Chapter

2 Biological Molecules

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

- Introduce biochemistry and describe the approximate chemical composition of protoplasm.
- Distinguish carbohydrates, proteins, lipids and nucleic acids as the four fundamental kinds of biological molecules.
- Describe and draw sketches of the dehydration-synthesis and hydrolysis reactions for the making and breaking of macromolecule polymers.
- Explain how the properties of water (high polarity, hydrogen bonding, high specific heat, high heat of vaporization, cohesion, hydrophobic exclusion, ionization and lower density of ice) make it the cradle of life.
- Define carbohydrates and classify them.
- Distinguish the properties and roles of monosaccharides, write their empirical formula and classify them.
- Compare the isomers and stereoisomers of glucose.
- Distinguish the properties and roles of disaccharides and describe glycosidic bond in the transport disaccharides.
- Distinguish the properties and roles of polysaccharides and relate them with the molecular structures of starch, glycogen, cellulose and chitin.
- Justify that the laboratory-manufactured sweeteners are "left-handed" sugars and cannot be metabolized by the "right-handed" enzymes.
- Define proteins and amino acids and draw the 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 hemoglobin.
- Classify proteins as globular and fibrous proteins.
- List examples and the roles of structural and functional proteins.
- Define lipids and describe the properties and roles of acylglycerols, phospholipids, terpenes and waxes.

Introduction

All material things in this world are made up of chemical elements. These elements are composed of atoms. The atoms are joined together forming molecules and compounds. The bodies of living organisms are made up of some of these chemical elements. The most common elements in the bodies of living organisms are carbon, hydrogen, nitrogen, oxygen, phosphorus and sulphur. Of these, carbon, hydrogen and oxygen constitute about 95% of human body by weight. Other elements are present in small proportion. **Biochemistry** is the science of biology that deals with the structure, composition and function of molecules that are present in the bodies of living organisms and chemical processes occurring in them.

The bonding of hydrogen, oxygen, nitrogen and other atoms to carbon atom forms the compounds called organic compounds. The organic molecules play most important role that characterize the structure and function of the cell organelles. Carbon-carbon bonds make chain of carbon atoms which form the skeleton or backbone of large organic molecules. The chemical analysis of protoplasm shows that it is composed of two types of compounds, i.e. organic compounds and inorganic compounds. These compounds are present in somewhat different proportions in different organisms and even in different types of cells of the same organism. Water is the most abundant of all compounds of protoplasm. It forms almost three-fourth of the body by weight, next to water are proteins. Proteins are the most abundant organic compounds present in the cell. Proteins have structural functional roles in the cell. Other organic compounds include carbohydrates, lipids and nucleic acids. Enzymes which are proteins in nature are also present. Hormones which play very important role and inorganic salts are present in small proportion.

A typical cell shows the following approximate percent composition of different compounds present inside it.

Table: 2.1 Approximate chemical percent composition of a Bacterial and a Mammalian animal) cell

Contents	Bacterial Cell	Mammalian Cell
Water	70	70
Proteins	15	18
Carbohydrates	3	4
Lipids	2	3
DNA	1	0.25
RNA	6	1.1
Enzymes, Hormones etc	2	2
Inorganic Ions etc	1	1

2.1 Fundamental Biological Molecules

There are four types of fundamental biological molecules present in protoplasm. These are carbohydrates, proteins, lipids and nucleic acids. These molecules are distinguished from one another on the basis of their chemical structures, composition and functions.

The organic molecules in living things such as fatty acids, amino acids, and carbohydrates have characteristic functional groups. These functional groups add to the diversity of organic molecules. Some functional groups are hydroxyl (alcohol) group, carboxyl (acid) group, aldehyde group, amine (amino) group etc.

Inorganic compounds such as water and inorganic salts are also present in the protoplasm. Water is vital for the life of living organisms and without sufficient quantity of water the protoplasm is unable to perform normal functions. Though inorganic salts are present in small quantities but they are important for most biochemical functions.

2.1.1 Condensation

Large organic molecules are called macromolecules or polymers. These are formed of particular types of small organic molecules or subunits called monomers. Two monomers join together when a hydroxyl group (OH) is removed from one monomer and a hydrogen (H) is removed from another. This is called **condensation reaction** (dehydration). In the process water molecule is removed e.g.

Amino acids join together to form a molecule called a dipeptide. The OH from the carboxyl group of one amino acid combines with a hydrogen atom from the amine group of the other amino acid to produce water (blue) in the equation below.

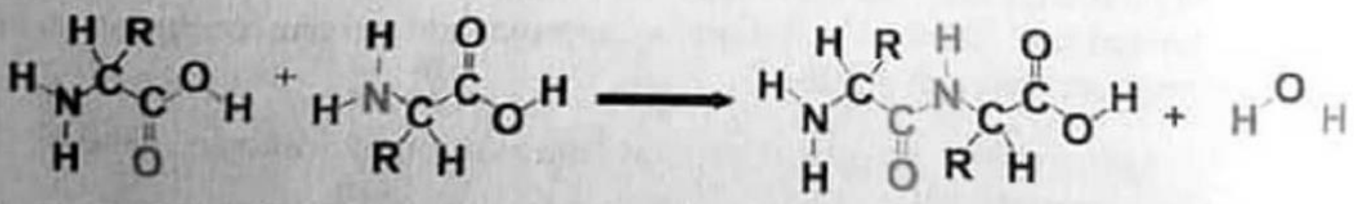


Fig: 2.1 Example of condensation reaction

Table: 2.2 Monomers of macromolecules (polymers) of some organic compounds

Polymers (Macromolecules)	Monomers (units)
Polysaccharides	Monosaccharides
Lipids	Glycerol and Fatty acids (for fats)
Proteins	Amino acids
Nucleic acids	Nucleotides

2.1.2 Hydrolysis (Hydro-water; lysis-splitting)

Polymers (macromolecules) are broken down into monomers by a process called hydrolysis. It is the reverse of condensation. In this process hydroxyl group from water attaches to one monomer and a hydrogen attaches to the other. This is called hydrolysis reaction because water *(hydro)* is used to break *(lyse)* a bond e.g.

$$\text{Sucrose} + \text{Water} \longrightarrow \text{Glucose} + \text{Fructose}$$

Both condensation reactions and hydrolysis need specific enzymes.

