrane-bounded organelles e.g., mitochondria, chloroplasts (in plants and algae), endoplasmic reticulum, Golgi apparatus, lysosomes, and peroxisomes. Cells also have cytoskeleton i.e., a complex network of microtubules, microfilaments, and intermediate filaments that provides structural support, enables cell movement, and facilitates intracellular transport.

2. Genetic Material: Their DNA is organized into multiple linear chromosomes within the nucleus. DNA is associated with histone proteins, which help in the organization and regulation of genetic material.

3. Reproduction: Most eukaryotes undergo sexual reproduction involving meiosis and fertilization, leading to genetic diversity. Some eukaryotes can also reproduce asexually through mitosis, producing genetically identical offspring.

5. Complex Cellular Organization: In multicellular eukaryotes, cells differentiate into specialized types forming tissues and organs with specific functions.

6. Evolutionary Relationships: Eukaryotes are believed to have originated through endosymbiosis, where certain prokaryotic cells (such as mitochondria and chloroplasts) were engulfed by a host cell, leading to a symbiotic relationship.

1.2- Taxonomic Hierarchy

The classification of living organisms is organized into a hierarchical system that allows scientists to categorize and understand the relationships between different forms of life. This system includes several levels, known as **taxa** (singular: taxon), each representing a rank in the biological classification system. The primary levels of this hierarchy are: kingdom, phylum, class, order, family, genus, and species. Below is a detailed description of each level.

1. Domain

It is the highest level of classification. Currently, there are three domains: Archaea, Bacteria, and Eukarya.

2. Kingdom

The kingdom is one of the highest taxonomic ranks, just below domain. It groups together all forms of life that share fundamental characteristics.

- Example: In the domain Eukarya, there are several kingdoms, such as Animalia (animals), Plantae (plants), Fungi (fungi), and Protista (protists).

3. Phylum

Phylum is the next level of classification below kingdom. Organisms within a phylum share a basic body plan and significant structural features.

- **Example:** In the kingdom Animalia, the phylum Chordata includes all animals with a notochord, such as mammals, birds, reptiles, amphibians, and fish.

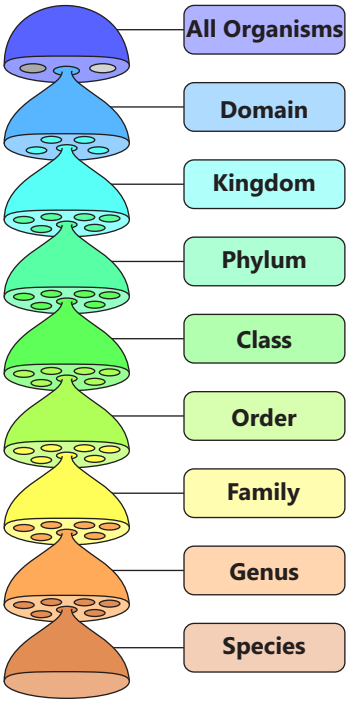


Figure 1.5: Taxonomic hierarchy

4. Class

Class further divides organisms within a phylum based on more specific common traits.

- **Example:** Within the phylum Chordata, the class Mammalia includes all mammals, which are characterized by having hair and mammary glands.

5. Order

Order categorizes organisms within a class based on additional shared characteristics and evolutionary history.

- **Example:** Within the class Mammalia, the order Primates includes humans, monkeys, and apes, characterized by their large brains and opposable thumbs.

6. Family

Family groups organisms within an order that are even more closely related, sharing more precise common attributes.

- **Example:** Within the order Primates, the family Hominidae includes great apes and humans.

7. Genus

Genus is a more specific rank within a family, grouping species that are very closely related and often visually similar.

- **Example:** Within the family Hominidae, the genus Homo includes humans and our closest extinct relatives.

8. Species

Species is the most specific level of classification, representing a single type of organism. Members of a species can interbreed and produce fertile offspring.

- **Example:** Within the genus Homo, the species Homo sapiens refers to modern humans.

Taxonomic Rank	Human (*Homo sapiens*)	Sparrow (*Passer domesticus*)	Onion (*Allium cepa*)
Domain	Eukarya	Eukarya	Eukarya
Kingdom	Animalia	Animalia	Plantae
Phylum	Chordata	Chordata	Angiosperms
Class	Mammalia	Aves	Monocots
Order	Primates	Passeriformes	Asparagales
Family	Hominidae	Passeridae	Amaryllidaceae
Genus	Homo	Passer	Allium
Species	*Homo sapiens*	*Passer domesticus*	*Allium cepa*

1.3- Salient Features of Kingdoms of Domain Eukarya

Eukarya consists of kingdoms protista, fungi, plantae and animalia. It includes all eukaryotes which consist of complex, eukaryotic cells containing nucleus and other membrane-bound organelles.

1. Kingdom Protista

Certain protists are parasitic and cause diseases like malaria (Plasmodium), amoebic dysentery (Entamoeba histolytica), and sleeping sickness (Trypanosoma).

Kingdom Protista includes eukaryote which are unicellular or colonial or filamentous or simple multicellular. Simple multicellular means that they do not have multicellular sex organs. There are three types of protists.

Major Groups or Protists

- The group Protozoa includes animal-like protists. They are unicellular and are heterotrophic. Examples are Paramecium, Amoeba, .Plasmodium, and Trypanosoma.
- The group Algae includes plant-like protists. They have cell walls made of cellulose. They have chlorophyll and are autotrophs. Examples include *Euglena*, diatoms.
- The groups Myxomycota and Oomycota include Fungi-like protists. They have hyphae-like structure and are saprophytic e.g., slime molds and water molds.

Figure 1.6: Common protists

2. Kingdom Fungi

Fungi are eukaryotic, heterotrophic organisms that are unicellular or multicellular. Their cells are covered by cell wall made of chitin (a polysaccharide). Fungi get nutrients in a unique way. They do not ingest food like animals and some protists. They absorb food from surroundings. Examples are mushrooms, rusts, smuts and molds.

Some fungi are used in the production of bread, cheese and beer. Others have medicinal properties, such as penicillin, an antibiotic derived from the fungus *Penicillium*.

Makro Groups of Fungi

There following are the major groups of fungi:

- Zygomycota includes the fungi which lack septa in their hyphae. Examples are Rhizopus (bread molds), which grow on moist bread, fruits etc.
- Ascomycota includes the largest groups of fungi. They have septate hyphae. Examples include common molds, morels, truffles, cup fungi, Neurospora and yeasts.
- Basidiomycota includes the fungi with septate hyphae. Examples are mushrooms, toadstools, puffballs, jelly fungi and bracket/shelf fungi, rusts and smuts.

There are about 100,000 known species of fungi. Most of the Ascomycetes are found in lichens and some are found in mycorrhizae.

Figure 1.7: Common fungi

3. Kingdom Plantae

It includes plants which are eukaryotic, multicellular organisms with cell walls made of cellulose.They are autotrophic and prepare food through photosynthesis. All

plants develop from embryos. Examples are mosses, ferns, conifers and flowering plants.

Major Groups of Plants

Plants are divided into two major groups:

- Nonvascular plants or bryophytes lack conducting tissues (xylem and phloem). Examples include liverworts, hornworts, and mosses.
- Vascular plants have conducting tissues. Vascular plants are of two types i.e., seedless plants (e.g., ferns) and seed plants (e.g., conifers and flowering plants).

Moss

Liverwort

Hornwort

Nonvascular plants

Sago palm

Pine

Cedrus

Ginkgo biloba

Seedless vasculaplants

Capsicum

Mustard

Seed plants

Figure 1.8: major groups of Kingdom Plantae

Table: Distinguishing Characteristics of the kingdoms of three domains						
Domain	**Bacteria**	**Archaea**	**Eukarya**			
Kingdom	**Monera**		**Protista**	**Fungi**	**Plantae**	**Animalia**
Cell Type	Prokaryotic	Prokaryotic	Eukaryotic	Eukaryotic	Eukaryotic	Eukaryotic
Nuclear Envelope	Absent	Absent	Present	Present	Present	Present
Presence of Cell Wall	In all	In all	In some	In All	In all	Absent
Composition of Cell Wall	Peptidoglycan	Various chemicals	Various chemicals	Chitin	Cellulose and other polysaccharides	No Cell wall
Mode of Nutrition	Autotroph or heterotroph	Autotroph or heterotroph	Photosynthetic or heterotroph, or combination	Absorptive heterotroph	Photosynthetic autotrophs	Ingestive heterotroph
Multi - cellularity	Absent	Absent	Absent in most forms	Present in most forms	Present in all forms	Present in all forms

4. Kingdom Animalia

This kingdom of eukaryotes includes animals which are eukaryotic, multicellular and heterotrophic. They develop from embryos. They ingest food and digest it within their bodies.

1.4- CLASSIFICATION OF KINGDOM ANIMALIA

The kingdom Animalia is broadly divided into the following phyla.

1- Phylum Porifera

This phylum contains sponges. Most of them are marine while some live in freshwaters. *Leucosolenia* and *Euplectella* (Venus' flower basket) are marine sponges. *Spongilla* is a common freshwater sponge.

A commercial sponge is prepared by drying, beating, and washing a sponge until all cells are removed.

Sponges do not have tissue level organization. Most sponges are asymmetrical but some have radially symmetry. They do not have nervous system. There are numerous pores in body wall called ostia. Through ostia, water enters the body. The larger pore through which water leaves the body is called osculum. The outer layer of body is made of thin, flat cells called pinacocytes. The second layer is jelly-like and is called mesohyle. It contains amoeboid cells. The third layer, which lines the spongocoel, is made of choanocytes or collar cells. They have skeleton in the form of minute needles of calcium carbonate or silica. Most sponges reproduce asexually by budding or regeneration. Some sponges form resistant capsules, called gemmules. When parent sponge dies, it releases its gemmules. In favourable environment, amoeboid cells come out of the gemmules and form a new sponge.

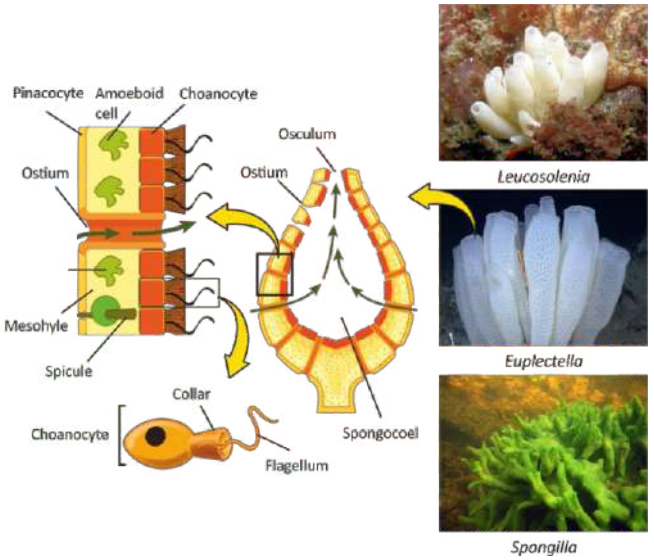


Figure 1.9: Representative sponges and general structure

2- Phylum Cnidaria

Almost all cnidarians are marine, although a few are found in freshwater e.g., *hydra* and jellyfish. Most cnidarians are colonial e.g., *obelia*, corals, sea fans etc. Most of them are sessile e.g., *hydra*, coral, *obelia* etc. Some cnidarians are motile e.g., jellyfish.

They are radially symmetrical animals and are diploblastic. It means that the adult body contains two tissue layers i.e., the epidermis and the gastrodermis, derived from ectoderm and endoderm respectively. Between the epidermis and gastrodermis, a jelly-like mesoglea is present. It contains amoeboid cells that have originated either from ectoderm or endoderm. They possess special cells, called cnidocytes. A cnidocyte contains a special organelle, called nematocyst. Nematocysts defend the body and captures prey. Cnidarians have a blind-ending cavity, called gastrovascular cavity or enteron. It opens outside by a single opening, the mouth. Mouth also acts as anus for the removal of undigested material. Mouth is surrounded by a series of projections, called tentacles. This types of digestive system in which there is a single opening for the entry of food and removal of undigested matter, is called **sac- like** digestive system.

Corals are colonial cnidarians. They produce hard exoskeleton of Calcium carbonate. The skeleton makes coral islands and coral reefs.

Coral reef

The nervous system is in the form of a network of neurons in the body wall. There is no central nervous system (brain and spinal cord). They do not have respiratory,

excretory and transport systems. There are two body forms in cnidarians i.e., polyps and medusae. **Polyps** are cylindrical and are attached to a substrate at the aboral end. They reproduce asexually. **Medusae** are umbrella-like and are free-swimming. They reproduce sexually.

Figure 1.10: Representative cnidarians

3- Phylum Platyhelminthes

They are called "flatworms". They are unsegmented and body is soft and dorsoventrally compressed. Most of them are free-living e.g., planaria. Some are endoparasites of humans and other animals e.g., liver fluke, tapeworm, and blood-fluke.

They are triploblastic i.e., the tissues of the body are derived from three embryonic layers; ectoderm, mesoderm and endoderm. They are acoelomates. A loose connective tissue called parenchyma fills space between the body wall and body organs. They have bilateral symmetry with distinct left and right sides as well as dorsal and ventral sides. They do not have respiratory and circulatory (transport) systems. They have a network of tubular protonephridia. These tubules have numerous branches. Each branch ends in a bulb-like cell called flame cell. The cilia of flame cells beat to suck surrounding fluid into the tubules. The tubules filter the waste materials from fluid and release them out of body wall through a small opening called a nephridiopore. They have a network of neurons. There are cerebral ganglia in the anterior end (head). These ganglia are attached to longitudinal nerve cords that are interconnected across the body by transverse branches. Most free-living flatworms have two simple eyespots at their anterior end. Flatworms reproduce asexually by "fission" in which the animal constricts in the middle and then divides into two pieces. Each piece then regenerates the missing part. The sexually-reproducing flatworms are hermaphrodites (bisexual).

Figure 1.11 : Representative flatworms

4- Phylum Nematoda

The pseudocoelomates are classified in seven phyla. These phyla are grouped as a unit called Aschelminths. Phylum Nematoda is the representative phylum of this group.

They are roundworms with elongated worm-like (round) body with pointed ends. Some roundworms are free-living (in water and soil) e.g., *Caenorhabditis elegans.* Many are parasites e.g., *ascaris,* hookworm, pinworm, and whipworm.

They are triploblastic, bilateral symmetrical, and possess unsegmented body. They are pseudocoelomates because they possess a false body cavity called pseudocoelom filled with fluid. They possess tube-like digestive system. It consists of an alimentary canal with two openings; mouth at anterior end and anus at posterior end. The parasitic roundworms have simplified digestive systems. Their excretory system consists of protonephridia and two excretory canals, which unite at the anterior end to form a single canal. The single canal then opens outside through a nephridiopore on the ventral surface. They possess a network of neurons in body. There is a nerve ring around the pharynx, which is attached to four longitudinal nerve cords. They have raised hair-like sense organ called sensory papillae, present on lips. They do not have defined respiratory and circulating systems. They are unisexual i.e.; male nematodes have testes and female nematodes have ovaries.

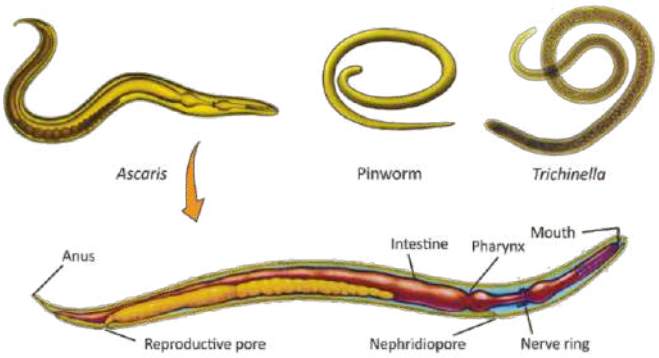


Figure 1.12: Representative roundworms and general structure

5- Phylum Mollusca

Molluscs have soft un-segmented bodies. They are widely distributed in natural habitats. Some of them are exclusively aquatic e.g., mussels, octopus and oyster. The others live in moist places e.g., land snail.

In open-type system, the blood does not retain the vessel. Rather, it directly bathes cells in tissue spaces (sinuses).

Molluscs are triploblastic and have bilateral symmetry. They possess true coelom. Among coelomates, they are included in the group called protostomes. Their body can be divided into three parts i.e., head, visceral mass (contains organs of digestion, excretion and reproduction), and foot (attached with visceral mass). They have an epithelial envelope around the visceral mass, called as mantle. The space between mantle and visceral mass is called as mantle cavity. In most molluscs, the outer surface of mantle secretes a calcareous shell. All molluscs (except bivalvia) have is a rasping tongue-like organ, called radula. All of them (except cephalopods) have open type blood circulatory system. Their heart consists of a single ventricle and two auricles. They possess tube-like digestive system in which the gut has two openings, i.e., mouth and anus. Their excretory system consists of paired tubular structures called nephridia. Wastes are gathered from sinuses and discharged into coelom around the heart. The nephridia open in this coelom. They have tiny cilia around their openings, which move the fluid from coelom into the nephridia. Nephridia discharge waste materials in mantle cavity, from where they are expelled out. In molluscs, gills work for the exchange of gases. They have three pairs of interconnected ganglia present in the head, visceral mass and foot. The ganglia are interconnected by means of nerve cord. They move with the help of muscular foot. Some molluscs are sessile. Most molluscs are unisexual.

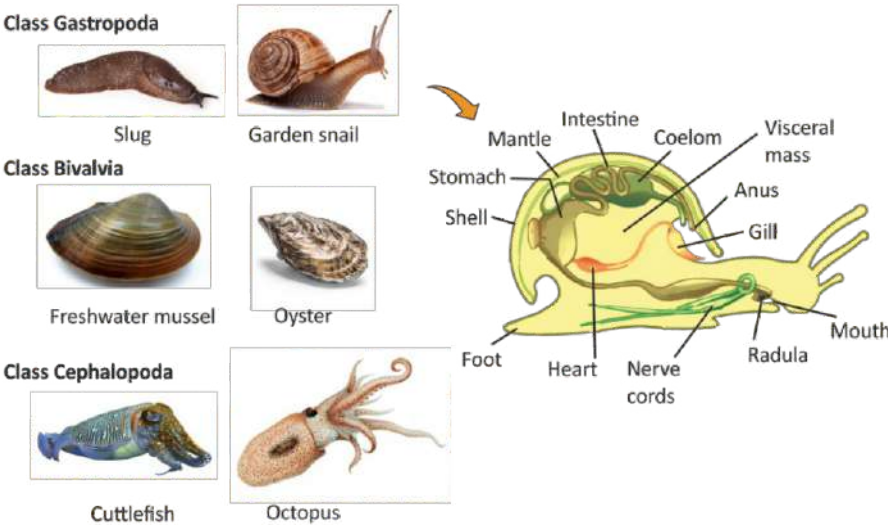


Figure 1.13: Representative molluscs and general structure

6- Phylum Annelida

Annelids are commonly called segmented worms. They are found in marine water (e.g., nereis), freshwater (e.g., leech), and in damp soil (e.g., earthworm). Some annelids are ectoparasites e.g., leeches.

Their body is divided transversely into a number of similar parts called segments. Internally, the segments are separated from each other by cross walls called septa. Each segment is provided with its own circulatory, excretory and neural elements. This type of segmentation in body is called metameric segmentation. Annelids are bilaterally symmetrical and triploblastic. They are protostome coelomates. Annelids have special parts called setae. Setae are chitinous bristles in the ventral wall of each segment. Setae are absent in leeches. Their body wall is surrounded by a moist, acellular cuticle secreted by epidermis. They possess tube-like digestive system. The digestive tube is divided into distinct parts, each performing a specific function. The parasitic annelids have simplified digestive system.

The segments are indicated externally by constrictions of the body surface in the form of little rings ("Annelid" means "little ring").

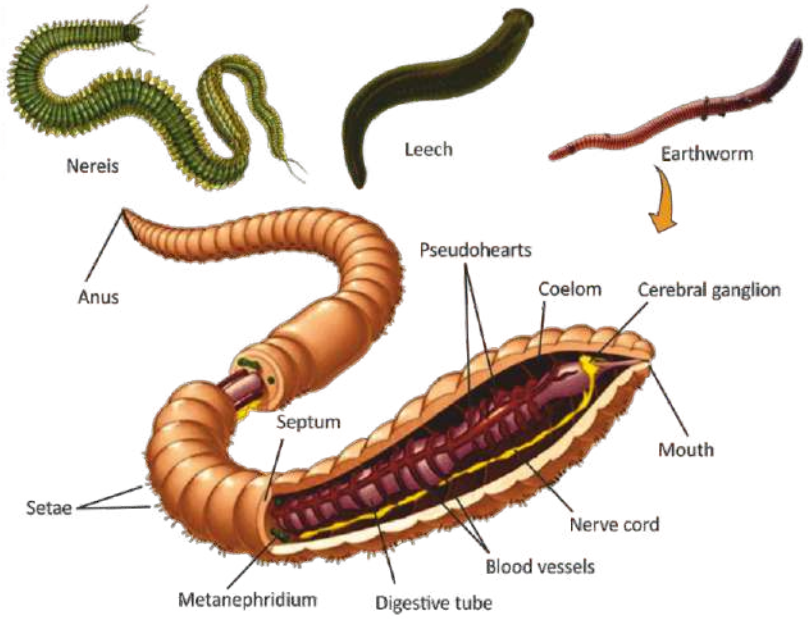


Figure 1.14: Representative annelids and general structure

Their excretory system consists of ciliated, funnel-shaped metanephridia. Each segment has one pair of metanephridia. They possess a closed-type circulatory system. Blood always flows in blood vessels. They have specialized pulsating blood vessels (pseudohearts). Blood of most annelids has respiratory pigment, haemoglobin, dissolved in blood plasma. Gaseous exchange occurs through the skin. There is a

cerebral ganglion or brain in the anterior segment. A double, longitudinal ventral nerve cord arises from brain and gives nerves in each segment. Ganglia are also present in each segment. They have tactile receptors, chemoreceptors, balance receptors, and photoreceptors. Some annelids also well-developed eyes with lenses. Most annelids are hermaphrodite (e.g., earthworm, leech) and some are unisexual (e.g., nereis).

7- Phylum Arthropoda

Diverse groups such as insects, crustaceans, spiders, scorpions, and centipedes are included in this phylum. They are found in every type of habitat. Many of terrestrial members can also fly.

Arthropods are the most successful of all invertebrates. About 900,000 species – two thirds of all the named species on Earth arthropods.

They are triploblastic, bilateral symmetrical, protostome coelomates. The coelom is reduced and is present only around reproductive and excretory systems. They have jointed appendages which are modified for specialized functions e.g., running, crawling swimming, capturing prey, respiration, reproduction etc. In different arthropods, the jointed appendages around the mouth, are modified in different ways and form mouth parts. The body is segmented. Some segments are fused to form specialized body regions called tagmata. These include head, thorax and abdomen. They have exoskeleton or cuticle, which is secreted by the epidermis of body wall. It is made chiefly of chitin. In young arthropods, exoskeleton is shed from time to time. After shedding the exoskeleton, the animal grows at a fast rate and then re-secretes new exoskeleton. This process is called ecdysis or molting.

They possess open-type circulatory system. Most of the time, blood flows in hemocoel, which is derived from an embryonic cavity called blastocoel. Their blood is colourless as it is without haemoglobin and is known as haemolymph. Most arthropods possess a respiratory system that consists of air tubes called trachea. Main tracheal tubes open out through openings called spiracles. Aquatic arthropods respire through gills. Arthropods have tube-like digestive system. The alimentary canal is divided into different parts. Their excretory system comprises of Malpighian tubules. These are narrow tubules projected from the alimentary canal, attached at the junction of midgut and hindgut. The nitrogenous wastes are excreted in the form of solid uric acid crystals. They have well-developed central nervous system with three fused pairs of cerebral ganglia (brain) in head. There is a double ventral nerve cord which has ventral ganglia in each segment. Smaller nerves arise from ventral ganglia in each segment. They have well developed compound eyes and antennae. They can swim, crawl or fly depending on their habitat.

They are unisexual.

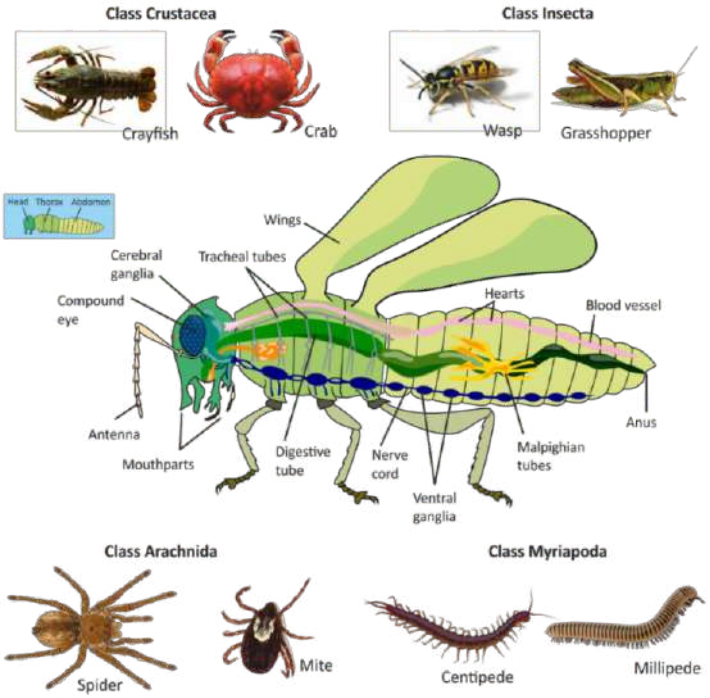


Figure 1.15: Representative arthropods and general structure

Important arthropods include insects (e.g., mosquito, butterfly, moth, wasp, beetles, grasshopper), crabs, lobsters, prawn, shrimps, crayfishes, spider, tick, mite, scorpion, centipedes and millipedes.

8- Phylum Echinodermata

They are exclusively marine animals. Some are flattened like biscuit (e.g., cake urchin), some are star-shaped with short arms (e.g., sea star or starfish), some are globular (e.g., sea urchin), some are star-shaped with long arms (e.g., brittle star), and some are elongated (e.g., sea cucumber).

They are triploblastic and deuterostomes coelomates. Their larvae are bilateral symmetrical but the adults show radial symmetry. In their radial symmetry, the body parts are arranged in five, or multiple of five, around an oral-aboral axis. They possess a calcareous endoskeleton in the form of plates called ossicles. These plates are derived from mesoderm but come out of skin also and make spines on the skin. They have water-vascular system consisting of tubes and spaces present in the coelom. A ring canal surrounds the mouth. It opens outside through a sieve-like plate, called madreporite. Five (or a multiple of five) radial canals branch from the ring canal. Many lateral canals emerge from each radial canal and each lateral canal ends at a tube foot. Tube feet are the extensions of water vascular system. The tube feet extend and attach with some substrate. When water is drawn back from the sucked tube feet, they

contracts and body is pulled. Echinoderms possess tube-like digestive system. The mouth leads to oesophagus, stomach, intestine and rectum. The rectum opens out through anus.

There are no specialized organs for respiration and excretion. They possess a poorly developed nervous system made of a nerve net, a nerve ring, and five (or multiple of five) radial nerves. Most sensory receptors are distributed over the surface of the body and tube feet. Asexual reproduction involves division of the body, followed by the regeneration of each half. Echinoderms are unisexual.

Many echinoderms are able to regenerate the lost parts, and some, especially sea stars and brittle stars, drop various parts when they are under attack and then regenerate the lost parts.

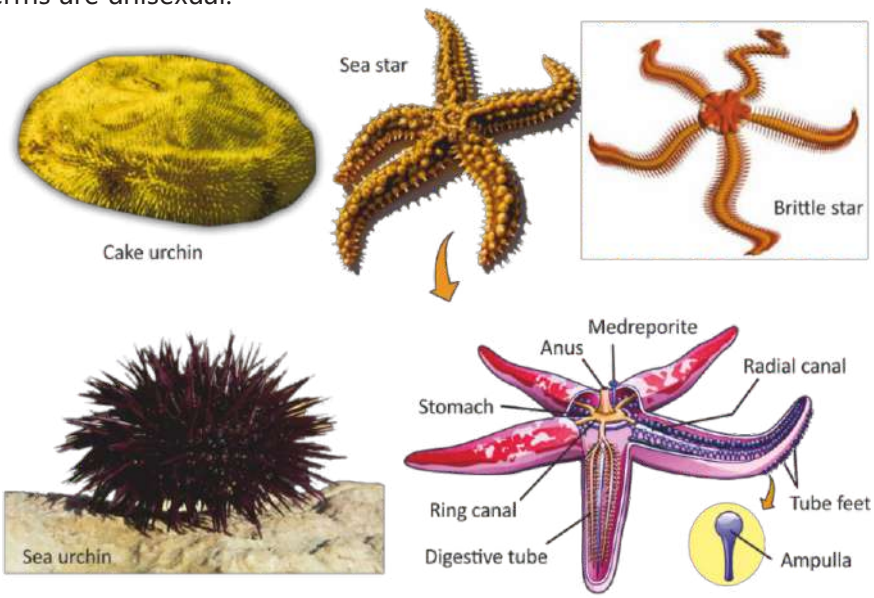


Figure 1.16: Representative echinoderms and general structure

10- Phylum Chordata

Chordates are bilateral symmetrical, triploblastic, deuterostome coelomates. The following four characteristics are unique to chordates, present at some stage in development.

1. Notochord: All chordates develop notochord during embryonic life. It is a rod-like semi rigid body of vacuolated cells. It extends throughout the length of body between gut and dorsal nerve cord. The lower chordates retain this notochord throughout life. While, in vertebrates it is partly or entirely replaced by vertebral column, during development.

2. Pharyngeal slits: These are a series of openings in the lateral walls of pharynx. All chordates develop paired gill slits in embryonic stage. In some chordates (e.g.,

Amphioxus and fishes), these develop into gills. In some (e.g., most amphibians), these are functional for some period in their life history. In others (e.g., reptiles, birds and mammals), these are modified for various purposes.

3. Tubular nerve cord: In all chordates, a tubular nerve cord runs through the longitudinal axis of the body, just dorsal to the notochord. It expands anteriorly as a brain.

4. Post anal tail: All chordates develop a tail, posteriorly beyond the anal opening. Some chordates retain it throughout life while others degenerate it during embryonic life.

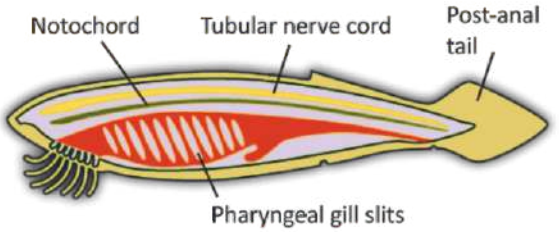


Figure 1.17: Diagnostic characters of chordates

Phylum chordata includes two major groups i.e., invertebrate chordates and vertebrates.

- **Subphylum Urochordata** includes the invertebrates chordates in which notochord and nerve cord are present only in their free-swimming larvae. Sea squirts are the examples of urochordates.
- **Subphylum Cephalochordata** includes the invertebrate chordates in which notochord persists throughout life. Amphioxus is a common cephalochordate.

Figure 1.18: Sea squirts

Figure 1.19: Amphioxus

- **Vertebrates:** They have a vertebral column and cranium. Vertebrates are divided into seven classes which are placed into two groups.

1.5- CLASSIFICATION OF VERTEBRATES

Vertebrates are divided into two groups.

1. **Group Pisces:** It includes 3 classes i.e., Cyclostomata, Chondrichthyes, and Osteichthyes. They do not have limbs.

2. **Group Tetrapoda:** It includes 4 classes i.e., Amphibia, Reptilia, Aves, and Mammalia. They have four limbs.

1. Class Cyclostomata

These are jawless fishes. Lampreys and hagfish are common examples. Their bodies are eel-like and not covered with scales. They possess cartilaginous skeleton. Like other fishes, they have a single-circuit heart with one atrium and one ventricle. Fertilization is external.

Figure 1.20: Jawless fishes

2. Class Chondrichthyes

The group includes sharks, skates, rays, and ratfishes. They have skeleton of cartilage. Their body is covered by placoid (tooth-like) scales, called denticles. They have jaws and biting mouthparts. The pectoral and pelvic fins are paired. There are two dorsal fins. They possess single-circuit heart with one atrium and one ventricle. There is a pair of small openings, called spiracle, behind eyes. These are used for breathing. They do not have swim bladder. Fertilization is internal.

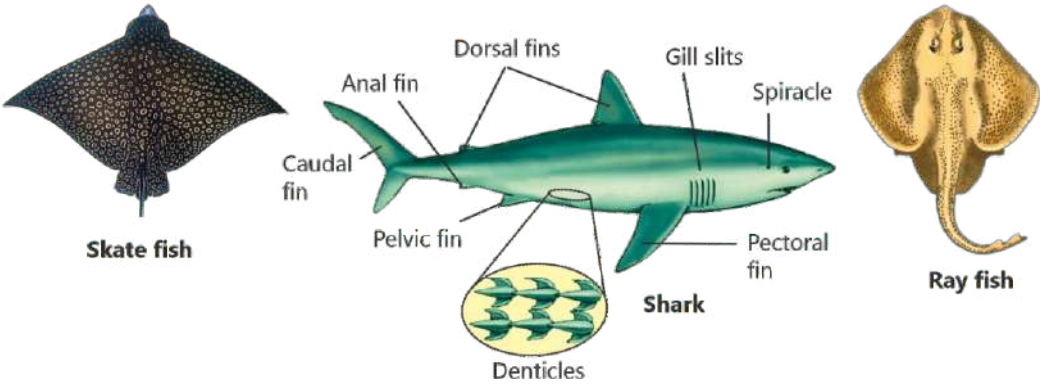


Figure 1.21: Cartilaginous fishes

3. Class Osteichthyes

The have bony endoskeleton, streamlined body, dermal bony scales, and terminal mouth with jaws (with or without teeth). Notochord is replaced by vertebral column, but some bony fishes may retain it in reduced form. They also have a swim bladder that helps in buoyancy. They possess both median (dorsal, caudal and ventral) and paired (pelvic and pectoral) fins. They contain four pairs of gills. A protective bony flap, operculum, protects the gills. They have well developed nervous system in which there are ten pairs of cranial nerves. Fertilization is mostly external. The freshwater bony

fishes include rohu, trout, Katla, catfish etc. The marine bony fishes include seahorse, flying fish and angler fish etc.

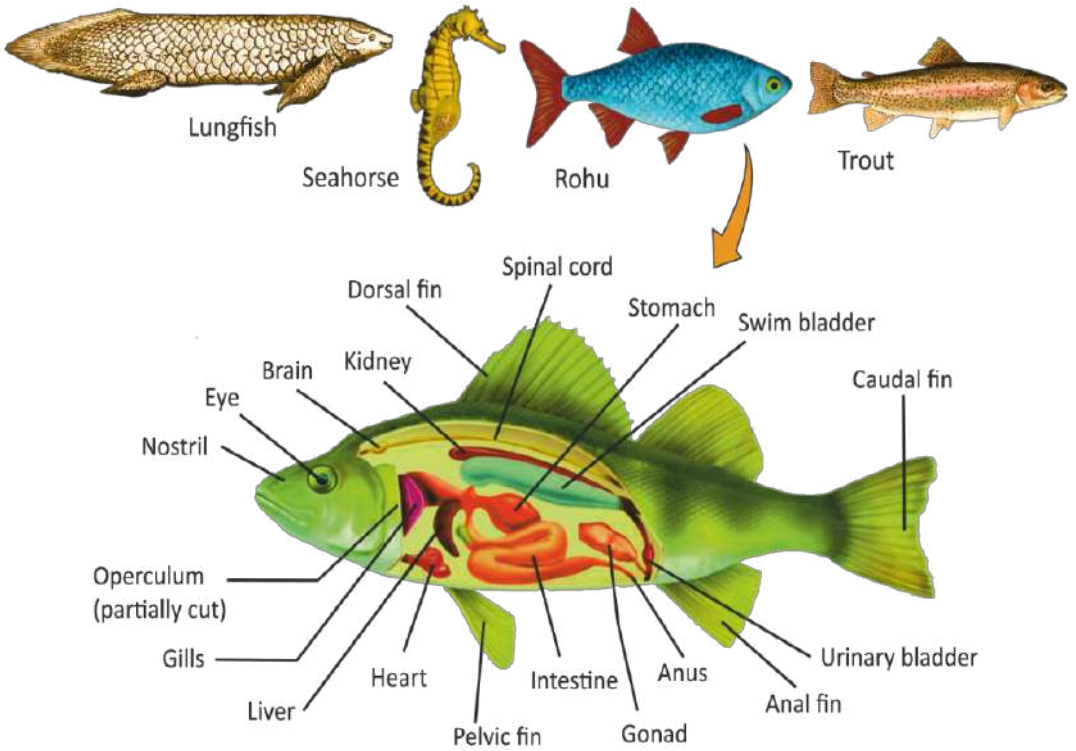


Figure 1.22: Representative bony fishes and general structure

4. Class Amphibia

It is the first class of tetrapods. They have bony endoskeleton. Unlike fishes, amphibians have a neck. The first vertebra (cervical vertebra) moves against the back of skull and allows the skull to nod vertically. Their skin is smooth (without scales) and moist. It helps in gas exchange, temperature regulation, and absorption and storage of water. Their heart is **double-circuit**. It is three-chambered, with two atria and one ventricle. They respire by gills in the larval stage and by lungs and skin in the adult stage. They depend on external heat source and so are **ectotherms**. They cannot regulate their body temperature and cannot maintain it constant. So, they are **poikilothermic** animals and hibernate in winter. Salamander, newts, and mud puppies are tailed amphibians. Frogs and toads are tail-less amphibians, and caecilians are leg-less amphibians. Amphibians are unisexual. Fertilization is usually external.

