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 Le. 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.

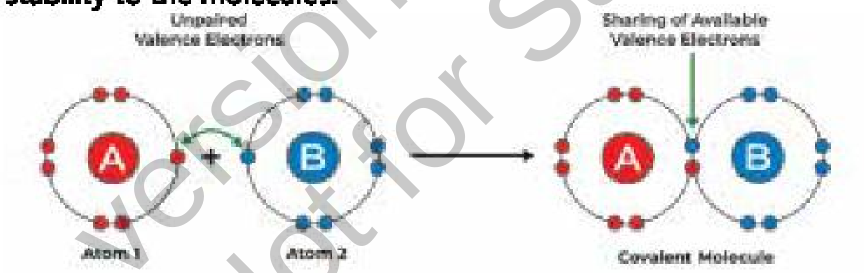


Figure 4.1: Covalent bond between two atoms

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.

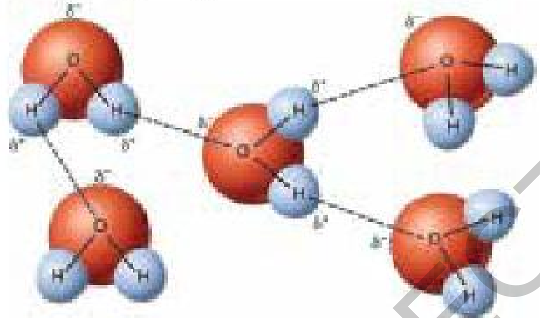


Figure 4.3: Hydrogen bond between water molecules

Hydrophobic interactions occur between nonpolar molecules which 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.

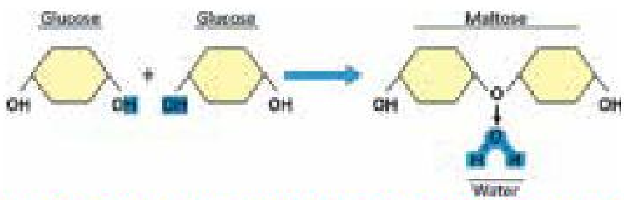


Figure 4.4: Making of macromolecules (Dehydration synthesis)

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.

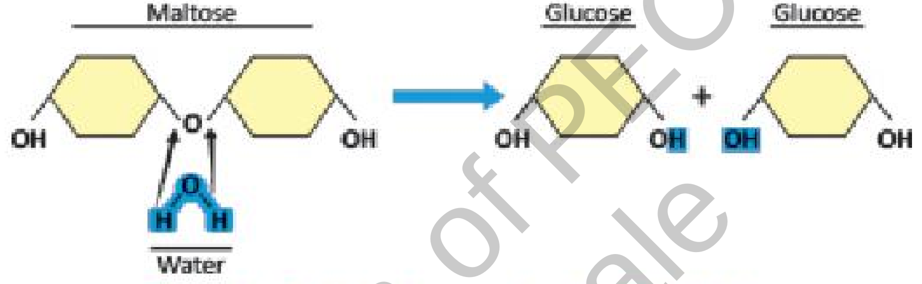


Figure 4.5: Breaking of macromolecules (Hydrolysis)

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.

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.

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

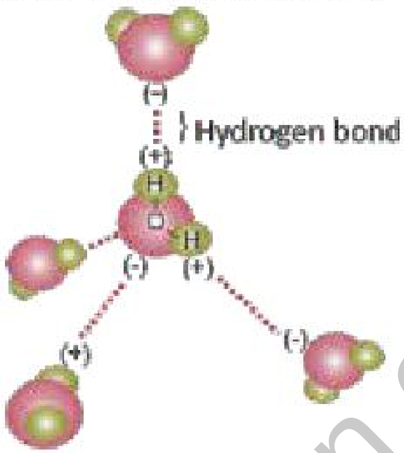


Figure 4.6: Hydrogen bonds among water molecules

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").

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).

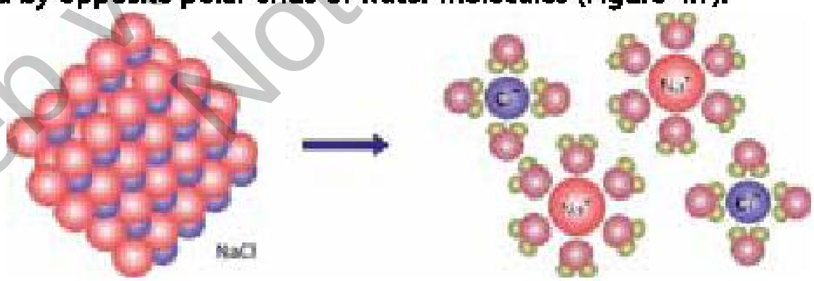


Figure 4.7: Water as a solvent of inorganic molecules (NaCl)

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.

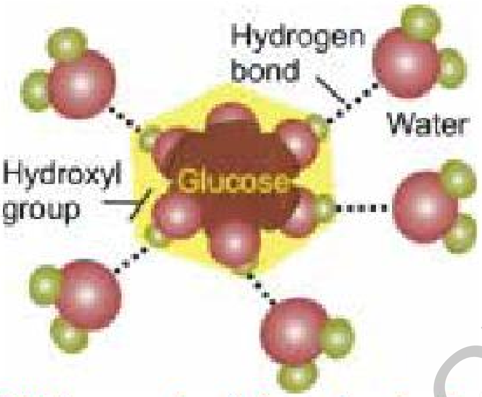


Figure 4.8: Water as a solvent of organic molecules (glucose)

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.