2.2 Biological Importance of Water

Water is essential for life. There is no existence of life without water. Allah the Almighty has created all living organisms from water. The bodies of living organisms contain 70 % to 90 % water. It is essential for existence of protoplasm because protoplasm cannot survive if its water content is reduced as low as 10 percent. Because of its immense importance water is present in sufficient amount in most of places on earth. The chemical and physical properties of water are so designed that they are absolutely important for the vital processes of life.

a. Polar Nature of Water

Water is polar molecule. The oxygen end of the molecule is electronegative bearing a partial negative charge and the hydrogen end is electropositive bearing a partial positive charge. Water molecules are bonded to one another through hydrogen bonds. Hydrogen bonds are much weaker than covalent bonds but they still cause water molecules to remain attached together.

b. Universal Solvent

Due to polar nature of water it dissolves almost all types of polar substances and is therefore regarded as **universal solvent**. This facilitates chemical reactions both inside and outside the living cell. Water provides the medium for most chemical reactions in cells. For example when sodium chloride is put into water,the electronegative ends of water molecules are attracted to the sodium ions and the electropositive ends of water molecules are attracted to the chloride ions. As a result the sodium and chloride ions separate and dissolve in water. Water dissolves all minerals present in soil which are absorbed by plant roots and transported to other tissues.

c. Cohesive and Adhesive Force of Water

The water molecules remain attached together and do not separate because of hydrogen bonding. This develops cohesive force among them and therefore water flows freely without breaking apart. Water molecules also adhere (stick) to surfaces It can fill a tubular vessel and still flows so that dissolved molecules are evenly distributed throughout a system.

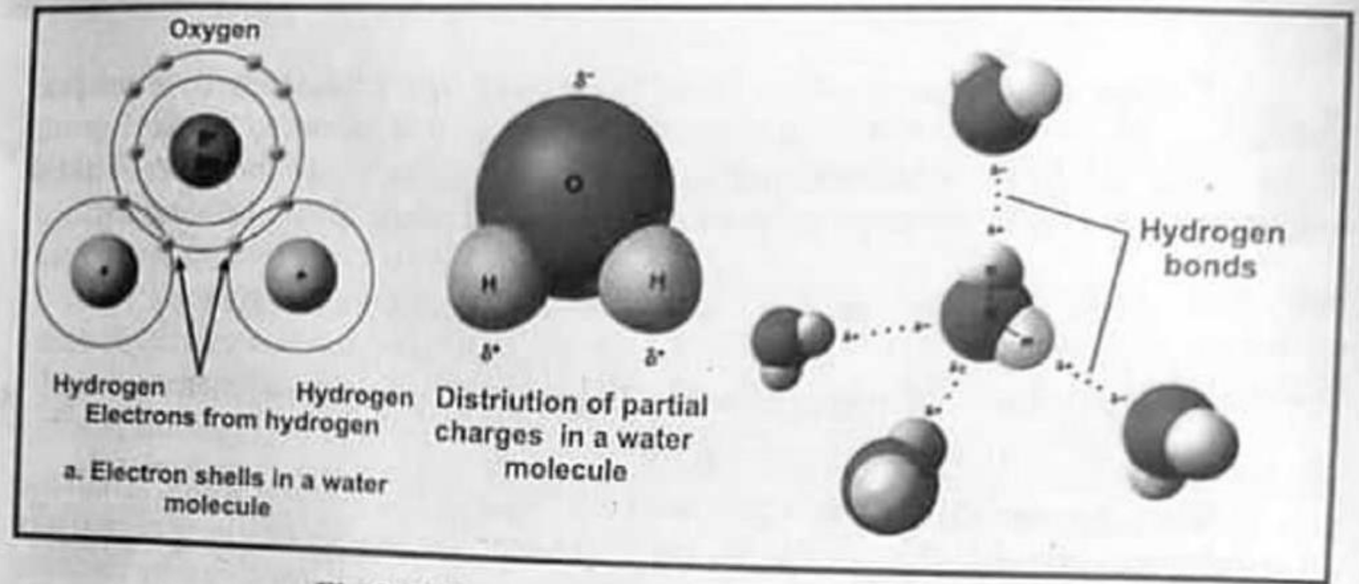


Fig:2.2 Chemical configuration of water

d. High Specific Heat and High Heat of Vaporization

Water has **high specific heat**. Specific heat is the amount of heat energy required to raise the temperature of one gram of water by one degree celsius. It means that water absorbs or releases large quantities of heat energy with little change in temperature. This is why the temperature of water rises and falls more slowly as compared to other liquids. This property helps the organisms to maintain body internal temperature and protect them from rapid temperature changes. Water also has high heat of vapourization. Heat of vapourization of water is the heat required to convert one gram of liquid water into vapours at its boiling point. High heat of vapourization helps animals and plants to get rid of excess body heat during sweating and transpiration respectively.

The presence of hydrogen bonds among the water molecules cause water to remain liquid rather than change to ice or steam. Without hydrogen bonds, water would boil at – 80 °C and would freeze at - 100 °C. In such conditions life for living organisms would become impossible.

Tidbit

The ice layer at surface acts as an insulator to prevent the water below it from freezing thus protecting the aquatic organisms from freezing.

e. Water Expands at Low Temperature

Water has a unique property, as it expands when temperature falls below 4 °C. Water is most heavy at 4 °C. Therefore ice (solid water) is less dense than liquid water and this is the reason that ice floats in liquid water. Water body freezes on the surface at low temperature.

f. Ionization of Water

Water molecules may ionize into hydrogen ions (H^+) and hydroxyl ions (OH^-). Very few molecules out of a very large number may ionize. The presence of ions is important for the normal functioning of enzymes.

2.3 Carbohydrates

Carbohydrates are polyhydroxy aldehydes or ketones or substances which yield such compounds on hydrolysis. Carbohydrates contain either aldehyde or ketone as functional groups attached to one of the carbon atoms. They also contain two or more hydroxyl groups. They are the most abundant organic biomolecules in nature. Carbohydrates are organic compounds that are mainly composed of carbon, hydrogen and oxygen. The name carbohydrates means that they are hydrates of carbon in which hydrogen and oxygen is present in the same ratio as in water that is 2:1. But now many carbohydrates are known that contain hydrogen and oxygen in different proportion. Examples of carbohydrates are glucose, sucrose, starch, cellulose etc. Carbohydrates are classified into three groups, i.e. monosaccharides, oligosaccharides and polysaccharides.