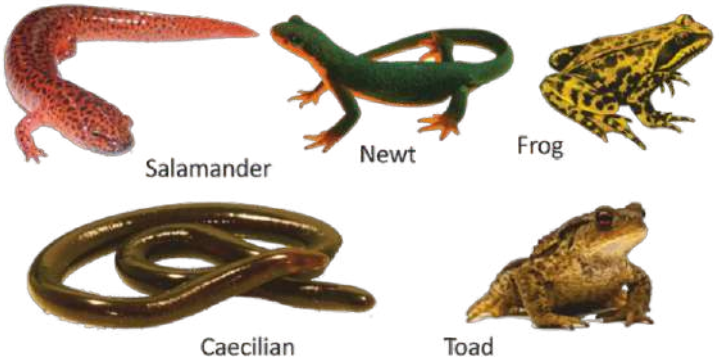


Figure 1.23: Representative amphibians

5. Class Reptilia

Reptiles are the first animal group that possess amniotic eggs. **Amniotic** eggs make protective extra-embryonic membranes i.e., amnion, allantois, and chorion. These membranes protect the embryo from drying out, nourish it and enable it to develop on land. The amniotic eggs also contain a large amount of yolk, the primary food supply for the embryo. Such eggs have abundant albumin, which provides additional nutrients and water. The amniotic eggs are also covered with leathery calcareous shell which is

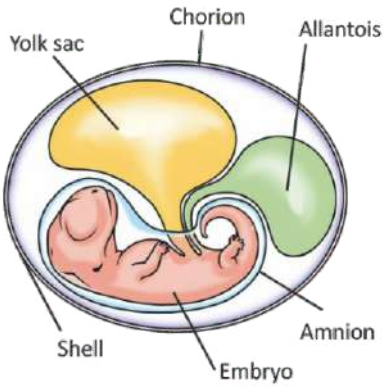


Figure 1.24: Amniotic egg

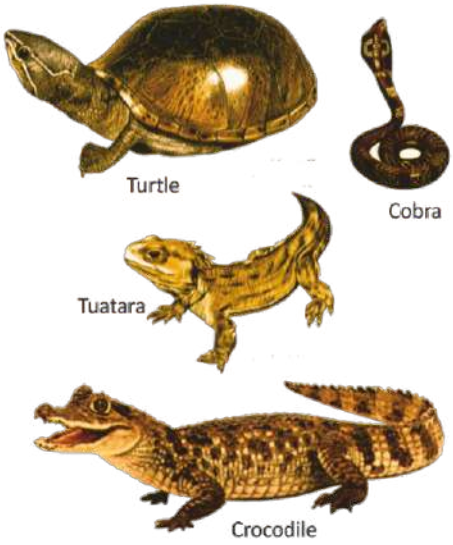


Figure 1.25: Representative reptiles

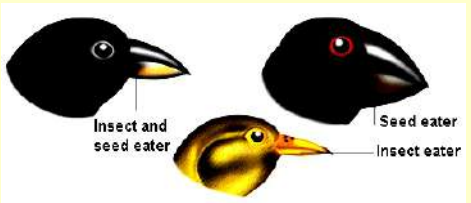
partly permeable to gases but not to water.

Reptiles have dry scaly skin. The bony endoskeleton of reptiles is harder than amphibians. The skull is longer than amphibians. In reptiles, first two cervical vertebrae (atlas and axis) allow more movements of head. In their heart, ventricle is incompletely partitioned, into left and right ventricles.

Reptiles, like amphibians, are **ectothermic** and use external heat source for thermoregulation. They cannot keep their body temperature at constant, and are **poikilotherms**. Fertilization in internal. They are oviparous (egg-laying). The present-day reptiles are lizards, snakes, tuatara and crocodiles.

6. Class Aves

Birds have a covering of feathers on the body. Feathers form the flight surfaces that provide lift and aid in steering. Feathers also prevent heat and water loss. Birds are **endotherms**. It means that they can obtain heat from cellular processes. A source of internal heat allows them to maintain a nearly constant core temperature. The animals who can maintain their core temperature are known as **homeotherms**.



Bills and tongues are modified for a variety of feeding habits and food sources.

The body of birds is streamlined and spindle shaped. The forelimbs are modified into wings. Their bones are light due to large air spaces. A lighter sheath called bill replaces the teeth. The sternum (chest bone) bears a large, bone called keel for the attachment of flight muscles.

In many birds a diverticulum of the oesophagus, called **crop**, is a storage structure that allows birds to quickly ingest large quantities of food. A region of stomach, called **gizzard**, has muscular walls to crush food. Their heart is four-chambered, with complete separation of atria and ventricles. Birds have much developed nervous system. Vision and hearing are important senses for most birds.

Their external nares open in pharynx through nasal passage ways. The pharynx leads to trachea and then bronchi. The organ of voice, called **syrinx**, is situated at the lower end of trachea. The bronchi lead to a complex system of **air sacs** that occupy much of the body and even extend to some of the bones. The air sacs connect to lungs, which are made of small air tubes called **parabronchi**.

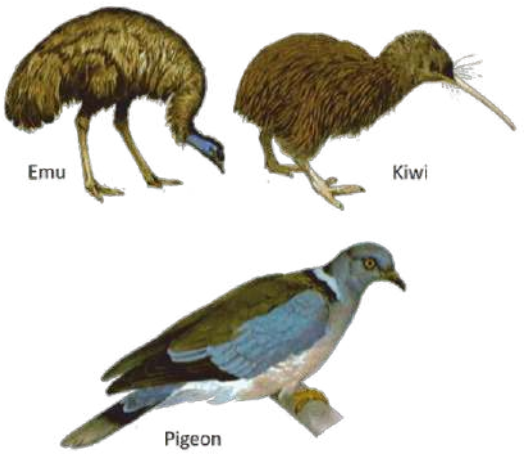


Figure 1.26: Representative birds

Like reptiles and mammals, birds have **amniotic** eggs with large amounts of yolk and albumin. Such eggs are also covered with leathery shell. In birds, fertilization is internal and development is external i.e., they are **oviparous**. Some birds have

secondarily lost the power of flight and are called **running birds** e.g., ostrich, kiwi, rhea, cassowary, and emu. The flying birds include pigeon, parrot, crow, eagle, robin etc.

7. Class Mammalia

Mammalia includes the group of vertebrates which are nourished by milk from the mammary glands of mother, and have hair on their body. Mammals have skin glands, developed from epidermis. Sebaceous (oil) glands secrete oily secretion. Sudoriferous (sweat) glands release watery secretions used in evaporative cooling. Mammary glands are functional in female mammals. Most mammals have two sets of teeth during their lives i.e., milk teeth and permanent teeth. External ear or pinna is present. The middle ear has a chain of three bones i.e., incus, malleus and stapes. Mammals are endothermic and homoeothermic animals. They possess four-chambered heart. They have a muscular diaphragm that separates the coelom into thoracic and abdominal cavities. They have well developed voice apparatus in the form of larynx (with vocal cords) and epiglottis. In mammals, fertilization is internal. There are three groups of mammals:

Most mammals (placental mammals) give birth to young ones i.e., they are **viviparous**. Some mammals lay eggs and so are **oviparous**. While some (marsupials).

1. In egg-laying mammals lay eggs in which whole development of their embryo proceeds. These mammals are found in Australia e.g., Duckbill platypus and echidna (spiny anteater).
2. Some mammals (marsupials) have a pouch (marsupium) on the abdomen of female. These mammals give birth to immature young ones which complete their development in mothers' pouch. They are called **ovoviviparous**. Opossum, kangaroo and Tasmanian wolf are the examples of such mammals.

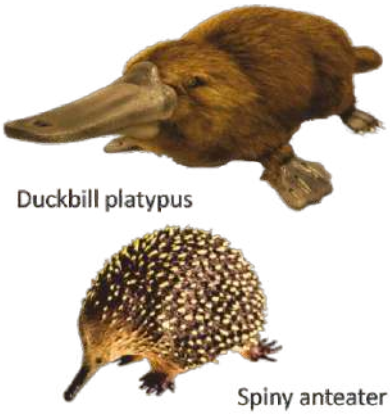


Figure 1.27: Representative egg-laying mammals

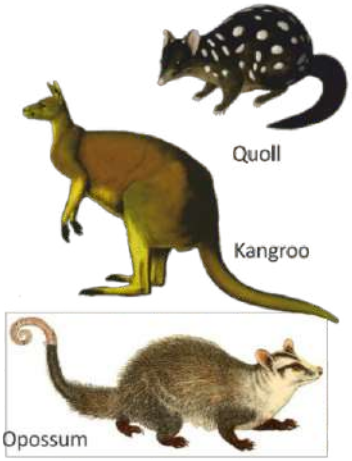


Figure 1.28: Representative pouched mammals

3. Placental mammals are the most advanced mammals. During development, a structure called placenta, is formed between mother's uterus wall and foetus body. The foetus is nourished and wastes from foetus are removed through this placenta. Dolphin, rat, monkey, bat, elephant and human are some examples of placental mammals.

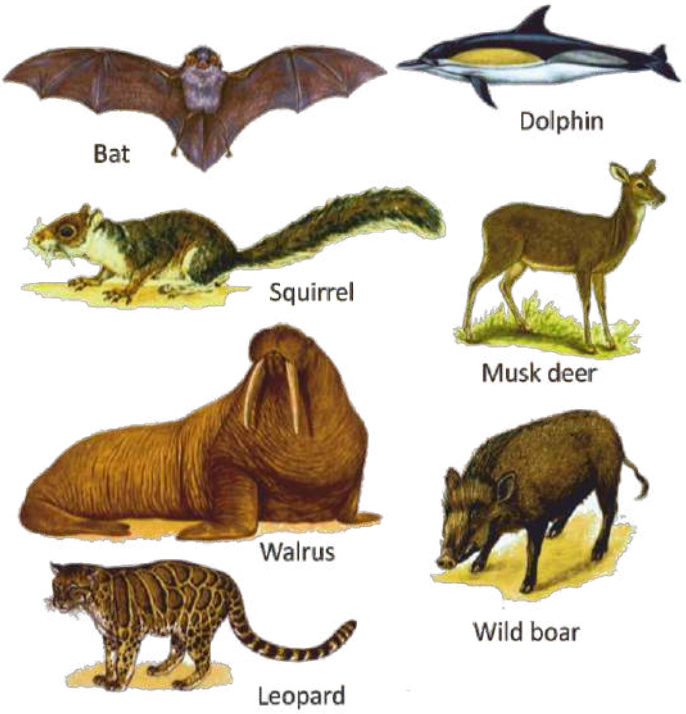


Figure 1.29: Representative eutherians

1.6- CLASSIFICATION OF VIRUSES

Viruses are not considered organisms because they are acellular i.e.; not made of cells. They lack any of the characteristics of the three domains of life and are not classified in any domain and kingdom.

Prions and viroids are also acellular. They are also not considered living organisms. Prions are composed of protein only and Viroids are composed of circular RNA only. Both these particles cause infectious diseases in certain plants.

A virus consists of nucleic acid (DNA or RNA) surrounded by a protein coat. They cannot run any metabolism and depend upon the host cell (including plants, animals, and bacteria) to replicate and synthesize their proteins.

Viruses are classified based on several characteristics, including their genetic material, replication strategy, morphology, and the hosts they infect. The classification of viruses follows guidelines established by the International Committee on Taxonomy of Viruses (ICTV).

Classification on the basis of Host Range

1. Animal Viruses: Infect animals, including humans. Examples: Influenza virus, Rabies virus.
2. Plant Viruses: Infect plants. Examples: Tobacco mosaic virus, Potato virus X.
3. Bacteriophages: Infect bacteria. Examples: T4 phage, Lambda phage.
4. Archaea Viruses: Infect archaea. Examples: Sulfolobus spindle-shaped virus.

Classification on the basis of Morphology

1. Helical Viruses: These have a capsid with a helical structure surrounding the nucleic acid. Examples: Tobacco mosaic virus, Rabies virus.
2. Icosahedral Viruses: These have a capsid with a symmetrical icosahedral shape. Examples: Adenoviruses, Herpesviruses.
3. Complex Viruses: These have a complex structure, often with a combination of icosahedral and helical features, and sometimes additional structures like tails. Examples: Bacteriophages (viruses that infect bacteria).
4. Enveloped Viruses: These have an outer lipid envelope derived from the host cell membrane, surrounding their capsid. Examples: Influenza virus, HIV.
5. Non-enveloped (Naked) Viruses: These lack an outer lipid envelope and consist only of a capsid enclosing the nucleic acid. Examples: Poliovirus, Adenovirus.

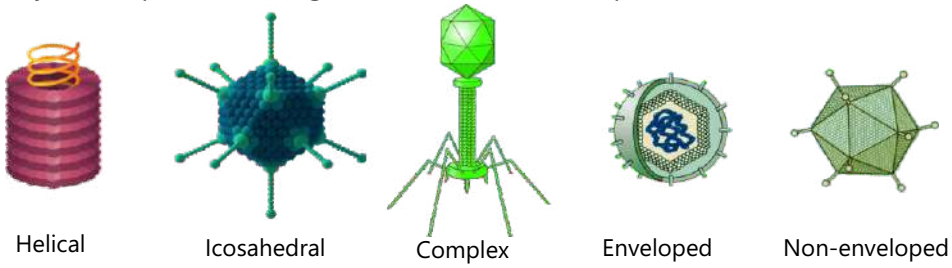


Figure 1.30: Basic shapes of viruses

Classification on the basis of Genetic Material

1. DNA Viruses: Viruses with DNA as their genetic material. This DNA can be single-stranded (ssDNA) or double-stranded (dsDNA). Examples include:
   - dsDNA viruses: Adenoviruses (cause respiratory infections), Herpesviruses (cause herpes, chickenpox).
   - ssDNA viruses: Parvoviruses (cause gastroenteritis).
2. RNA Viruses: Viruses with RNA as their genetic material. This RNA can be single-stranded (ssRNA) or double-stranded (dsRNA). Examples include:
   - ssRNA viruses: Coronaviruses (cause COVID-19), Influenza viruses (cause flu).
   - dsRNA viruses: Rotaviruses (cause gastroenteritis).

Classification on the basis of Replication Strategy

1. Positive-Sense RNA Viruses: The RNA genome is directly translated into proteins by the host cell's ribosomes. Examples include Poliovirus, Hepatitis C virus.

2. Negative-Sense RNA Viruses: The RNA genome is transcribed into mRNA by a viral RNA polymerase before translation. Examples include Rabies virus, Ebola virus.
3. Reverse Transcribing Viruses: These viruses replicate through a DNA intermediate using the enzyme reverse transcriptase. They can have RNA or DNA genomes. Examples include:
   - RNA genome: Retroviruses like HIV (cause AIDS).
   - DNA genome: Hepadnaviruses like Hepatitis B virus.

1.7- BIODIVERSITY

Biodiversity, a term derived from "biological diversity," refers to the variety of life forms present in different ecosystems, encompassing the diversity of species, genes, and ecosystems. It represents the richness and variability of living organisms and their interactions with each other and their environments.

Ecosystem:
An ecosystem is a dynamic and interactive system composed of living organisms and their physical environment. It includes all the biotic factors as well as the abiotic factors.

Niche:
A niche refers to the role or function of an organism or species within an ecosystem. It includes its habitat, its interactions with other organisms (predation, competition, and symbiosis), and its role in energy flow within the ecosystem.

Biodiversity Assessment Levels

The assessment of biodiversity involves multiple levels, each providing unique insights into the complexity of life.

Species Level: At the species level, biodiversity is assessed by identifying and counting the different species present within a given area. Species diversity includes not only the number of species but also their relative abundance and distribution.

Genetic Level: At the genetic level, biodiversity refers to the variety of genetic information contained within all individual organisms of a species. This genetic diversity is crucial for the adaptability and survival of species, enabling them to cope with environmental changes and challenges.

Ecosystem Level: At this level, biodiversity assessment includes the range of habitats, from forests and wetlands to grasslands and deserts. It involves understanding how different ecosystems function and how they contribute to overall ecological health.

Importance of Random Sampling in Determining Biodiversity

Random sampling is a fundamental technique in ecological studies for assessing biodiversity within a specific area. This method is crucial for several reasons:

1. **Minimizes Bias:** It ensures that every part of the study area has an equal chance of being sampled, which provides a more accurate representation of the overall biodiversity.

2. **Provides Reliable Estimates:** Random sampling allows for the collection of data that can be statistically analyzed to estimate species richness, abundance, and distribution.
3. **Facilitates Comparisons:** It enables comparisons between different areas or habitats by providing standardized methods of data collection.
4. **Enhances Representativeness** By covering different parts of the study area, random sampling ensures that the sample represents the diversity of the entire area.
5. **Supports Conservation Efforts:** Accurate biodiversity assessments through random sampling are essential for identifying areas of high conservation value and for monitoring changes in biodiversity over time.

Methods to Assess Biodiversity

Various methods are employed for assessing the distribution and abundance of organisms in an area:

Methods to Assess Distribution

1. Quadrat Sampling

It involves dividing the study area into a grid and sampling within randomly selected squares (quadrats). This method is particularly useful for studying plant populations or sessile organisms. For example, in a forest, a researcher might lay out quadrats of a fixed size and record the presence or absence of each plant species within these quadrats.

2. Transect Sampling

It involves laying out a line or strip (transect) across the study area and recording species at regular intervals along this line. This method is effective for studying the distribution of species across environments. For example, in a coastal zone, a transect can be laid from the high tide line to the low tide line, to record the types and abundance of intertidal organisms.

3. Aerial Surveys

Aerial surveys use aircraft or drones to observe and record the distribution of organisms over large areas. For example, it can be used to track the distribution of bird species across a large wetland area or to monitor large mammal populations in savannas.

Quadrat Sampling Transect Sampling Aerial Surveys

Figure 1.31: Methods to assess distribution of organisms

Methods to Assess Abundance

1. Point Counts: Point counts involve observing and recording the number of individuals of a species from a fixed point over a specified period. This method is commonly used for birds and other mobile animals.

2. Mark-Recapture: It involves capturing, marking, and releasing individuals of a species, then recapturing them later to estimate population size and density. This method is useful for animals that are difficult to count directly.

3. Quadrat Counts: In this method, researchers use quadrats to count the number of individuals of a species within each quadrat and then infer these counts to estimate overall abundance.

4. Capture-Recapture Methods: These models account for variables such as varying capture probabilities and movement between areas.

5. Remote Sensing: Remote sensing uses satellite or drone imagery to assess the abundance and distribution of species, particularly for large-scale or inaccessible areas.

1.8- SPECIES AND SPECIATION

Species

The term "species" is a fundamental concept in biology. A species is generally defined as a group of individuals that can interbreed and produce fertile offspring under natural conditions. Members of the same species share common characteristics and genetic makeup, which distinguishes them from individuals of other species.

Identification of species by using physical traits and similarities can sometimes be problematic due to the existence of cryptic species - organisms that appear similar but are genetically distinct. To address this, German-American biologist, **Ernst Mayr**, emphasized reproductive isolation as the key criterion. According to this concept, species are groups of interbreeding natural populations. Members of different species do not typically mate or produce viable, fertile offspring.

Speciation

Speciation is the evolutionary process by which new species arise from a common ancestor. It involves the accumulation of genetic changes that lead to reproductive isolation between populations. There are several mechanisms of speciation, for example:

1. Allopatric Speciation

It occurs when a population is geographically separated into two or more isolated groups. These groups experience different environments and evolve independently. Over time, the accumulated differences can become significant enough to prevent interbreeding, even if the geographical barrier is removed. An example is the speciation observed in Darwin's finches on the Galápagos Islands, where different populations adapted to diverse environments.

2. Peripatric Speciation

It involves a small, isolated population at the edge of a larger population. The small population undergoes rapid evolutionary changes, leading to divergence from the original population. An example can be seen in island species that evolve from a small founding population.

3. Parapatric Speciation

This occurs when populations are adjacent to each other but occupy different environments along a gradient. Gene flow between the populations is limited, and they evolve adaptations to their specific environments. Over time, this can lead to reproductive isolation. An example is the grass species *"Anthoxanthum odoratum"*, which exhibits different adaptations to varying soil conditions across a gradient, leading to reproductive isolation in different soil types.

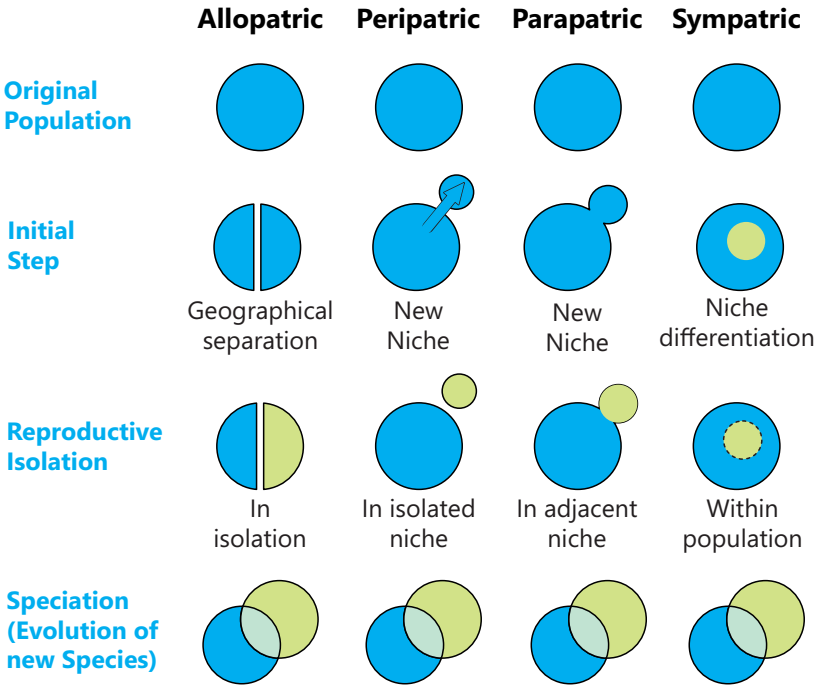


Figure 1.32: Modes of speciation

4. Sympatric Speciation

In this form, new species arise within the same geographical area without physical barriers. Sympatric speciation often occurs through mechanisms such as polyploidy (where an organism has multiple sets of chromosomes) or niche differentiation (where different subpopulations exploit different resources). For instance, certain plants can undergo polyploidy, leading to immediate reproductive isolation and the formation of new species.

EXERCISE

SECTION 1:MULTIPLE CHOICE QUESTIONS

1. Which domain of life is characterized by organisms that often inhabit extreme environments and have cell membranes with ether-linked lipids?
   (a) Bacteria (b) Archaea (c) Eukarya (d) Protista
2. What is a key difference between the domains Bacteria and Archaea?
   (a) Bacteria have membrane-bound organelles, while Archaea do not.
   (b) Bacterial cell walls have peptidoglycan, while Archaeal cell walls do not have it.
   (c) Archaea are only found in extreme environments, while Bacteria are not.
   (d) Bacteria are all unicellular, while Archaea include multicellular organisms.
3. Which of the following kingdoms includes organisms that are mostly unicellular, eukaryotic, and can be autotrophic or heterotrophic?
   (a) Fungi (b) Animalia (c) Plantae (d) Protoctista
4. In which kingdom are organisms predominantly multicellular, autotrophic, and have cell walls made of cellulose?
   (a) Animalia (b) Fungi (c) Plantae (d) Protoctista
5. Which of the following criteria is commonly used to classify viruses?
   (a) Their ability to cause specific diseases
   (b) The type of nucleic acid they contain
   (c) The colour of the virus particles
   (d) Their mode of transmission
6. Which virus group includes viruses such as Coronaviruses and influenza viruses?
   (a) Double-stranded DNA viruses (b) Single-stranded DNA viruses
   (c) Double-stranded RNA viruses (d) Single-stranded RNA viruses
7. At which level of biodiversity assessment do we evaluate the variety of different species within a particular habitat or ecosystem?
   (a) Genetic diversity (b) Ecosystem diversity
   (c) Species diversity (d) Functional diversity
8. Which method is best suited for assessing the distribution of species across a gradient of environmental conditions within a single geographical area?
   (a) Quadrat Sampling (b) Point Counts
   (c) Transect Sampling (d) Remote Sensing
9. Which of the following statements is true regarding the concept of a species?
   (a) A species is always defined by its physical characteristics alone.
   (b) Different species can interbreed and produce fertile offspring.
   (c) Members of the same species are reproductively isolated from members of other species.
   (d) The concept of a species can be defined solely based on genetic similarity.

10. What type of speciation occurs when populations are geographically separated by a physical barrier?
    (a) Sympatric Speciation
    (b) Parapatric Speciation
    (c) Allopatric Speciation
    (d) Peripatric Speciation

SECTION 2:SHORT QUESTIONS

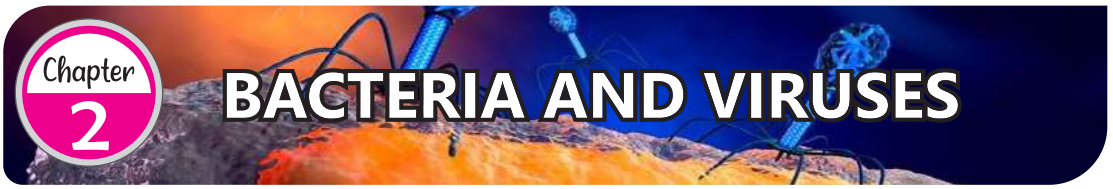
1. What are the three domains of life and how do they differ in terms of cellular structure?
2. Describe one key feature that differentiates Archaea from Bacteria.
3. Which kingdom is characterized by organisms with chitin in their cell walls and that are mostly decomposers?
4. What type of speciation occurs when populations are geographically separated?
5. What is the role of genetic drift in the process of speciation?
6. What is the primary method used to assess species distribution along an environmental gradient?
7. Which level of biodiversity assessment involves evaluating the variety of ecosystems in a region?

SECTION 3: LONG QUESTIONS

1. Compare and contrast the domains Archaea and Bacteria and discuss how these differences reflect their evolutionary histories.
2. Explain the concept of a species according to the biological species concept. How does this definition help in understanding species boundaries and the process of speciation? Provide examples to illustrate your points.
3. Discuss the mechanisms of allopatric and sympatric speciation.
4. Describe the main characteristics of the kingdoms Protoctista, Fungi, Plantae, and Animalia. Provide examples for each kingdom.
5. Outline the major classification systems for viruses based on their structural features and replication methods. Discuss the significance of these classifications in virology.
6. Explain the different levels at which biodiversity can be assessed. How do these levels contribute to our understanding of biological diversity and conservation efforts?
7. Discuss the importance of random sampling methods in ecological studies.
8. Describe the concept of an ecosystem and niche.

INQUISITIVE QUESTIONS

1. How are viruses classified based on their nucleic acid content and replication method?
2. What may be the drawback in the definition of species according to the biological species concept?
3. How does biodiversity help maintain balance in an ecosystem?



Chapter 2

BACTERIA AND VIRUSES

STUDENTS'LEARNING OUTCOMES

After studying this chapter, the students will be able to:

- Draw an annotated diagram of a generalized bacterial cell.
- Describe detailed structure and chemical composition of bacterial cell wall and other coverings.
- Justify the endospore formation in bacteria to withstand unfavourable conditions.
- Explain motility in bacteria.
- Describe with diagram structure of bacterial flagellum.
- Describe bacteria as recyclers of nature.
- Outline the ecological and economic importance of bacteria.
- Explain the use of bacteria in research and technology.
- Define the term normal flora.
- Describe the benefits of the bacterial flora of humans.
- Describe the structure of a model bacteriophage, and HIV.

Recalling:
Robert H. Whittaker proposed the five-kingdoms of life i.e., Monera, Protista, Fungi, Plantae, and Animalia. The first one includes prokaryotes and the other four include eukaryotes.

You know that over the years many schemes have been proposed for classifying organisms into kingdoms. You have studied in chapter 1, the five-kingdom classification system, proposed by **Robert H. Whittaker**, is recommended in biology. This system classified the organisms in a comprehensive way that reflects evolutionary history of organisms. According to this classification system, all prokaryotes are included in a separate kingdom i.e., the kingdom Monera.

In the last decade, molecular studies have highlighted serious flaws in the five-kingdom classification system. You have also studied in chapter 1, most biologists favour replacing it with a new system, called **three-domain system** It is more aligned with the data gained from molecular studies.

You know that bacteria are the prokaryotes classified in the domain of their own, i.e., the domain Bacteria. In this chapter we will study detailed structure of bacterial cell. We will also study the importance of bacteria.

2.1- STRUCTURE OF BACTERIA

Bacteria are a diverse group and all of them have unicellular prokaryotic organization, which lack membrane bounded organelles, including a well-defined nucleus. They have the simplest cellular organization.

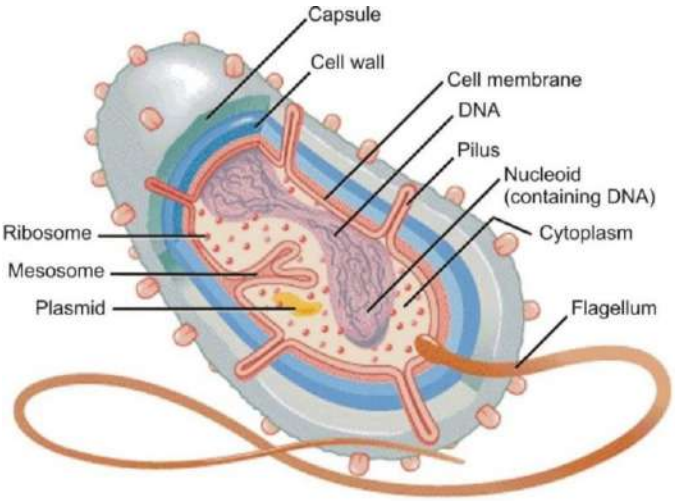


Figure 2.1: Structure of a generalized bacterium

Cell Wall

It is a rigid wall around the plasma membrane of bacterial cell. The major component of bacterial cell wall is a unique macromolecule, called **peptidoglycan** or **murein**. It is composed of long glycan (polysaccharide) chain, cross-linked with short peptide fragments (Figure 2.2). Its amount differs in different bacteria. Cell wall also contains lipids, which are linked to peptidoglycan.

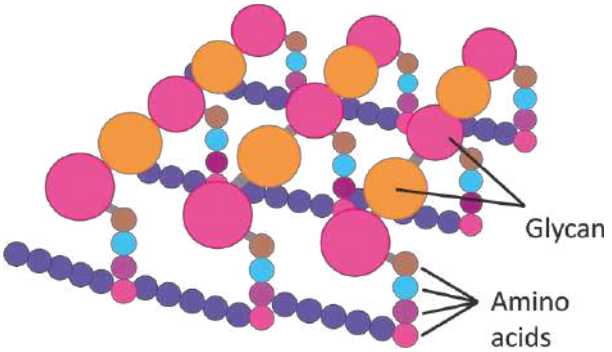


Figure 2.2: The molecular model of peptidoglycan

Sir Hans Christian Gram devised the technique of Gram's staining. Gram-positive bacteria stain purple because they retain violet dye. Gram-negative bacteria do not retain violet dye and so they appear in original colour.

The composition of cell wall is quite different in Gram-positive and Gram-negative bacteria. The cell wall of Gram-positive bacteria contains thick layer of peptidoglycan and has less lipid content. While the cell wall of Gram-negative bacteria has a thin layer of peptidoglycan.

The cell wall of Gram-negative bacteria has an outer membrane made of lipopolysaccharides and lipoproteins. The outer membrane makes Gram-negative bacteria resistant to many antibiotics. It contains a protein called porin, which acts like a pore for specific molecules. The cell wall of Gram-negative bacteria has more

periplasmic space (space between peptidoglycan layer and cell membrane) than Gram-positive.

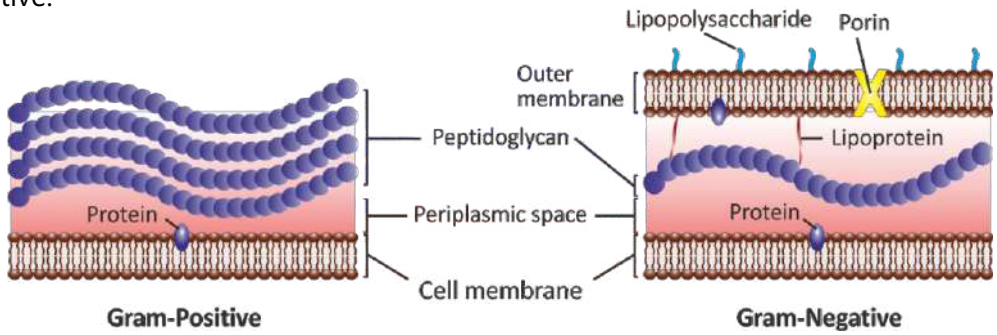


Figure 2.3: Cell wall composition of Gram-positive and Gram-negative bacteria

Some bacteria produce **capsule** outside their cell walls. It is a gelatinous layer and gives sticky characters to bacterial colonies.

Cell Membrane

Cell membrane or plasma membrane is present just beneath cell wall. It lies at the outermost in bacteria that lack cell wall (e.g., *Mycoplasmas* and *Sarcoplasmas*). The cell membrane of bacteria does not have sterols (e.g., cholesterol) in its chemical makeup. At some points, cell membrane invaginates and forms vesicles, tubules or lamellae in cytoplasm. These structures are known as **mesosomes** These are involved in DNA replication and cell division and also serve as respiratory centres.

Cytoplasm and Genetic Material

Cytoplasm contains dissolved substances and large structures such as nucleoid, ribosomes, and mesosomes. It lacks cytoskeleton and membrane-bounded organelles. Many ribosomes are freely dispersed in cytoplasmic matrix and some are loosely attached to plasma membrane. Bacterial ribosomes are smaller than eukaryotic ribosomes. Each ribosome sediments at 70S (larger subunit at 50S and smaller subunit at 30S). Near the centre of cytoplasm, there is an irregular-shaped dense area i.e., **nucleoid**. It contains DNA. A bacterium possesses a single, circular, double stranded DNA. Bacterial DNA does not have attached histones. It is sometimes called the chromosome of bacterium.

Some bacteria have circular, double-stranded extra chromosomal DNA molecules, called **plasmids**. They are self-replicating and can replicate before or after division. They contain genes that enable bacteria for resistance against unfavourable conditions (e.g., antibiotics).

Plasmids also serve as important vectors, in genetic engineering. They are used to carry selected genes to bacteria for cloning or for the synthesis of specific proteins.

2.2- ENDOSPORE FORMATION IN BACTERIA

Many bacteria can survive extended periods of harsh conditions by forming specialized "resting" cells, called **endospores** (Figure 2.4). Endospores are thick-walled and metabolically inactive (dormant). The process by which bacteria make endospores, is called **sporulation**. It happens in the following way:

When a bacterium faces unfavourable conditions, it replicates its DNA. Cell membrane makes a septum to isolate the new DNA and a small portion of cytoplasm. Cell membrane again grows around the new DNA, cytoplasm, and septum. In this way, the new DNA is surrounded by two membranes. The DNA of vegetative cell disintegrates and whole cell begins to dehydrate. A new peptidoglycan layer forms between the membranes around separated DNA and cytoplasm. A spore coat also forms around it. The structure matures into endospore. The vegetative cell breaks and endospore is released. Endospore remains dormant unless favourable conditions return. Under favourable conditions, endospore germinates to give rise to a new vegetative cell.