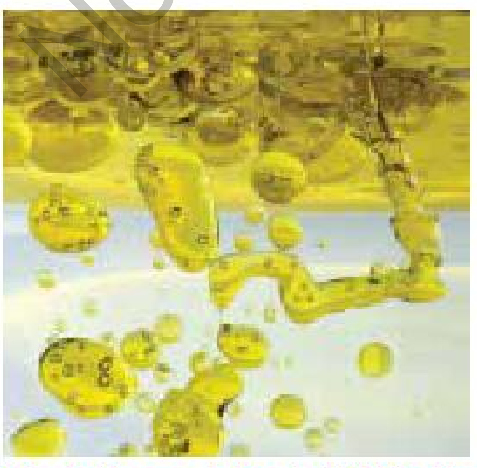


Figure4.9: Hydrophobic association of oil (lipid) with water molecules

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

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.

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

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.

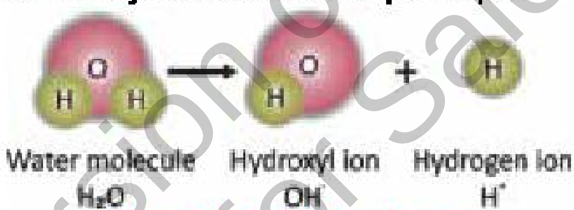


Figure 4.11: Ionization of water

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 molecular formula is **$C_6H_{12}O_6$**.

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

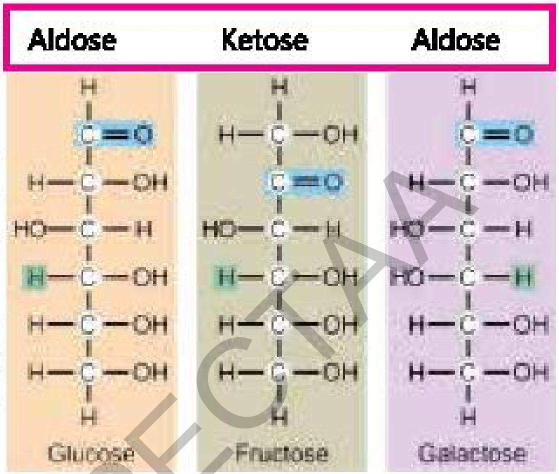


Figure 4.12: Structural and stereoisomers of glucose

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.

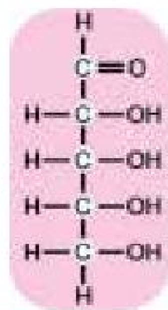


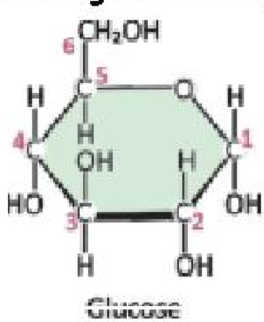
Figure 4.13: Structure of Ribose

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**.

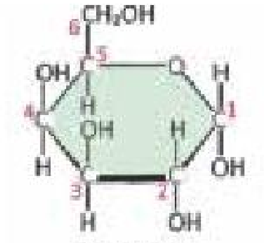
Common five-carbon or pentose sugars include ribose and deoxyribose (found in nucleic acids and ATP) and ribulose (which occurs as a precursor in photosynthesis).

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).

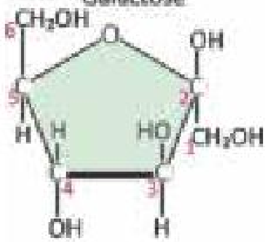


In case of glucose, oxygen-bridge develops between carbon number 1 and 5. So, a six cornered ring is formed.



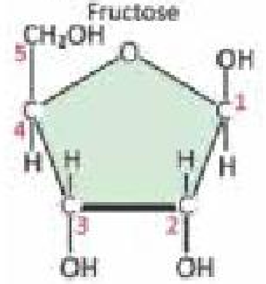
Galactose

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



Fructose

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

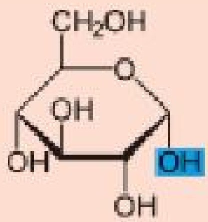


Ribose

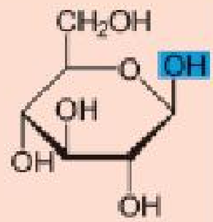
When ribose goes in solution, oxygen-bridge develops between carbon number 1 and 4. So, a five cornered ring is formed.

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

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.

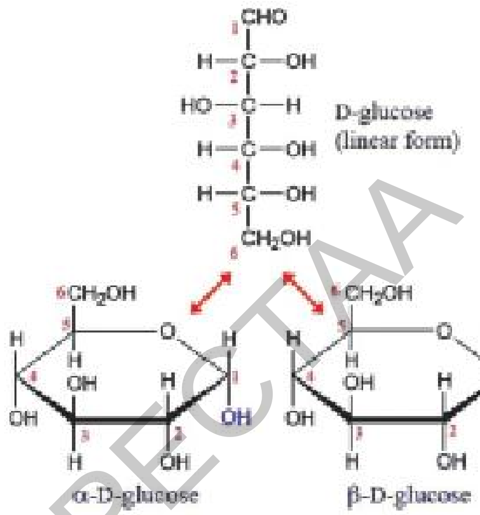


α-D-glucose



β-D-glucose

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).