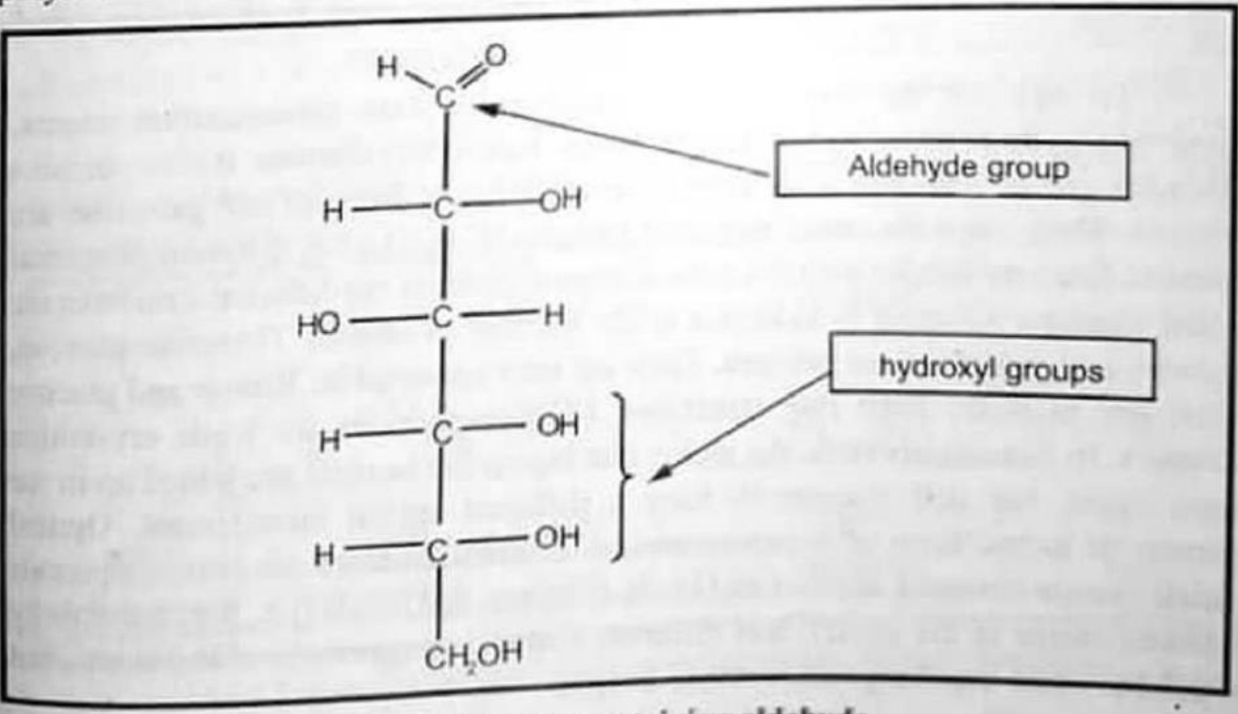


Fig: 2.3 Glucose containing aldehyde

2.3.1. Monosaccharides: (Mono = one; Saccharum = sugar)

Monosaccharides are simple sugars. They are not hydrolyzed (broken down by the addition of water) into more simple units. They are easily soluble in water. They are sweet in taste. They have empirical formula $(CH_2O)_n$ containing the same ratio of hydrogen and oxygen as in water, i.e. 2:1. They contain either aldehyde or keto group. They have carbon backbone that may contain from three to seven carbon atoms. They have names which end in –ose. Those with three carbon atoms are celled trioses, with four atoms-tetroses, with five atoms-pentoses, and so on.

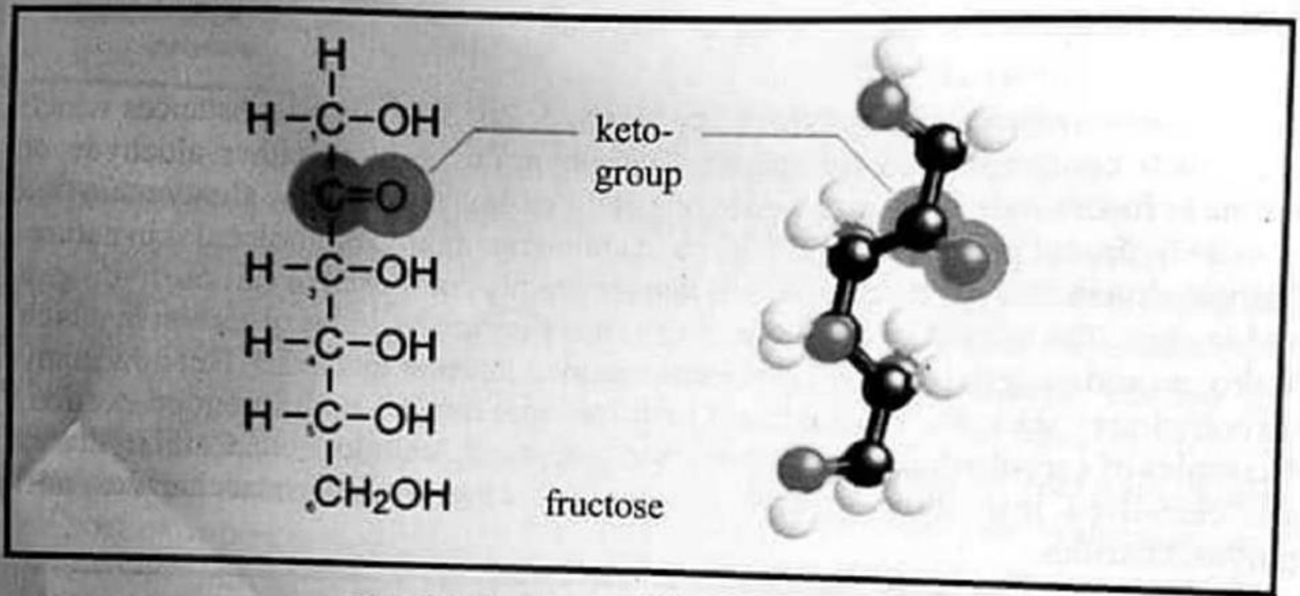


Fig: 2.4 Fructose containing keto group

Trioses are the simplest monosaccharides with three carbon atoms. Glyceraldehyde is triose with aldehyde group. Ribose is a pentose. It also contains aldehyde group. Ribulose is its ketonic form. Glucose, fructose and galactose are hexoses. They have the same empirical formula $(C_6H_{12}O_6)$ but different structural formula. Such molecules with the same empirical formula but different structures are called isomers. Glucose is aldehyde while fructose is ketone. Therefore glucose, fructose and galactose are isomers. They are inter-convertible. Ribose and glucose when put in water from ring structures. Monosaccharides are white crystalline powders. In stereoisomerism, the atoms making up the isomers are joined up in the same order, but still manage to have a different spatial arrangement. Optical isomerism is one form of stereoisomerism. **Optical isomers** are two compounds which contain the same number and kinds of atoms, and bonds (i.e., the connectivity between atoms is the same), and different spatial arrangements of the atoms, but which have non-superimposable mirror images.