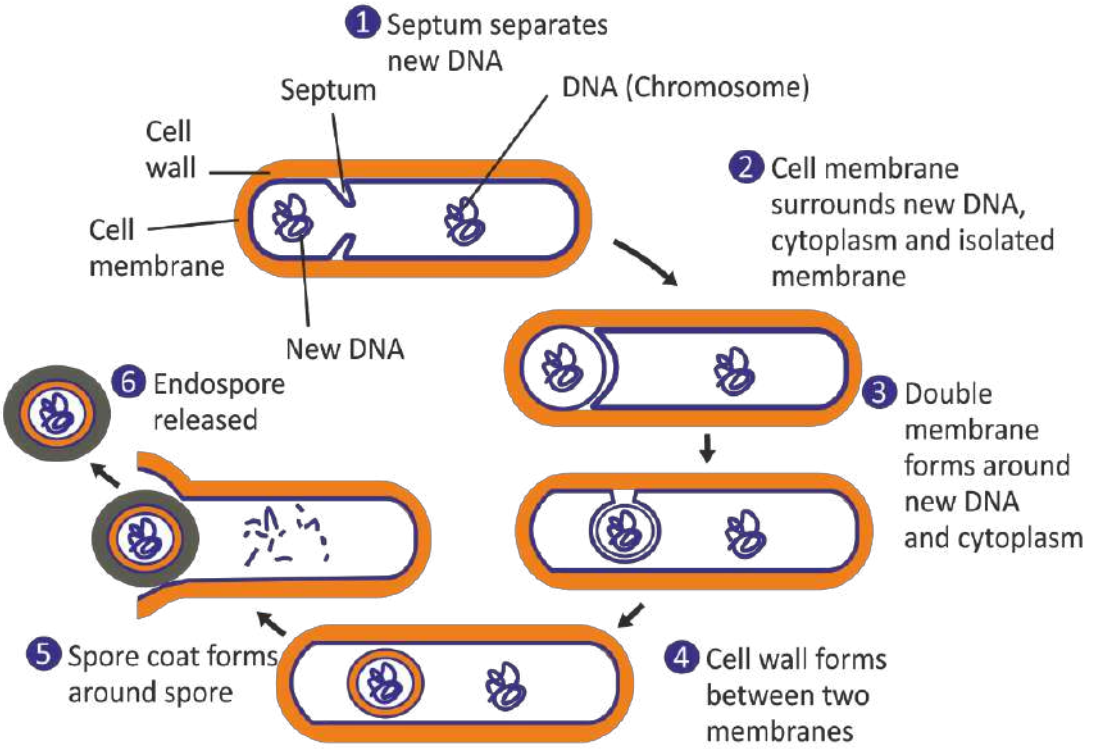


Figure 2.4: Process of endospore formation (sporulation) in bacteria

2.3- MOTILITY IN BACTERIA

Bacteria use different motility patterns to navigate and explore natural habitats.

Flagellar movements: Most bacilli and spirilla bacteria move by means of flagella. They swim by using their flagella. When a bacterial population moves together by means of flagella, the movement is called **swarming**. Flagellar movement allows bacteria to travel in liquid media. Counter clockwise rotation of flagellum pushes the cell forward with the flagellum trailing behind.

Twitching or crawling: It is used to move over surfaces. It is mediated by pili, which bind to surrounding solid surface and retract. Thus, bacterial cell is pulled forward.

Gliding: It is similar to twitching. In gliding, bacteria secrete slimy substance, which help them for smooth gliding over solid surfaces.

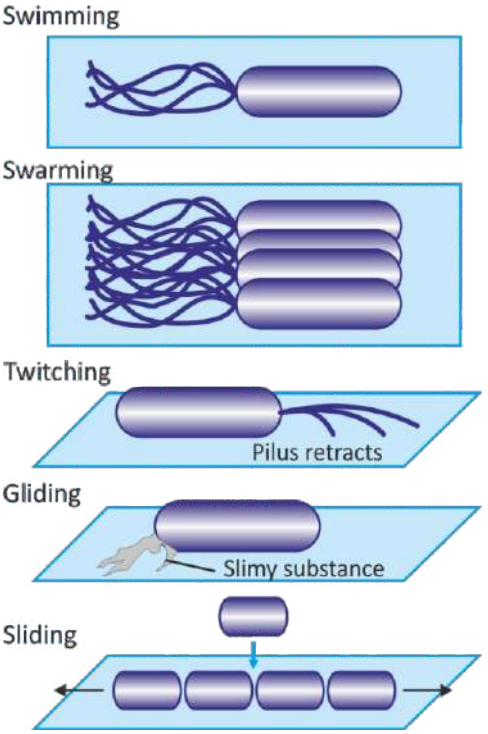


Figure 2.5: Motility in bacteria

Sliding: It is due to the expansion created by the pushing force of dividing cells.

Brownian movement: Some bacteria (e.g., *Streptococcus*) that do not have flagella or pili, move due to the random and uncontrolled movements of the particles present in fluid.

Movement by axial filament: Some bacteria (e.g., spirochaetes), have a modified flagellum. It is known as axial filament. It is anchored at one end and runs length-wise in periplasmic space (between cell membrane and outer membrane). It consists of two sets of flagella-like fibrils anchored at the two poles of cell. It helps spirochaetes for flexing, swimming, creeping and spinning movements.

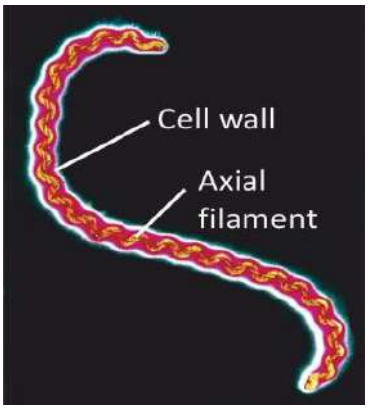


Figure 2.6: Axial filament in a spirochaete

2.5- FLAGELLA

Many kinds of bacteria have flagella, which enable them to move. The secondary function of flagella is to detect and respond to chemical signals. The bacteria which do not possess flagella are called atrichous. The bacteria with single polar flagellum are called monotrichous. The bacteria with a tuft of flagella at one pole are called lophotrichous. The bacteria with flagella at each of two poles are called amphitrichous. The bacteria with flagella surrounding the whole cell are called peritrichous (Figure 2.7).

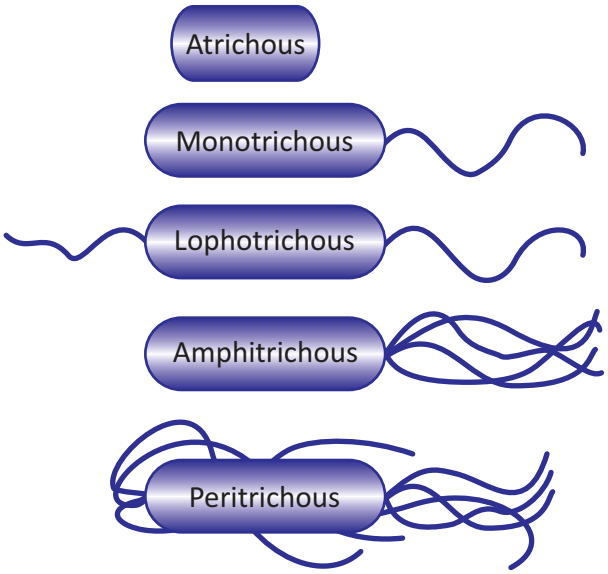


Figure 2.7: The different arrangements of bacterial flagella

Structure

The flagellum of bacteria is entirely different in structure from the flagellum of eukaryotes. They are not built on 9+2 pattern of microtubules, but are composed of flagellin protein. The bacterial flagellum consists of a basal body, a hook and a filament. The basal body is present just beneath cell membrane. It consists of rotating rings (one pair in Gram-positive bacteria and two pairs in Gram-negative bacteria). The rings anchor the flagellum in cell membrane and cell wall. The hook is a curved structure that connects basal body with the filament.

Some bacteria have pili (singular; pilus). These are non-helical, filamentous appendages and are smaller and thinner than flagella. Pili are used for attachment of bacteria to various surfaces. They are also involved in the mating process (conjugation) between cells.

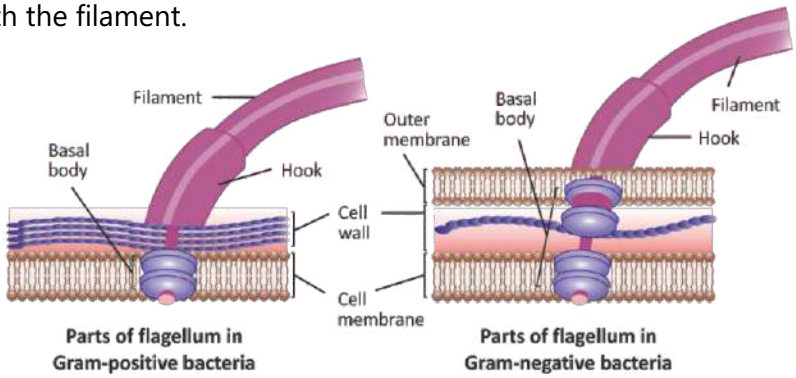


Figure 2.8: The structure of bacterial flagella

2.6- BACTERIA;ECOLOGY AND DIVERSITY

The fossil record shows that prokaryotes i.e., archaea and bacteria were abundant 3.5 billion years ago. They evolved and remained all alone on Earth for the next 2 billion years. Today, prokaryotes (archaea and bacteria) are found wherever there is life. Bacteria are found in water, air, soil, food and in the bodies of animals and plants. They outnumber all eukaryotes. They can survive in extreme habitats.

Diversity in Bacteria and their Ecology

Margulis and **Schwartz** proposed a useful classification system for all prokaryotes. They classified them into 16 phyla. The following discussion deals with the important groups of the domain bacteria (Figure 2.9).

Perhaps most interesting of all is the recent discovery that the bulk of our modern petroleum deposits were formed by masses of decayed cyanobacteria.

1- Omnibacteria: These are rigid, rod-shaped, heterotrophic, Gram-negative bacteria. Many important pathogens are included in this group. Most of these bacteria have flagella. They do not produce spores. They are usually aerobic. *Escherichia coli* is an example of such bacteria. This group also includes vibrios.

2. Cyanobacteria: These are photosynthetic bacteria. They played most important role in the history of the Earth for increasing free oxygen in atmosphere. They contain chlorophyll-a and accessory pigments like carotenoids, and blue and red phycobilins. Many cyanobacteria fix atmospheric nitrogen in their special cells called **heterocysts** They are common in soil in the form of mats. Cyanobacteria-containing lichens are found on rock surfaces. The mats on the sediments in the sea are dominated by cyanobacteria.

Colourful blooms may occur in polluted water as a result of the rampant growth of cyanobacteria. The colours of such blooms result from the photosynthetic pigments of cyanobacteria.

3. Mycoplasmas and **Spiroplasmas** These groups differ from all other bacteria in that they lack cell walls. As they lack cell walls, they are resistant to penicillin and other antibiotics that work by inhibiting cell wall growth. Some mycoplasmas cause diseases in mammals e.g., certain types of pneumonia in humans. Spiroplasmas cause significant plant diseases e.g., the lethal yellowing disease of coconuts.

4. Spirochaetes These are long spirilla with Gram-negative cell walls. They may have 2 to more than 100 flagella. *Treponema* are important spirochaetes. They cause syphilis (a fatal sexually transmitted disease).

5. Pseudomonads These are straight or curved Gram-negative rods with one or many flagella at one end. They are found in soil and water. They can easily break down organic compounds. Some of them are autotrophic but many are plant pathogens. Some of them play role in denitrification. *Pseudomonas aeruginosa* occurs in soil, water and raw

vegetables. Although it is usually harmless, it can form serious infections in weak people.

6. Actinomycetes These have filamentous growth forms. They produce spores that are resistant to unfavourable conditions. Some actinomycetes are nitrogen fixers and are found in the root nodules of many flowering plants. Some actinomycetes are responsible for dental plaque, in which the enamel of teeth is destroyed. A member of this group i.e., *Mycobacterium leprae* causes leprosy. Another member i.e., *Mycobacterium tuberculosis*is the cause of tuberculosis. Many antibiotics e.g., tetracycline, chloramphenicol, erythromycin, and neomycin were derived originally from actinomycetes.

7. Nitrogen-fixing aerobic bacteria: This group includes economically important bacteria. They are Gram-negative and most are flagellated. *Azotobacter*is a member of this group. It is found in soil and water and converts atmospheric nitrogen into nitrates.

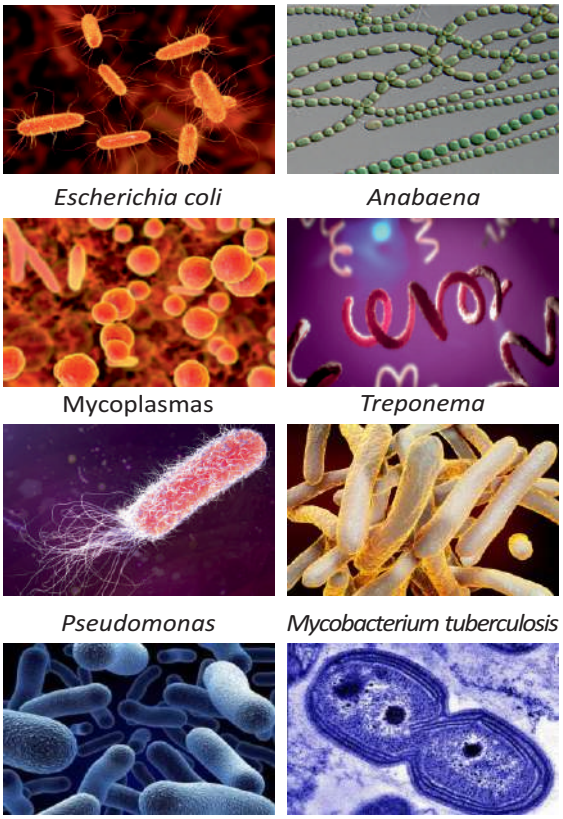


Figure 2.9: Major groups of bacteria

About 150 new antibiotics from actinomycetes are being discovered each year.

8. Chemosynthetic bacteria: These bacteria derive energy from the oxidation of inorganic compounds of nitrogen, sulphur and iron. They use this energy for the synthesis of their food. *Nitrosomonas* and *Nitrobacter* are included in this group. They oxidize nitrogen compounds (NH_3) to gain energy. The NH_3 is in turn converted to nitrite and nitrate. Thus, they play vital role in nitrogen cycle.

Table: Characteristics of some Groups of Bacteria

Name of Group	Form	Motility	Nutrition	Ecological role
Omnibacteria	R	N, F	H	Pathogens and decomposers
Cyanobacteria	R, C, M	G, N	P	Carbon and nitrogen fixers
Mycoplasmas and Spiroplasmas	No wall	N	H	Pathogens
Spirochaetes	S	F	H	Decomposers and pathogens

Pseudomonads	R	F	H, C	Decomposers and plant pathogens
Actinomycetes	M, R	N	H	Pathogens and nitrogen fixers
N-fixing aerobes	R	N, F	H	Free-living and mutualistic nitrogen fixers
Chemosynthetic	R, C	N, F	C	Oxidize nitrogen and sulphur compounds, play role in nitrogen cycle

Form: R, rods (bacilli); C, cocci; S, spirilla; M, regular chains or aggregations
Motility: F, flagellated; N, nonmotile; G, gliding
Nutrition: H, heterotrophic; C, chemosynthetic; P, photosynthetic

2.7- IMPORTANCE OF BACTERIA

Bacteria are very important organisms not only for environment but also for all other organisms. They have beneficial as well as harmful effects on life on Earth.

Beneficial Bacteria

Among the great diversity of bacteria, many bacteria are beneficial ecologically as well as economically.

Recyclers of nature

Bacteria are involved in almost all biogeochemical cycles in which different essential elements move to and fro between organisms and environment. Nitrifying bacteria (*Nitrosomonas, Nitrobacter* and *Azotobacter*) and denitrifying bacteria (*Pseudomonas*) play significant role in the completion of nitrogen cycle. Decomposer bacteria decompose dead organic matter and play key role in carbon-hydrogen-oxygen cycle. The activities of photosynthetic bacteria e.g., cyanobacteria play role in the increase of free oxygen in Earth's atmosphere.

Makers of useful products

Many bacteria e.g., *Lactobacillus* in combination with yeasts and molds, have been used for thousands of years in the preparation of fermented foods such as cheese, pickles, soy sauce, vinegar, wine and yogurt. In pharmaceutical and agrochemical industry, bacteria are most important in the production of important chemicals. Some bacteria are used for the production of antibiotics. Commercial preparation of animals' skin for making leather goods, involves the use of bacteria.

Environmental cleaners

Many bacteria can degrade organic compounds very easily. Such bacteria have been used for the removal or degradation of pollutants (bioremediation) from environment. For example, bacteria are used to decompose city sewage into harmless products. Some bacteria can digest the hydrocarbons present in petroleum. These bacteria are used to clean up oil spills. Bacteria are also used for the bioremediation of industrial toxic wastes.

Biopesticides

Bacteria are used in the place of pesticides in biological pest control. This commonly involves Bacillus thuringiensis, a Gram-positive, soil dwelling bacterium.

These biopesticides are environmentally friendly and have little or no effect on humans, wildlife, pollinators and most other beneficial insects.

Research and technology tools

Bacteria can grow quickly and scientists can manipulate with them very easily. Due to these reasons, bacteria are used in the fields of molecular biology, genetics and biochemistry. Scientists make mutations in bacterial DNA and examine the changes in characteristics. In this way, they determine the function of genes and enzymes in bacteria. This knowledge is then applied to study the same genes and enzymes in more complex organisms. Scientists also insert human genes in bacteria and produce therapeutic proteins e.g., insulin, growth hormones, or antibodies.

2.8- NORMAL FLORA

In a healthy animal, the internal tissues, e.g., blood, brain, muscle, etc., are normally free of microorganisms. On the other hand, the surface tissues, e.g., skin and mucous membranes, are constantly in contact with environment and are colonized by certain microbial species. The mixture of organisms regularly found at any anatomical site is referred to as the normal flora.

The normal flora of humans consists of bacteria, a few fungi and protists, and some methanogenic archaea. Bacteria are the most numerous and obvious microbial components of normal flora.

Benefits of Bacterial Flora of Humans

The associations between humans and their normal flora are mutualistic. In human body, normal flora gets nutrients, a stable environment and constant temperature, protection, and transport. Similarly, body also gets many benefits from normal bacteria; for example;

1. Synthesis of vitamins: Bacteria in alimentary canal produce vitamins. They excrete vitamins which are in excess of their needs. From alimentary canal, these vitamins are absorbed and distributed in body. For example, enteric bacteria secrete Vitamin K and Vitamin B12, and lactic acid bacteria produce certain B-vitamins.

2. Prevent colonization by pathogens: The bacteria of normal flora compete with pathogens for attachment sites and nutrients. So, pathogens have less chance of entering body tissues.

3. Inhibit or kill pathogens: The intestinal bacteria produce a variety of substances, which inhibit or kill pathogen bacteria.

4. Stimulates the production of cross-reactive antibodies: Since the normal flora behaves as antigens, they induce immunological response. Low levels of antibodies produced against the normal flora are known to cross-react with certain pathogens, and thereby prevent infection or invasion.

2.9- VIRUS

You are familiar with the five kingdoms of living organisms. You also know that there are some creatures that do not possess cellular organization yet show some characteristics of livings. Viruses are the representatives of such organisms.

Structure of Virus

Viruses are extremely small infectious agents and can only be seen under electron microscope. They range in size from 20 nm (parvovirus) to 250 nm (pox viruses). They are 10 to 1000 times smaller than most bacteria. That is why, they can pass through the pores of filter paper.

The central core of a virus is its genome. It is made up of nucleic acid (either DNA or RNA). The core is surrounded by a protein coat, called **capsid** It gives definite shape to virus. Capsid is made up of protein subunits called as **capsomeres** The number and kind of capsomeres is characteristic of a particular virus. Central core and capsid are collectively called as **nucleocapsid**

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

In some animal viruses only, nucleocapsid is covered by another membrane called **envelope**. It is a lipid-rich membrane and is derived from host cell. Non enveloped viruses are known as naked-viruses. There is a great diversity in the general appearance of viruses (Figure 2.10). The animal and plant viruses may be polyhedron (having many sides) or helical. The bacterial viruses (bacteriophages) may be cubical, icosahedral (having 20 faces), helical, or complex (polyhedral head and rod-shaped tail).

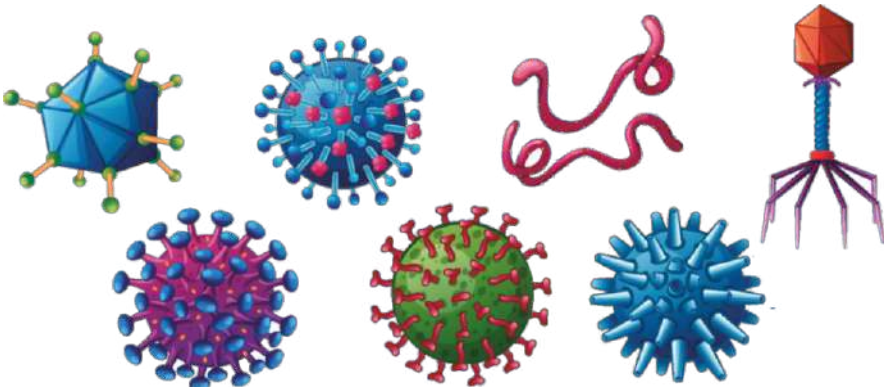


Figure 2.10: Diversity in viruses' shapes

Structure of Bacteriophage

Bacteriophages are used as carriers in genetic engineering. The gene of interest is inserted into the DNA of bacteriophage, which carries it to the

target bacterial cell. When virus incorporates its DNA into bacterial chromosome, the gene of interest also becomes a part of bacterial DNA. Such transgenic bacteria (transgenic: whose genome has DNA of some other organism) can be grown to get copies of the gene of interest and to get the required protein.

Bacteriophages are a diverse group of viruses that attack bacteria. They are among the most complex viruses. The best known phages of *Escherichia coli* are T-phages. There are many varieties of T-phages. A T4 phage consists of a head and a tail (Figure 2.11). The head is an elongated pyramidal (with two triangles having a common base), hexagonal (six sided), prism-shaped structure. Its capsid is made of proteins while core contains a long double stranded DNA. A straight tail is attached with head. The tail is also made of inner core and outer sheath, both of which are made of different proteins. A neck attaches sheath with head and an end plate is present on the other side of sheath. Six tail fibres are attached with end plate. They help the phage to attach with bacterial wall. These structures are also made of proteins.

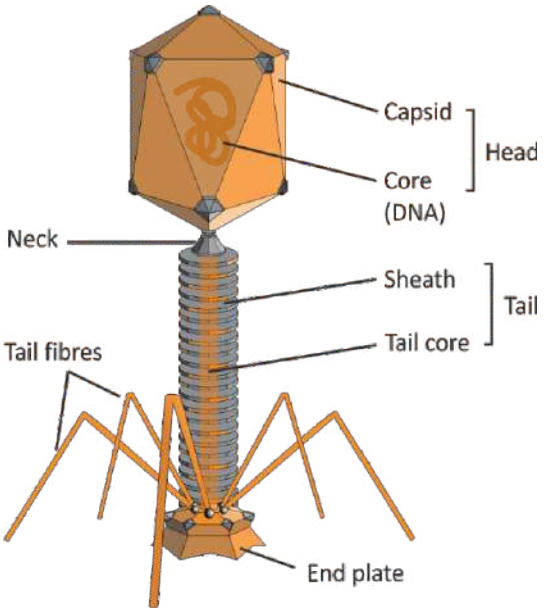


Figure 2.11 : Structure of a bacteriophage (T4 phage)

Structure of HIV

Human Immunodeficiency Virus (HIV) belongs to the group called **retroviruses** It is a special group of animal viruses. Retroviruses contain RNA and their capsids. These structures are surrounded by lipid rich envelops. The envelope also comprising glycoproteins spikes, which help the virus identify and bind to its target. They are spherical in form and are about 100 nm in diameter. The most distinguishing character of retroviruses is the presence of a specific enzyme, **reverse transcriptase** This enzyme

catalyses the process of reverse transcription in which a single stranded RNA is reversely transcribed into a strand of DNA. The enzyme then uses DNA strand to complete a double helix of DNA.

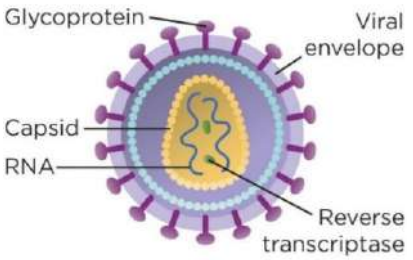


Figure 2.12: Structure of HIV

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

HIV is responsible for the disease **AIDS (acquired immunodeficiency syndrome)**. AIDS weakens the immune system of patient. The disease is fatal because no one can survive without immune system to defend against other viral and bacterial infections. The disease was first reported in 1981 and the patients were found homosexual. Later on, AIDS was discovered in non-homosexual patients too who had received blood or blood products from other AIDS patients.

In 1984, it was discovered that the agent causing AIDS was a virus. In 1986, the AIDS causing virus was given the name Human Immunodeficiency Virus (HIV). It is a host specific virus. It can multiply in monkeys but do not cause AIDS in them.

EXERCISE

SECTION 1: MULTIPLE CHOICE QUESTIONS

1. Which of the following component is not found in all kinds of bacteria?
   (a) Ribosomes (b) Cell membrane
   (c) Nucleoid (d) Capsule
2. The bacterial chromosome is typically:
   (a) Linear, double-stranded DNA (b) Circular, single-stranded RNA
   (c) Circular, double-stranded DNA (d) Linear, single-stranded DNA
3. In bacterial cells, respiration occurs at:
   (a) Mitochondria (b) Cell membrane
   (c) Ribosomes (d) Endoplasmic reticulum
4. Which group of bacteria is known as a good source of antibiotics?
   (a) Omnibacteria (b) Spirochaetes
   (c) Pseudomonads (d) Actinomycetes
5. What is the primary function of flagella in bacterial cells?
   (a) DNA replication (b) Cell division

(c) Motility (d) Protein synthesis

6. Which type of motility in bacteria is mediated by pili?
   (a) Brownian movement (b) Gliding motility
   (c) Twitching motility (d) Swarming motility
7. Which of the following bacterial structures is responsible for detecting and responding to chemicals?
   (a) Capsule (b) Pili
   (b) Flagella (d) Ribosomes
8. Which one of the following are not Nitrifying bacteria?
   (a) Nitrosomonas (b) Nitrobacter
   (c) Azotobacter (d) Pseudomonas
9. The enzyme responsible for converting HIV RNA into DNA is:
   (a) RNA polymerase (b) Reverse transcriptase
   (c) DNA helicase (d) Integrase
10. The HIV capsid contains:
   (a) Single-stranded DNA and reverse transcriptase
   (b) Single-stranded RNA and reverse transcriptase
   (c) Double-stranded DNA and integrase
   (d) Double-stranded RNA and RNA polymerase

SECTION2: SHORT QUESTIONS

1. Write about the structural components of a bacterial cell wall and their arrangement.
2. Write the composition of the peptidoglycan layer in bacterial cell walls.
3. What are mesosomes? What are their functions?
4. How can plasmids be used in genetic engineering?
5. Define sporulation.
6. What is the function of the bacterial capsule?
7. Write the role of pili in bacterial cells. How do they differ from flagella?
8. What are plasmids, and how do they contribute to enabling bacteria to resistance against unfavourable conditions?
9. Write about the role of endospores in bacterial survival.
10. What is the significance of lipopolysaccharides and lipoproteins in Gram-negative bacteria?
11. How do spirochetes achieve motility?
12. Differentiate between twitching and gliding movements in bacterial motility.
13. How do bacteria without flagella achieve motility?

14. What is the difference between swimming motility and swarming motility in bacteria?

SECTION 3: LONG QUESTIONS

1. Compare and contrast the cell wall of Gram-positive and Gram-negative bacteria.
2. Explain different methods of movement in bacteria.
3. Explain the structure of bacterium flagellum.
4. State the formation of endospore in bacteria.
5. Briefly describe the ecological and economic importance of bacteria.
6. Explain the use of bacteria in research and technology.
7. Define the term normal flora. State the benefits which we get from normal bacterial flora.
8. Explain the structure of a model bacteriophage and HIV.

INQUISITIVE QUESTIONS

1. Why do bacteria have ribosomes even though they do not have membrane-bound organelles?
2. If bacteria do not have mitochondria, how do they generate energy for survival?
3. Why do certain bacteria exhibit twitching motility using pili instead of flagella?
4. Give reasons in favour of the statement "Prevention is better than cure" and present your arguments in the class.
5. Correlate the social and cultural values of a country with the prevalence of AIDS.

Chapter 3

CELLS AND SUBCELLULAR ORGANELLES

STUDENTS'LEARNING OUTCOMES

After studying this chapter, the students will be able to:

- Describe that cells are the basic unit of life with respect to seven properties of life (movement, respiration, homeostasis, growth, reproduction, excretion, nutrition).
- State cell theory (including how to validate it and exceptions to it).
- Compare and contrast the workings of a light microscope and electron microscope with focus on resolution and magnification and live vs dead samples.
- Identify the ultrastructure of animal and plant cells.
- Describe the structure and functions of cell wall, cell membrane and subcellular organelles (endoplasmic reticulum, ribosomes Golgi apparatus, vesicles, lysosomes, peroxisome, vacuoles, mitochondria, plastids, centrioles, nucleus).
- Differentiate between prokaryotic and eukaryotic cells with diagrams.
- Explain the structure of the cell membrane and the techniques that can be used to study it.
- Define cell signalling.
- Discuss the pathway of a signal from outside the cell to the inside. (protein signal and steroid signal).
- Explain the 4 membrane transport mechanisms with diagrams (simple diffusion, facilitated diffusion, osmosis, active transport).
- Describe endocytosis and exocytosis with diagrams.
- Compare and contrast simple and facilitated diffusion.
- Define stem cells and advantages of using stem cells
- Categorize different types of stem cells.
- Evaluate the advantages and disadvantages of using induced Pluripotent Stem Cells.

In this chapter "Cell and Subcellular Organelles," we will do a detailed study of cells, the fundamental units that compose all living things. Building on your previous knowledge from Grade IX, we will explore the cell theory and examine the structures of both animal and plant cells. You'll also discover the vital processes of cell signalling, and the revolutionary potential of stem cells. Additionally, we will investigate the mechanisms of membrane transport that are crucial for cellular function.

3.1- CELLS – THE BASIC UNIT OF LIFE

Cells are the basic unit of life, making up every living organism. In unicellular organisms like amoebas and bacteria, a single cell carries out all the functions necessary for life. Multicellular organisms, such as plants and animals, are composed of numerous specialized cells that work together to sustain life.

You know that all living organisms show the seven basic properties of life i.e., movement, respiration, homeostasis, growth, reproduction, excretion, and nutrition.

These properties actually define living organisms. Cells perform all the fundamental activities that characterize living organisms.

1. **Movement:** Cells can move. For example, sperm cells move with their flagella. White blood cells travel through the bloodstream to fight infections. Inside cells, organelles move to carry out vital functions.
2. **Nutrition:** Cells obtain nutrients from their environment to produce energy, build cellular structures, and drive biochemical reactions.
3. **Respiration:** Cells generate energy through respiration. This process breaks glucose to release ATP, the energy currency that powers cellular activities.
4. **Excretion:** Cells remove waste products through diffusion and active transport, preventing toxic buildup.
5. **Homeostasis:** Cells maintain a stable internal environment by regulating the movement of substances across their membranes.
6. **Growth:** Cells grow by taking in nutrients and converting them into cellular components.
7. **Reproduction:** Cells reproduce through mitosis and meiosis. Mitosis produces identical daughter cells for growth and repair, while meiosis creates gametes for sexual reproduction.

3.2- CELL THEORY

At the beginning of 17th century, many scientists began the use of microscopes to study very small objects. In 1665, English scientist **Robert Hooke** examined a thin slice of cork of oak tree under microscope. He observed that the cork was made of "many little boxes". Hooke also examined the pieces of stem and root of oak tree under microscope. He found that these were also made of similar little boxes. He concluded that the parts of plants were made of compartments. Hooke named these compartments as **"cellulae"**.

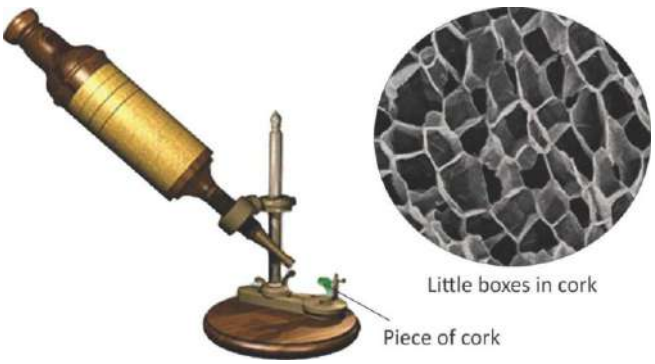


Figure 3.1: Robert Hooke's microscopeand observation

In 1673, a Dutch scientist **Anton van Leeuwenhoek** made a better microscope and observed living cells in pond water. He called these cells as **animalcules**

In 1809, the French biologist **Jean Baptiste de-Lamarck** also observed cells when he examined the parts of animals and plants under microscope. Later on, in 1831 the British botanist **Robert Brown** discovered nucleus in the cell.

After these studies, biologists began to organize information about cells. In 1838, the German botanist **Matthias Schleiden** observed many parts of plants under microscope. He concluded that all plants were composed of cells. The next year, the German zoologist **Theodor Schwann** concluded the same for animals. In 1885, the German physician **Rudolf Virchow** (1821–1902) observed that all cells come from other cells. In 1862, **Louis Pasteur** provided the experimental proof of this idea. These observations were combined to form a basic theory about cells. It is called cell theory. It has three essential points.

1. All living organisms are composed of one or more cells.
2. Cells are the basic units of structure and function in an organism.
3. Cells come only from the division of pre-existing cells.

Validation of Cell Theory

Cell theory can be validated through several observations and experiments. For example:

1. By using light microscopes and electron microscopes, scientists visualize cell structures and find tangible evidence that cells are indeed the structural units of all living organisms.
2. Through techniques like live-cell imaging and genetic studies, scientists can track how cells replicate and give rise to new cells. These techniques validate the principle that all cells originate from pre-existing cells.
3. Techniques like DNA sequencing reveal that cells share common genetic material and metabolic pathways, reinforcing the notion that the cell is the fundamental unit of life.
4. Experiments, such as cell culture studies and tissue engineering, validate cell theory by demonstrating cellular growth, differentiation, and reproduction.

Exceptions to Cell Theory

While cell theory is widely accepted, there are notable exceptions. For example:

1. Viruses challenge cell theory because they are not made of cells and cannot carry out life processes independently. They require a host cell to replicate and are considered by many scientists to be at the border of living and non-living entities. Similarly, prions and viroids show properties of living organism but are not composed of cells. They are made of only DNA, RNA or proteins.

2. Eukaryotic organelles mitochondria and chloroplasts have their own DNA and can replicate independently of the cell's nucleus. This suggests they may have originated from free-living prokaryotic cells.
3. Some organisms, such as certain fungi and algae, have structures where multiple nuclei coexist within a shared cytoplasmic mass. These structures blur the boundaries of individual cells as defined by traditional cell theory.
4. Muscle cells (myocytes) in vertebrates can fuse to form multinucleated fibres, challenging the concept of a single cell as the basic unit in complex tissues.

3.3- MICROSCOPY

The discovery of cells and then the further studies of the internal structure of cells were dependent upon the use of microscope. Microscopy is the technique of using microscopes to observe and study objects that are too small to be seen with the naked eye. Microscopes use lenses and light or electron beams to magnify and illuminate specimens.

Magnification and Resolution

These are two key characteristics of microscopes.

Magnification: This refers to a microscope's ability to enlarge the image of an object. Different lenses within a microscope offer varying levels of magnification. It is denoted by the symbol 'X', indicating how many times larger the image appears compared to the actual size. For example, a 10X lens can enlarge a 1 µm object to 10 µm. Total magnification in a microscope is determined by multiplying the magnification of all lenses.

Resolution: This refers to a microscope's ability to distinguish between two points that are close together on an object. The greater the resolution, the finer the detail that can be observed. The naked human eye has a resolution of about 0.1 mm. In contrast, a light microscope can resolve details down to approximately 250 nm (nanometres).

Light Microscopy

In light microscope, light is used to make the image of object. Light passes through object and then through two glass lenses. One lens produces an enlarged image of the object and the second lens magnifies the image more. After passing through object and lenses, the light forms enlarged clear image of object in viewer's eye.

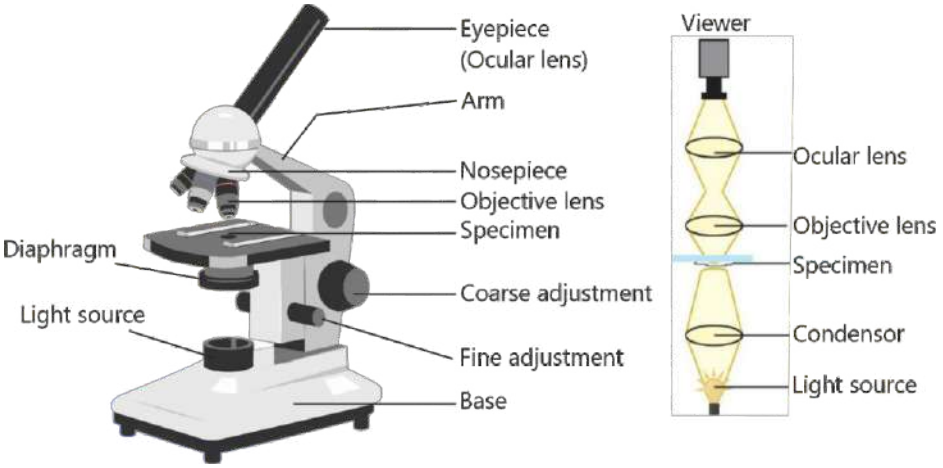


Figure 3.2: (a) Major parts of light microscope; (b) Working Principle of Light Microscope

The magnification of a light microscope is 1500X. It means it can magnify objects about 1500 times. Its resolving power is 0.2 micrometre (µm) and 1µm = 1/1000 mm. In other words, the light microscope cannot distinguish objects smaller than 0.2 µm.