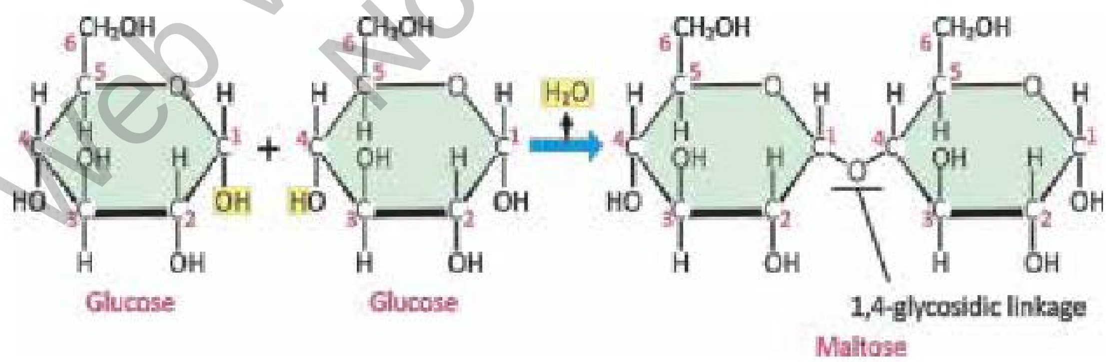


Figure 4.15: Dehydration synthesis of one maltose by the condensation of two glucose

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.

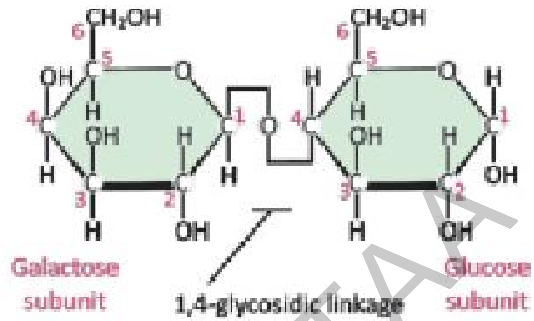


Figure 4.16: Structure of lactose

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.

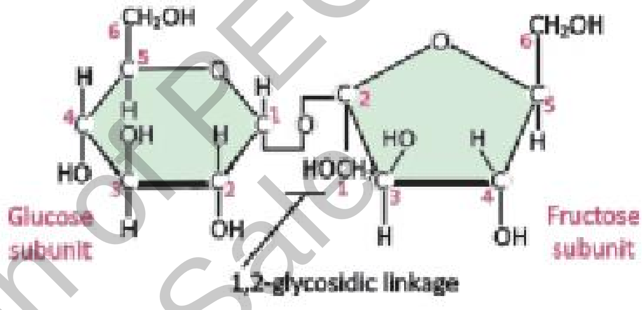


Figure 4.17: Structure of sucrose

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.

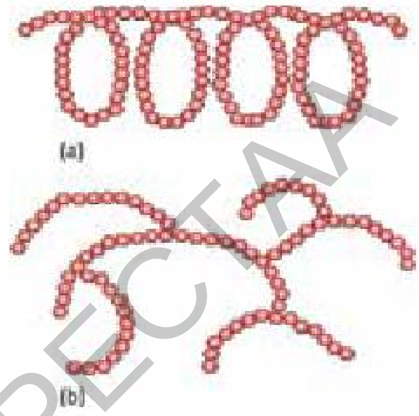


Figure 4.18: (a) Amylose, (b) Amylopectin

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.

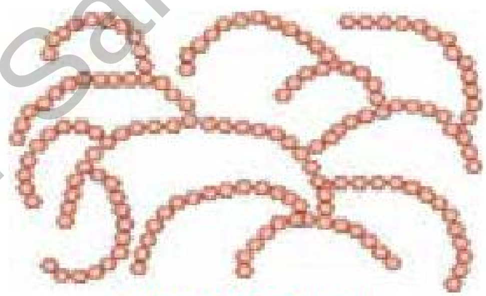


Figure 4.19: Glycogen

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).

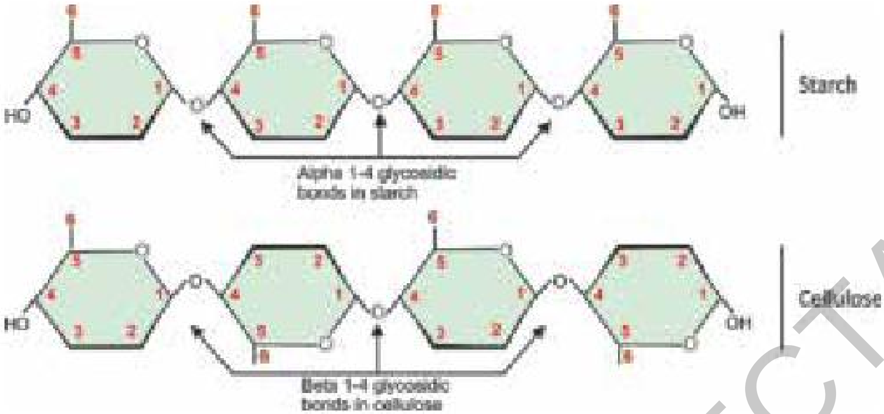


Figure 4.20: Difference between starch and cellulose

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.