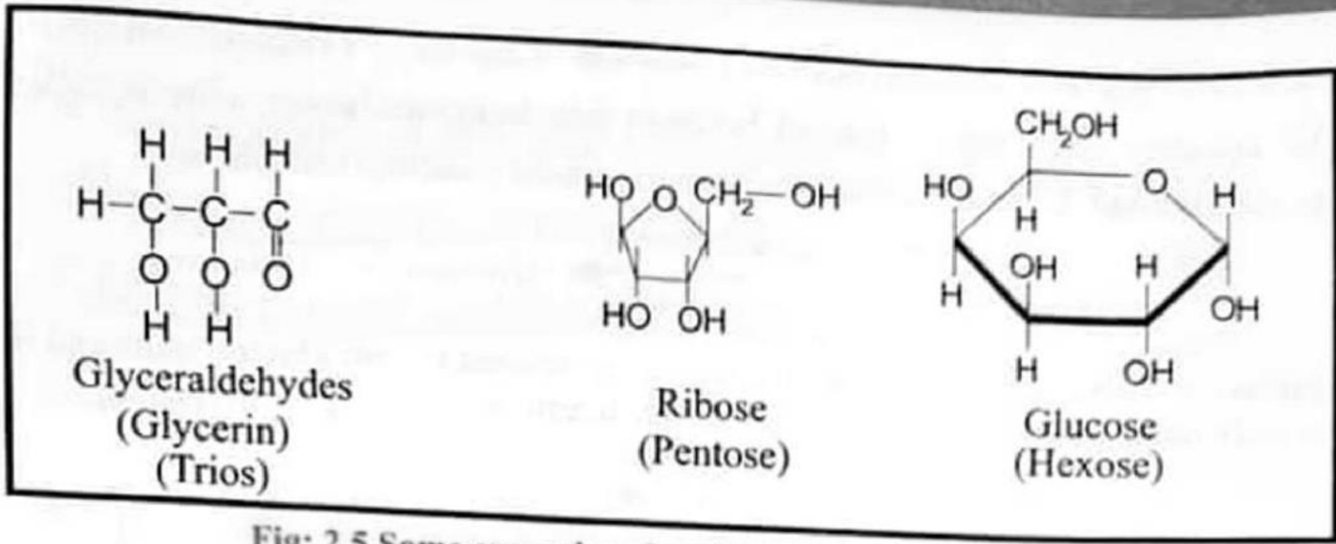


Fig: 2.5 Some examples of various types of Monosaccharides.

2.3.2 Oligosaccharides

Oligosaccharides are hydrolyzed to form (break up) from two to ten simple monosacharide units. The units or monomers are bonded together by glycosidic bonds. The oligosaccharides that are hydrolyzed into two simple units are called disaccharides, those hydrolyzed into three units are trisacchrides and so on.

Disaccharides are the most common oligosaccharides.

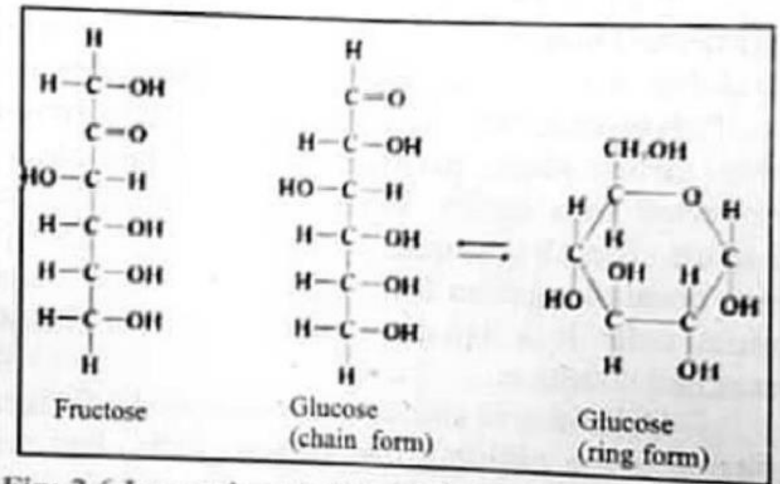


Fig: 2.6 Isomerism and stereoisomerism in glucose.

Common disaccharides are sucrose, lactose and maltose. Sucrose is present in sugarcane and is hydrolyzed into glucose and fructose.

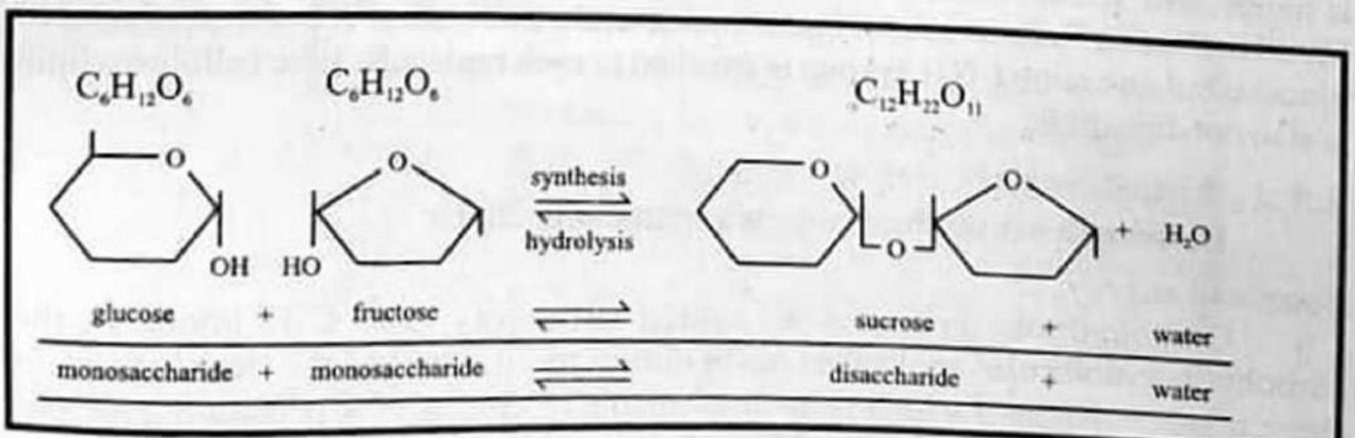


Fig: 2.7 Formation of disaccharides from monosaccharides monomers

Sucrose + Water + Sucrase (enzyme) $\longrightarrow$ Glucose + Fructose + Sucrase