Light microscopes are advantageous for viewing living organisms, but since individual cells are generally transparent, their components are not distinguishable unless they are coloured with special stains (coloured chemicals). Staining, however, usually kills the cells.

Electron Microscopy

In electron microscope, a beam of electrons passes through the object. Magnetic lenses focus the electron beam on a screen or photographic film and make much enlarged image. Its resolving power is much greater than light microscope. It can clearly show objects as small as 0.2 nanometre (nm) and 1 nm = 1/1000,000 mm. However, electron microscope cannot be used for viewing living material because of the methods needed to prepare the specimens. Biologists use two types of electron microscopes.

Transmission Electron Microscope (TEM) is used to view the internal structure of cell. TEM transmits a beam of electrons through a very thin specimen. It can magnify objects up to 250,000 times. **Scanning Electron Microscope (SEM)** is used to study the details of surfaces of cells or any other objects. The surfaces are coated with metal. When electron beam hits the metal, it is reflected and makes enlarged image. SEMs can magnify objects up to 100,000 times.

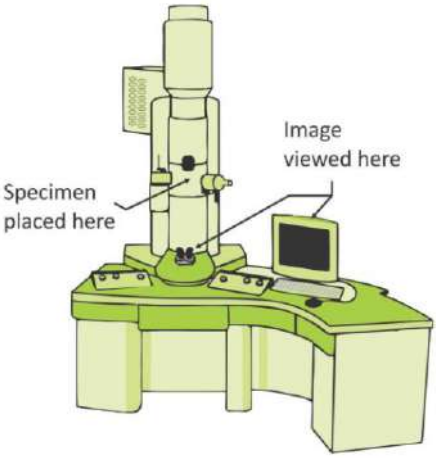


Figure 3.3: Electron microscope

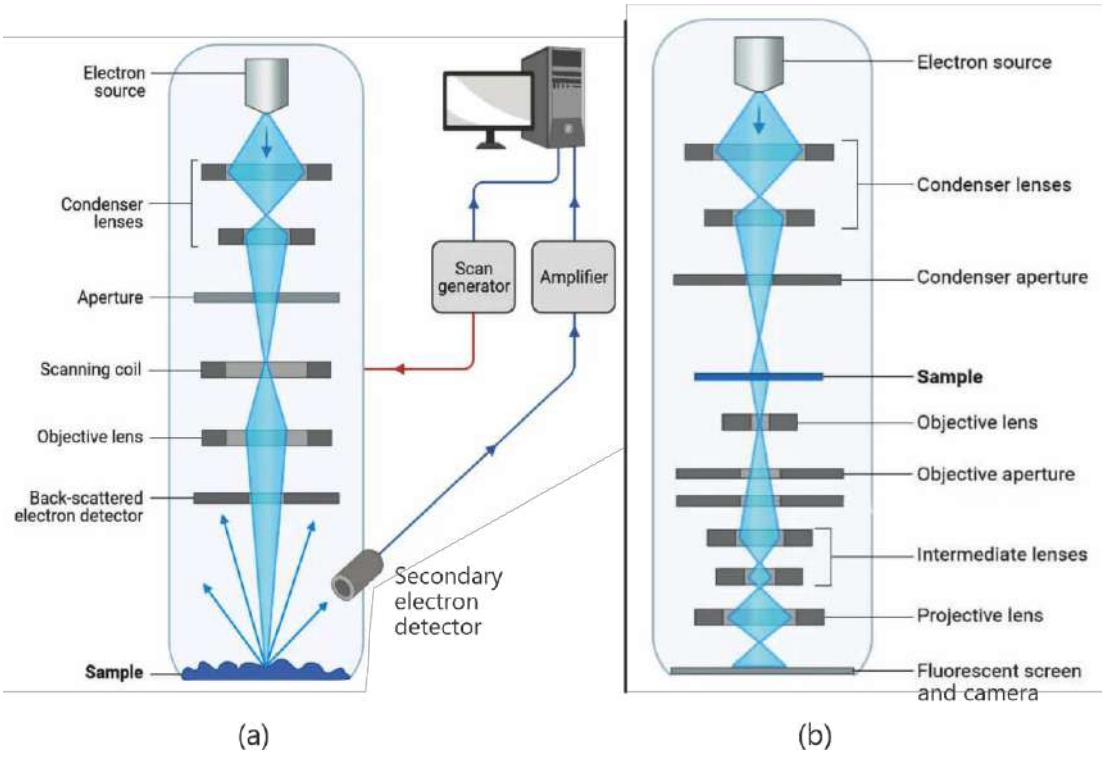


Figure 3.4: Working principle of; (a) Scanning electron microscope; (b) Transmission electron microscope

Difference Between Electron Microscope and Light Microscope	
Light Microscope	**Electron Microscope**
Uses light (approx. 400-700 nm) as an illuminating source	Uses electron beams (approx. 1 nm) as an illuminating source
Lower magnification (usually 500X to 1500X) than an electron microscope	Higher magnification (direct magnification is 16000X and photographic magnification is 1000000X)
Low resolution (may be 0.2 µm)	High resolution (may be 0.2 nm)
Both live and dead specimens can be seen	Only dead and the dried specimen can be seen
Specimen preparation takes about a few minutes or an hour	Specimen preparation takes several days
The image is seen through the ocular lens. No screen needed	The image is received on a zinc sulphate fluorescent screen

3.4- Structure of Cell

You know that there are two basic types of cells i.e., prokaryotic and eukaryotic. All bacteria are prokaryotes. Yeast and Euglena are examples of unicellular eukaryotes. Plants and animals are examples of multicellular eukaryotes. Eukaryotic cells are more complex than the prokaryotic cells. In the following paragraphs we will study the structures present in cells and their functions.

Cell Wall

Cell wall is a more or less solid layer surrounding a cell. It is found in bacteria, fungi, plants, and algae. When a cell wall is removed using cell wall degrading enzymes, the remaining components of the cell are called a **protoplast**.

The **primary wall** is the actual cell wall of cell. It is composed of polysaccharides i.e. cellulose, hemicellulose and pectin. The cellulose microfibrils are aligned at all angles and are held together by

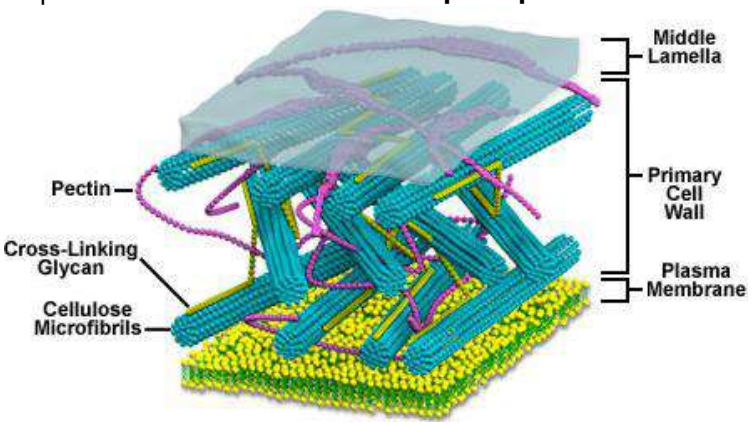


Figure 3.5: The composition of primary cell wall

hydrogen bonds. Many proteins are also present in primary walls. The **middle lamella** is a gelatinous layer that separates and holds the primary walls of the neighbouring cells. It is laid first, formed from the cell plate during cytokinesis, and the primary cell wall is then expanded inside the middle lamella. It contains magnesium and calcium pectates (salts of pectic acid). In some plant cells, after maturation, a **secondary wall** is made between protoplast and primary wall. Secondary cell walls contain lignin, cellulose and hemicellulose. Due to the presence of lignin, secondary wall is more rigid than the primary wall.

Plasmodesmata (singular, plasmodesma): These are small channels that directly connect the cytoplasm of neighbouring plant cells to each other. Plasmodesmata penetrate both the primary and secondary cell walls. They allow certain molecules to pass directly from one cell to another. So, they are important in cellular communication.

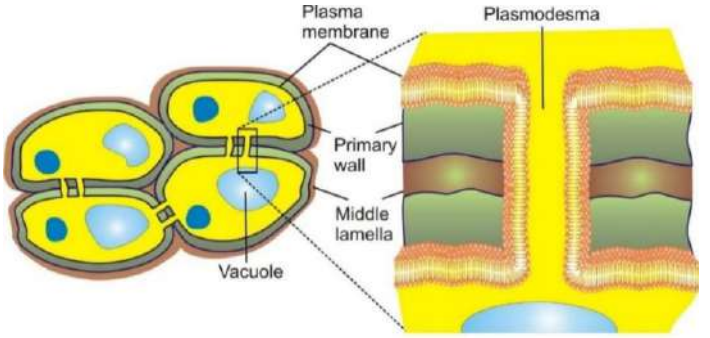
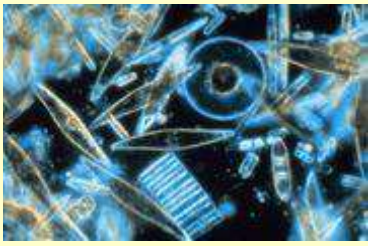


Figure 3.6: The cell walls of two neighbouring cells showing a plasmodesma

Plasmodesmata have caused debate among scientists regarding cell theory. Some scientists suggest that the cells of higher plants are not really cells since they are not physically separated or independent from one another.

The group of algae called diatoms synthesize their cell walls from silicic acid. The acid is polymerized inside cells, then the wall is extruded to protect the cell. The synthesis of Silica cell walls requires less energy. That is why there are higher growth rates in diatoms.



Plasmodesmata are formed during cell division when parts of the endoplasmic reticulum of the parent cell get trapped in the new cell wall.

Cell walls have a number of functions: They provide rigidity to the cell for structural and mechanical support; maintain cell shape and the direction of cell growth and ultimately the architecture of the plant. The cell wall also prevents expansion when water enters the cell. Cell walls protect against pathogens and the environment and are a store of carbohydrates for the plant.

The cell wall of algae contains cellulose and a variety of glycoproteins.
The cell wall of fungi is composed of chitin, the same carbohydrate that gives strength to the exoskeletons of insects.
The cell wall of prokaryotes (bacteria and cyanobacteria) is composed of peptidoglycan, that is a single large polymer of amino acids and sugar.
The cell wall of archaebacteria is composed of different polysaccharides and proteins, with no peptidoglycan.

Plasma Membrane

All prokaryotic and eukaryotic cells have a plasma membrane that encloses their contents and serves as a semi-porous barrier to the outside environment.

Structure of plasma membrane

The fluid mosaic model is a widely accepted concept that describes the dynamic nature of plasma membrane. It was proposed by two American biologists S.J. Singer and Garth Nicolson in 1972. According to the fluid mosaic model, the basic foundation of plasma membrane is a **lipid bilayer**. This bilayer is made of phospholipids. A collection of proteins float within the lipid bilayer.

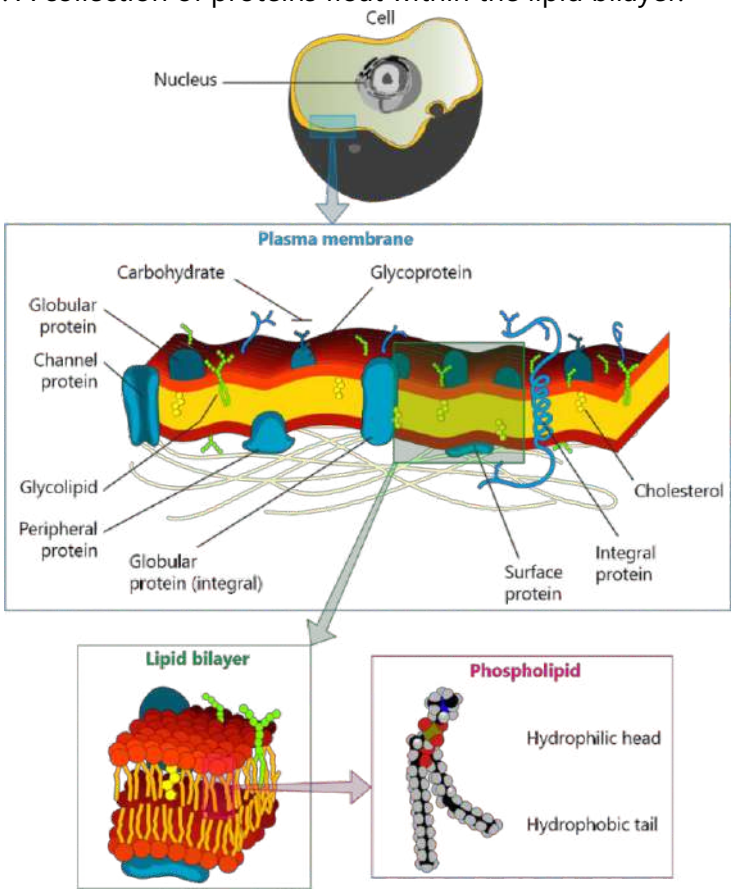


Figure 3.7: Structural components of plasma membrane

The phospholipids have a phosphate group at one end of each molecule. Phospholipids are characteristically **hydrophilic** ("water-loving") at their phosphate ends and **hydrophobic** ("water-fearing") along their tail regions containing C-H chains. In the lipid bilayer of plasma membrane, the hydrophobic lipid tails are oriented inwards and the hydrophilic phosphate groups are aligned outwards, either toward the cytoplasm of the cell or the extracellular environment.

The interior of lipid bilayer sheet is hydrophobic. It repels water-soluble molecules that attempt to pass through it. If a cell was fully encased in pure lipid bilayer, it would be completely impermeable to water-soluble molecules e.g., sugars, polar amino acids etc. That is why, in addition to phospholipids molecules, the membranes also contain proteins that provide passageways across the membrane.

In eukaryotes, plasma membranes have cholesterol molecules, wedged into the phospholipid bilayer. They keep the fluidity of membrane at low temperatures. Many proteins float within the phospholipid bilayer of plasma membrane. Some other proteins simply adhere to the surfaces of the bilayer. The positioning of proteins is related to the organization of cytoskeleton. Plasma membrane proteins function in several different ways.

- Many proteins play role in the selective transport of certain substances across the phospholipid bilayer, either acting as channels or active transport molecules.
- Some proteins help in attachment of plasma membrane to cytoskeleton and external fibres.
- Some proteins, on the exterior surface, attach with sugars and make identification marks.
- Other proteins function as receptors, which bind messenger molecules (e.g. hormones) and transmit signals to the interior of cell.
- Some proteins also exhibit enzymatic activity, catalysing various reactions related to the plasma membrane.

The ability to distinguish among different cells is crucial to life. In allows cells in an embryo to sort themselves into tissues and organs. It also helps cells of the immune system to recognize and reject foreign cells, e.g., infectious bacteria.

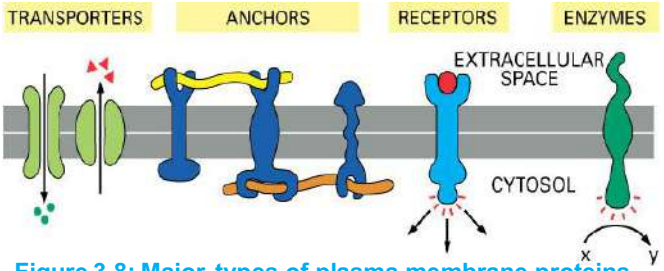


Figure 3.8: Major types of plasma membrane proteins

Membrane	Percent by weight		
	Protein	Lipid	Carbohydrate
Human red blood cell	49	43	8
Mitochondria (outer membrane)	52	48	0
Mitochondria (inner membrane)	76	24	0
Bacteria	75	25	0

The outside surface of plasma membrane has chains of sugars bonded to proteins and lipids. A protein with attached sugar is called a **glycoprotein**, whereas a lipid with attached sugar is called a **glycolipid**. The glycoproteins and glycolipids vary from species to species, from individual to individual in the same species, and even from one cell type to another in the same individual. The glycolipids and glycoproteins (collectively called glycocalyx) function as cell identification marks that are recognized by other cells.

Functions of plasma membrane

Plasma membranes serve as semi-porous barriers to the outside environment. The membrane acts as a boundary, holding the cell constituents together. The plasma membrane is permeable to specific molecules, however, and allows nutrients and other essential elements to enter the cell and waste materials to leave the cell. Small molecules, such as oxygen, carbon dioxide, and water, are able to pass freely across the membrane, but the passage of larger molecules, such as amino acids and sugars, is carefully regulated. Eukaryotic cells also have membranes around some of their interior organelles. Like the exterior plasma membrane, these membranes also regulate the flow of materials into and out of organelles.

Techniques to study the structure of plasma membrane

1. Transmission Electron Microscopy can reveal detailed structures of the lipid bilayer and associated proteins.
2. Scanning Electron Microscopy is useful for examining the surface topology of cells and membranes.
3. Confocal Microscopy uses laser scanning and fluorescence to create sharp, detailed images of the cell membrane.
4. Total Internal Reflection Fluorescence Microscopy is used for high-resolution images of the membrane and its interactions with the cytoskeleton and other cellular components.
5. Atomic Force Microscopy provides topographical images of cell membrane at high resolution.
6. X-ray Crystallography is used to determine the atomic structure of membrane proteins.

7. Lipidomics involves the comprehensive analysis of lipids in the cell membrane using techniques like mass spectrometry.
8. Fluorescence Recovery After Photobleaching is used to study the mobility and dynamics of membrane proteins and lipids. It involves bleaching a fluorescently labelled region of the membrane with a laser and observing the recovery of fluorescence as unbleached molecules move into the area.

Cytoplasm and Organelles

You know that a cell consists of three major components i.e., plasma membrane, cytoplasm and nucleus. The cytoplasm is a semi-viscous and semi-transparent substance. In eukaryotic cells, it is present between the plasma membrane and nuclear envelope. In prokaryotic cells, it covers all the space beneath plasma membrane. It consists of an aqueous ground substance, known as **cytosol**, which contains a variety of organelles and other inclusions. Cytosol contains water in which many organic (proteins, carbohydrates, lipids) and inorganic salts are completely or partially dissolved. The cytoplasm of the cell provides space for the proper functioning of the organelles and also acts as the site for various biochemical (metabolic) reactions for example Glycolysis (breakdown of glucose during aerobic respiration).

The cytoplasm contains discrete structures which are specific for various cellular functions and are called **cell organelles** The organelles are generally enclosed by membrane except few such as ribosome. The following paragraphs describe the structures and functions of important organelles.

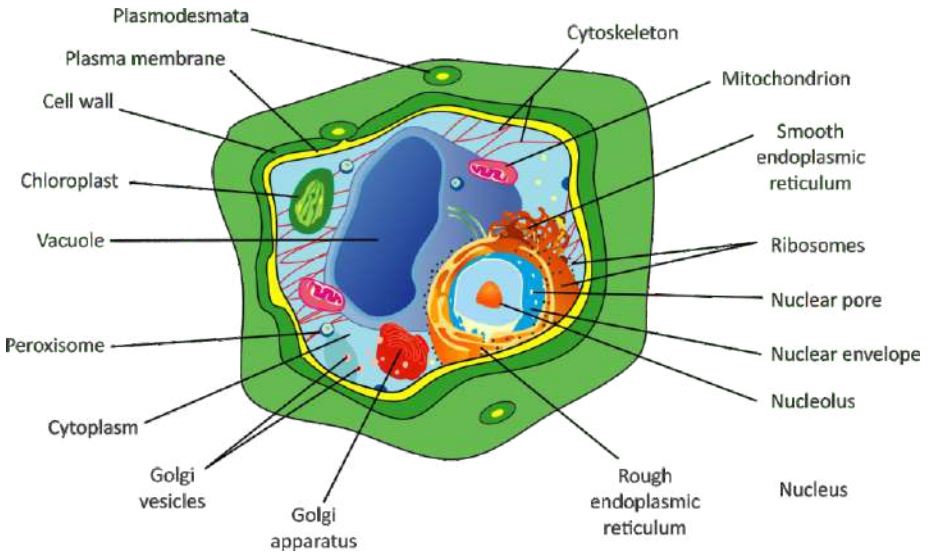


Figure 3.9: The Ultra-structure of a Plant cell

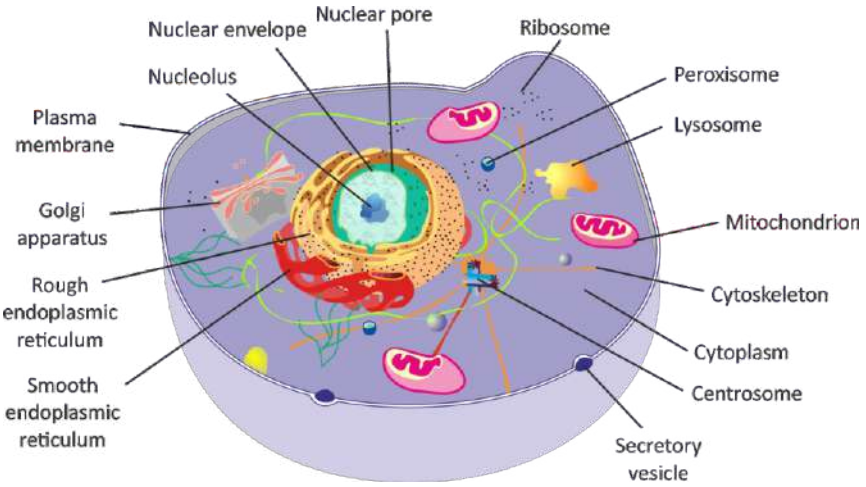


Figure 3.10: The Ultra-structure of an Animal cell

1- Nucleus

A prominent nucleus is present in all eukaryotic cells (at centre in animal cells while pushed to side in plant cells). The spherical nucleus typically occupies about 10 percent of a eukaryotic cell's volume. It serves as information processing and administrative centre of the cell. It performs two major functions: it stores the cell's hereditary material (DNA) and coordinates the cell's activities e.g., growth, protein synthesis and cell division.

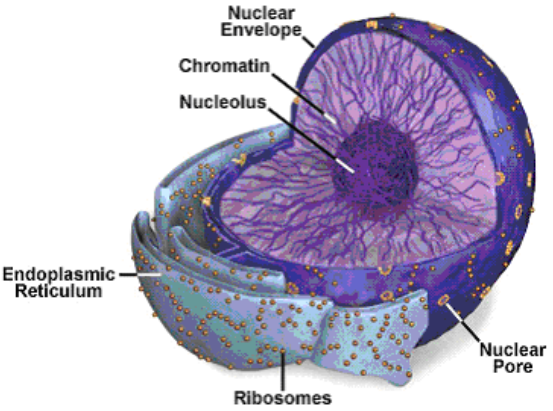


Figure 3.11 : The structure of nucleus

Building blocks of DNA and RNA and ATPs are allowed to enter into the nucleus. Ribosomal subunits which are built in nucleoli are the examples of materials that are allowed to leave the nucleus and enter the cytoplasm.

The semifluid matrix found inside the nucleus is called **nucleoplasm** Within the nucleoplasm, most of the nuclear material consists of chromatin that organizes to form chromosomes during cell division. The nucleus also contains one or more nucleoli, which synthesize ribosomes.

The Nuclear Envelope and Nuclear Pores

The nuclear envelope is a double-layered membrane that encloses the contents of the nucleus during most of the cell's lifecycle. The space between the

double layers is called the perinuclear space and is connected with the rough endoplasmic reticulum. During cell division, the nuclear envelope disintegrates, but reforms in the daughter cells. On the inner side of nuclear envelope, there is a protein lining, called **nuclear lamina**. It binds to chromatin to give it structural support.

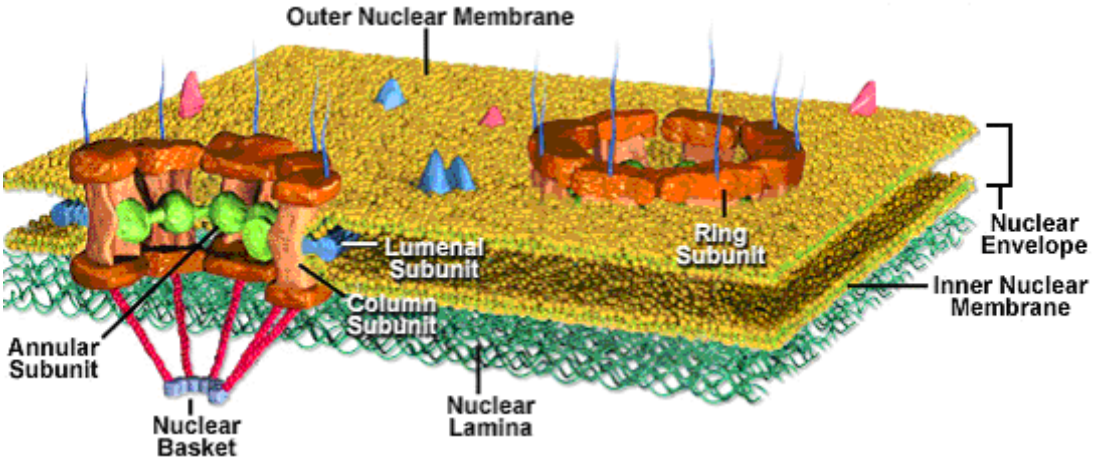


Figure 3.12: The structure of nuclear envelope and nuclearpore complex

The nuclear envelope has tiny holes known as **nuclear pores** These pores regulate the passage of molecules between nucleus and cytoplasm. Nuclear pores are permeable to small molecules. Some larger proteins, e.g., histones, are also allowed to enter into nucleus. A nuclear pore is made of an elaborate structure called the nuclear pore complex. It is composed of several subunits. These are; **annular subunit** (surrounding the inside of the pore), **column subunit** (making the wall of the complex), **ring subunit** (attached to the outer side of the column subunit), and **lumenal subunit** (anchoring the pore complex into the nuclear envelope). Tiny fibrils usually extend form the complex and make a basket-like structure on the nuclear side of the complex.

In cells that produce large amounts of protein, and thus require significant numbers of ribosomes, the size of the nucleolus is considerable.
At the onset of mitosis, the single nucleolus present in cell disappears, and after division new nucleolus is formed from the NORs.

Nucleolus

The nucleolus is a prominent darkly stained structure in the nucleoplasm. There may be one or two nucleoli in a nucleus. Nucleoli manufacture the subunits that combine to form ribosomes. Nucleoli are formed at certain sites in chromosome, called Nucleolus Organizer Regions (NORs). The DNA found at NORs encodes the ribosomal RNA (rRNA).

The nucleolus consists of granular and fibrillar components, and DNA. The granules consist of ribosomal subunits that have already been formed. The fibrils are composed of the raw materials of ribosome subunits i.e., rRNA molecules and associated proteins.

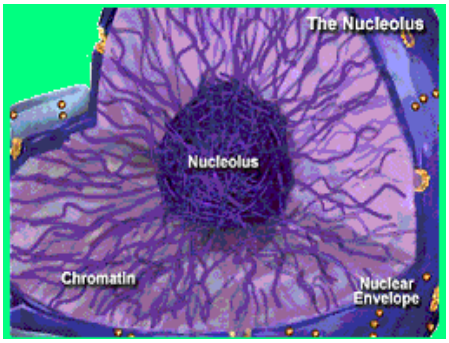


Figure 3.13: The nucleolus within a nucleus

Chromatin and Chromosomes

Nucleus contains string-like fibres, collectively called chromatin. It is composed of DNA and proteins. The structure of chromatin reveals that it is made of a series of bead-like structures, called nucleosomes. In a nucleosome, DNA strand wraps around groups of small proteins called histones.

Inside the nucleus of every human cell, there is a 6 feet long DNA. It is subdivided into 46 individual molecules (each 1.5 inches long), one for each chromosome.

During interphase (when the cell is carrying out its normal functions), the chromatin is dispersed throughout the nucleus in the form of a tangle of fibres. When the cell begins to divide, all chromatin strands are compressed into specialized structures, the chromosomes. A chromosome is made of arms, called chromatids, and a central point, called centromere.

There are two types of chromatin. **Euchromatin** is the genetically active chromatin involved in transcribing RNA to produce proteins. The other kind of chromatin is termed **heterochromatin**. Its DNA is genetically inactive.

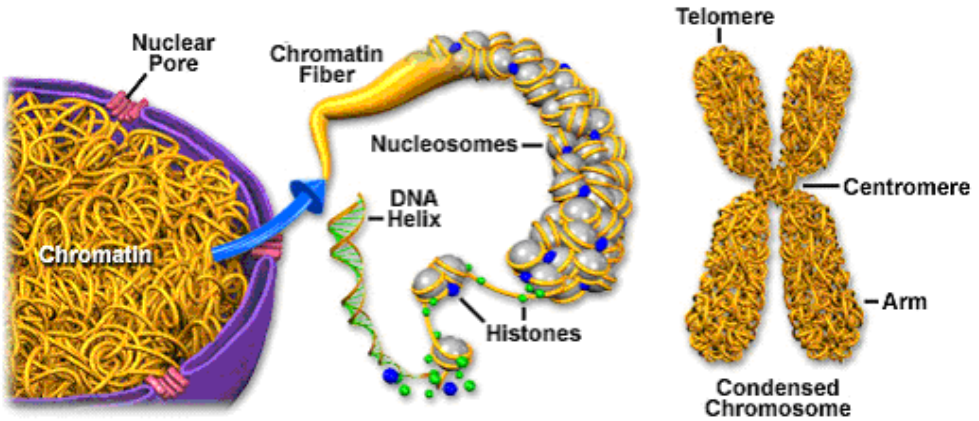


Figure 3.14: Condensation of chromatin to form a chromosome

The number of chromosomes within the nuclei of an organism's cells is species-specific. Human diploid cells (those that are not gametes) have 46 chromosomes. The chromosome number may be as low as 2, as in some ants and

roundworms, or more may be than a thousand, as in the Indian fern (*Ophioglossum reticulatum*), which has 1,260 chromosomes. It means that the number of chromosomes in a species does not correlate to the complexity of the organism.

2- Endoplasmic Reticulum(ER)

It is a network of flattened sacs and branching tubules that extends throughout the cytoplasm in plant and animal cells. These sacs and tubules are called cisternae (singular *cisterna*).

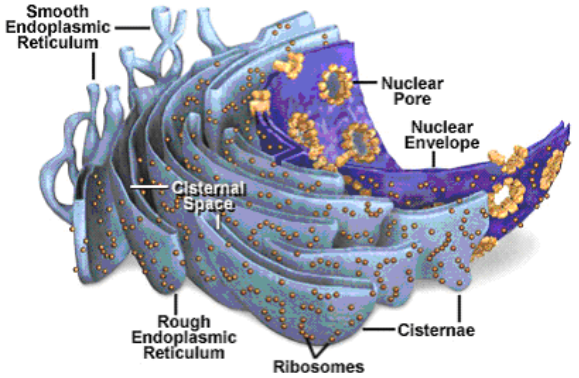


Figure 3.15: Endoplasmic reticulum

Due to their physical membranous connection, the lumen of the endoplasmic reticulum and the space between the layers of the nuclear envelope comprise a single compartment. This close association enables the endoplasmic reticulum and the nucleus to share information in a very efficient manner.

All cisternae are interconnected so that the ER has only one large and highly convoluted lumen, called cisternal space. It takes up more than 10 percent of the total volume of a cell. The cisternae are also connected to the double-layered nuclear envelope. So, the ER provides a pipeline between nucleus and cytoplasm. The ER manufactures, processes, and transports a wide variety of biochemical compounds for use inside and outside of the cell. There are two kinds of endoplasmic reticulum: rough and smooth.

The surface of **rough endoplasmic reticulum** (RER) is covered with ribosomes, giving it a bumpy appearance when viewed through the microscope. This type of endoplasmic reticulum is involved mainly in the production and processing of proteins. During processing of proteins, RER adds other chemicals (e.g. sugars) to proteins. Then RER transports the processed proteins to areas of the cell where they are needed, or sends them to Golgi apparatus for further processing and modification.

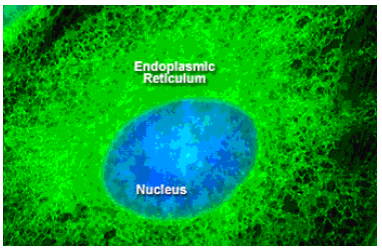


Figure 3.17: A fluorescence image of an endothelial cell showing ER (green)

Smooth endoplasmic reticulum is much more extensive in the cells which do lot of lipid and carbohydrate metabolism (brain and muscle) or detoxification (liver).

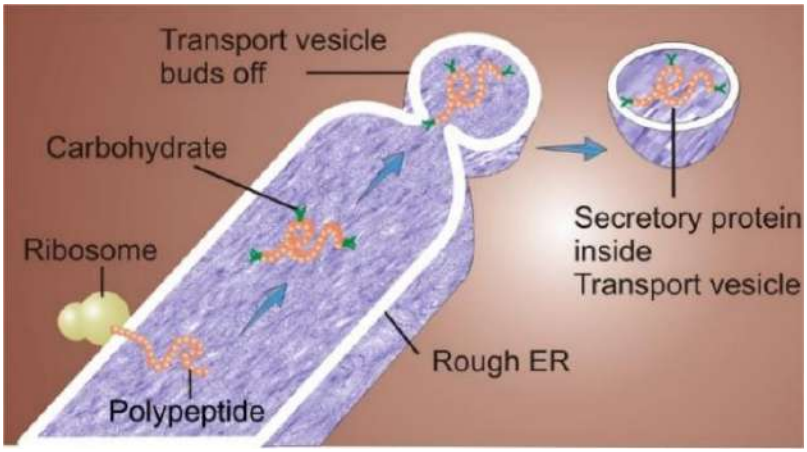


Figure 3.16: The functioning of rough endoplasmic reticulum

The surface of **smooth endoplasmic reticulum** (SER) lacks ribosomes. So, it appears more even under the microscope. In most cells, it is much less extensive than the rough endoplasmic reticulum. Smooth endoplasmic reticulum is chiefly involved in the production of lipids, building blocks for carbohydrate metabolism, and the detoxification of drugs and poisons. Smooth endoplasmic reticulum also plays a role in various cellular activities by storing calcium and doing calcium metabolism. In muscle cells, smooth endoplasmic reticulum releases calcium to trigger muscle contractions.

3- Ribosomes

All living cells contain ribosomes that are tiny granular structures composed of approximately 60 percent ribosomal RNA (rRNA) and 40 percent protein. Ribosomes are not bound by a membrane and are much smaller than other organelles. In eukaryotic cells, ribosomes are mainly found attached to rough endoplasmic reticulum and some are scattered freely. In prokaryotic cells, all ribosomes are freely scattered in cytoplasm. Ribosomes serve as the protein production machinery for the cell. They are most abundant in cells that are active in protein synthesis, such as pancreas and brain cells. A typical cell contains several thousand ribosomes but some cell types may have a few million ribosomes.

Eukaryote ribosomes are produced and assembled in the nucleolus. Ribosomal proteins enter the nucleolus and combine with rRNA strands to create the two ribosomal subunits (one small and one large). The ribosome subunits leave the nucleus through the nuclear pores. In the cytoplasm, both subunits combine for the purpose of protein synthesis. When protein synthesis is not being done, the two subunits get separated.

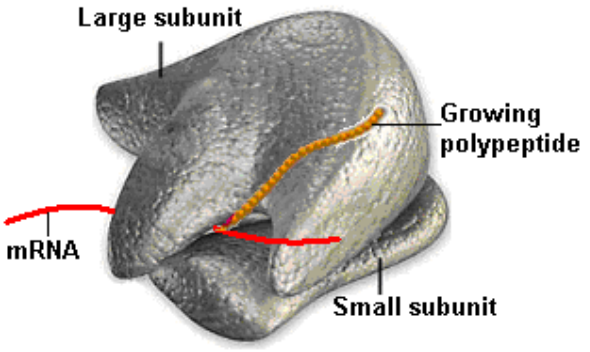


Figure 3.18: Ribosometranslating the mRNA

In addition to the most familiar cellular locations of ribosomes, they can also be found inside mitochondria and the chloroplasts of plants. These ribosomes notably differ in size and makeup than the ribosomes found in cytoplasm, and are more like those present in prokaryotes.

Protein synthesis requires the assistance of two other kinds of RNA molecules in addition to rRNA. Messenger RNA (mRNA) provides the instructions, which it has taken from the DNA. Transfer RNA (tRNA) brings amino acids to the ribosome. Once the chain of amino acids has been synthesized, the ribosome releases it.

The proteins that are synthesized by free ribosomes are for the cell's own internal use. While the proteins produced by the ribosomes bound to RER are transported outside of the cell.

The subunits of a ribosome are described by their **Svedberg (S) values**, which are based upon their rate of sedimentation in a centrifuge. The complete ribosome in a eukaryotic cell has a Svedberg value of 80S. The smaller subunit has value of 40S while the larger subunit has 60S. Prokaryotic cells, on the other hand, contain 70S ribosomes, each of which consists of a 30S and a 50S subunit.