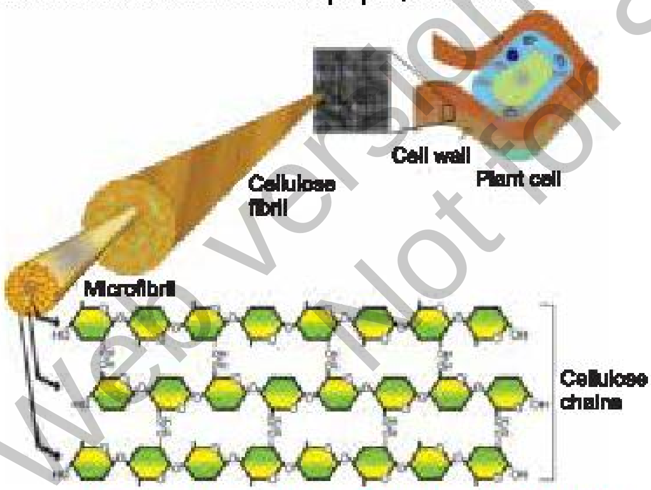


Figure 4.21: Cellulose fibrils in plant cell wall

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.

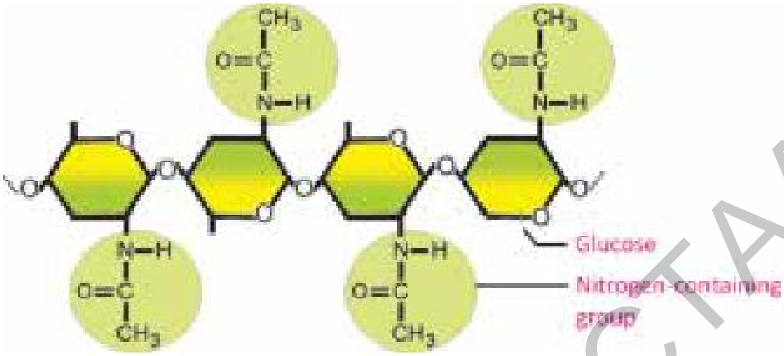


Figure 4.22: A part of the chitin molecule

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).

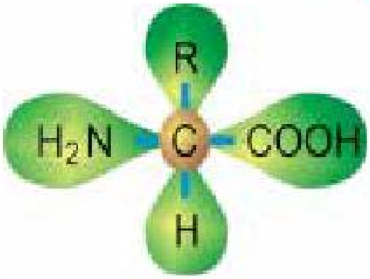


Figure 4.23: Structure of an amino acid

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).

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

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.

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).

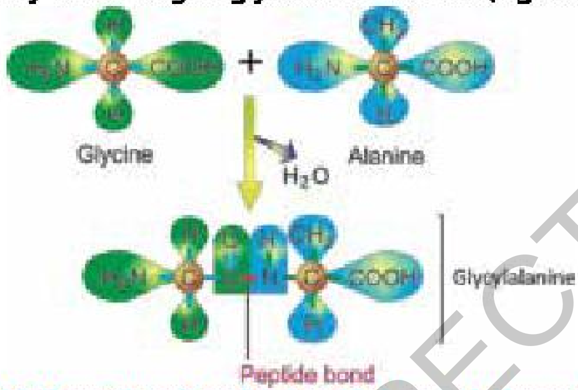


Figure 4.25: Formation of peptide bond between glycine and alanine

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.

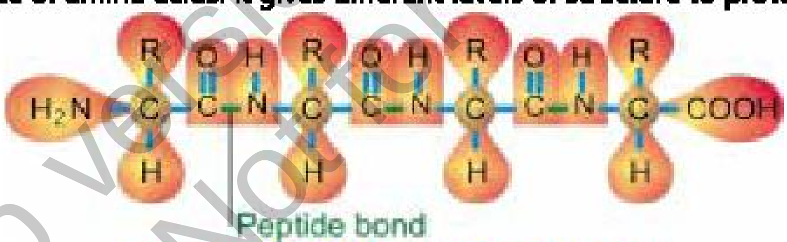


Figure 4.26: Section from a polypeptide chain

Structural Levelsof 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).

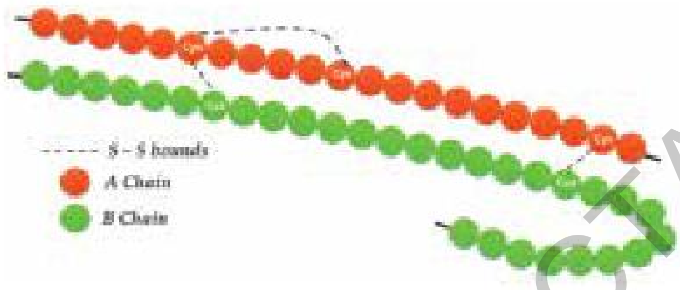


Figure 4.27: Chains of Insulin

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).