The covalent bond that is formed between two monosaccharide units is called glycosidic bond. Lactose is found in milk that contains galactose and glucose.

$$\text{Lactose} + \text{Water} \xrightarrow[\text{Lactase}]{\text{Hydrolase}} \text{Glucose} + \text{Galactose}$$

Maltose is disaccharide found in fruits. It is composed of two glucose units and is found in our digestive tract as a result of starch digestion.

$$\text{Maltose} + \text{Water} \xrightarrow[\text{Maltase}]{\text{Hydrolase}} \text{Glucose} + \text{Glucose}$$

2.3.3 Polysaccharides

Polysaccharides are polymers of monosaccharide units (monomers). They are hydrolyzed into more than ten monomers of glucose units. They are tasteless and are insoluble in water. Examples of polysaccharides are starch, glycogen, cellulose, chitin etc. Polysaccharides act as macromolecules (polymers) for the small carbohydrate units. Green plants prepare glucose during photosynthesis, which is immediately converted into starch. When plant needs glucose, starch is again converted into glucose. Starch is stored in plant cells. Starch is a polymer made up of many glucose units bonded together forming unbranched or branched chain. Glycogen is stored in animal cells. It is also a polymer made up of glucose monomers forming extensively branched chains.

Cellulose is another polysaccharide, formed of unbranched chain of glucose units. It is the building material of green plant cell walls and is probably the most abundant carbohydrate in nature. The bonds linking glucose units in a cellulose molecule are oriented differently from starch and glycogen. Cellulase refers to a group of enzymes which, acting together, hydrolyze cellulose. In human digestive system this enzyme is not present. Cotton fibers are example of cellulose. **Chitin** is a polysaccharide. It is found in the exoskeleton of arthropods such as crabs and insects. It is also a polymer of glucose but an amino ($-NH_2$) group is attached to each molecule. Like cellulose chitin is also not digestible.

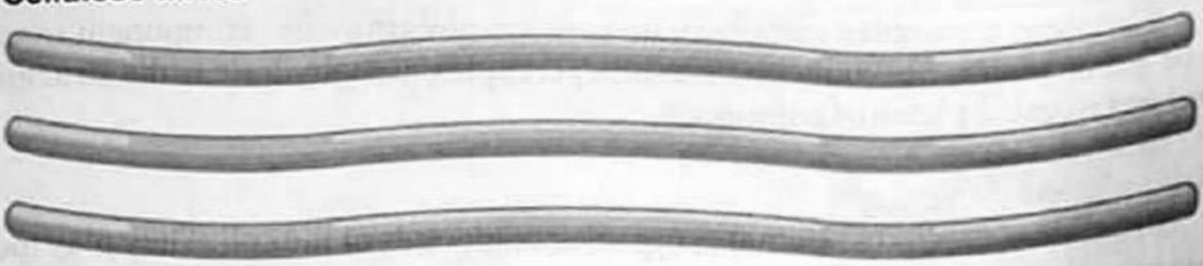
2.3.4 Functions of Carbohydrates

Carbohydrates perform various important functions:

Source of energy

Carbohydrates are used as source of energy. The C-H bonds in the carbohydratemolecules are broken down during respiration and the stored energy in these bonds is released which is made available to the cells for performing various functions. Human blood contains 100 mg of glucose per 100 ml of blood.

Cellulose fibers



Cellulose structure

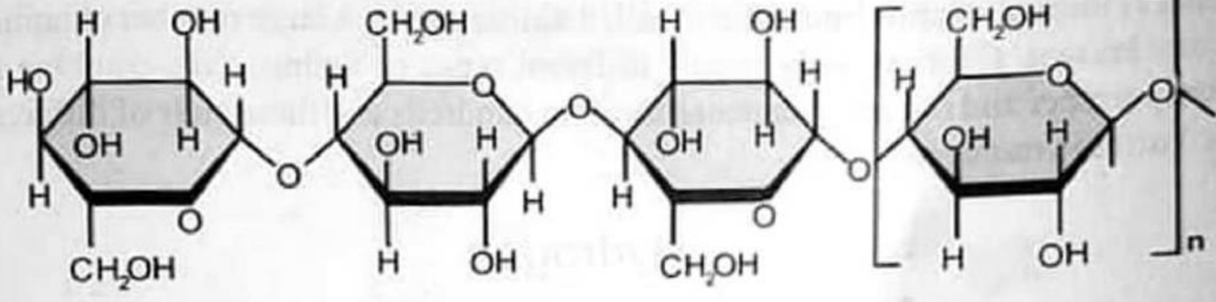


Fig: 2.8 Cellulose is a polysaccharide, formed of unbranched chain of glucose units.

Storage Molecules

Carbohydrates are stored in the cells as reserve food. Grapes contain as much as 27 % glucose. Honey contains large amounts of glucose and fructose. Some of these polysaccharides such as starch and glycogen excess amount of food is stored for future use.

> **For your information**
>
> The shape of a molecule affects lots of things besides its smell. Our bodies, for example, can only use right-handed sugar; left-handed sugar is indigestible. Amino acids, the building blocks of proteins, are almost all left-handed--our bodies can't manufacture proteins out of the right-handed version. (The cell walls of bacteria are one exception; they contain right-handed amino acids.)

Cellulose a complex carbohydrate is the major structural component of cell walls of green plants. Similarly chitin another complex carbohydrate is the structural component of exoskeleton of arthropods.

2.4 Proteins

Proteins are the most abundant organic compounds of the cell. They play most important role in cellular functions. They contain elements carbon, hydrogen, oxygen and nitrogen. Some proteins also contain sulphur. Proteins are macromolecules (polymers) formed of units (monomers) called **amino acids**. A large number of amino acids are known. Of these, only twenty different types of amino acids combine in different number and different sequence forming hundreds and thousands of different types of protein molecules.