The Svedberg values are not additive i.e. the values of the two subunits of a ribosome do not add up to the Svedberg value of the complete ribosome. This is because the rate of sedimentation of a molecule depends upon its size and shape, rather than simply its molecular weight.

4- Mitochondria

Mitochondria (sing., *mitochondrion*) are rod-shaped organelles that are considered the power generators of the cell. A mitochondrion is bounded by two membranes. There is a narrow intermembrane space between the two membranes. Beneath the inner membrane, there is a larger internal matrix. The outer membrane is smooth and acts like a sieve, filtering out molecules

Scientists hypothesize about the origin of mitochondria. According to them, millions of years ago small, free-living prokaryotes were engulfed, but not consumed, by larger prokaryotes. The two organisms developed a symbiotic relationship over time, the larger organism providing the smaller with ample nutrients and the smaller organism providing ATP molecules to the larger one.

that are too big. The inner membrane is highly convoluted and forms many infoldings called cristae which increase the surface area.

The inner surface of the cristae has knob-like extensions into the matrix, known as F-1 particles. These particles are actually the enzymes called ATP-synthase. Other complexes are also found in inner mitochondrial membrane, which serve as electron carriers in electron transport chain. Mitochondria are different from most other organelles. A mitochondrion has its own circular DNA (similar to the DNA of prokaryotes), all kinds of RNA and 70S ribosomes. A mitochondrion can replicate independently of the cell.

Mitochondria are the sites of cellular respiration. They generate adenosine triphosphate (ATP) from oxygen and nutrients. ATP is the chemical energy "currency" of the cell that powers the cell's metabolic activities. Enzymes in the matrix catalyse some of the steps of cellular respiration like Krebs cycle. Other proteins that function electron transport chain are found on the inner membrane.

The number of mitochondria present in a cell depends upon the metabolic requirements of that cell, and may range from one to thousands. Mitochondria are found in nearly all eukaryotes, including plants, animals, fungi, and protists, and are large enough to be observed with a light microscope.

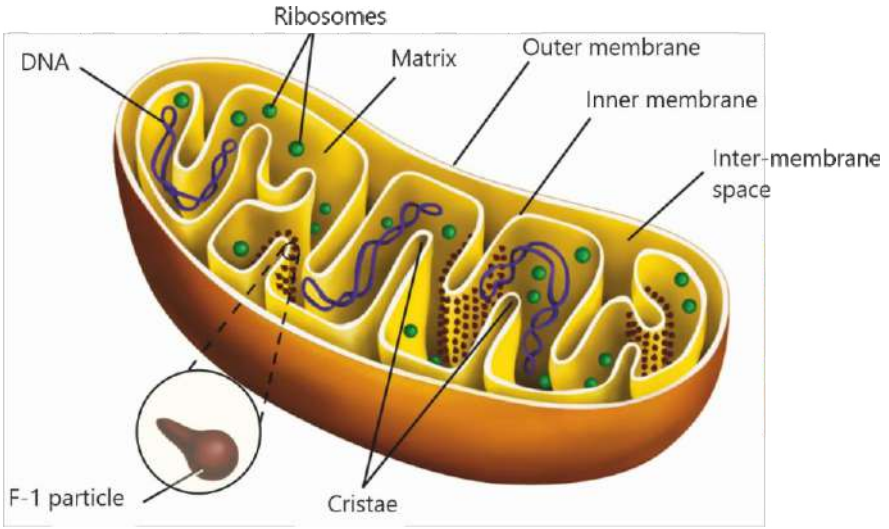


Figure 3.19: Structure of a mitochondrion

5- Chloroplasts

One of the most important characteristics of plants is their ability to conduct photosynthesis

Recalling:
Cells of plants and many protists have three types of plastids i.e., chloroplasts, chromoplasts and leucoplasts. The colourless leucoplasts are involved in the storage and yellow-to-red coloured chromoplasts give colours to plant parts.

i.e., to make their own food by converting light energy into chemical energy. This process occurs in almost all plant species and is carried out in specialized organelles known as chloroplasts. All of the green structures in plants, including stems and un-ripened fruit, contain chloroplasts, but the majority of photosynthetic activity in most plants occurs in the leaves. On the average, the chloroplast density on the surface of a leaf is about one-half million per square millimetre. Chloroplasts contain the pigments chlorophyll "a" and chlorophyll "b", which are able to absorb the light energy needed for photosynthesis to occur.

The ellipsoid-shaped chloroplast is enclosed by two membranes and the area between the two membranes is called the intermembrane space. A semi-fluid called stroma is present inside the inner membrane. It contains dissolved enzymes and comprises most of the chloroplast's volume. The outer membrane is much more permeable than the inner layer.

The inner membranes lie in close association with one another and fuse along their peripheries. In this way, two adjacent membranes form a disk-shaped compartment called **thylakoid**. Many thylakoids form stacks called **grana** (singular *granum*). The **lamellae** are the non-green compartments that connect two grana. Each granum may contain a few to several thylakoids, and a chloroplast may contain a hundred or more grana. Like the mitochondrion, the chloroplast is different from most other organelles because it has its own DNA and reproduces independently of the cell in which it is found.

Mitochondria are similar to chloroplasts. Both organelles convert energy for the cell. Mitochondria perform aerobic respiration. They generate chemical energy in the form of ATP by metabolizing sugars, fats and other chemical fuels with the assistance of oxygen. Chloroplasts perform photosynthesis. They convert energy from the sun into the biosynthesis of organic nutrients using carbon dioxide and water. Like mitochondria, chloroplasts also contain their own DNA and are able to grow and reproduce independently of the cell.

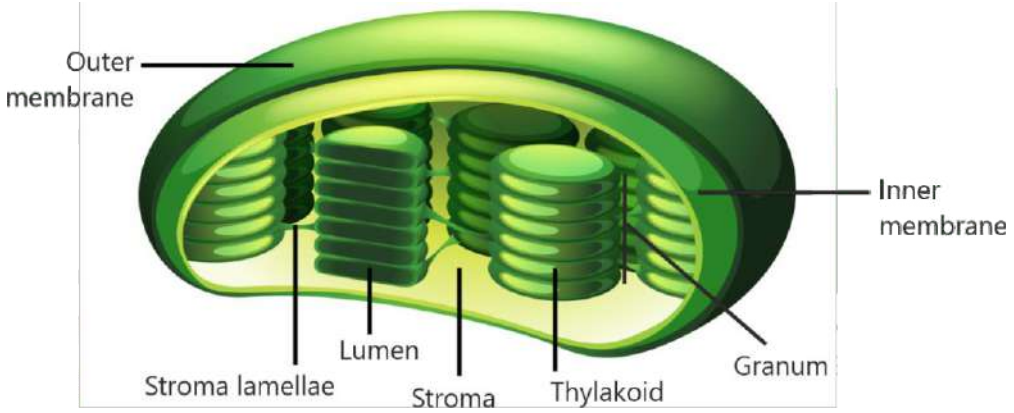


Figure 3.20: Structure of chloroplast

Light is absorbed by chlorophyll molecules embedded in the thylakoid disks. When these chlorophyll molecules absorb light, they emit electrons and thus ATPs are formed. Using these ATPs, in the stroma, low-energy carbon dioxide is transformed into a high-energy compound like glucose.

6- Golgi Apparatus

Recalling:
Golgi apparatus was discovered by Camillo Golgi.

Golgi apparatus consists of five to eight cup-shaped, membrane-covered sacs called cisternae that are stacked over each other. It is found in the cells of plant, animal and unicellular eukaryotes. In some unicellular flagellates, the Golgi apparatus may consist of 60 cisternae. Similarly, the number of Golgi apparatuses in a cell varies according to its function. Animal cells generally contain between ten and twenty Golgi stacks in their Golgi apparatus. This complex is usually located close to the nucleus.

Each Golgi stack has two distinct faces. The 'cis' face is found near the endoplasmic reticulum. The 'trans' face is positioned near the plasma membrane.

The Golgi apparatus is the distribution and shipping department for the cell's chemical products. It modifies proteins and lipids that have been built in the endoplasmic reticulum and prepares them for export outside the cell or for transport to other locations in the cell.

Camillo Golgi was investigating the nervous system by using a new staining technique (known as Golgi staining). He observed a structure inside cells and named it as reticular apparatus. He publicly announced his discovery in 1898 and the structure was named after him as the Golgi apparatus. Many scientists did not believe that what Golgi observed was a real organelle and instead argued that the apparent body was a visual distortion caused by staining. The invention of the electron microscope in the twentieth century finally confirmed that the Golgi apparatus is a cellular organelle.

Small vesicles that contain proteins, carbohydrates, phospholipids and other molecules, bud off from the ER. These vesicles move through the cytoplasm until they reach the 'cis' face of Golgi apparatus. The vesicles fuse with Golgi apparatus and release their molecules into it. Here, the compounds are further processed. Enzymes present in the Golgi lumen convert them into glycoproteins and glycolipids.

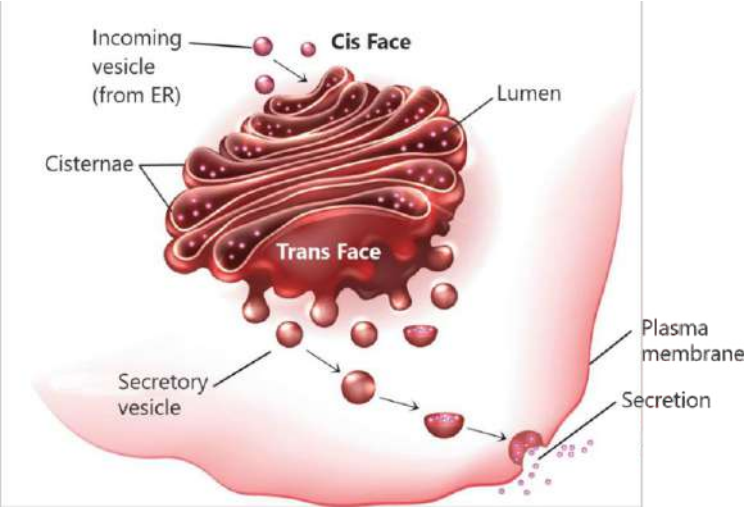


Figure 3.21: Structure of Golgi apparatus and its functioning

The product is extruded from the 'trans' face of the Golgi apparatus in a vesicle and directed to its final destination inside or outside the cell. The exported products are known as secretions. Other products are returned to the endoplasmic reticulum or may undergo maturation to become lysosomes. In addition, the Golgi apparatus in plant cells produces pectin and other polysaccharides specifically needed for plant structure and metabolism.

7- Lysosomes

Recalling:
Lysosomes were discovered by a Belgian scientist Christian René de Duve. They contain strong digestive enzymes.

Lysosomes are spherical organelles bounded by a single membrane. They serve as digestive compartments of the cell. Lysosomes are found in most eukaryotic cells. In animals, they are most numerous in disease-fighting cells, such as white blood cells. This is because white blood cells must digest materials like bacteria, viruses, and other foreign intruders.

The cell is safe from the enzymes of lysosomes. These enzymes require acidic environment (of pH of about 4.8). The lysosomal matrix is acidic but cytosol is a neutral environment. So, even if a lysosome is ruptured, its digestive enzymes become inactive and the cell remains uninjured.

They are also involved in breaking the cellular materials that have exceeded their lifetime or are no longer useful. In this regard, the lysosomes perform **autophagy**. They break down cellular waste products, fats, carbohydrates, proteins, and other macromolecules into simple compounds, which are then transferred back into the cytoplasm for making new materials.

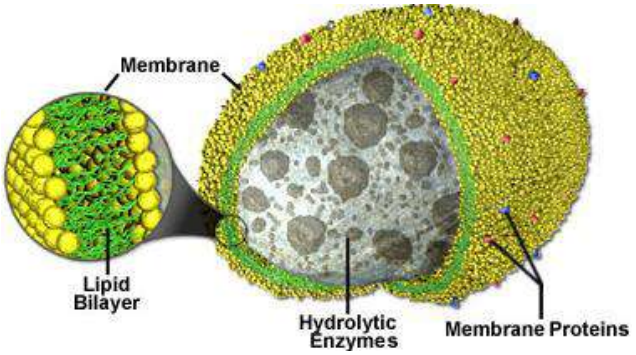


Figure 3.22: Structure of lysosome

Lysosomes have about 40 different hydrolytic enzymes, all of which are manufactured in the endoplasmic reticulum and modified in the Golgi apparatus. The membrane covering of the lysosome protects the rest of the cell from the harsh digestive enzymes contained in the lysosomes, which would otherwise cause significant damage.

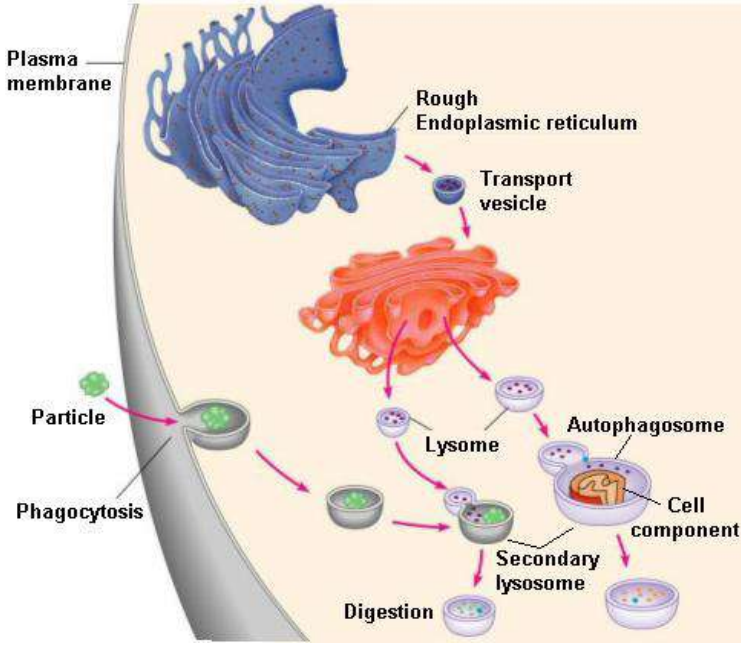


Figure 3.23: Role of lysosome in the breakdown of the phagocytosed particle and cellular component

In the mid-18th century, Belgian scientist Christian René de Duve was investigating carbohydrate metabolism in liver cells. He observed that when cells are damaged in the centrifuge, they release acid phosphatase. He suggested that this digestive enzyme was encased in some membrane bounded organelle within the cell, which he named as lysosome.

In **lysosomal storage diseases**, the patient lacks one of the hydrolytic enzymes of lysosome. The abnormal lysosome fills with

Many cells in your brain die during development. This directed suicide is accomplished by the rupture of the lysosomes within the cells that are being eliminated.

indigestible substances, which interfere with cellular functions. For example, in Pompe's disease the lysosome lacks a glycogen-digesting enzyme. So, harmful amounts of glycogen accumulate in liver cells. In Tay-Sachs disease an essential lipid-digesting enzyme is missing. Accumulation of these lipids in the nerve cells of brain damages the nervous system, causes mental retardation, and death in early childhood.

Lysosomes also function in the elimination of whole cell. Selective cell death is a mechanism used by multicellular organisms in their development. For example, when a tadpole develops into a frog, the cells of the tail are destroyed by the enzymes of lysosomes.

8- Peroxisomes

Peroxisomes are single membrane bounded organelles in all eukaryotic cells. These were discovered by Christian de Duve, who also discovered lysosomes.

Peroxisomes contain a variety of enzymes. Many of these enzymes are oxidative that carry out oxidation i.e. the removal of electrons and hydrogens. These enzymes primarily function to rid the cell of toxic substances. Some peroxisomes, such as those in liver cells, detoxify alcohol and other harmful compounds by carrying out their oxidation.

Some peroxisomes contain catalase enzymes, which break down hydrogen peroxide (a common by-product of cellular metabolism) into water and oxygen.

$$\underset{\text{Hydrogen peroxide}}{2H_2O_2} \xrightarrow{\text{Catalase}} \underset{\text{Water}}{2H_2O} + \underset{\text{Oxygen}}{O_2}$$

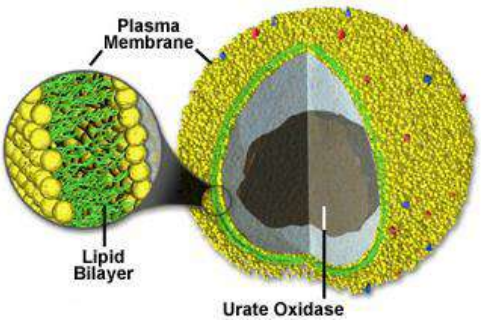


Figure 3.24: Structure of peroxisome

Defects in peroxisomes cause a number of metabolic disorders. The most serious of these disorders is Zellweger syndrome, which is characterized by absence or reduced number of peroxisomes in the cells. It is congenital disorder (present at birth) and has no cure or effective treatment and usually causes death within the first year of life.

9- Glyoxysomes

Glyoxysomes are similar to peroxisomes but are found only in plant cells. These organelles contain enzymes that convert lipids into carbohydrates. They are most abundant in the cells of lipid-rich seeds (e.g. castor beans and soyabeans). During germination, these organelles convert stored lipids into carbohydrates that provide energy for seed germination.

10- Vacuoles

Recalling:
Vacuoles are fluid filled single-membrane bounded organelles. Cells have many small vacuoles in their cytoplasm. However, when a plant cell matures its small vacuoles fuse to form a single large vacuole.

These are membrane-bounded sacs. Vacuoles function in several ways. For example, in mature plant cells, a single large vacuole provides structural support, as well as serves functions in storage, waste disposal, protection, and growth. Vacuoles in animal cells, however, are much smaller, and are more commonly used to temporarily store materials or to transport substances.

Many plant cells have a large, single central vacuole. This large vacuole slowly develops by fusion of smaller vacuoles. It takes up most of the space in the cell (80 percent or more). The vacuole in plant cells is enclosed by a membrane called tonoplast. The material inside the vacuole is called cell sap. The cell sap differs markedly from the surrounding cytoplasm.

Several materials commonly stored in plant vacuoles have been found to be useful for humans, such as opium, rubber, and garlic flavouring.

The central vacuole in plant cells plays an important structural role for the plant. This role of the vacuole is related to its ability to control turgor pressure. Turgor pressure makes the rigidity of the cell.

Under optimum conditions, a plant receives adequate amounts of water and the central vacuoles of its cells swell as the liquid collects within them. It creates a high turgor pressure, which helps maintain the structural integrity of the plant, along with the support from the cell wall. Vacuoles also often store the pigments that give certain flowers their colours, which aid them in the attraction of bees and other pollinators. Vacuoles also release molecules that are poisonous to various insects and animals, thus discouraging them from consuming the plant.

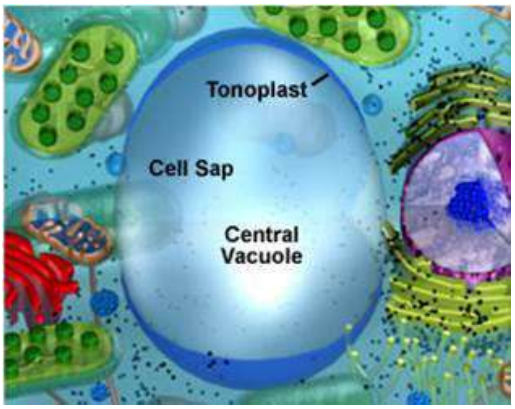


Figure 3.25: Structure of vacuole in plant cell

11 - Centrioles

Recalling:
Centrioles are hollow and cylindrical organelles. A centriole is made of nine triplets of microtubules.

In the cells of animals and most protists, centrioles are organelles

associated with the assembly and organization of the fibres of cytoskeleton i.e., microtubules (including spindle fibres).

In eukaryotic cells centrioles occur in pairs. The two centrioles are located at right angles to one another near the nuclear envelope. In ciliated or flagellated cells centrioles are involved in the formation of cilia and flagella. Each cilium and flagellum is anchored by a centriole, known as **basal body**.

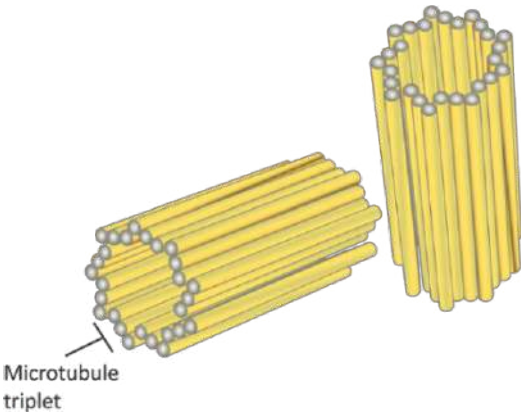


Figure 3.26: Two centrioles

The cells of plants and fungi lack centrioles and basal bodies, and their microtubules and spindle fibres are organized from the structures of cytoplasm.

12- Cytoskeleton

It is a network of protein fibres present in cytoplasm. It includes the following types of fibres:

1. **Microfilaments:** These are present in all eukaryotic cells. Microfilaments are solid rods made of a globular protein, called **actin**. Microfilaments disassemble and re-assemble and help the cells to change shape and move. Microfilaments also enable a dividing cell to pinch off into two cells. In association with myosin, microfilaments help in cellular contraction.
2. **Microtubules:** These straight, hollow cylinders are composed of subunits. Each subunit is made of two different **tubulin** proteins known as *alpha*-tubulin and *beta*-tubulin. Microtubules give structure and shape to a cell. They also serve as highways for the transport of organelles. Moreover, microtubules are the major components of cilia and flagella, and participate in the formation of spindle fibres during cell division.
3. **Intermediate filaments:** These are found only in some higher animal groups. They are made of different proteins but the most common type of protein subunit is **vimentin**. Some cells may have intermediate filaments made of other proteins. For example, skin cells contain a protein **keratin**. Intermediate filaments maintain cell shape and rigidity, and serve to anchor several organelles, including the nucleus.

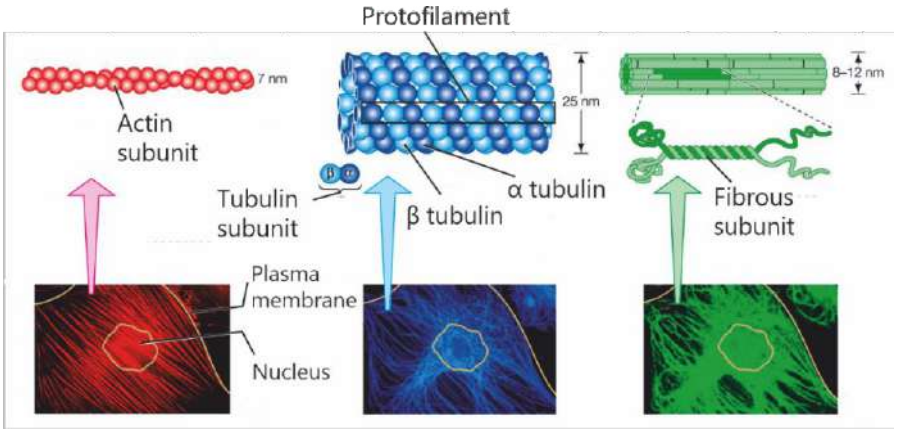


Figure 3.27: Components of cytoskeleton

13- Cilia and Flagella

Cilium (plural *cilia*) and flagellum (plural *flagella*) are the locomotor appendages that protrude from certain cells. They are thin, tail-like projections extending from the cell body. Cilia are short in length and are usually numerous in number; while flagella are longer but less numerous in number. Cilia are rare in plants. Many protozoans (ciliates) possess cilia. Larger eukaryotes such as mammals have cilia on some cells' surfaces. For example, in humans, cilia are found in the lining of the trachea where they sweep mucus and dirt out of breathing tubes.

The core of eukaryotic cilia and flagella is called **axoneme**. It contains two central microtubules that are surrounded by an outer ring of nine doublet microtubules. Dynein molecules are located around the circumference of the axoneme. These dynein molecules bridge the gaps between adjacent microtubule doublets. Biologists refer to this organization as a "9 + 2" structure. A plasma membrane surrounds the entire axoneme. At the base of the cilium its organising centre, called basal body, is present. Basal body has the same basic structure of the outer ring of

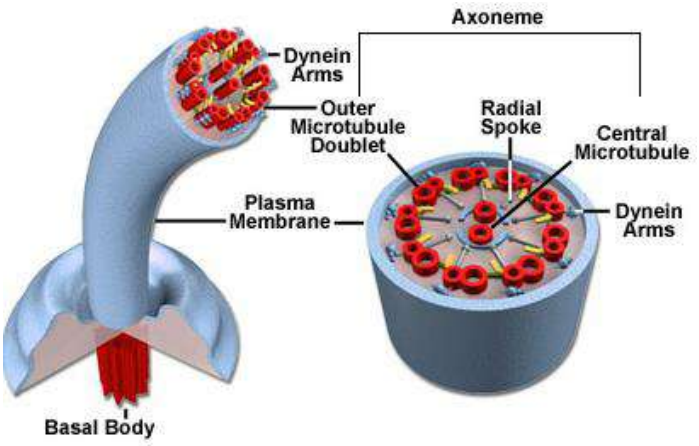


Figure 3.28: Structure of eukaryotic cilium and flagellum

axoneme, but each of the nine sets of outer filaments is composed of three microtubules, rather than a doublet of microtubules. The basal body is actually the centriole. Prokaryotic flagella have a completely different structure built from the protein flagellin.

3.5- PROKARYOTIC AND EUKARYOTIC CELLS

Bacteria and archaea are made of prokaryotic cells whereas all other forms are composed of eukaryotic cells. Both prokaryotic and eukaryotic cells have DNA as their genetic material; both have plasma membranes as their coverings; and both have ribosomes for protein synthesis. You have gone through the details of the cell organelles.

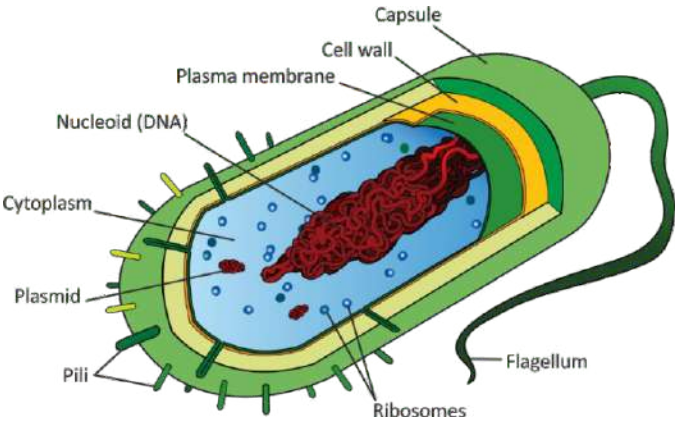


Figure 3.29: Structure of a generalized prokaryotic cell

Prokaryotic cells are much simpler than eukaryotic ones. Most prokaryotic cells range from 2 to 8 µm in length i.e., about one-tenth of the size of a typical eukaryotic cell. A prokaryotic cell lacks a nucleus. The much less extensive DNA of prokaryotic cell is present in the more-or-less central region known as **nucleoid** (*nucleus-like*).

A prokaryotic cell also lacks other membrane-bounded organelles like endoplasmic reticulum, mitochondria, chloroplasts, Golgi apparatus, lysosomes, peroxisomes etc. The entire cytoplasm of a prokaryotic cell is one unit with no internal support structures. Ribosomes are present in prokaryotic cell but these are smaller in size than those of eukaryotic cells.

The Svedberg values (sedimentation rates) of the smaller and larger subunits of ribosomes of prokaryotic cells are 30S and 50S respectively. The sedimentation rate of a complete ribosome is 70S. Surrounding the plasma membrane of most prokaryotic cells is a cell wall but it does not contain cellulose. It composed of peptidoglycan that is a single large polymer of amino acids and sugar. In bacteria the cell wall may also be surrounded by a capsule and may also have extensions for attachment known as pili (singular *pillus*). Prokaryotic flagella are made of repeating units of the protein flagellin and they do not contain microtubule triplets. Mitosis and meiosis are missing in prokaryotic cell and it divides by direct division (binary fission).

Difference between Eukaryotic and Prokaryotic cells		
Characteristics	**Eukaryotic Cell**	**Prokaryotic Cell**
Distinct Nucleus	Present	Absent
Number of chromosomes	More than one	One--but not true chromosome: Plasmids
Cell Type	Usually multicellular	Usually unicellular (some cyanobacteria may be multicellular)
Example	Protozoans, Algae, Fungi, Animals, Plants	Bacteria and Archaea
Lysosomes and peroxisomes	Present	Absent
Microtubules	Present	Absent or rare
Endoplasmic reticulum	Present	Absent
Mitochondria	Present	Absent
Cytoskeleton	Present	May be absent
Vacuoles	Present	Present
Ribosomes	Larger	Smaller
Golgi apparatus	Present	Absent
Chloroplasts	Present (in plants)	Absent; chlorophyll scattered in the cytoplasm
Cell Division	Mitosis or meiosis	Mitosis and meiosis are missing; cell divides by direct division (binary fission)
Flagella	Membrane bounded; contains two central microtubules surrounded by an outer ring of nine doublet microtubules	Not membrane bounded; made of repeating units of flagellin; do not contain microtubule triplets
Cell wall	Only in plant cells and fungi (chemically simpler)	Composed of peptidoglycan (a single large polymer of amino acids and sugar)
Cell size	10-100 um	1-10 um

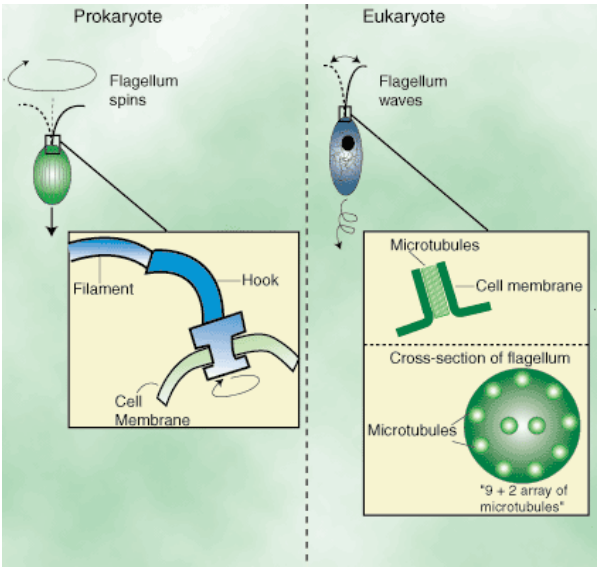


Figure 3.30: Difference between the structures of prokaryotic and eukaryotic flagella

3.6- CELL SIGNALLING

Cell signalling is the ability of cells to respond to stimuli from their environment producing cellular responses. It involves the transmission of signals between cells through a series of molecular events, often leading to a cellular response.

Steps of Cell Signalling

1- Signal Reception

Cell signalling begins when a signal molecule (ligand) binds to a receptor on the membrane of a target cell. These receptors are typically proteins embedded in the cell membrane but can also be located inside the cell. Each receptor is specific to a particular ligand.

2- Signal Transduction

Once the receptor binds to the ligand, it undergoes a conformational change that activates an intracellular signalling pathway. This often involves a series of interactions and modifications, creating a signalling cascade that amplifies the signal. Small molecules like cAMP (cyclic AMP), calcium ions, and inositol triphosphate (IP3) can act as second messengers, transmitting the signal from the receptor to target molecules inside the cell.

3- Cellular Response

The signal transduction pathway often leads to changes in gene expression, turning specific genes on or off. This can result in various cellular responses, such as cell growth, division, differentiation, or apoptosis (programmed cell death). Signalling can also lead to changes in cellular metabolism, enzyme activity, or the opening and closing of ion channels.

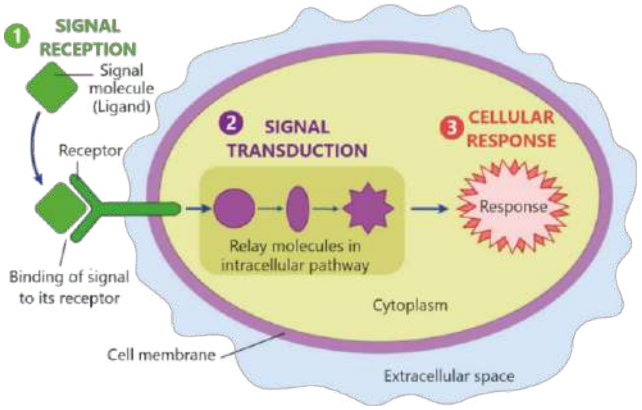


Figure 3.31: Steps of cell signalling

Pathways of Cell Signals from Outside to Inside

Cell signalling pathways involve the transmission of signals from the cell's exterior to its interior, resulting in a specific cellular response. There are two main types of signalling pathways based.

Protein/Peptide Signalling

Protein or peptide signalling molecules are water-soluble. So, they cannot pass through plasma membrane. When such ligand approaches the cell surface, it binds to its specific receptor on plasma membrane. This binding causes a conformational change in the receptor protein and activates it. The activated receptor triggers a series of reactions within the cell. These reactions generate second messenger like cyclic AMP (cAMP) which starts changes e.g., changes in gene expression. The pathway can lead to changes in metabolism, cell growth, division, or apoptosis.

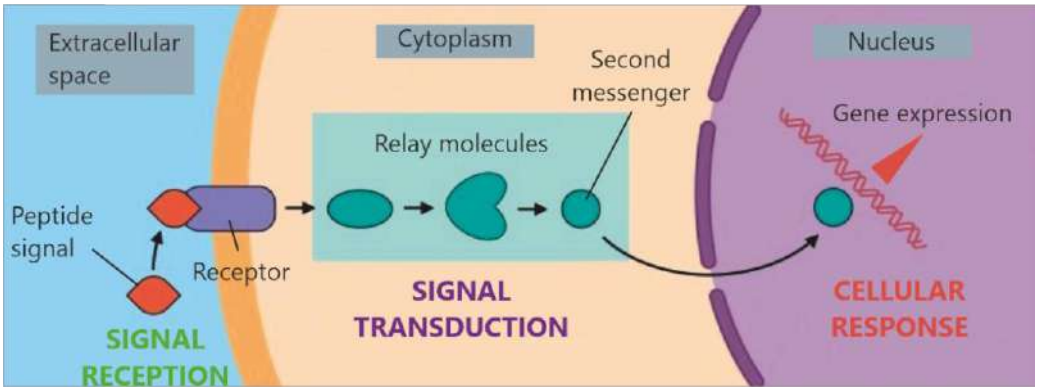


Figure 3.32: Protein/peptide signalling pathway

Steroid Signalling

Steroid hormones, being lipophilic, can diffuse through the plasma membrane of the target cell. Once inside, they bind to specific intracellular receptors located in the cytoplasm or nucleus. This binding results in the formation of active receptor-hormone complex which moves into the nucleus if it was not already there. Inside nucleus, the receptor-hormone complex binds to specific DNA sequences in target genes. This binding regulates the transcription of these genes, leading to increased or decreased production of specific proteins.

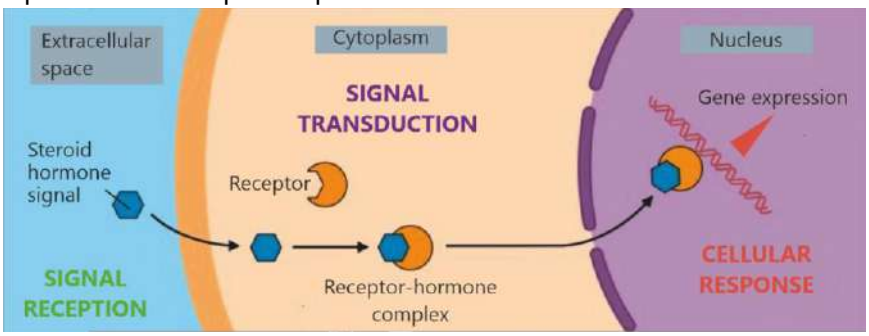


Figure 3.33: Steroid signalling pathway

3.7- Membrane Transport Mechanisms

While exchanging matter with cells' environment, plasma membranes maintain equilibrium inside the cell as well as outside.

You know that the movement of substances in and out of cells is crucial for cellular functions. These movements are done for nutrient uptake, waste elimination, gas exchange, and signal transduction. Cells rely on the plasma membrane for regulating the movement of substances in and out of the cell. Membrane transport mechanisms are essential processes that enable the cell to maintain homeostasis, acquire nutrients, remove waste products, and communicate with its environment.

These mechanisms include two mechanisms i.e., passive transport (which requires no energy input) and active transport (which utilizes energy).

Passive Transport

The movement of molecules across plasma membrane without any expenditure of energy is called passive transport. The following are the types of passive transport.