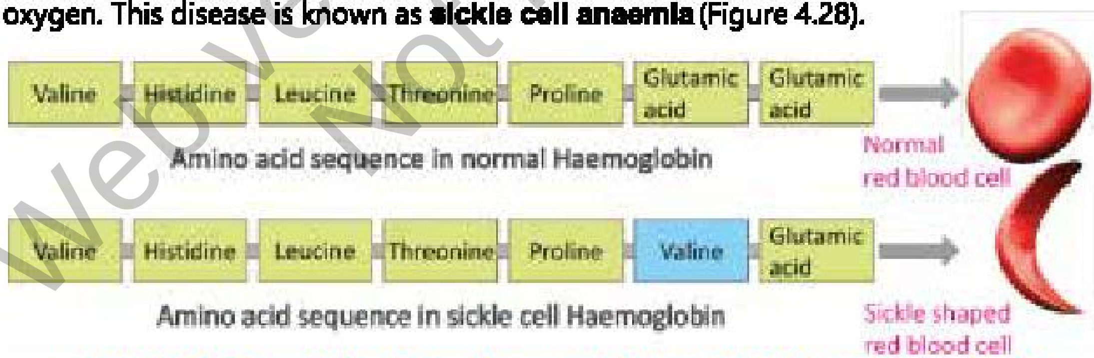


Figure 4.28: Difference in amino acid sequence in normal and sickle cell haemoglobin

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.

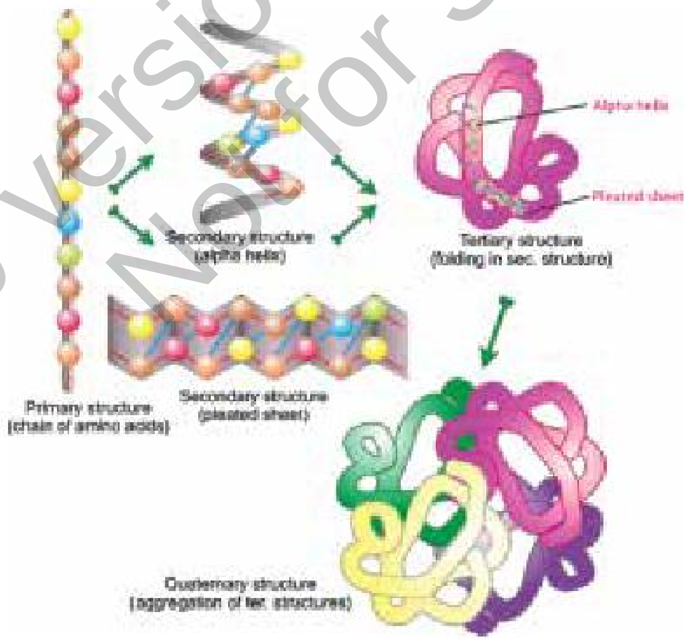


Figure 4.29: Levels of protein structure

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.

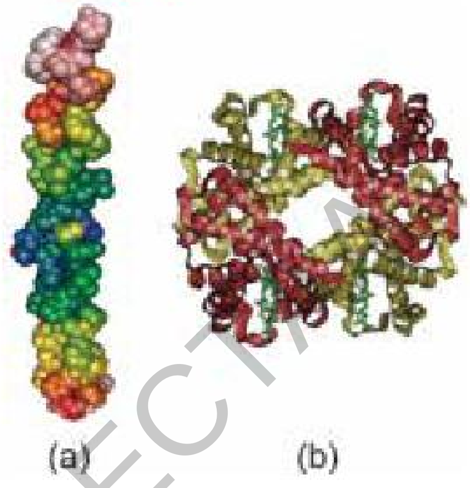


Figure 4.30: (a) Collagen – a fibrous protein, (b) haemoglobin – a globular protein

- 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.

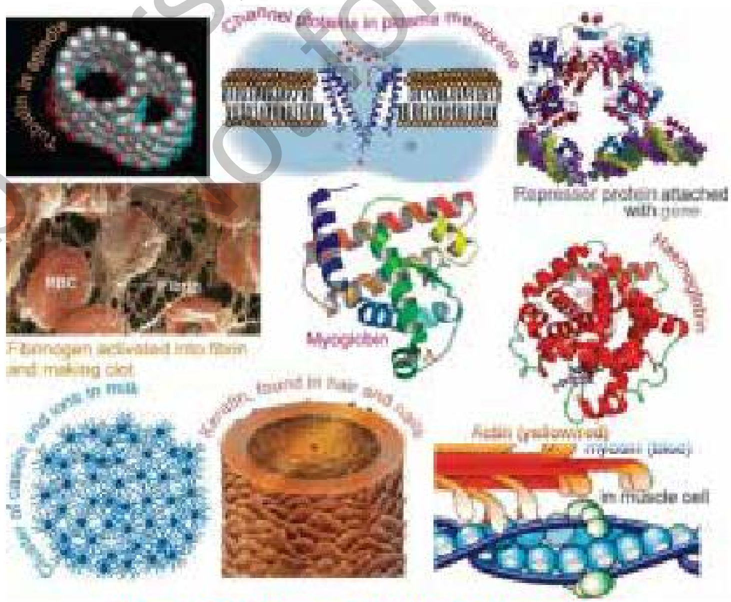


Figure 4.31: Different proteins of human body

- 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.