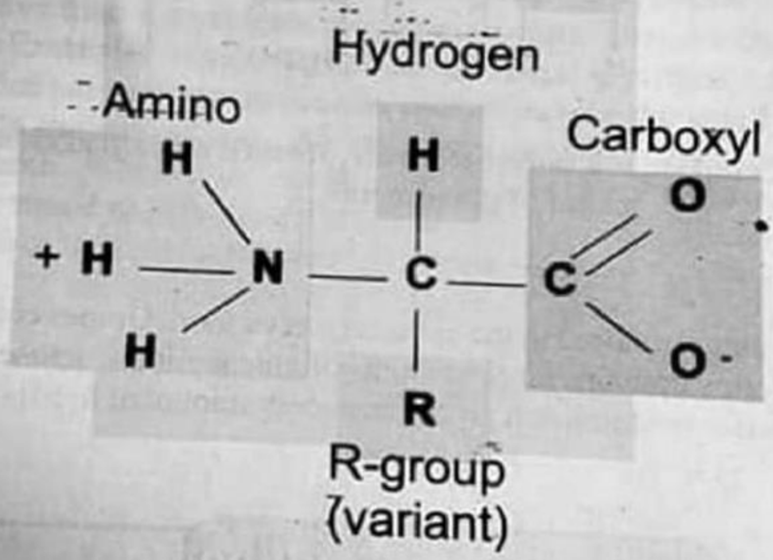


Fig: 2.9 Structure of Amino Acid

2.4.1 Structure of Amino Acids

Amino acids are carboxylic acids having amino groups. Each amino acid has a central carbon atom called alpha carbon. There are four different groups attached to the alpha carbon. These are amino group, carboxyl group, hydrogen of alpha carbon and R group. The former three groups attached to the alpha carbon are constant members and are present in all amino acids while the fourth one i.e. R-group is **variable**. It is either hydrogen or alkyl group. Due to this variable the amino acids are different from one another.

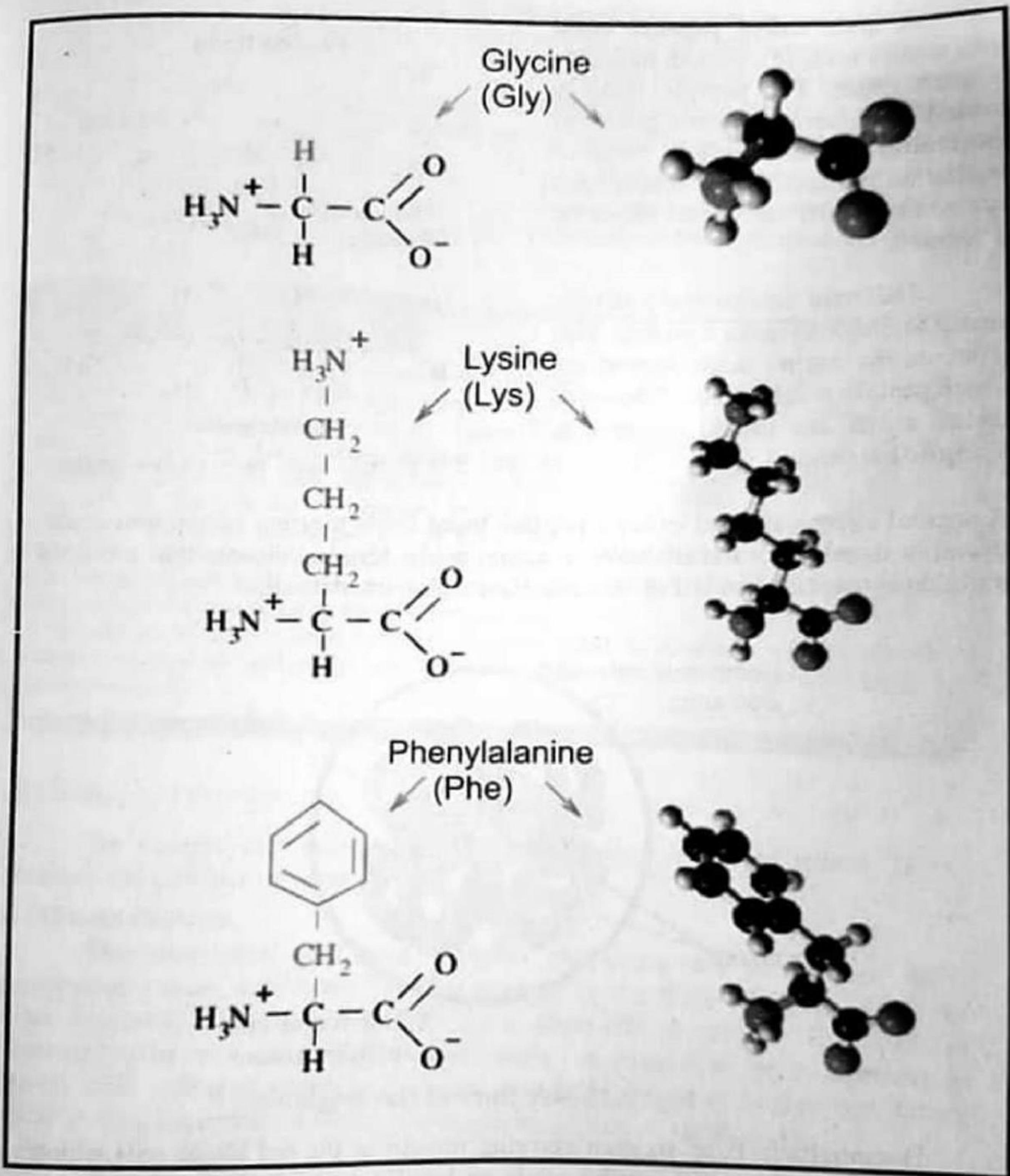


Fig: 2.10 Different types of amino acids

A bond called **peptide bond** links amino acids in a protein molecule to each other. The peptide bond is formed between an carboxyl group of one amino acid and amino group of another amino acid. This is condensation reaction in which one water molecule is formed.

Different amino acids can be joined together to make a protein. The order of the amino acids determines which protein will be made. When two amino acids are joined together, a **dipeptide** is formed.