Diffusion

Diffusion is the net movement of a substance (liquid or gas) from an area of higher concentration to one of lower concentration i.e., along concentration gradient. Because a cell does not expend energy when molecules diffuse across its membrane, the diffusion of molecules is a type of **passive transport**

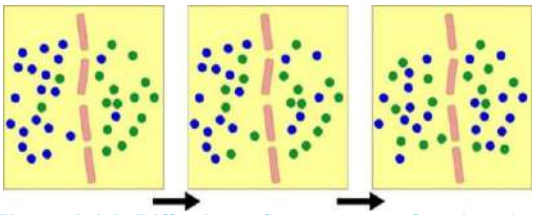


Figure 3.34: Diffusion of two types of molecules

Facilitated Diffusion

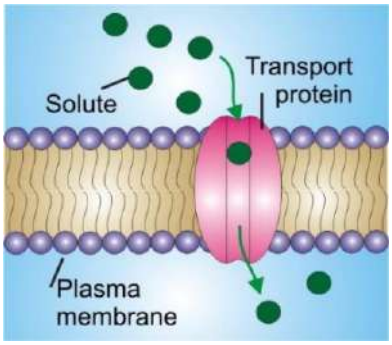


Figure 3.35: Facilitated diffusion

Some molecules are taken into or out of the cells with the help of **transport-proteins** present in plasma membranes. When a transport protein helps a substance to move it down its concentration gradient (from higher to lower concentration), the process is called facilitated diffusion. It is also a type of passive transport because no energy is used in facilitated diffusion. The rate of facilitated diffusion depends on how many transport-protein molecules are available in the membrane. The main types of transport proteins involved in facilitated diffusion are:

1. Channel Proteins: These proteins form hydrophilic channels across the membrane that allow specific molecules or ions to pass through. They can be gated or non-gated. Gated channels open or close in response to specific stimuli (such as voltage changes, ligand binding, or mechanical stress). Examples include ion channels (allow the passage of specific ions e.g., Na^+, K^+, Ca^{2+}, Cl^-) and aquaporins (facilitate the rapid transport of water molecules).

2. Carrier Proteins (Transporters): These proteins bind to the specific molecule they transport, undergo a conformational change, and move the molecule across the membrane. They are highly specific for the molecule they transport. They can become saturated, meaning there is a maximum rate of transport when all carrier proteins are occupied. Examples include glucose transporters (facilitate the transport of glucose) and amino acid transporters (transport specific amino acids into or out of the cell).

Difference between Simple and Facilitated Diffusion

	Simple Diffusion	Facilitated Diffusion
Mechanism	• Substances move from higher concentration to lower concentration directly through	• Substances move from higher concentration to lower concentration through specific

Difference between Simple and Facilitated Diffusion		
	the lipid bilayer of plasma membrane.	transport proteins embedded in plasma membrane.
Energy Requirement	• It is a passive transport mechanism, requiring no energy input from cell.	• It is also a passive transport mechanism and does not require energy.
Types of Molecules	• Typically involves small, nonpolar molecules such as oxygen, carbon dioxide, and lipid-soluble substances.	• Primarily involves polar or charged molecules, such as glucose, amino acids, and ions, which cannot easily pass through the hydrophobic core of the lipid bilayer.
Rate of Movement	• The rate depends on the concentration gradient, temperature, and the permeability of the membrane.	• The rate can be affected by the number and availability of transport proteins and can reach a maximum rate when all transport proteins are saturated.

Osmosis

The process by which water molecules diffuse across a cell membrane from an area of higher concentration to an area of lower concentration is called osmosis. Because water is moving from a higher to lower concentration, osmosis does not require cells to expend energy. Therefore, osmosis is the passive transport of water. The direction of osmosis depends on the concentration of solutes on the two sides of membrane. Water always moves from hypotonic solution (with lower solute concentration) hypertonic solution (with higher solute concentration).

The term **tonicity** refers to the relative concentration of solutes in the solutions.
Hypertonic solutions are those in which more solute is present.
Hypotonic solutions are those with less solute.
Isotonic solutions have equal concentrations of solutes.

Osmosis occurs through selectively permeable membrane, which allows water to pass while restricting many solutes. Osmosis is crucial for maintaining cell turgor, which is vital for plant cells, and for balancing the internal water content in cells. The direction and rate of osmosis are influenced by the osmotic gradient and the permeability of the membrane to water. Specialized proteins called aquaporins facilitate the rapid transport of water molecules across the cell membrane, ensuring efficient regulation of cellular hydration and volume.

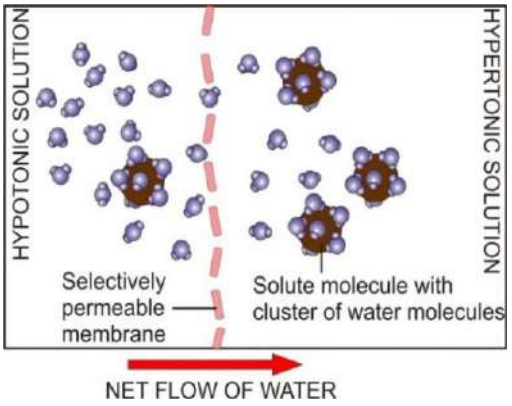
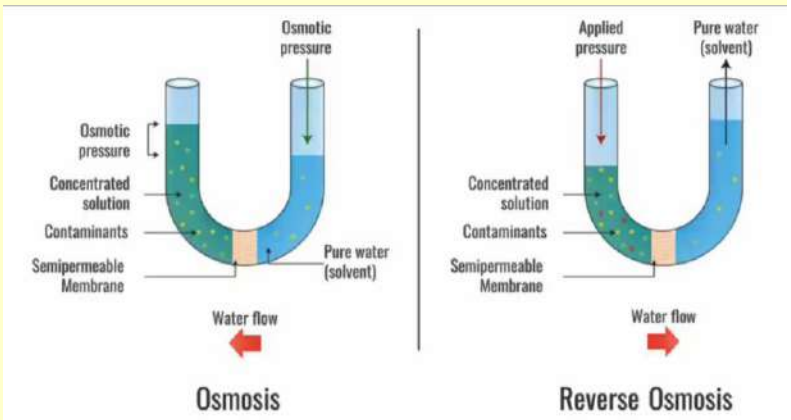


Figure 3.36: Osmosis at molecular level

Reverse osmosis

It is a widely used technology for purifying water by removing contaminants and impurities. Unlike natural osmosis, which moves water from a lower to a higher solute concentration, reverse osmosis applies external pressure to push water through a semi-permeable membrane from a higher to a lower solute concentration. This process effectively filters out dissolved salts and other impurities, providing clean and safe drinking water. Reverse osmosis is commonly used in water treatment plants, desalination facilities, and even in household water purification systems.



Active Transport

The movement of substances across plasma membrane from lower concentration to higher concentration with the expenditure of energy is known as active transport. Following types of active transport occur through plasma membrane.

Active transport through carrier proteins

In this process, carrier (transport) proteins in the plasma membrane use energy to move the molecules against the concentration gradient. For example, the membranes of nerve cells have carrier proteins in the form of **"sodium-potassium pump"**. In a resting (not conducting nerve impulse) nerve cell, this pump spends energy (ATP) to maintain higher concentrations of K^+ and lower concentrations of Na^+

inside the cell. For this purpose, the pump actively moves Na^+ to the outside of the cell and K^+ to the inside of the cell.

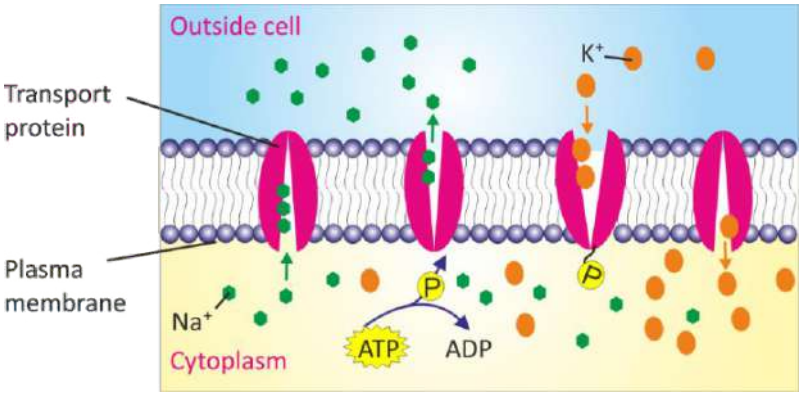


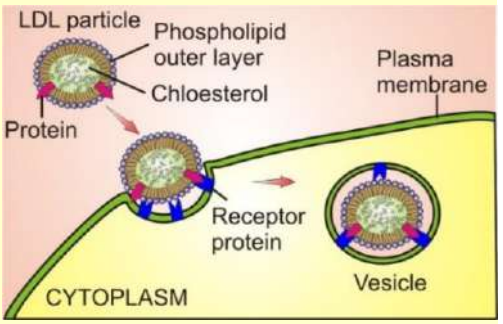
Figure 3.37: Active transport through carrier proteins

Endocytosis

In endocytosis, bulky materials are moved into the cell across plasma membrane. During endocytosis a portion of plasma membrane invaginates (depressed inward). The material from outside is taken inside the invagination, and its ends seal. Thus, a small vesicle is formed. It detaches from the plasma membrane and moves into cytoplasm. The two common forms of endocytosis are phagocytosis and pinocytosis. In **phagocytosis** cell takes in solid material while in **pinocytosis** cell takes in liquids in the form of droplets.

Receptor-mediated endocytosis

Specific receptor proteins of plasma membrane pick up material from outside and pinch inside to form a vesicle. For example, the cells of liver have receptor proteins for cholesterol. Cholesterol circulates in our blood in the form of low-density-lipoproteins (LDLs). The receptor proteins of plasma membrane of liver cells, recognize and take up LDLs from the blood by receptor-mediated endocytosis.



Exocytosis

It is the process through which bulky material is exported out of cell. In exocytosis, the bulky material is packed inside a membrane and a vesicle is formed. The vesicle moves to the plasma membrane and fuses with it to release its contents into the extracellular environment.

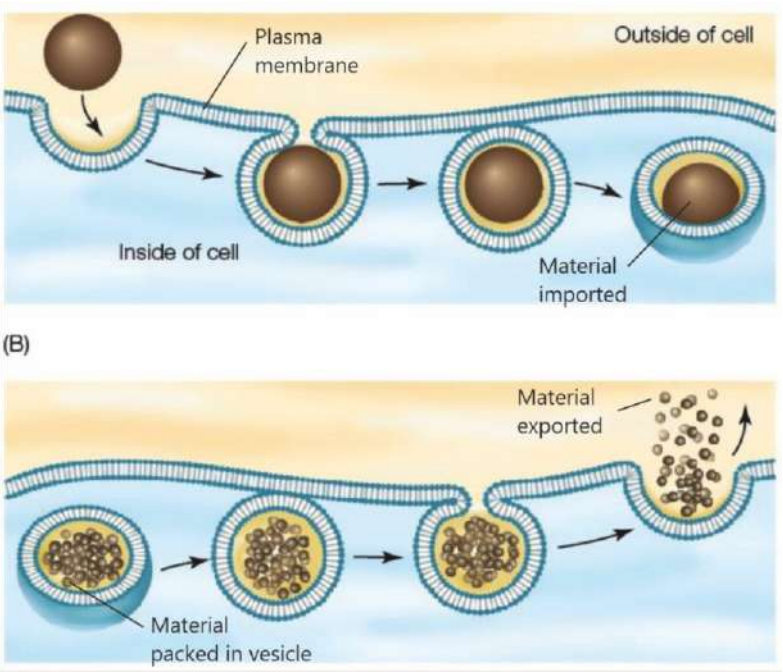


Figure 3.38: (A) Endocytosis, (B)Exocytosis

3.8- STEM CELLS

Stem cells are unique cells with the remarkable ability to develop into many different cell types in the body. When a stem cell divides, each new cell has the potential either to remain a stem cell or to become specialized cell, such as a muscle cell, a red blood cell, or a brain cell. The following are the major categories of stem cells on the basis of the number of types of cells which they can make.

1. **Totipotent:** These stem cells can differentiate into all possible cell types. For example, zygote and the cells produced by the first few divisions in zygote.
2. **Pluripotent:** These cells can turn into almost any cell. For example, cells from the early embryo.
3. **Multipotent:** These cells can differentiate into a closely related family of cells. For example, the hematopoietic stem cells can become red and white blood cells or platelets.
4. **Oligopotent:** These can differentiate into a few different cell types. For example, adult lymphoid or myeloid stem cells.
5. **Unipotent:** These can only produce cells of one kind, which is their own type. However, they are still stem cells because they can renew themselves. For example, adult muscle stem cells.

Use of Stem Cells

1. **Regenerative Medicine:** Stem cells have the potential to repair or replace damaged tissues and organs. Therefore, they are used for treating conditions such as spinal cord injuries, type 1 diabetes, Parkinson's disease, and heart disease.
2. **Drug Testing and Development:** By differentiating stem cells into specific cell types, researchers can create models of human diseases, allowing for more accurate testing of drug effects and reducing the reliance on animal models.
3. **Personalized Medicine:** Stem cells can be derived from a patient's own cells, reducing the risk of immune rejection when used in treatments. This personalized approach can lead to more effective and safer therapies.

Categories of Stem Cells

The following are the major categories of stem cells on the basis of their origin.

1- Embryonic Stem Cells (ESCs)

ESCs are derived from the inner cell mass of blastocysts (early-stage embryos). These stems cells are pluripotent, meaning they can differentiate into nearly all cell types in the body. They have high differentiation potential, making them extremely versatile for research and therapy. Ethical concerns of using ESCs include the use of human embryos, risk of teratoma formation, and potential immune rejection.

2- Adult Stem Cells (ASCs)

These stem cells are found in various tissues throughout the body, such as bone marrow, fat, and blood. They are multipotent, meaning they can differentiate into a limited range of cell types related to their tissue of origin. Using them involves less ethical controversy, lower risk of immune rejection when derived from the patient's own tissues. However, they have limited differentiation potential and are harder to isolate and culture.

3- Induced Pluripotent Stem Cells (iPSCs)

They are generated in the lab by reprogramming adult somatic cells to a pluripotent state using specific transcription factors. They are pluripotent, similar to embryonic stem cells.

Advantages of using iPSCs: They do not have the ethical controversies linked to embryonic stem cells, as they do not require the destruction of embryos. They can be generated from a patient's own cells, minimizing the risk of immune rejection. They offer potential for regenerating damaged tissues and organs (e.g., new heart cells for patients with heart disease or new neurons for patients with neurodegenerative conditions).

Disadvantages of using iPSCs: The reprogramming process can introduce genetic changes that may affect iPSCs. They could form tumours (teratomas) when transplanted into patients. Directing iPSCs to differentiate into specific, fully functional cell types remains a complex task. It is still difficult to ensure that these cells function properly.

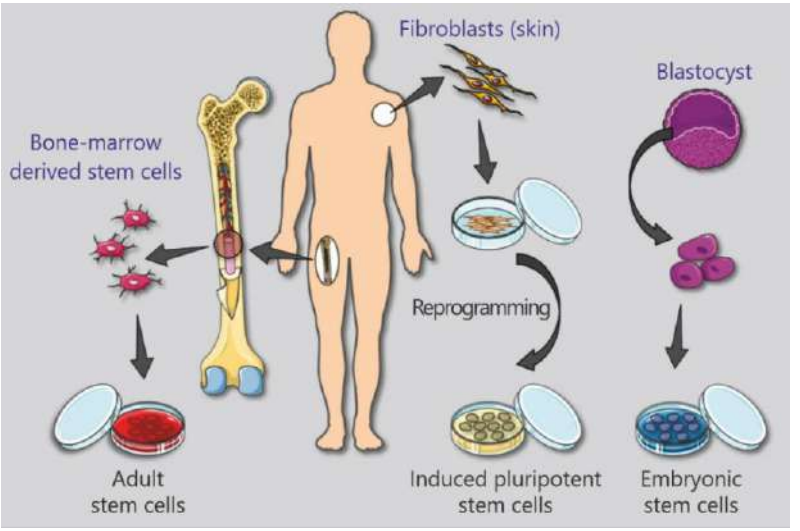


Figure 3.39: Stem cells- Sources and types

EXERCISE

SECTION 1:MULTIPLE CHOICE QUESTIONS

1. Which one of the following eukaryotic cell structures does not contain DNA?
   (a) Nucleus (b) Mitochondrion
   (c) Endoplasmic reticulum (d) Chloroplast
2. Which of the following is not an accurate description of a chromosome?
   (a) It is a coloured body localized in the nucleus
   (b) It is a protein and nucleic acid complex
   (c) It is the cellular structure that contains the genetic material
   (d) In eukaryotes, it is composed of many DNA molecules attached end to end
3. A centriole is an organelle that is:
   (a) Present in the centre of a cell's cytoplasm
   (b) Composed of microtubules and important for organizing the spindle fibres
   (c) Surrounded by a membrane
   (d) Part of a chromosome

4. The rough endoplasmic reticulum is:
   (a) An intracellular double-membrane system to which ribosomes are attached
   (b) b) An intracellular membrane that is studded with microtubular structures
   (c) c) A membranous structure found within mitochondria
   (d) d) Only found in prokaryotic cells
5. In the nucleus of eukaryotic cells, the genetic material is complexed with protein and organized into linear structures called:
   (a) Centrioles (b) Histones
   (c) Chromosomes (d) Plasmids
6. Which of the following statements does not apply to the nuclear envelope?
   (a) It is a double membrane
   (b) It is continuous with the endoplasmic reticulum
   (c) It has pores through which material enters and leaves
   (d) It has infoldings to form cristae
7. Lysosomes are formed by budding from which cellular organelle?
   (a) Smooth endoplasmic reticulum (b) Golgi apparatus
   (c) Rough endoplasmic reticulum (d) Nucleus
8. All peroxisomes carry out this function:
   (a) Break down fats and amino acids into smaller molecules that can be used for energy production by mitochondria
   (b) Digest macromolecules using the hydrolytic enzymes they contain
   (c) Synthesize membrane components such as fatty acids and phospholipids
   (d) Control the flow of ions into and out of the cell
9. How would the absence of peroxisomes in a cell affect its metabolism, and what would be the likely symptoms?
   (a) The cell would be unable to carry out oxidative phosphorylation, leading to reduced ATP production.
   (b) The cell would accumulate hydrogen peroxide, leading to oxidative stress and potential cellular damage.
   (c) The cell would have impaired protein synthesis, leading to muscle weakness.
   (d) The cell would fail to produce lipids, causing membrane instability

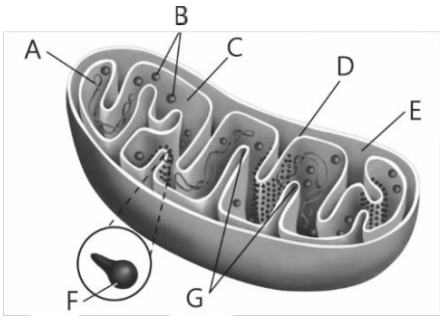
10. Which of the following does not apply to chloroplasts?
    (a) They contain chlorophyll and the enzymes required for photosynthesis.
    (b) They contain an internal membrane system consisting of thylakoids.
    (c) They synthesize ATP.
    (d) They are bounded by two membranes, the inner of which is folded into the cristae.
11. What is the correct sequence of membrane compartments through which a secretory protein moves from synthesis to release from the cell?
    (a) SER → Golgi apparatus → RER → Cell membrane
    (b) Cell membrane → Golgi apparatus → RER → SER
    (c) RER → Golgi → Cell membrane → SER
    (d) RER → SER → Golgi apparatus → Cell membrane
12. How does the process of facilitated diffusion differ from active transport?
    (a) Facilitated diffusion requires energy, active transport does not
    (b) Facilitated diffusion does not require energy, active transport does
    (c) Both processes require energy
    (d) Both processes do not require energy

SECTION 2:SHORT QUESTIONS

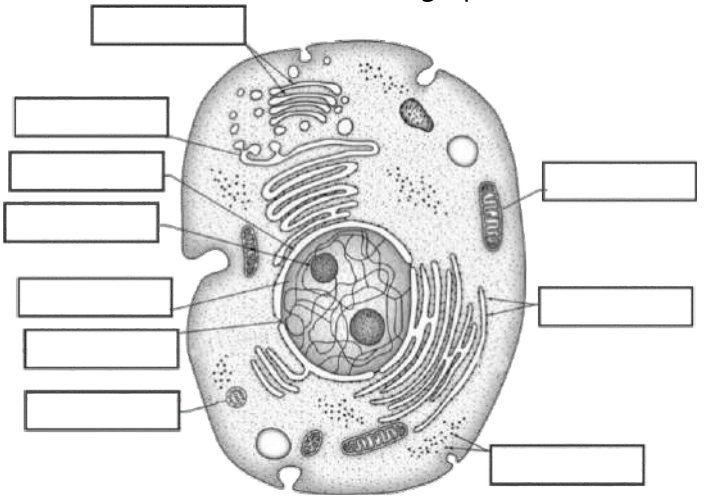
1. Compare the resolution and magnification of light microscope and electron microscope?
2. State the cell theory. How we can validate it? What are the exceptions to cell theory?
3. The table below compares the process of diffusion, facilitated diffusion and active transport.Fill in the blank cells , using the words"YES" or "NO".

	Process		
Description	Simple Diffusion	Facilitated Diffusion	Active Transport
Is ATP required?			
Are carrier proteins involved?			
Is direction of transport always from higher to lower concentration?			

4. Categorize the organelles as (i) single membrane bounded, (ii) double membrane bounded and (iii) lacking any membrane.
5. State two functions of the proteins in the plasma membrane.
6. State two features that mitochondria have in common with prokaryotes.
7. List three ways in which prokaryotic cells differ from eukaryotic cells.
8. List the structures and molecules, which can cross the nuclear envelope.
9. Distinguish each of the following pairs.
   a- exocytosis and endocytosis
   b- phagocytosis and pinocytosis
   c- peroxisome and glyoxysomes
10. What are the main functions of lysosomes?]
11. Describe the role of the Golgi body in forming lysosomes.
12. What are histones? Where are these found in eukaryotic cells?
13. What do you mean by "stem cell"? What are the main usages of stem cells?
14. The following diagram shows the structure of a mitochondrion. Name structures A to G.



15. The diagram below shows an electron micrograph of a cell.



a- Label the parts of the cell.
b- What evidence can be seen in the diagram that suggests that the cell is metabolically active and involved in secretion of enzymes?

SECTION 3: LONG QUESTIONS

1. Write details of the structure and the chemical composition of cell walls of eukaryotes and prokaryotes.
2. Explain the chemical composition and the functions of plasma membrane.
3. Identify the role of glycolipids and glycoproteins as the cell surface markers.
4. Explain the structure, chemical composition and function of ribosomes.
5. Explain the structure, and functions of Golgi complex.
6. Describe the structure, chemical composition and function of chromosome.
7. Discuss nuclear envelope and nuclear pore complex in detail.
8. Explain how Golgi apparatus is involved in making cell secretions.
9. Describe the structure and functions of smooth and rough endoplasmic reticulum.
10. Explain the role of lysosomes and peroxisomes in regulating the amounts of cellular contents.
11. Describe the structures of the three fibres that make the cytoskeleton.
12. Describe the formation and functions of lysosomes.
13. Compare mitochondria and chloroplasts as the organelles that are involved in cellular energetics.
14. Describe the basic structure of a mitochondrion, from outside inward.
15. Describe the pathway of protein signal and steroid signal from outside of a cell to inside.
16. Categorize and explain different types of stem cells.
17. What are the advantages and disadvantages of using induced Pluripotent Stem Cells?

INQUISITIVE QUESTIONS

1. If a researcher observes that a certain cell type has an exceptionally large Golgi apparatus, what can be inferred about the function of this cell?
2. If a signalling molecule is lipid-soluble, like a steroid hormone, what is the most likely mechanism for its action within the target cell?
3. Why do we categorize endocytosis and exocytosis in active transport?
4. Justify why the membrane may be described as fluid.

Chapter 4

BIOMOLECULES

STUDENTS'LEARNING OUTCOMES

After studying this chapter, the students will be able to:

- Define biochemistry/molecular biology.
- Describe Briefly the different types of bonds found in biology (hydrogen bonds, covalent bonds, interactions, Ionic, hydrophobic and hydrophilic interactions etc.).
- Distinguish carbohydrates, proteins, lipids and nucleic acids as the four fundamental biological molecules.
- Describe and draw sketches of the condensation synthesis and hydrolysis. reactions for making and breaking of macromolecule polymers.
- State the properties of water (high polarity, hydrogen bonding, high specific heat, high heat of vaporization, cohesion, hydrophobic exclusion, ionization and lower density of ice) which allow it to be the medium of life.
- Define carbohydrates and classify them.
- Compare and contrast the properties and roles of monosaccharides and write their formulae.
- Compare the isomers and stereoisomers of glucose.
- Distinguish the properties and roles of disaccharides.
- Describe glycosidic bond in disaccharides.
- Describe the structure properties and roles of polysaccharides starch, glycogen, cellulose and chitin.
- Define protein, amino acid and recognized essential amino acid and structural formula of amino acid.
- Outline the synthesis and breakage of peptide linkages.
- Justify the significance of the sequence of amino acids through the example of sickle cell haemoglobin.
- Classify proteins as globular and fibrous proteins.
- List the roles of structural proteins and functional proteins with 3 examples.
- Define lipids.
- Describe the properties and roles of acylglycerols, phospholipids, terpenes and waxes.
- Illustrate the molecular structure (making and breaking) of an acylglycerol, a phospholipid and a terpene.
- Evaluate steroids and prostaglandins as important groups of lipids.
- Describe nucleic acids and molecular structure of nucleotides.
- Distinguish among the nitrogenous bases found in the nucleotides of nucleic acids.
- Outline the examples of a mononucleotide (ATP) and a dinucleotide (NAD).
- Illustrate the formation of phosphodiester bond.
- Explain the double helical structure of DNA as proposed by Watson and Crick.
- Explain the general structure of RNA.
- Distinguish in terms of functions and roles, the three types of RNA.
- Discuss the Central Dogma.
- Define conjugated molecules and describe the roles of common conjugated molecules i.e. glycolipids, glycoproteins, lipoproteins and nucleoproteins.

Recall "levels of biological organization" that you have studied in your previous classes. You got a brief introduction about biological molecules in reference of levels of biological organization. Now you would get detailed study of carbohydrates, proteins, lipids and nucleic acids as well as the importance of water and the role of conjugated molecules.

Biochemistry

Biochemistry is the study of chemical components and chemical processes, occurring in living organism. All structures of living organisms have biochemical organization and all functions occurring in them are due to biochemical processes taking place in this organization. Therefore, a basic knowledge of biochemistry is helpful to understand anatomy and physiology of living organisms. Photosynthesis, respiration, digestion, contraction etc. can be described in biochemical terms.

Recalling

Life of an organism depends upon the ceaseless chemical activities in its cells. All the chemical reactions taking place within a cell are collectively called metabolism. The processes in metabolism may be either anabolism or catabolism. In anabolism, simpler substances are combined to form complex substances and in catabolism complex molecules are broken down into simpler ones.

4.1- BIOLOGICAL MOLECULES

Life on Earth evolved in water, and all life still depends on water. At least 80% of the mass of living organisms (protoplasm) is water, and almost all chemical reactions of life take place in aqueous solutions. The other chemicals that make up living things are mostly organic macromolecules and certain inorganic molecules. The molecules synthesized by cells and containing carbon are known as organic molecules. They occur naturally only in the bodies of living organisms or in their products and remains. Carbohydrates, proteins, lipids and nucleic acids are important organic molecules in living organisms. They make 93% of the dry mass of living organisms (Table 4.1). The remaining 7% comprises of small organic molecules (like vitamins) and inorganic molecules (like carbon dioxide, acids, bases, and salts).

Organic molecules have carbon-based core with special groups of atoms attached. These groups are called **functional groups** for example OH, CO, COOH, NH_2 etc. Most biochemical reactions involve the transfer of a functional group from one molecule to another, or the breaking of carbon-carbon bond.

Table 4.1: %age of major organic molecules in the dry mass of

Group name	% Dry mass
Proteins	50
Nucleic acids	18
Carbohydrates	15
Lipids	10

Most of the organic molecules are large in size and biologists call them macromolecules. Many macromolecules are in the form of polymers. A polymer is a molecule consisting of many identical molecular units, called monomers. Important macromolecules like carbohydrates, proteins, and nucleic acids are the polymers of simple monomers i.e., sugars, amino acids and nucleotides respectively.

4.2- TYPES OF BONDS IN BIOLOGY

Different types of bonds and interactions play vital roles in the structure and function of biological molecules.

Carbon is the basic element of organic molecules. It is tetravalent and can react with many other known elements like H, O, N, P and S. Carbon and hydrogen bond (C-H bond) is the potential source of chemical energy for cellular activities. Carbon-oxygen association in glycosidic linkages provides stability to the complex carbohydrate molecules. Carbon combines with nitrogen in amino acid linkages to form peptide bonds and forms proteins which are very important due to their diversity in structure and functions.

Covalent bonds form when two atoms share electrons (Figure 4.1). These bonds are often found in organic molecules like proteins and nucleic acids, providing stability to the molecules.

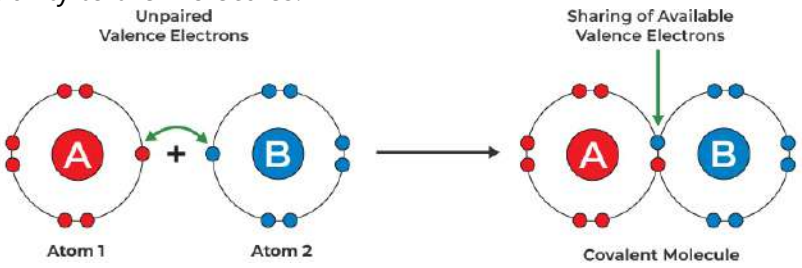


Figure 4.1: Covalent bond between two atoms

Ionic bonds are formed when one atom donates an electron (becomes a positive ion, or cation) and another atom accepts the electron (becomes a negative ion, or anion) (Figure 4.2). The electrostatic attraction between these oppositely charged ions forms the ionic bond. Ionic bonds are relatively strong in the solid state and are formed mostly in inorganic molecules like sodium chloride.

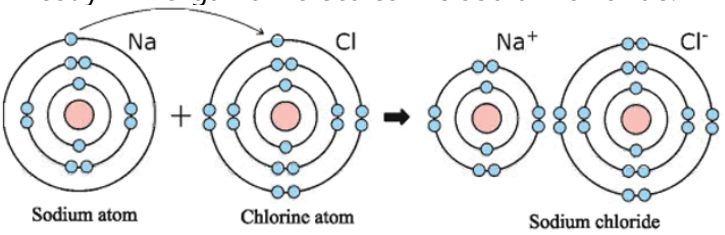


Figure 4.2: Ionic bond between sodium and chlorine atoms

Hydrogen bonds are weak attractions that occur between a hydrogen atom and an electronegative atom (such as oxygen or nitrogen). These bonds are important in maintaining the structure of large molecules like proteins and nucleic acids, as well as in various biological processes like DNA replication.

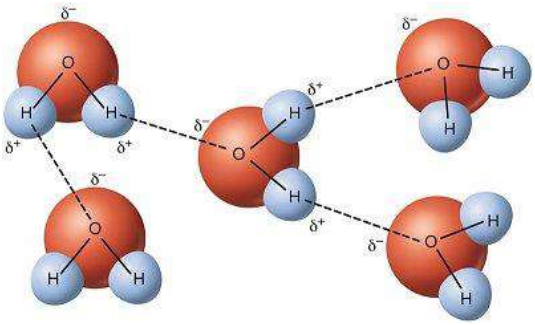


Figure 4.3: Hydrogen bond between water molecules

Hydrophobic interactions occur between nonpolar molecules and polar molecules (like water). Nonpolar molecules tend to cluster together in aqueous environments to minimize contact with water molecules. This phenomenon is crucial for the folding of proteins and the formation of lipid bilayers in cell membranes.

Hydrophilic interactions occur between polar molecules and water molecules. These interactions are essential for the dissolution of polar and ionic compounds in water. These interactions help in various biological processes such as nutrient transport and chemical reactions within cells.

4.3- CONDENSATION (SYNTHESIS) AND HYDROLYSIS

Energy is required to break chemical bonds when water is extracted from monomers. So, cells must supply energy to make macromolecules.

Proteins, nucleic acids, carbohydrates, and lipids are assembled from different kinds of monomers. All these biomolecules join their monomers by condensation or dehydration process. During condensation, an -OH group is removed from one monomer and an -H atom is removed from another monomer. It is also known as dehydration synthesis because the removal of OH and H groups means the removal of a water molecule. The formation of maltose by two glucose monomers is an example of a condensation reaction.

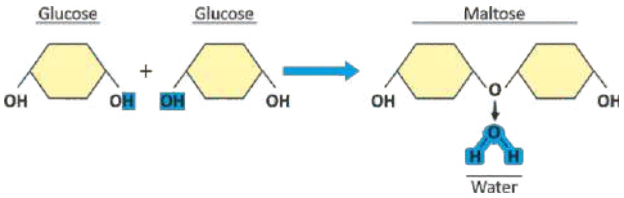


Figure 4.4: Making of macromolecules (Dehydration synthesis)

Along with making polymers by combining their monomers, cells keep on breaking polymers too. Hydrolysis is a chemical process in which macromolecule (polymer) is broken down into smaller fragments by the addition of water molecules. It is the reverse of dehydration synthesis. Cells break bonds between monomers by adding water to them. In this process, OH group from a water molecule joins to one monomer and hydrogen joins to the second monomer. Breakdown of maltose into two glucose monomers by the addition of a water molecule is an example of hydrolysis.

This breakdown of macromolecules is essential in various biological processes, such as digestion and cellular respiration, where smaller molecules are needed for energy production.

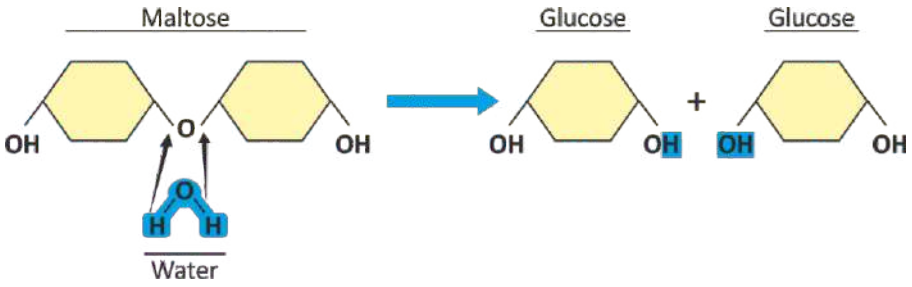


Figure 4.5: Breaking of macromolecules (Hydrolysis)

4.4- IMPORTANCE OF WATER

An oxide of hydrogen, water has the chemical formula H_2O. This seemingly simple molecule has many surprising properties, which give it the status of "the medium of life". About two third of our bodies are composed of water and we cannot exist without it. In fact, it is the most abundant compound found in all organisms. Its concentration varies from 65 to 89 percent in different organisms. In multicellular organisms, its concentration varies from tissue to tissue. For example, bone cells are made up of about 20 percent water and brain cells contain 85 percent water. Water plays important roles in making and maintaining the matter of life (protoplasm) and in establishing suitable environment, necessary for the working of life. Water has many important properties which make it essential for life.

Solvent Properties

The ability of water to dissolve a wide variety of substances is due to its two properties, the **polarity of water molecules** and the ability of water molecules to form **hydrogen bonds**.

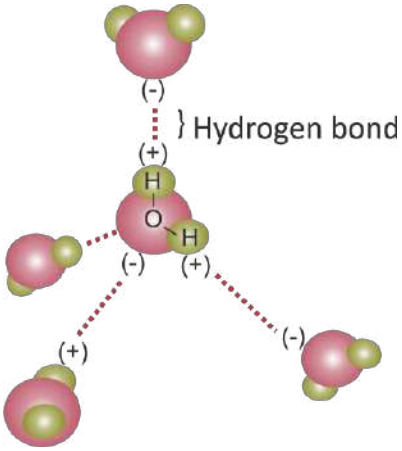
The water molecule has distinct ends, each with a partial charge. Hydrogen atom is partially positive and oxygen atom is partially

Hydrogen bonds help in maintaining the three-dimensional structures of proteins and the double helix structure of DNA.

negative. Such molecules are called polar molecules.

Without hydrogen bonding water would boil at – 80 ℃ and freeze at – 100 ℃. making life impossible.

Partial negative charge at one end of a water molecule is attracted to partial positive of another water molecule. This weak attraction is called a **hydrogen bond**. Water forms a network of such bonds. Many of the properties of water are due to hydrogen bonds in water.



Charged or polar molecules such as salts, sugars, amino acids dissolve readily in water and so are called hydrophilic ("water loving"). Uncharged or non-polar molecules such as lipids do not dissolve in water and are called hydrophobic ("water hating").

Figure 4.6: Hydrogen bonds among water molecules

Due to the polar nature of water molecules, they gather around any other molecule that has an electrical charge, whether in the form of full charge (ions) or partial charge (polar molecules). For example, when sodium chloride (a salt) is placed in water, it breaks into positive (Na^+) and negative ions (Cl^-). These ions are surrounded by opposite polar ends of water molecules (Figure 4.7).