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.

- **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.

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.

$$\underset{\text{alcohol}}{C_2H_5OH} + \underset{\text{acetic acid}}{HOOCCH_3} \rightarrow \underset{\text{an ester}}{C_2H_5OCOCH_3} + H_2O$$

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.

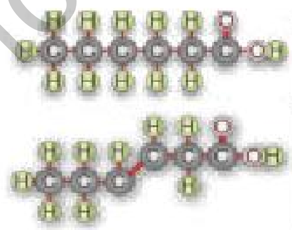


Figure 4.32 Fatty acids

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.

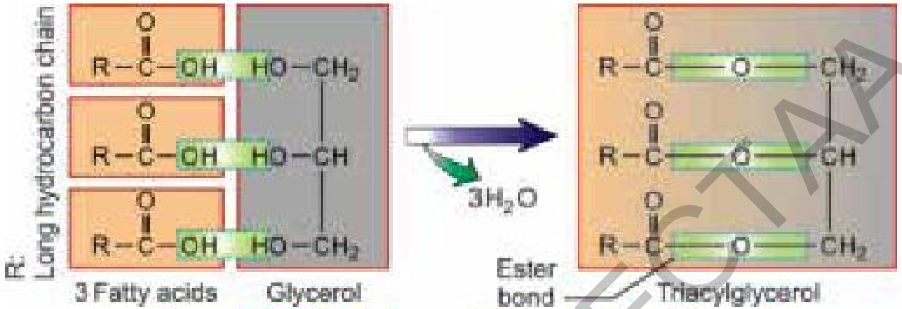


Figure 4.33: Dehydration synthesis of a triacylglycerol

Waxes

Waxes 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.

> 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.

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.

Wax on cuticle of leaves — Candles made of wax — Wax crayons — Waxy polish

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.

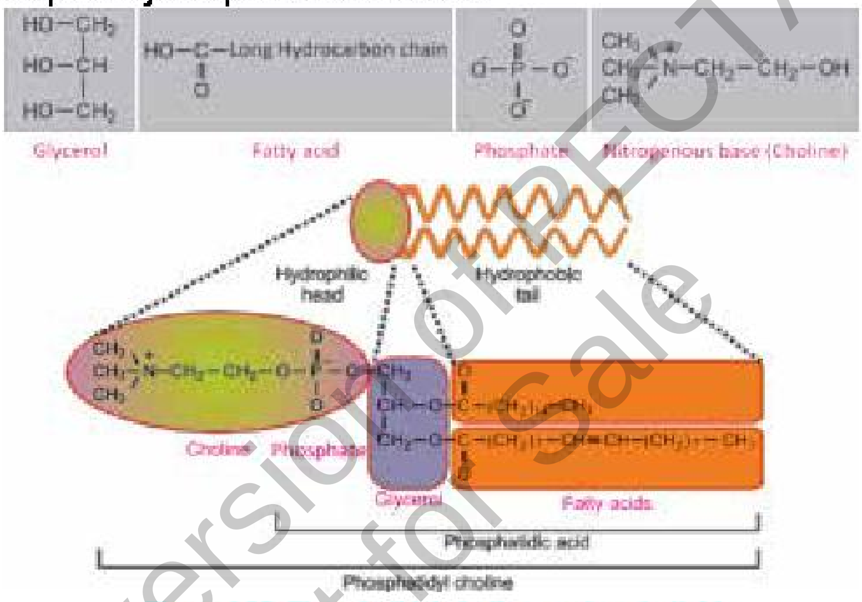


Figure 4.35: Phosphatidyl choline– a phospholipid

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.

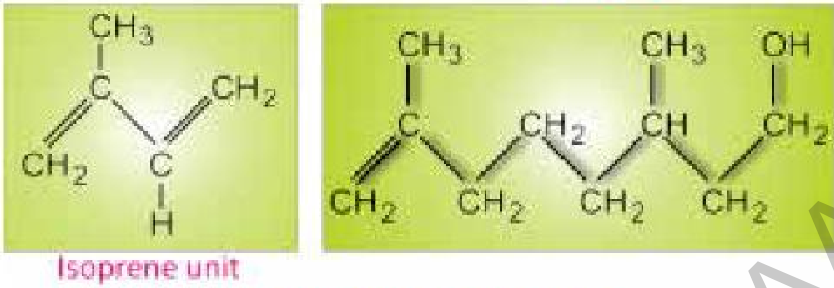


Figure 4.36: Structure of terpenes

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.

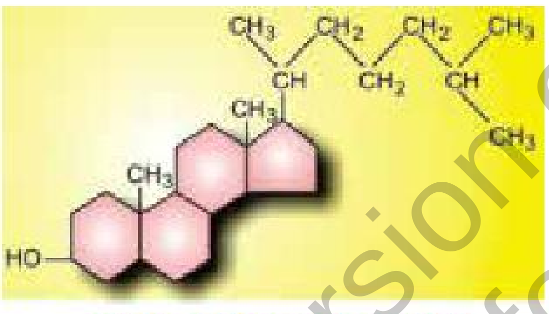


Figure 4.37: Cholesterol: a steroid

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.