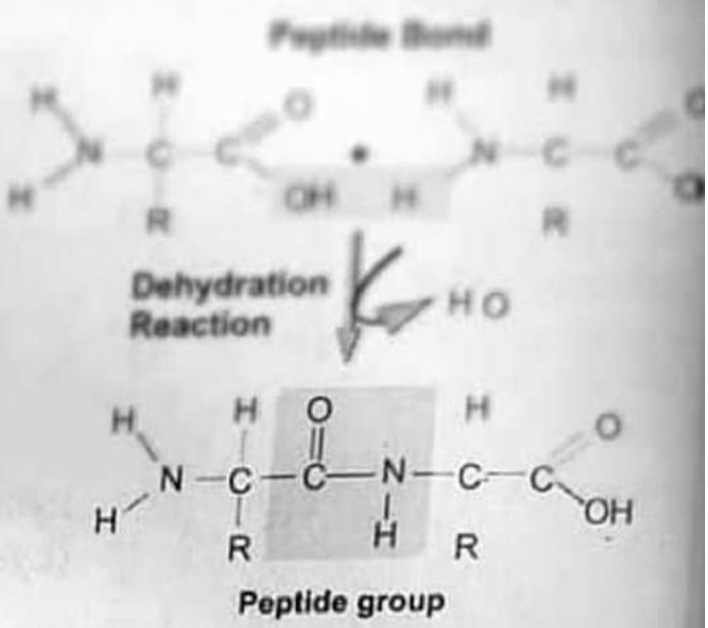


Fig: 2.11 Peptide bond between two amino

A special chemical bond called a **peptide bond** holds together two amino acids. Proteins usually consist of multiple amino acids, forming chains, that are held together by peptide bonds. For example, Haemoglobin and insulin.

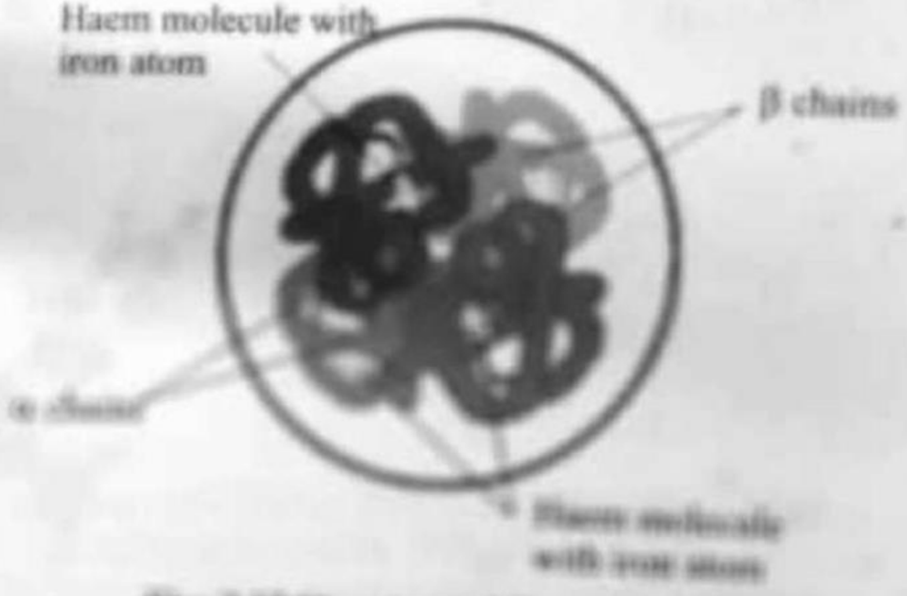


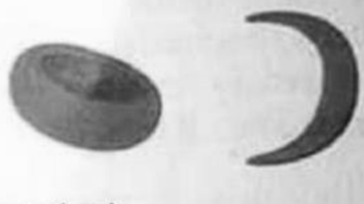
Fig: 2.12 Structure of Haemoglobin

Haemoglobin is an oxygen carrying protein in the red blood cells which consists of four polypeptide chains while an **insulin** molecule consists of two polypeptide chains. The number and sequence of amino acids in a protein molecule is highly specific for its normal function.

If an amino acid is not occupying its specific position in a protein molecule it will fail to perform its function. For example if one out of 574 amino acids in a haemoglobin molecule is not present in its specific position then haemoglobin changes its normal globular shape and becomes sickle-shaped. As a result the disc-shaped red blood cells also become sickle-shaped. In sickle cell haemoglobin molecule glutamic acid is replaced by valine. Such type of haemoglobin cannot perform its function and the person with sickle cell haemoglobin dies. The size of protein molecule depends upon the number and kinds of total amino acids present in the molecule.

For your information

Sickle cell anemia is a blood disorder that affects heamoglobin. Sickle cell anemia occurs when a person inherits two abnormal genes (one from each parent) that cause their RBCs to change shape. Instead of being flexible and disc-shaped, these cells are more stiff and curved in the shape of the old farm tool known as a sickle — that's where the disease gets its name. The shape is similar to a crescent moon. Red blood cells with normal haemoglobin (haemoglobin A, or HbA) move easily through the bloodstream, delivering oxygen to all the cells of the body. Normal RBCs are shaped like discs or doughnuts with the centers partially "scooped out" and are soft and flexible. They can easily "squeeze" through even very small blood vessel.



Normal red blood cell

Sickle Cell

2.4.2 Shape of Proteins

As regards the shape, proteins are classified into two types; fibrous proteins and globular proteins

a. Fibrous Proteins

The molecules of fibrous proteins are composed of one or more polypeptide chains, which are linearly arranged in the form of fibers. They are water insoluble. Some of these may form sheet-like structures. Examples of fibrous proteins are keratin found in hairs, nails, fur, outer skin, myosin present in muscle cells, collagen which is the most abundant protein in higher vertebrates found in skin, ligaments, tendons, bones and in the cornea of the eyes.

b. Globular Proteins

Globular proteins, as the name indicates, are globular or spherical in shape due to folding of polypeptide chains. They are usually water-soluble. Examples of globular proteins are hemoglobin, albumen of egg white, enzymes, antibodies and the proteins of cell membranes.

2.4.3 Levels of Structure (Organization)

There are four levels of organization of protein molecules. This is because each type of polypeptide chain bends, folds and twists in particular way within a protein molecule. This gives protein molecule a characteristic structure that classifies protein into four different types. The primary structure is the sequence of the amino acids joined together by peptide bonds. Sanger in 1951 was the first person who determined the sequence of amino acids in insulin molecule.