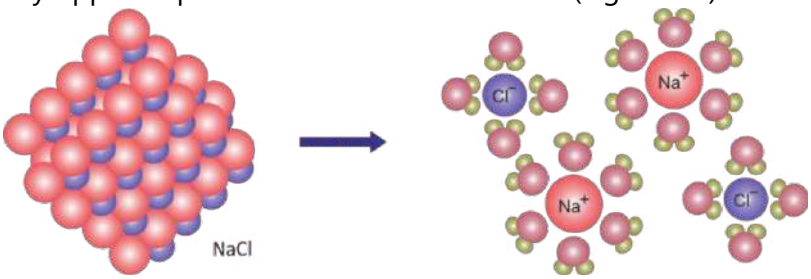


Figure 4.7: Water as a solvent of inorganic molecules (NaCl)

Similarly, when a glucose is placed in water, the molecules of water form hydrogen bonds with polar hydroxyl groups of glucose molecules. In this way, glucose dissolves in water (Figure 4.8). It means that charged or polar molecules are soluble in water. In the state of solution, ions and molecules can react with each other easily. So, water provides a medium for chemical reactions i.e., metabolism of cells.

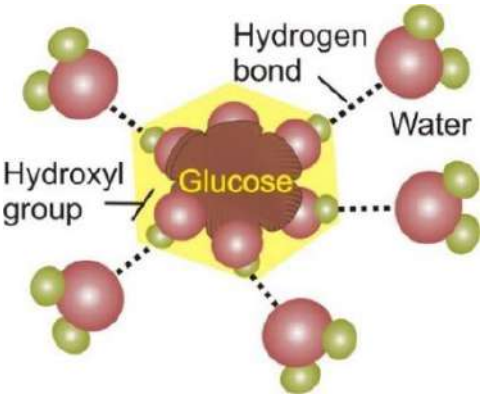


Figure 4.8: Water as a solvent of organic molecules (glucose)

So, charged or polar molecules are soluble in water. In the state of solution, ions and molecules can react with each other easily. So, water provides a medium for metabolism (chemical reactions in cells).

Polar molecules such as salts, sugars, and amino acids dissolve readily in water and are called hydrophilic (water-loving). Uncharged or non-polar molecules such as lipids do not dissolve in water and are called hydrophobic (water-hating).

Hydrophobic Exclusion

Non-polar or uncharged molecules are insoluble in water because water molecules do not make hydrogen bonds with them. When they are placed in water, water molecules move them out. The insoluble molecules make hydrophobic associations with one another. For example, lipids molecules are insoluble in water. When they are excluded from water, they make strong associations among themselves. Therefore, lipids help to maintain membranes of cells.

Figure 4.9: Hydrophobic association of oil (lipid) with water molecules

Heat Capacity

Specific heat of water is twice than that of most carbon compounds and is nine times more than that of iron.

Specific heat capacity is defined as the number of calories (amount of heat) required to raise the temperature of 1 gram of a substance from 15°C to 16°C (i.e.,1°C). Water has a high specific heat capacity i.e., 4.184 Joules. It means that water has great ability to absorb and releasing heat with minimum change in its own temperature. Most of the heat energy absorbed by water is used to break hydrogen bonds between its molecules. Due to this breakage of hydrogen bonds, individual water molecules start moving more freely and temperature of water rises.

Due to high specific heat capacity, water heats up more slowly. Similarly, when it is given a cooler environment, it holds its temperature longer. Water thus works as temperature stabilizer not only for organisms' internal environment but also for their external environment.

Heat of Vaporization

Evaporation of 2ml of water out of 1 litre lowers the temperature of the remaining 998 ml water by 1 °C.

It is the amount of heat required to change a liquid to gas. Water has high heat of vaporization. So, it absorbs much heat while changing from liquid state to gas. Its heat of vaporization is 574 Kcal/kg which means a considerable amount of heat energy (574 Kcal) is required to change 1kg of liquid water into vapours.

Due to this property, Earth's temperature is kept moderate. It also provides cooling effects to plants and animals when they transpire and perspire (sweat). Every gram of water that evaporates from plant or animals' body surface removes 574 calories of heat from the body.

Cohesion

Figure 4.10: A water strider walking on the surface of water

Hydrogen bonds among water molecules enable them to "stick together". This type of attraction between same type of molecules is called cohesion. Inside water, molecules have high cohesion. The cohesion of water is important for living world. Plants depend on cohesion among water molecules for the transport of water and nutrients from roots to leaves. The evaporation of water from a leaf exerts a pulling force on water within xylem vessels of the leaf. Because of this cohesion, the force is relayed through xylem vessels all the way down to roots. As a result, water rises against the force of gravity.

Hydrogen bonds also give water high surface tension. Water behaves as if it were coated with some invisible film. You can see in Figure 4.10, the insect water-strider walks on water without breaking surface.

Ionization of Water

When the covalent bonds among the atoms of water molecule break, water is ionized to form hydrogen ions (H+) and hydroxyl ions (OH-). At normal conditions, this reaction is reversible and equilibrium is maintained. At room temperature (25 °C), in a litre of water one molecule out of each 550 million is ionized and thus the concentration of each of H^+ and OH^- in pure water remains at 10^{-7} moles/litre.

Acids combine with OH^- ions, leaving H^+ ions in medium and make medium acidic. Similarly bases combine with H^+ ions, leaving OH^- ions in medium, and make medium basic.

H+ and OH- ions take part in many chemical reactions in the cells e.g., hydrolysis of macromolecules. Relative concentrations of H+ and OH- ions determine the acidity and alkalinity of medium i.e., pH of medium. The pH affects the biochemical reactions. Enzymes work best at specific pH.

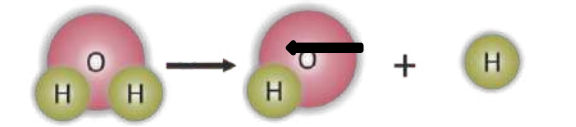


Figure 4.11 : Ionization of water

Maximum Density at 4°C

Water exhibits its maximum density at 4°C. Its density decreases when the temperature lowers. It is because of the hydrogen bonds which keep water molecules relatively far apart. When temperature falls to 0°C, water freezes but the resulting ice is less dense than liquid water, because at this temperature, hydrogen bonding keeps water molecules further apart than in liquid water.

In rivers, streams or lakes, ice is formed on the surface water due to falling of temperature. As ice is less dense than water, it floats on surface. It acts as an insulator and does not allow heat to escape from the water beneath it. In this way aquatic organisms are protected.

Table 4.2: Properties of water and benefits to life

Properties	Bonding	Benefits to life
Best solvent	Polarity	Provides medium for chemical reactions
Maximum heat capacity	Hydrogen bonding	Keeps temperature constant internally and externally for organism

Maximum density at 4 °C	Change in hydrogen bonding	Ice floats on water
High heat of vaporization	Hydrogen bonding	Moderates Earth's temperature
Ionization	Covalent bond breaks	Determine the acidity and alkalinity of medium
Cohesion	Polarity, Hydrogen bonding	Water and nutrients are transported from roots to leaves

4.5- CARBOHYDRATES

Carbohydrate are naturally occurring organic compounds. The word "carbohydrate" literally means "hydrated carbon". Carbohydrates are synthesized as the primary products of photosynthesis. During photosynthesis, when reduction of CO_2 occurs, the resulting carbohydrate molecule contains carbon, hydrogen and oxygen in the molar ratio of 1:2:1. Their empirical formula is **$C(H_2O)n$** where 'n' is the number of carbon atoms.

Classification of Carbohydrates

Carbohydrates are also known as "Saccharides" (Latin: "Saccharum" meaning sugar) and are classified into three groups after this name: 1. Monosaccharides 2. Disaccharides, and 3. Polysaccharides.

1- Monosaccharides

Monosaccharides (simple sugars) are made of single sugar molecule. They are easily soluble in water. They may have 3 – 7 carbon atoms. They are further classified into subgroups on the basis of number of carbon atoms. Pentoses and hexoses are most common and found in all living organisms. Hexoses play central role in energy storage. The primary energy-storage molecule is **glucose** with seven energy-storing CH bonds. Its empirical formula is **$C_6H_{12}O_6$ or $(CH_2O)_6$**

Table 4.3: Classification of monosaccharides

Monosaccharides	Carbon atoms	Formula	Examples
Trioses	3	$C_3H_6O_3$	Glyceraldehyde, Dihydroxyacetone
Tetroses	4	$C_4H_8O_4$	Erythrose, Erythrulose (intermediate in photosynthesis in bacteria)
Pentoses	5	$C_5H_{10}O_5$	Ribose, Deoxyribose ($C_5H_{10}O_4$), Ribulose
Hexoses	6	$C_6H_{12}O_6$	Glucose, Fructose, Galactose
Heptoses	7	$C_7H_{14}O_7$	Rare in nature (intermediate in photosynthesis)

Isomers of monosaccharides

The molecules which have the same number of atoms (same molecular formula) but differ in how the atoms are arranged (different structural formula) are called isomers of each other. For example, glucose is not the only monosaccharide with the formula $C_6H_{12}O_6$. **Fructose** and **galactose** also have the same molecular formula but their structural formulas are different. The structural and orientation differences have important consequences in the making of polymers.

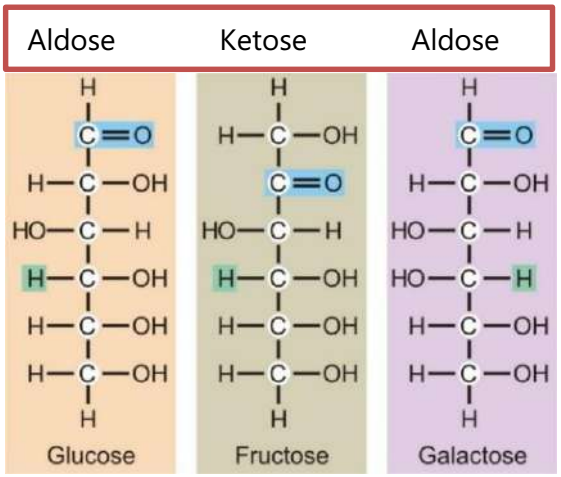


Figure 4.12: Structural and stereoisomers of glucose

In fructose, the double-bonded oxygen is attached to an internal carbon (no. 2) rather than to a terminal one. In other words, glucose and fructose are **structural isomers** Glucose and galactose have a difference in the orientation of one hydroxyl (OH) group at carbon no. 4 (Figure 4.12). It means that glucose and galactose are **stereoisomers**

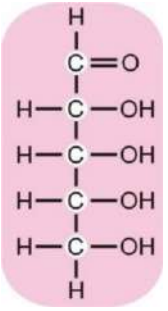
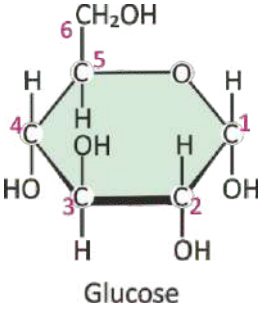


Figure 4.13: Structure of Ribose

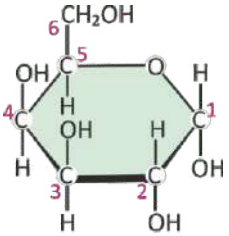
Common five-carbon or pentose sugars include ribose and deoxyribose (found in nucleic acids and ATP) and ribulose (which occurs as a precursor in photosynthesis).

Ring Structures of Monosaccharides

When in solution, most of the monosaccharides form ring structures. Ring formation occurs when an oxygen-bridge develops between two carbon atoms of the same sugar molecule (Figure 4.14).

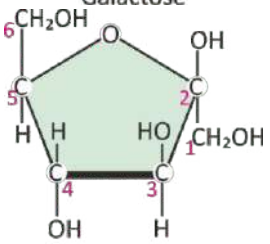


In case of glucose, oxygen-bridge develops between carbon number 1 and 5. So, a six cornered ring (Pyran) is formed.



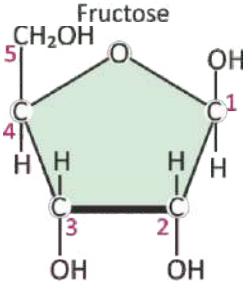
Galactose

In galactose too, oxygen-bridge is formed between carbon number 1 and 5. It again gives a six-cornered (Pyran) ring.



Fructose

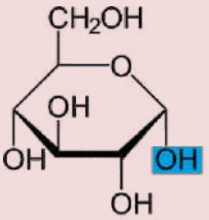
In fructose, oxygen-bridge is formed between carbon number 2 and 5. So, a five cornered ring (Furan) is formed.



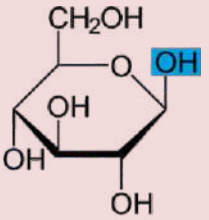
Ribose

When ribose goes in solution, oxygen-bridge develops between carbon number 1 and 4. So, a five cornered ring (Furan) is formed.

There are two forms of D-glucose i.e., alpha-D-glucose and beta-D-glucose. They differ only in the direction of OH groups on carbon 1. The α-D-glucose has OH group on the lower side while the β-D-glucose has OH- on above side. When many alpha-D-glucose molecules join together, they form a polymer called starch. When many beta-D-glucose molecules join together, they form a polymer called cellulose.



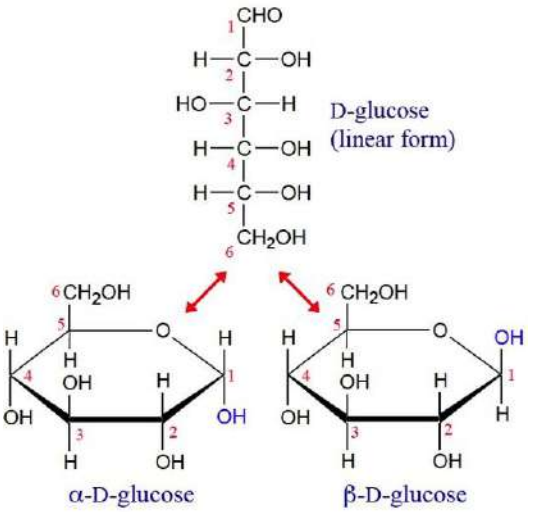
α-D-glucose



β-D-glucose

Figure 4.14: Ring structures of glucose, galactose, fructose, and ribose

Fischer and Haworth projections are two ways to represent the structure of sugar molecules. The Fischer projection was devised by German chemist Emil Fischer in 1891, In a Fischer projection the carbohydrate is shown in its open chain form, rather than a cyclical one. The Haworth projection is named after British chemist Sir Norman Haworth. It shows sugars in their cyclic forms.



2. Disaccharides

They are made from two monosaccharides by the process of dehydration synthesis. The covalent bond between two monosaccharides is called **glycosidic bond** On hydrolysis, they yield monosaccharide monomers, of which they are made. As compared to monosaccharides, they are less soluble in water. Physiologically important disaccharides are:

Maltose (Malt Sugar)

It is made up of two glucose monomers. The glucose molecules are attached by 1,4-glycosidic bond between carbon 1 of one and carbon 4 of the other glucose. It is found in many cereals (wheat, corn etc.) and is also formed (as an intermediate product) during the digestion of starch (Figure 4.15).

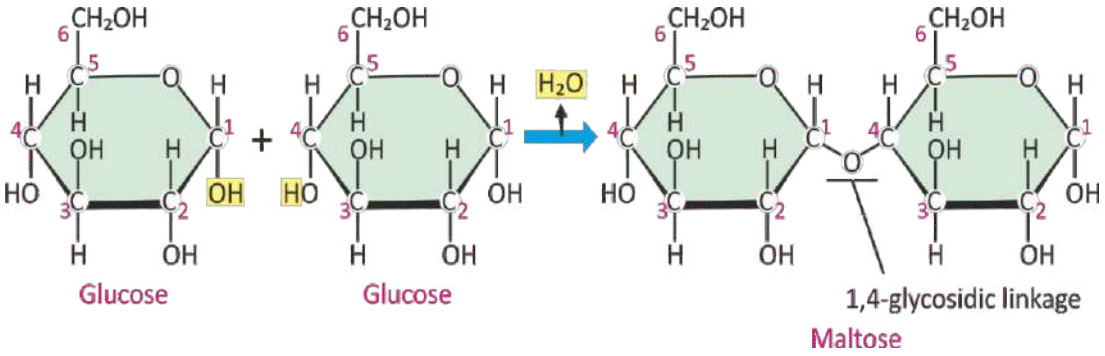


Figure 4.15: Dehydration synthesis of one maltose by the condensation of two glucose

Lactose (Milk Sugar)

It is made up of one glucose and one galactose subunit i.e., it is galactose 1-4 glucose. It is found only in mammalian milk, and is the main source of energy for infant mammals.

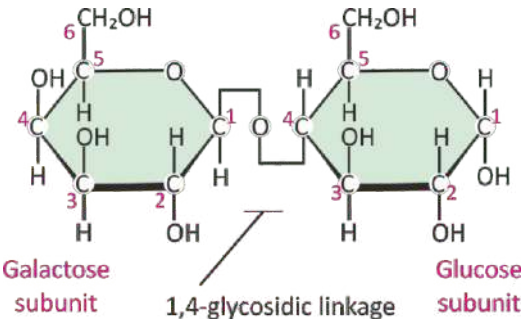


Figure 4.16: Structure of lactose

Sucrose (Cane Sugar)

It is made up of one glucose and one fructose subunits i.e., it is glucose 1-2 fructose. It is the most familiar disaccharide and is also known as table sugar. It acts as a sweetener in our food. Its molecular formula is ($C_{11}H_{22}O_{11}$). It is also found in phloem vessels of higher plants where it acts as a transport product for the conduction of glucose to and from different parts of plant. That is why it is also known as transport disaccharide.

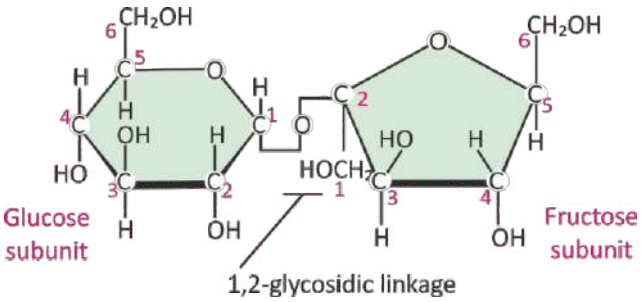


Figure 4.17: Structure of sucrose

By 1950, food sweeteners were taken from sucrose extracted from sugarcane and beet. In a small part of market, sweeteners were obtained by breaking down the starch of corn into glucose monomers. Because glucose is only half as sweet as sucrose, this method was not a serious rival to cane and beet sugar. In 1980s, a method was developed to convert the glucose, obtained from corn starch, into its isomer i.e., fructose. Fructose is even sweeter than sucrose. The resulting high-fructose corn syrup is inexpensive and has replaced sucrose in many prepared foods. The manufacturers of soft drinks "Cola", were the largest commercial users of sucrose in the world. Now they have almost completely replaced sucrose with high-fructose corn syrup.

3. Polysaccharides

Polysaccharides are the most complex and most abundant carbohydrates found in nature. They are long chains of many monosaccharides joined together by glycosidic bonds. There are three important polysaccharides:

Starch

Starch is the plant storage polysaccharide. It is insoluble and forms starch granules inside many plant cells. Because it is insoluble, it does not change water

potential of plant cells. So, it does not cause the cells to take up water by osmosis. Starch is not a pure substance, but is a mixture of amylose and amylopectin (Figure 4.18).

Amylose is a chain made of glucose monomers (with 1,4-glycosidic linkages). It is straight and unbranched. However, it tends to coil up into a helix.

Amylopectin is also a chain of glucose monomers (with 1,4-glycosidic linkages). It also has branches (with 1,6-glycosidic linkages). In this way, it has more ends that can be broken more quickly by amylase enzymes. Both amylase and amylopectin are broken down by the enzyme amylase into maltose, though at different rates.

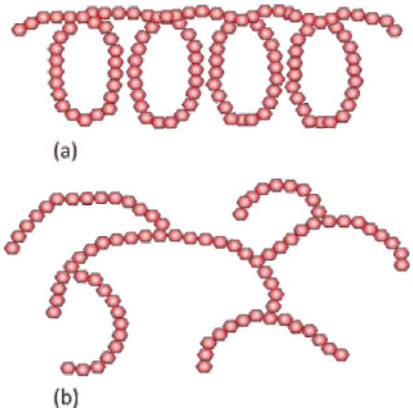


Figure 4.18: (a) amylose, (b) amylopectin

Glycogen

It is similar in structure to amylopectin. It is a chain of glucose monomers (with 1,4-glycosidic linkages) with branches (with 1,6-glycosidic linkages). It is made by animals as their storage polysaccharide, and is found mainly in muscles and liver. Because it is so highly branched, it can be broken down to glucose very quickly.

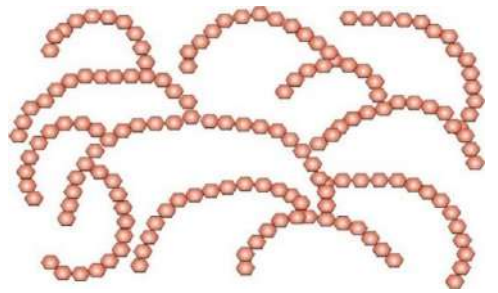


Figure 4.19: Glycogen

Cellulose

Cellulose is only found in plants, where it is the main component of cell walls It is a chain of glucose monomers (with 1,4-glycosidic linkages), but with a different isomer of glucose. Starch and glycogen contain alpha-glucose, in which OH group on carbon 1 sticks down from the ring, while cellulose contains beta-glucose, in which OH group on carbon 1 sticks up. This means that in cellulose, alternate glucose molecules are inverted (Figure 4.20).

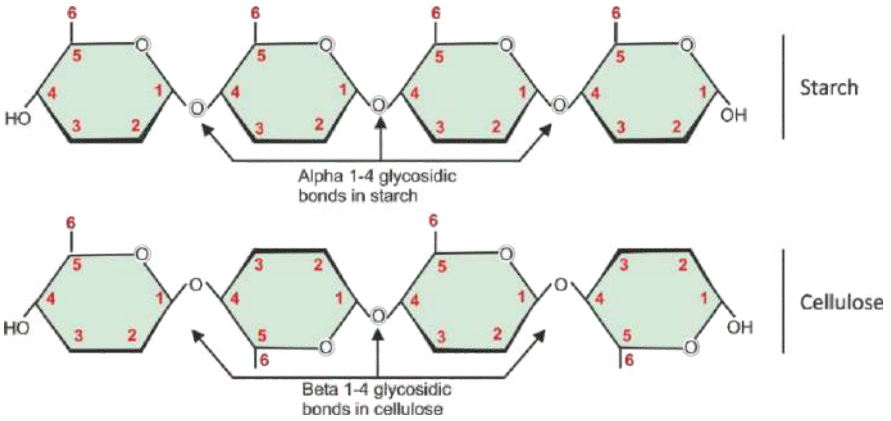


Figure 4.20: Difference between starch and cellulose

This apparently tiny difference makes a huge difference in structure and properties. The alpha 1-4 glucose polymer in starch coils up to form granules. On the other hand, the beta 1-4 glucose polymer in cellulose forms straight chains. Hundreds of these chains are linked together by hydrogen bonds to form cellulose microfibrils. These microfibrils make cellulose fibrils (Figure 4.21). They are very strong and rigid, and give strength to plant cells, and therefore to young plants and also to materials such as paper, cotton etc.

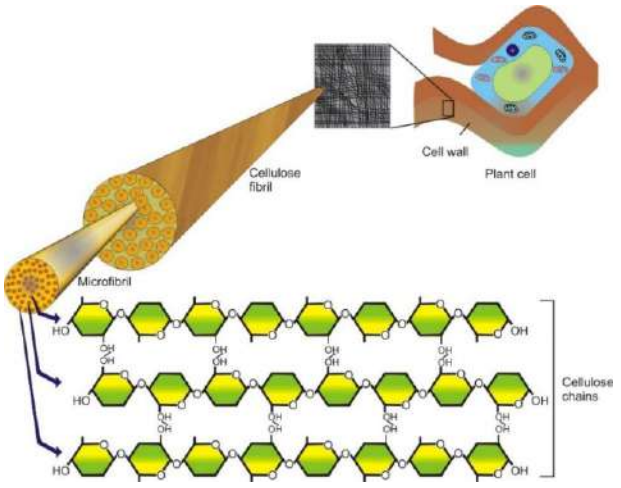


Figure 4.21: Cellulose fibrils in plant cell wall

The beta-glycosidic bond cannot be broken by amylase. It requires a specific **cellulase** enzyme. Some bacteria and some protozoans are only organisms that possess cellulase enzyme. Herbivore animals, like cows and termites whose diet is mainly cellulose, have mutualistic bacteria in their guts. These bacteria digest their cellulose. Humans cannot digest cellulose, and it is referred to as dietary fibre.

Chitin

It is a modified form of cellulose. It is found in the exoskeletons of crabs, lobsters and insects. It also makes the cell wall of fungi. Like cellulose, it is also a polymer of glucose. The linkage between glucose monomers is also like that found in cellulose. However, in chitin each glucose molecule has been modified by the

addition of a nitrogen-containing group (Figure 4.22). Only few organisms can digest it.

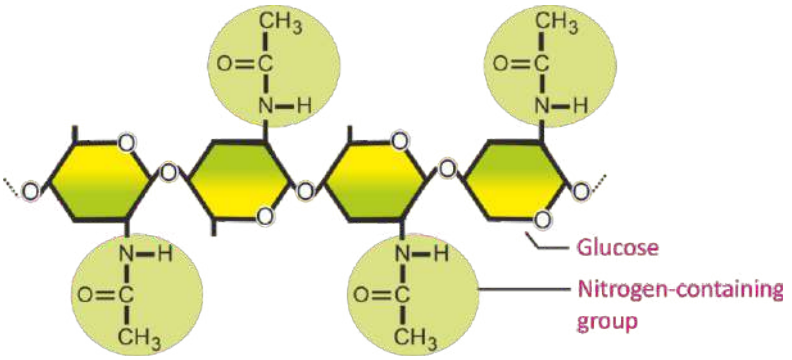


Figure 4.22: A part of the chitin molecule

Pectin and Lignin: They are also the polysaccharides used as building material. They are present in the cell walls of plant cells.

Agar: It is found in the cell walls of red algae. It is used as a thickener in foods. It is also used as a medium on which bacteria and fungi are grown in laboratories.

Murein: It is a sugar-peptide polymer and is found in the cell walls of prokaryotes.

4.6- PROTEINS

The most abundant organic compounds in cell are proteins. They may be defined as the polymers of **amino acids**. Proteins are regarded as the principal compounds of cells. J. J. Berzelius (in 1938) coined the term "protein" (Greek "Proteios"- molecules of the first rank) to emphasize the importance of this group of macromolecules. Proteins are important for the structures of cells and organisms and participate in everything they do. In this way, they act as the building blocks of life.

The diversity in biological world is the reflection of the diversity of structure and function that exists in proteins.

Structure of Proteins

Proteins are the polymers formed by the inter-linkage of monomers called amino acids. Different proteins may have a few to 3000 amino acids in their make-up (e.g., Insulin has 51 amino acids, Haemoglobin has 574 amino acids).

Amino acid

Amino acid is the basic structural unit of proteins. It is an organic molecule, in which four groups; an amino group (NH_2), a carboxyl group (COOH), a hydrogen group (H) and a side group (R); are attached to the same carbon atom (alpha carbon).

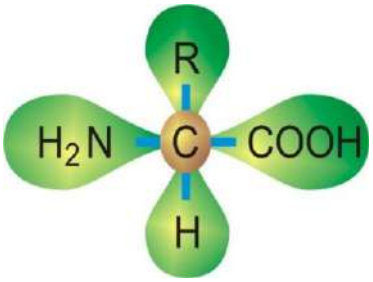


Figure 4.23: Structure of an amino acid

Although many different amino acids occur in nature, about 170 types of amino acids have been reported to occur in living organisms (in cells and tissues). Of these, about 25 types of amino acids may take part as building units of proteins. Most of the proteins are, however, made of 20 types of amino acids.

The identity and unique chemical properties of each amino acid are determined by the nature of its side group (R), covalently bonded to alpha carbon. For example, R may be a hydrogen atom as in glycine, or CH_3 as in alanine, or any other group. (Figure 4.24).

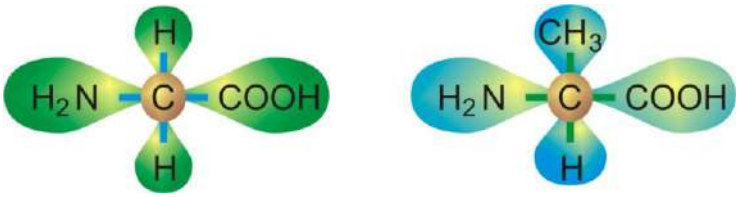


Figure 4.24: General structures of glycine and alanine

Essential and Non-essential Amino acids

Out of 20 amino acids, our bodies can make eleven amino acids. These are called **non-essential amino acids** and include alanine, arginine, asparagine, aspartic acid, cysteine, glutamic acid, glutamine, glycine, proline, serine, and tyrosine. The remaining nine amino acids cannot make our bodies on its own and must obtain these amino acids by eating various foods. These are called **essential amino acids** and include methionine, valine, tryptophan, isoleucine, leucine, lysine, threonine, phenylalanine and histidine (necessary only for babies).

A covalent bond that links two amino acids is known as a **peptide bond**. Note that each amino acid has an amino group at one end and a carboxyl group at the other end. When two amino acids are brought closer, dehydration synthesis occurs between the amino group of one and the carboxyl group of second amino acid. It results in the release of a molecule of water and formation of a peptide bond between "N" and "C" of adjacent amino acids.

Like disaccharide, the production of a dipeptide is dehydration synthesis.

The amino acids, which are linked by peptide bond, are called **peptides**. A dipeptide is formed by the linkage of two amino acids. For example, glycylalanine (a dipeptide) is formed by the linking of glycine and alanine (Figure 4.25).

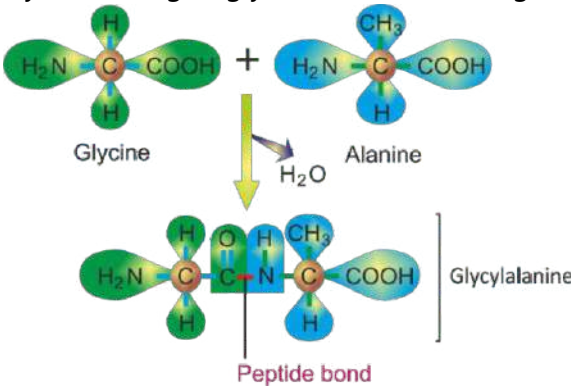


Figure 4.25: Formation of peptide bond between glycine and alanine

A dipeptide has an amino group at one end and a carboxyl group at the other end of molecule. So, both reactive parts are available for further peptide bonds. Addition of amino acids ultimately leads to **polypeptide** chains (Figure 4.26). A protein is composed of one or more polypeptide chains, e.g., insulin protein contains two polypeptide chains while haemoglobin protein has four polypeptide chains. Polypeptide chains assume different shapes on the basis of number, types and sequence of amino acids. It gives different levels of structure to proteins.

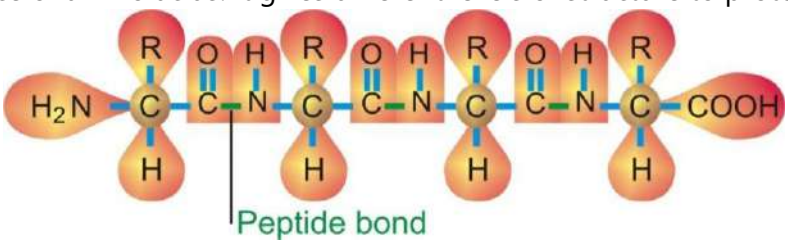


Figure 4.26: Section from a polypeptide chain

Structural Levels of Proteins

The diversity of proteins ranges from simpler (consisting of linear chains of amino acids) to complex proteins (structural modifications in linear chains). The following are different levels at which proteins are built (Figure 4.27).

Primary Structure

The primary structure of a protein molecule is formed by the **linear arrangement** of amino acids. It represents the number and sequence of amino acid molecules in a polypeptide chain. All protein molecules (whether simple or complex) have specific

These are over 10,000 proteins in human body and each of these has its specific primary structure, i.e., specific number, specific sequence and specific types of amino acids.

primary structures. The primary structure of insulin reveals that it is composed of two polypeptide chains. The smaller alpha chain has 21 amino acids while the longer beta chain is made of 30 amino acids (Figure 4.27).

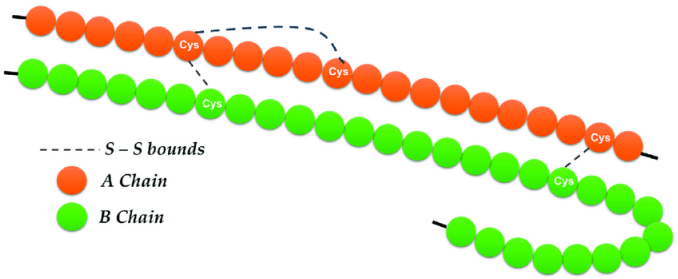


Figure 4.27: Chains of Insulin

Similarly, the primary structure of haemoglobin shows that it is made of four polypeptide chains i.e., two alpha (141 amino acids in each chain) and two beta chains (146 amino acids in each chain).

The number, sequence and types of amino acids is highly specific in the primary structure of a protein, for its proper functioning. This specificity in primary structure is determined by the order of nucleotides in DNA. Any change results in abnormal protein that fails to carry out its normal function. For example, **sickle cell haemoglobin** is formed by a mistake in the arrangement of only one amino acid in position six in each beta chain. In sickle cell haemoglobin, amino acid **valine** is present in the place of **glutamic acid**. Due to sickle cell haemoglobin, red blood cells get sickle shapes and abnormal haemoglobin cannot transport sufficient oxygen. This disease is known as **sickle cell anaemia**(Figure 4.28).

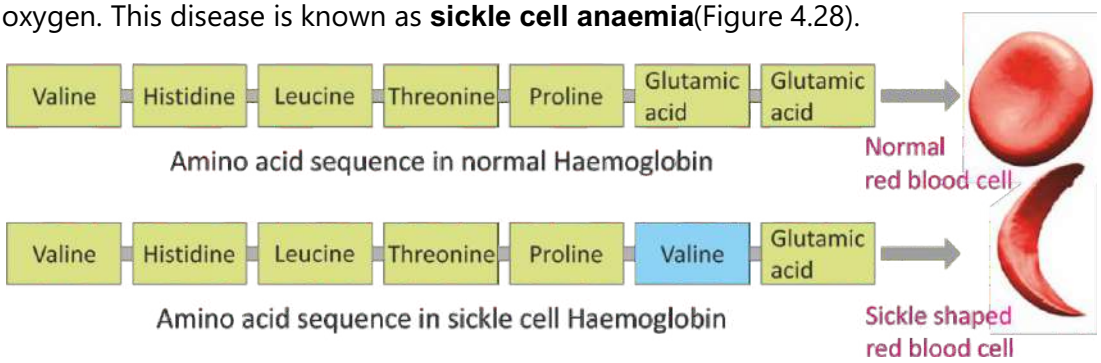


Figure 4.28: Difference in amino acid sequence in normal and sickle cell haemoglobin

Secondary Structure

In many proteins folding or coiling patterns occur within a polypeptide chain. This structure is called secondary structure. Coiling of a polypeptide chain results in **alpha helix** while folding makes a **pleated sheet**. Both these structures are

maintained by hydrogen bonds between amino and carboxyl groups of nearby amino acids in the chain.

Tertiary Structure

When the secondary structure further folds up and gets a complicated globular shape. It is called the tertiary structure of protein. These are more complex proteins. The globular shape is maintained by ionic, hydrogen and disulphide bonds. These bonds contribute to the overall stability and shape of the protein.

Amino acids in a polypeptide chain interact with water to give the most stable tertiary structure in the form of a globular shape. These are hydrophilic and hydrophobic interactions. The hydrophobic (non-polar) amino acids aggregate in such a way that they disrupt hydrogen bonding of water molecules and so are buried inside. At the same time the hydrophilic (polar) amino acids turn out, towards the surface of water.

Quaternary Structure

When two or more polypeptide chains with tertiary structures are held together by hydrophobic interactions, hydrogen bonds and ionic bonds, they form most complex proteins. This **aggregation of tertiary structures** makes the quaternary structure of protein.