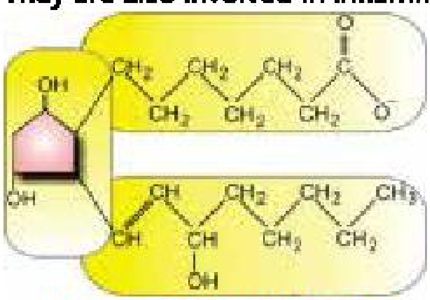


Figure 4.38: A prostaglandin

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).

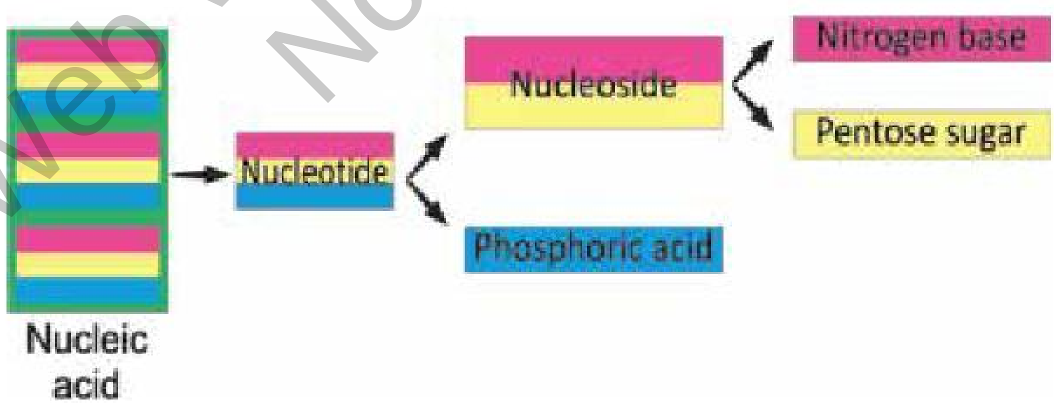


Figure 4.39: Components of nucleic acids

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.

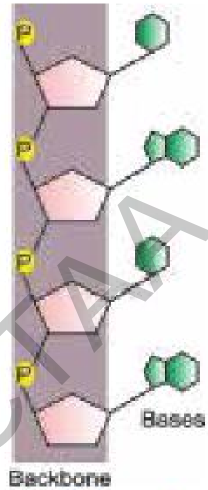


Figure 4.40: Sugar-phosphate backbone of nucleic acids

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).

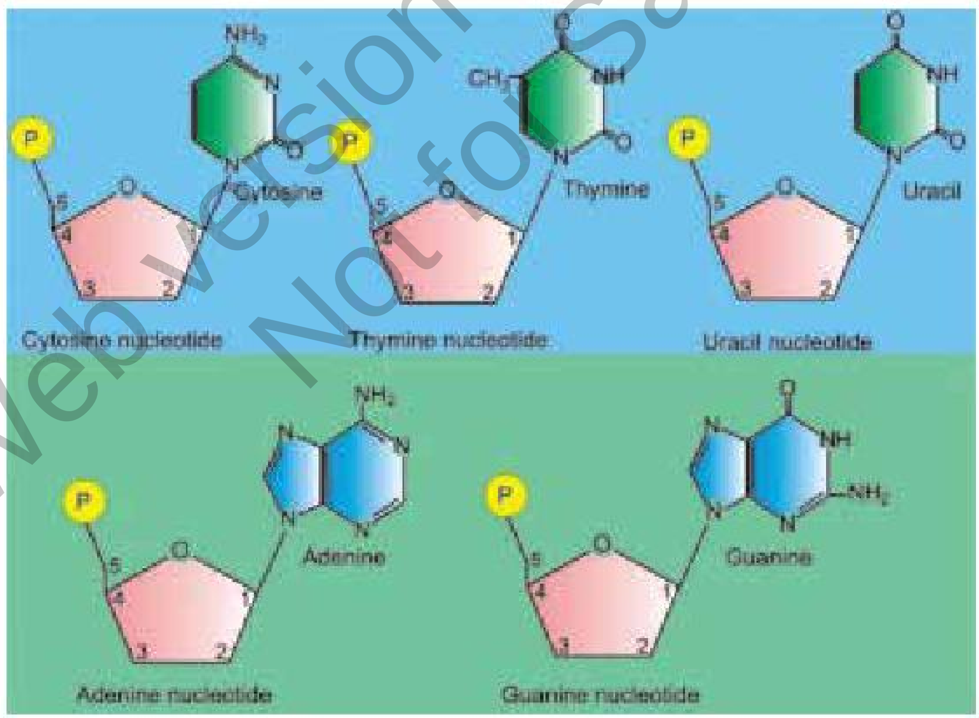


Figure 4.41: Nucleotides of RNA and DNA

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.

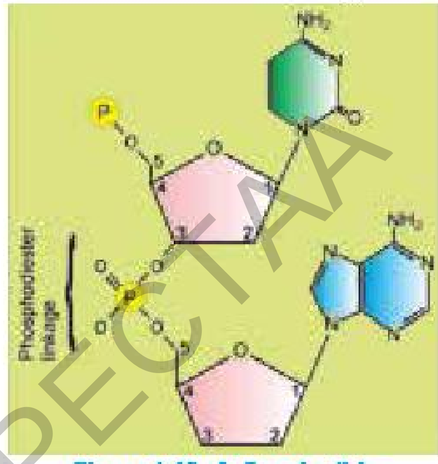


Figure 4.42: A dinucleotide

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.