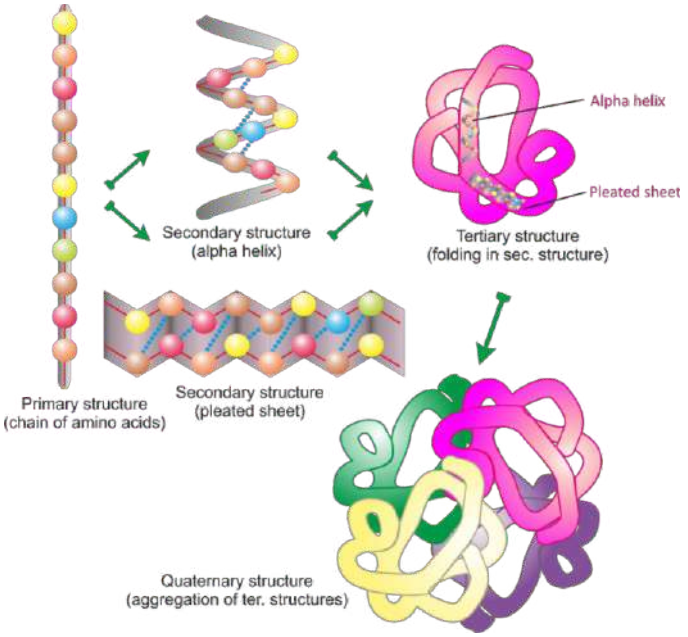


Figure 4.29: Levels of protein structure

Classification of Proteins

Proteins make a very diverse group of organic compounds in living organisms. They can be classified on different basis. For example, on the basis of their role in living organisms, these are "structural proteins" and "functional proteins". The recommended classification of proteins is based on their structure. In this classification proteins are classified as "fibrous proteins" and "globular proteins". We can describe the characteristics of both these classes by a comparison in table 4.4.

Table 4.4: Characteristics of Fibrous and Globular Proteins

Characteristics	Fibrous proteins	Globular proteins
Shape	In the form of fibrils	Spherical or ellipsoidal
Structure	Primary or secondary	Tertiary or quaternary
Role	Structural	Functional
Crystallization	Non crystalline and elastic	Can be crystallized
Solubility	Insoluble	Soluble in salt, acid or base solutions and in aqueous alcohol
Disorganization	Do not disorganize easily	Disorganized with changes in environment
Examples	Silk fibre-form the webs of silk worm and spider Actin in muscle cells Fibrin –in blood clots Keratin – in nails, hairs, beak, skin etc. Collagen – in matrix of connective tissues	Enzymes – biocatalyst Antibodies – active against invading antigens Some hormones – regulate body's activities Haemoglobin – oxygen carrying protein

Role of Proteins in life

Proteins carry out virtually all activities of living organisms. Some of their remarkable structural and functional roles are given below.

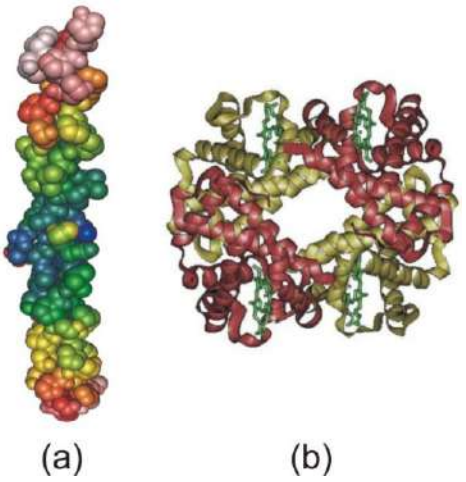


Figure 4.30: (a) Collagen – a fibrous protein, (b) haemoglobin – a globular protein

- Proteins are an important part of the composition of all plasma membranes.
- Channel proteins in the membranes of cells control the movement of materials in and out of cells. For example, proteins make **sodium–potassium pump** in the cell membrane of neurons. This pump controls the movement of Na^+ and K^+ ions in and out of nerve cell.
- Some fibrous proteins e.g., **collagen** and **keratin** make almost whole structures of cartilage and hair, nails respectively.
- **Enzymes** are a class of proteins that catalyse the metabolism of cells. They are a much diverse class of proteins. For example, proteases catalyse the breakdown of proteins, polymerases catalyse the synthesis of polymers.

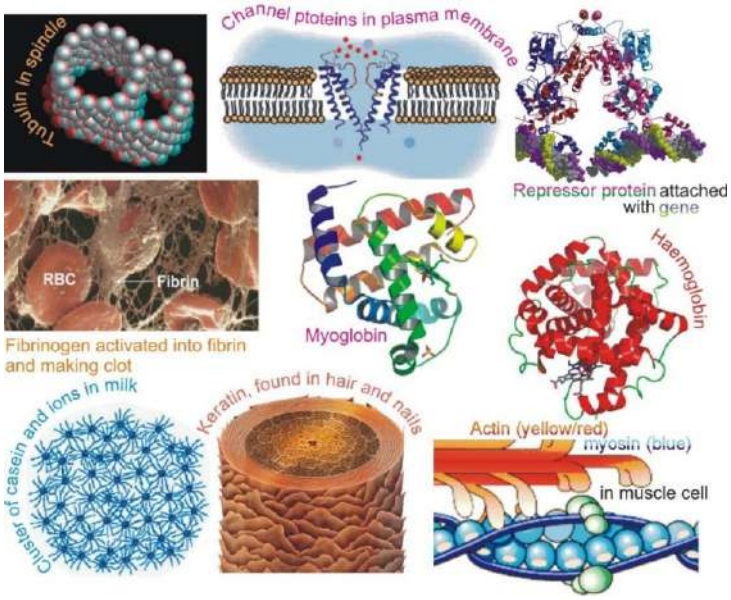


Figure 4.31: Different proteins of human body

- Some very important hormones of animals are proteins or peptides in nature. For example; **insulin** (controls blood glucose level), **antidiuretic hormone** (increases water retention by kidneys), **oxytocin** (regulates milk production).
- Some globular proteins work to transport different materials throughout the body. For example; **haemoglobin** and **myoglobin** transport O_2 and some CO_2, and **cytochromes** work in electron transport chain as electron carriers.
- **Albumin** is a blood protein that maintains osmotic concentration of blood and keeps its ability to flow.
- Blood clotting is important to prevent the loss of blood after an injury. **Fibrinogen** protein is present in blood. When an injury occurs, fibrinogen is activated into fibrin. The fibrin makes fibres and a clot is formed.
- All types of contractions in living matter are due to the actions of proteins. For example, **actin** and **myosin** are main proteins of muscles. They are responsible for muscular contractions. **Tubulin** protein makes spindle fibres.
- **Antibodies** are important proteins. They recognize and combine with foreign substances (antigens) and convert them into harmless products.
- Some ion-binding proteins store ions in different parts of body. For example, **ferritin** is the main intracellular iron storage protein. Similarly, casein is a milk protein that stores potassium and calcium ions.
- **Repressors** are the proteins that regulate gene action by preventing the synthesis of RNA. These proteins allow genes to work where and when required.

Blood ferritin levels are measured in patients as a diagnostic tool of anaemia. If ferritin is high there is iron in excess. If ferritin is low there is a risk for lack of iron which sooner or later could lead to anaemia.

4.7- LIPIDS

Lipids are a loosely defined group of non-polar molecules that are insoluble in water but soluble in organic solvents (e.g., ether, alcohol, etc.). They are a diverse group of molecules and are classified as acylglycerols, waxes, phospholipids, terpenes, steroids and prostaglandins.

Acylglycerols (Fats and Oils)

Acylglycerols are composed of two subunits; glycerol and fatty acid. The acylglycerols which are liquid at room temperature, are called **oils**. The acylglycerols which are solid at room temperature, are called **fats**. In animals, most acylglycerols are fats. In plants, most acylglycerols are oils; for example, peanut oil, corn oil, castor oil etc.

An ester is the compound produced as the result of a chemical reaction of an alcohol with an acid and a water molecule is released

Chemically, acylglycerols are the esters of fatty acids and alcohol. They are synthesized through dehydration synthesis (OH is released from alcohol and H from an acid) as shown below.

$$\underset{\text{alcohol}}{C_2H_5OH} + \underset{\text{acetic acid}}{HOOCCH_3} \longrightarrow \underset{\text{an ester}}{C_2H_5OCOCH_3} + H_20$$

The most widely found acylglycerols are **triacylglycerol** (triglycerides), also called neutral lipids. In triacylglycerols, three molecules of fatty acid (same or different) are joined to a single glycerol backbone.

Glycerol: It is a 3C alcohol and each of its carbon bears a hydroxyl group. The 3 carbons of glycerol form the backbone of acylglycerol molecule, to which three fatty acids are attached.

Fatty acids: These are responsible for all the characteristics of acylglycerols. Fatty acids are long hydrocarbon chains (with carbon in even number 4 – 30), ending in a carboxyl (-COOH) group. They vary in length and may be as straight chains (in animals) or branched or ringed (in plants). They are of two types:

If a fatty acid has one double bond it is called mono-unsaturated and if there are more than one double bond, it is called poly-unsaturated.

- **Saturated** fatty acids contain no double bond in their hydrocarbon chain. In saturated fatty acids, all internal carbon atoms possess hydrogen side-groups. These fatty acids make straight chains, and have a high melting point.
- **Unsaturated** fatty acids have double bonds (6 maximum) between one or more pairs of carbon atoms. The double bonds replace some of the hydrogen atoms. Therefore, unsaturated fatty acids contain fewer than the maximum number of hydrogen atoms. These fatty acids form bent chains, and have a low melting point.

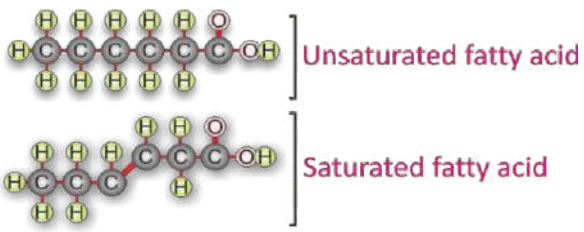


Figure 4.32 Fatty acids

Solubility of fatty acids (in organic solvents) and their melting points increase with increasing number of carbon atoms in their chains.

Acylglycerols are efficient energy-storage molecules. It is due to higher number of C-H bonds in them. They are insoluble, because of their non-polar structure. Therefore, they can be deposited at specific storage locations within organism. Animal fats contain more energy than do plant oils, because they contain

saturated fatty acids and so contain more C-H bonds. On the other hand, plant oils have unsaturated fatty acids and contain comparatively lesser number of C-H bonds. When organisms have to store glucose for long periods, they usually convert it into fats or oils.

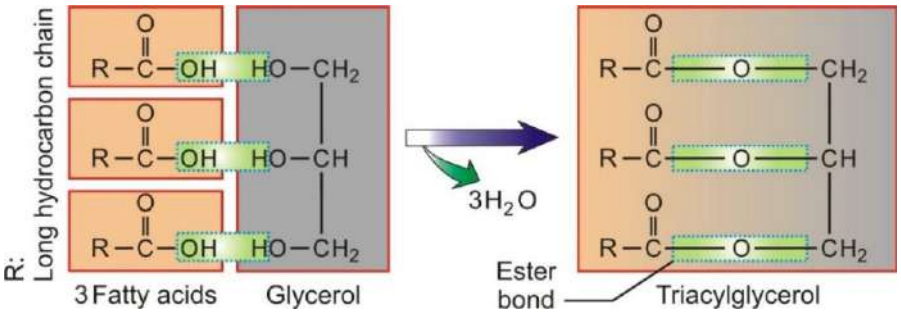


Figure 4.33: Dehydration synthesis of a triacylglycerol

Waxes

Honeybees produce waxes and use it to make six sided (hexagonal) chambers of their combs, where honey is stored. In humans, wax is secreted by glands of the outer ear canal.

Waxed are derived from acylglycerols. They have high melting points, because of large number of C atoms and so are solid at room temperature. Chemically, waxes do not have any well-defined structure and composition. They are mixtures of long chain alkanes (with carbon atoms in odd number; 25-35), alcohols (other than glycerol), ketones and long chain fatty acids.

Waxes are chemically inert. Like other lipids, waxes are strongly hydrophobic. So, they act as protective coverings and water barriers for living organisms. Waxes are widespread as protective coatings on fruits and leaves. Some animals like insects, birds, sheep etc. also secrete waxes over their skin.

Waxes are used to waterproof paper and cards. Waxes are also used in wax polishes for furniture, footwear and vehicles. Waxes are also used to make candles. Waxes with coloured pigments are used in making crayons and coloured pencils.

Figure 4.34: Some uses of waxes

Phospholipids

Phospholipids play important structural roles in making plasma membranes. Chemically they are the derivatives of **phosphatidic acid** Phosphatidic acid is composed of one glycerol, two fatty acids and one phosphoric acid (phosphate). Any nitrogenous base e.g., choline, ethanolamine or serine attaches with its phosphoric acid and makes phospholipid. Common examples are phosphatidyl choline (lecithin), phosphatidyl ethanolamine and phosphatidyl serine. Phosphatidyl choline (Figure 4.35) forms lipid bilayer in plasma membranes.

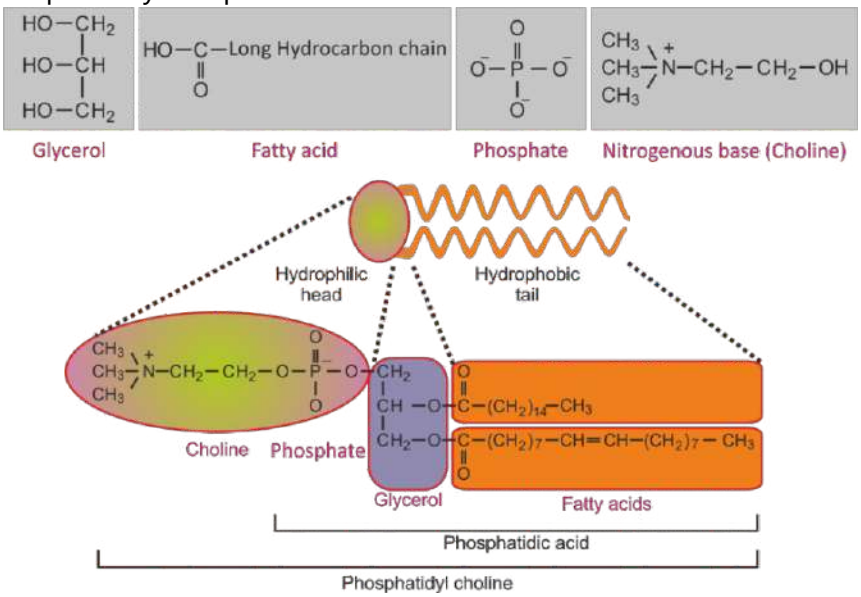


Figure 4.35: Phosphatidyl choline– a phospholipid

Phospholipids have two parts of their molecules i.e., head and tail. Head is polar and contains nitrogenous base and phosphate group while tail is non polar and contains the two fatty acids.

Terpenes

It is a very large and diverse group of lipids. All terpenes are made of isoprene units. An isoprene unit is a branched unsaturated hydrocarbon chain with the formula $CH_2=C(CH_3)-CH=CH_2$. Terpenes form many biologically important pigments, such as chlorophyll in plants and retinal pigments in eyes. Vitamin A and rubber are also terpenes.

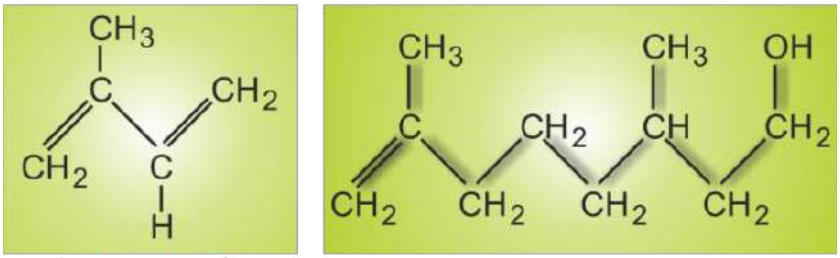


Figure 4.36: Structure of terpenes

Steroids

Steroids are lipids whose carbon skeleton is bent to form four fused rings. All steroids have the same ring pattern i.e., three 6-cornored rings and one 5-cornored ring. Cholesterol is a common steroid in animal cell membranes. Animal cells also use it for making other steroids e.g., male and female sex hormones.

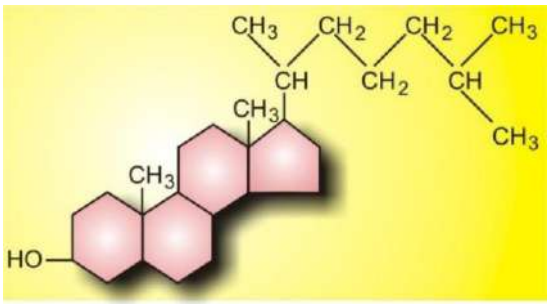


Figure 4.37: Chdesterol: a steroid

The synthesized anabolic steroids resemble male sex hormone (testosterone) and cause general build-up in muscles and bone mass during puberty in males. In 1950s some pharmaceutical companies produced anabolic steroids for the treatment of general anaemia. Some athletes began using anabolic steroids to build-up their muscles quickly and enhance their performance. Today, anabolic steroids are banned. Anabolic steroids can cause serious physical and mental problems e.g., deep depression, liver damage etc.

Prostaglandins

Prostaglandins are a group of lipids that are modified fatty acids, with non-polar tails attached to a five-carbon ring. They occur in many tissues of vertebrates, where they act as local chemical messengers. Some of them stimulate smooth muscles to contract and relax; others constrict or expand the diameter of blood vessels. They are also involved in inflammatory response to infection.

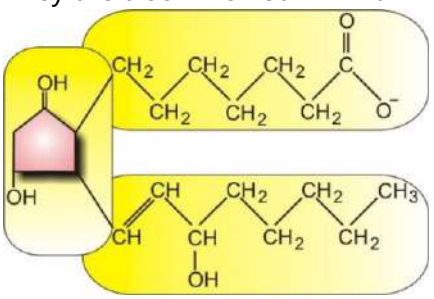


Figure 4.38: A prostaglandin

Aspirin is a prostaglandin inhibitor and that is why it reduces inflammation, pain, and fever.

Role of lipids in life

Lipids are important sources of energy (ATP). In fact, lipids are the most energy rich of all nutrients. One gram of lipids provides 9.5 kilocalories of energy. The same amount of protein provides 5.6 kilocalories while that of carbohydrate provides 4.1 kilocalories.

Lipids are essential components of all cellular and subcellular membranes.

They serve as biological carriers for the absorption of fat-soluble vitamins A, D, E and K.

Lipids are a source of fatty acids, which are essential for various metabolisms.

Lipids play a role as a mechanical cushion/support for vital body organs.

The lipids (fats) present beneath skin, insulate the body from extreme temperatures.

Steroids perform a wide range of important biological functions. For example, cholesterol is involved in the maintenance of membranes. It also helps in lipid transport. It as a precursor of vitamin D, bile acids, and steroid hormones (androgens, oestrogens), adrenal hormones and corticosteroids.

4.8- NUCLEIC ACIDS

Nucleic acids are the polymers of nucleotide units. There are two main types of nucleic acids i.e., deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). DNA is found mainly in chromosomes, with small amounts in mitochondria and chloroplasts. RNA is found in nucleolus, ribosomes and cytosol. A nucleotide is made up of a nucleoside and phosphoric acid. A **nucleoside** is made of a nitrogen base and a pentose sugar (Figure 4.39).

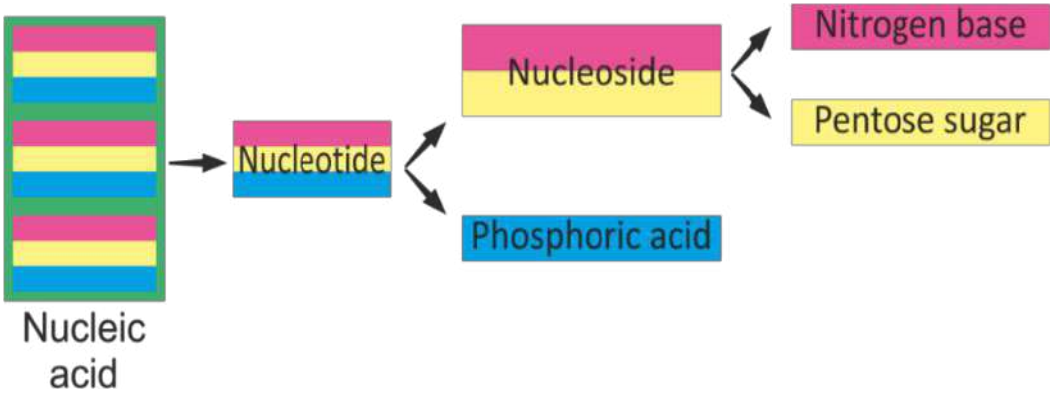


Figure 4.39: Components of nucleic acids

Pentose sugars: RNA contains ribose while DNA contains deoxyribose as their pentoses.

Nitrogenous bases: There are two types of nitrogenous bases in nucleic acids i.e., pyrimidine bases and purine bases. Pyrimidine is a single ringed nitrogenous base. There are three pyrimidine bases in nucleic acids. Cytosine (C) is present in both DNA and RNA, thymine (T) is present only in DNA, and uracil (U) is present only in RNA. Purine is a double ring nitrogenous base. Both DNA & RNA contain two purine bases i.e., adenine (A) and guanine (G). One nitrogenous base is attached with carbon 1 of pentose sugar and makes a nucleoside.

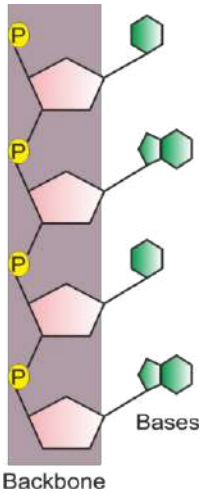


Figure 4.40: Sugar-phosphate backbone of nucleic acids

Phosphoric acid: A nucleoside develops ester linkage with a phosphoric acid and becomes nucleotide. In this ester linkage, phosphoric acid is linked with C-5 of pentose sugar. The backbone of the structure of nucleic acids is made of sugars and phosphates (Figure 4.40).

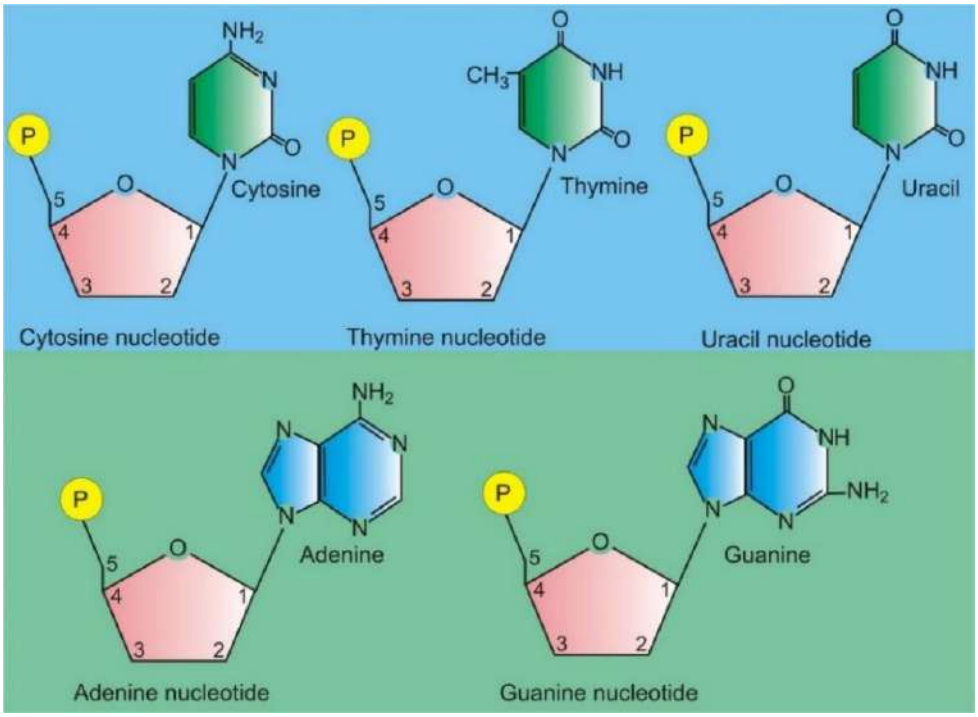


Figure 4.41: Nucleotides of RNA and DNA

Formation of Phosphodiester Bond

We know that in one nucleotide, phosphoric acid has an ester linkage at C-5 of pentose sugar. This phosphoric acid develops another ester linkage at C-3 of pentose sugar of another nucleotide. In this way, each phosphoric acid has two ester linkages with two pentose sugars (one at C-5 and other at C-3). The two ester linkages developed by phosphoric acid with two pentose sugars are known as **phosphodiester linkage** (Figure 4.42). This linkage joins two nucleotides.

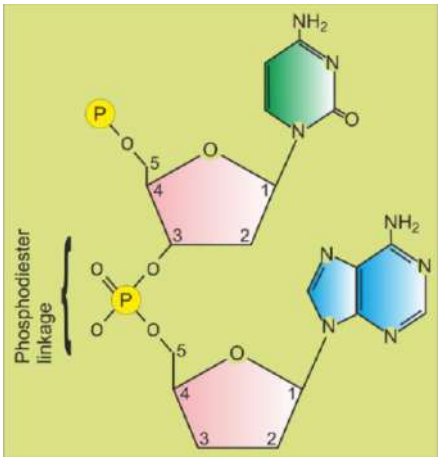


Figure 4.42: A dinucleotide

The nucleotides of RNA are known as ribonucleotides and those of DNA are known as deoxyribonucleotides. Nucleotides are named after the type of nitrogenous base. The ribonucleotides and deoxyribonucleotides are:

Nucleotides also play other critical roles in the life of cell. For example; **ATP** is a triphosphate nucleotide of adenine. In ATP, three phosphate groups are attached with one ribose sugar. You know that ATP is the "energy currency" of cell. It provides energy by successively detaching its two phosphate groups and changing to ADP and AMP. Similarly, Nicotinamide Adenine Dinucleotide (NAD) is a co-enzyme. It acts as a hydrogen acceptor in oxidation–reduction reactions in cell.

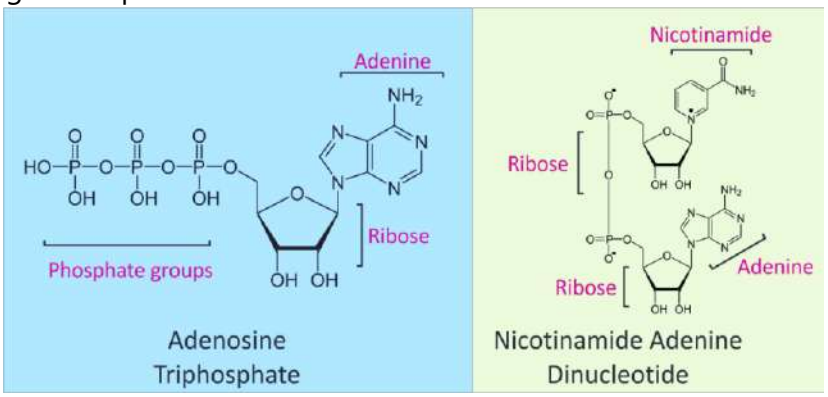


Figure 4.43: ATP and NAD

Nucleotides join together through phosphodiester linkages to form long polynucleotide chains. In a polynucleotide chain, phosphate group at 5′ end and OH group at 3′ are always free. RNA is made of a single polynucleotide chain. On the other hand, DNA is a **double helix** and is made of two polynucleotide chains.

Deoxyribonucleic Acid(DNA)

Rosalind Franklin (1953) and Maurice Wilkins (1967) studied the molecular architecture of DNA. James D. **Watson** and Francis **Crick**, in 1953 put forward the model of DNA. The observation by Chargaff was also of basic importance in working out the structure of DNA. Watson and Crick's Model of DNA suggests the following points:

In 1950, Linus Pauling concluded that DNA is a fibrous substance and the fibre is coiled into a helix. In 1951 Erwin Chargaff provided an informative data and it was found that adenine and thymine are equal in ratio in DNA and so are guanine and cytosine.

- DNA is made of two polynucleotide chains or strands.
- The two strands are coiled around each other and make a double helix.
- The double helix is like a ladder. Its poles are made of sugars and phosphate groups. Its rungs are made of nitrogenous base pairs.
- Each base pair (rung) is made of one purine (A or G) and one pyrimidine (C or T) base.
- Two strands are held together by weak hydrogen bonds between their bases.

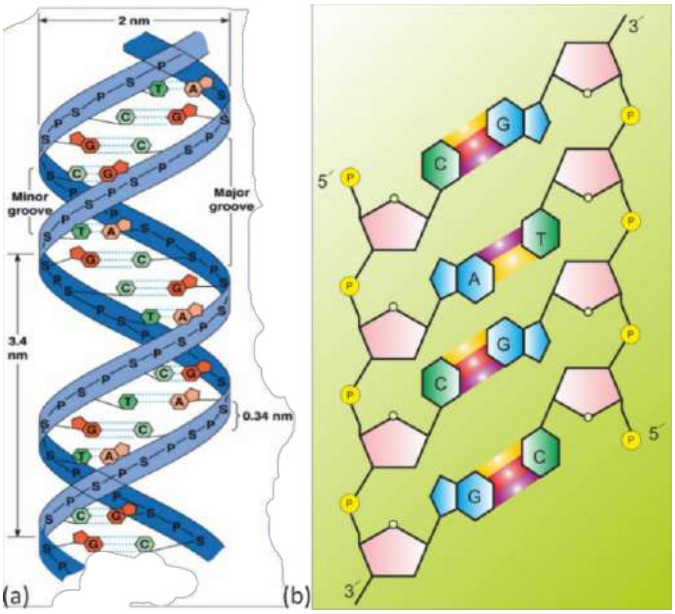


Figure 4.44: (a) Watson and Crick model of DNA, (b) The detailed structure of DNA

- Adenine in one chain makes hydrogen bonds with thymine in second chain, or vice versa. Guanine in one chain makes hydrogen bonds with cytosine in second chain, or vice versa.
- There are two hydrogen bonds between A and T pair and three hydrogen bonds between G and C pair.
- Two strands are not in the same direction with respect to their phosphodiester linkages, but are anti-parallel to each other.

DNA is the fundamental part of chromosomes and so is located inside nucleus in eukaryotes. As there is no distinct nucleus in prokaryotes, their DNA is present in cytoplasm. In viruses, DNA is located as a core molecule, covered by a protein coat.

Recalling:
In eukaryotes, small amount (about 2%) of DNA are also present in mitochondria and chloroplasts.

DNA is the hereditary material for all organisms (except some viruses). DNA contains the "program" that ultimately directs all cellular activities. The program in DNA is in the form of genes. A **gene** is a sequence of nucleotides of DNA, which codes for the formation of a polypeptide. When a gene is turned "ON", the sequence of DNA nucleotides is transcribed into RNA and then translated into specific proteins. In this way DNA controls the properties and activities of a cell.

In the chromosome of bacterium *E. coli*, each strand of DNA contains about 5 million bases arranged in a particular linear order. It has genes, each consisting of several hundred bases.

Ribonucleic Acid RNA

It is composed by ribonucleotides. RNA is synthesized by joining ribonucleotides in front of deoxyribonucleotides of DNA by transcription process. All living cells contain three types of RNA.

1. Messenger RNA (mRNA)

It consists of a single strand of ribonucleotides. Its sequence of nucleotides is complimentary to the sequence of nucleotides of one of the strands of DNA. mRNA is about 3-4% of the total amount of RNA in cell. It carries the genetic message of DNA to ribosomes to form particular protein.

2. Transfer RNA (tRNA)

It is comparatively small. It is a helical structure and its molecule resembles a clover leaf. It consists of 10-15% of the total amount of RNA in cell. tRNAs transport amino acids to ribosome and mRNA, in the process of protein synthesis.

3. Ribosomal RNA (rRNA)

It is synthesized by the DNA of nucleoli. After its synthesis, ribosomal RNA is joined with ribosomal protein and ribosomes are formed. It comprises about 80% of the total RNA in cell. rRNA acts as the machinery for synthesis of proteins in ribosomes.

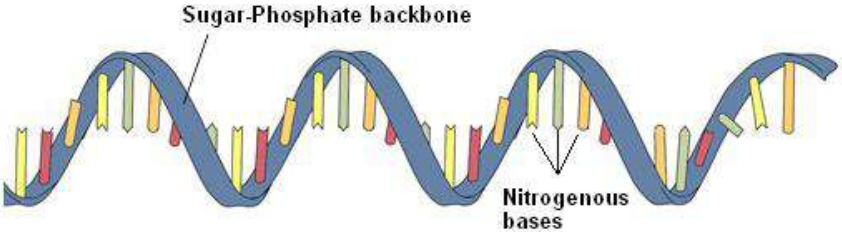


Figure 4 45: A model of RNA structure

Central Dogma

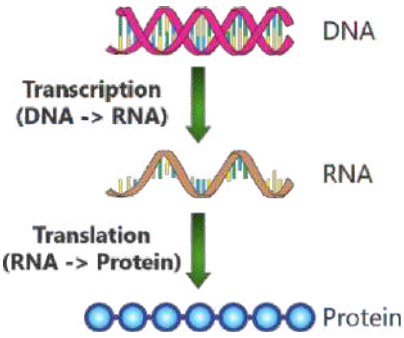


Figure 4.46: Flow sheet of Central dogma

All organisms use the same basic mechanism of reading and expressing genes, which is often referred to as central dogma. The first step of central dogma is the transfer of information from DNA to RNA, which occurs when an RNA copy of the gene is produced. The process is called **transcription**. The second step of the central dogma is the transfer of information from RNA to proteins, which occurs when the information contained in the RNA is used to direct the synthesis of proteins. This process is called **translation**. In this way DNA controls the properties and activities of a cell.

4.9- Conjugated Molecules

Conjugated molecules are formed by the combination of two or more molecules belonging to different categories. Some important conjugated molecules are as follows.

Glycoproteins

They are formed by covalent linkage between a protein and a carbohydrate polymer. They occur widely in nature as integral structural component of membranes; in blood serum; as cellular secretions; and in cartilage, eyes, skin etc.

Glycolipids

They are formed by a covalent linkage between a lipid and a carbohydrate. They are an integral structural component of membranes.

Lipoproteins

They are a class of biomolecules which are formed by hydrophobic interactions (not covalent or ionic bonds) between lipids and proteins. Lipoproteins are the basic structural framework of all types of plasma membranes. Lipids are transported in blood as very low-density lipoproteins.

Nucleoproteins

They are formed by ionic bonds between chromosomal DNA and proteins. For example, histone proteins are bound to DNA to form nucleosomes. They stabilize chromosomal structure in eukaryotes and also play an important role in the regulation of gene expression.

EXERCISE

SECTION 1: MULTIPLE CHOICE QUESTIONS

1. Which domain of life is characterized by organisms that often inhabit extreme environments and have cell membranes with ether-linked lipids?
   (a) Bacteria (b) Archaea (c) Eukarya (d) Protista
2. Which characteristic of water molecules is responsible for most of the unique properties of water?
   (a) Small in size (b) Held together by covalent bonds
   (c) Can easily separate from one another (d) Stick together
3. To which group of lipids, the human sex hormones belong?
   (a) Steroid (b) Waxes (c) Prostaglandins (d) Phospholipids
4. Which of the following is NOT a protein?
   (a) Haemoglobin (b) Cholesterol (c) Pepsin (d) Antibody
5. Which one is the largest carbohydrate?
   (a) Cellulose (b) Ribose (c) Glyceraldehyde (d) Glucose
6. What compound would be manufactured difficultly when soil has a shortage of phosphorous?
   (a) DNA (b) Fatty acids (c) Proteins (d) Cellulose
7. A compound whose chemical composition is most closely related to maltose is;
   (a) Starch (b) Protein (c) ATP (d) RNA
8. Which group is found in all fatty acids?
   (a) PO4 (b) SO_4 (c) C-N (d) COOH
9. Haemoglobin has:
   (a) Primary structure (b) Secondary structure
   (c) Tertiary stru cture (d) Quaternary structure
10. Which process produces peptide bonds?
    (a) Digestion (b) Dehydration synthesis
    (c) Hydrolysis (d) Enzyme deactivation

SECTION 2:SHORT QUESTIONS

1. Draw a sketch of hydrolysis reactions.
2. Draw the ring structure of glucose and fructose.

3. Define isomers and stereoisomers.
4. Draw the sketch of amino acid.
5. Outline the synthesis of peptide linkages.
6. Draw the sketch of acylglycerol, phospholipid and terpene.
7. Differentiate between nucleoside and nucleotide.
8. Illustrate the formation of phosphodiester bond.
9. State the central dogma of gene expression.

SECTION 3: LONG QUESTIONS

1. Distinguish carbohydrates, proteins, lipids and nucleic acids as the four fundamental biological molecules.
2. Describe and draw sketches of dehydration synthesis reactions.
3. Explain how the properties of water make it the medium of life.
4. Distinguish the properties and roles of monosaccharides and classify them.
5. Compare the structural isomers and stereoisomers of glucose.
6. Distinguish the properties and roles of disaccharides.
7. Define proteins and amino acids and outline the synthesis and breakage of peptide linkages.
8. Justify the significance of the sequence of amino acids through the example of sickle cell haemoglobin.
9. Describe the properties and roles of acylglycerols, phospholipids, terpenes and waxes.
10. Describe the molecular level structure of nucleotide.
11. Explain the double helical structure of DNA as proposed by Watson and Crick.
12. Explain the general structure of RNA and differentiate between the three types of RNA.
13. Define conjugated molecules and describe the roles of common conjugated molecules.

INQUISITIVE QUESTIONS

1. What happens if even one amino acid is substituted for another in a polypeptide chain? Provide a specific example.
2. How does the three-dimensional structure of a protein relate to its function?
3. How do nucleic acids encode genetic information, and how is this information translated into proteins?