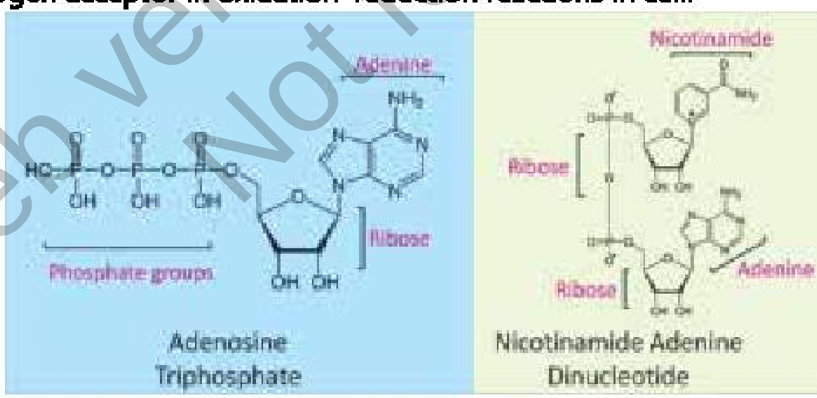


Figure 4.43: ATP and NAD

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.

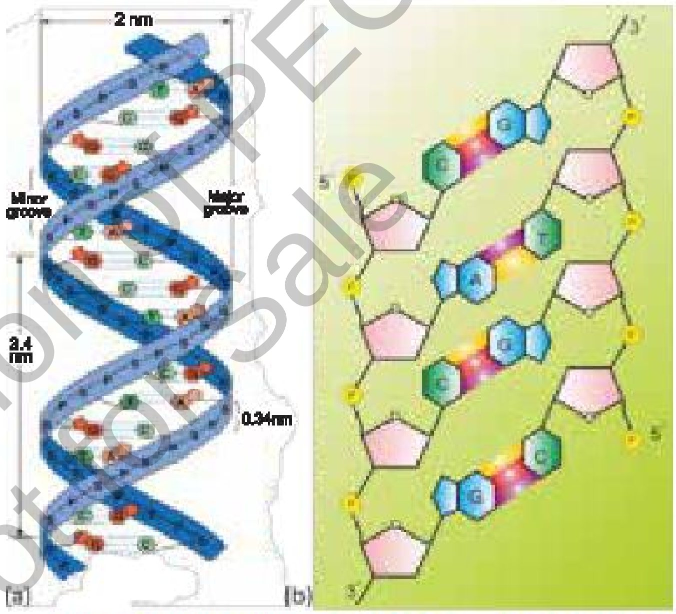


Figure 4.44: (a) Watson and Crick model of DNA, (b) The detailed structure of DNA

- 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 complementary 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.

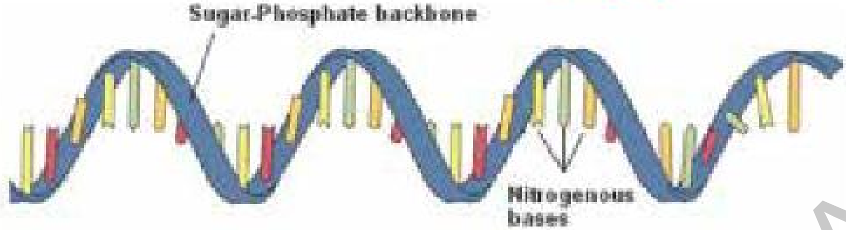


Figure 4.45: A model of RNA structure

Central Dogma

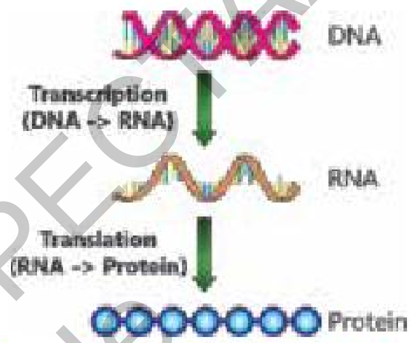


Figure 4.46: Flow sheet of Central dogma

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 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
2. To which group of lipids, the human sex hormones belong?
   (a) Steroid (b) Waxes (c) Prostaglandins (d) Phospholipids
3. Which of the following is NOT a protein?
   (a) Haemoglobin (b) Cholesterol (c) Pepsin (d) Antibody
4. Which one is the largest carbohydrate?
   (a) Cellulose (b) Ribose (c) Glyceraldehyde (d) Glucose
5. What compound would be manufactured difficultly when soil has a shortage of phosphorous?
   (a) DNA (b) Fatty acids (c) Proteins (d) Cellulose
6. A compound whose chemical composition is most closely related to maltose is;
   (a) Starch (b) Protein (c) ATP (d) RNA
7. Which group is found in all fatty acids?
   (a) PO4 (b) SO_4 (c) C-N (d) COOH
8. Haemoglobin has:
   (a) Primary structure (b) Secondary structure
   (c) Tertiary structure (d) Quaternary structure
9. 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?