A polypeptide chain having a linear sequence of amino acids is called primary structure. When a polypeptide chain of amino acids become spirally coiled, the structure is called a secondary structure of protein. When the secondary structure of protein is arranged into a three dimensional structure,it is called a tertiary structure. When two or more polypeptide chains are arranged into a large sized molecule, it is called a quaternary structure e.g. haemoglobin.

2.4.4 Functions of Proteins

Proteins perform the most important functions in the life of living organisms. Proteins are the structural and building materials of cellular membranes called lipo-protein membranes. All enzymes are proteins. They speed up biochemical reactions inside the body of living organisms. The digestive enzymes are important for the process of digestion. Without their presence food cannot be digested. Some hormones such as insulin are proteins which regulate biochemical processes. Myosin and actin fibers play an important role in the contraction of muscles and movements. Haemoglobin is oxygen-carrying protein of red blood cells. In animals' proteins form most structures such as skin, nails, hairs, claws, hooves etc. In plants proteins are stored in most seeds for the future need of the embryos e.g. bean, pulses, pea etc.

2.5 Lipids

Lipids are a group of different types of organic compounds. They contain carbon, hydrogen and oxygen. Other elements such as nitrogen and phosphorus may also be present in lipids. Most lipids are non-polar and are insoluble in water (hydrophobic). They are easily soluble in organic solvent such as ether, acetone, petrol, alcohol etc. They usually contain more carbon-hydrogen bonds and less oxygen as compared to carbohydrates. Lipids are classified into various types such as acylglycerol, phospholipids, waxes, terpenoids etc.

2.5.1 Acylglycerol

Acylglycerol are lipids which are composed of glycerol and fatty acids. The most common acylglycerol are triglycerides containing one glycerol molecule and three fatty acids. **Glycerol** is a three-carbon compound, to each carbon a hydroxyl group is attached. Hydroxyl groups are polar and therefore glycerol is soluble in water. The acid portions of three fatty acids react with three hydroxyl groups of the glycerol so that a triglycerid and three water molecules are formed. This reaction is condensation. The triglyceride molecule can be hydrolyzed into its components i.e. glycerol and three fatty acids.
Triglycerids are stored in animals as fats.

A **fatty acid** consists of a long hydrocarbon chain with a carboxyl (acid) group (-COOH) at one end. Most of fatty acids in cell contain 16-18 carbon atoms per molecule. Fatty acids may be saturated or unsaturated.

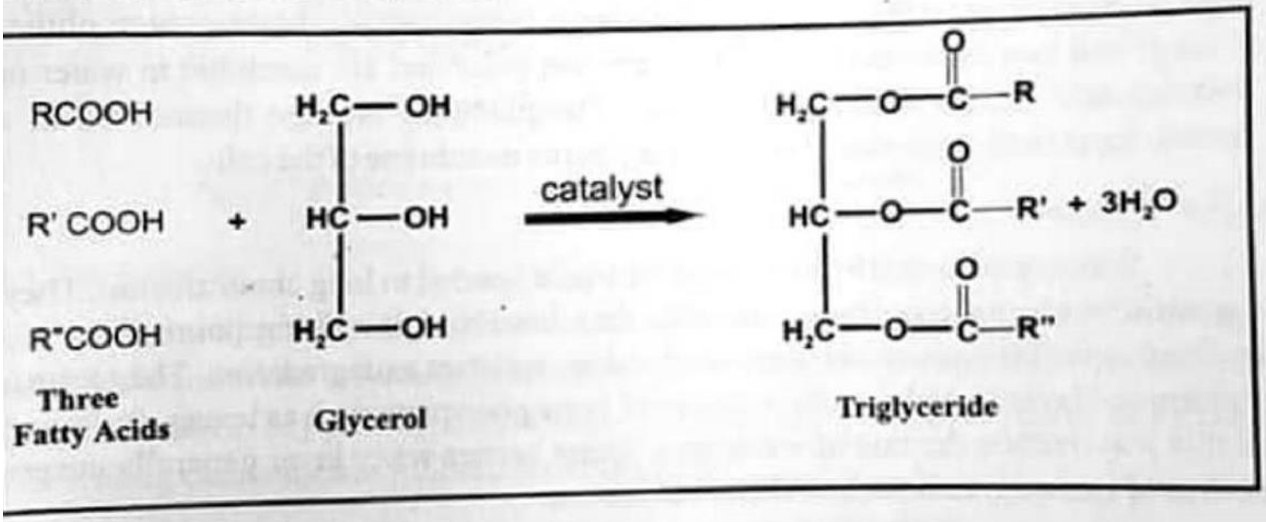


Fig: 2.13 Formation of Triglyceride from fatty acids and glycerol

Saturated fatty acids have no double bond between carbon atoms. Such molecules cannot accommodate any more hydrogen atoms if added to them. Acylglycerol with saturated fatty acids such as palmatic acids are called fats and are solid at room temperature. Saturated fatty acids are stored in animals as fats.

Unsaturated fatty acids have one or more double bonds between some carbon atoms (C=C). In such molecules the number of hydrogen is less than two per carbon atom. Any more hydrogen can be added to these molecules. Unsaturated fatty acids such as oleic acids are stored in plant seeds. Acylglycerol with unsaturated fatty acids are usually liquid at room temperature.

The triglyceroids have high caloric value and usually yield twice as much energy per gram as that of carbohydrate.

> **For your information**
>
> Ghee with saturated fatty acids is prepared from vegetable oil by passing hydrogen through it. Intake of ghee should be minimized as it may store in blood vessels reducing their flow capacity increasing risk of heart attack.

2.5.2 Phospholipids

Phospholipids are composed of one glycerol molecule, two fatty acids and one phosphoric acid molecule usually linked to some nitrogen group.

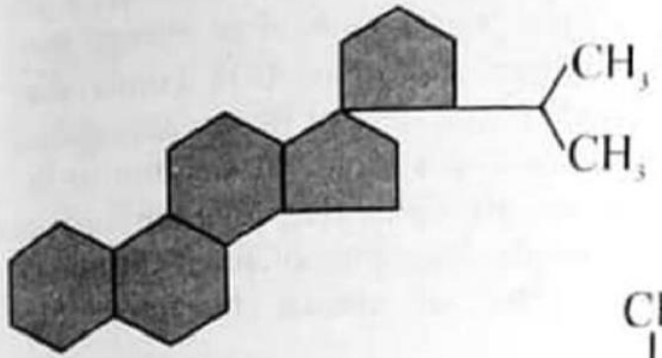
A triglyceride molecule is converted into phospholipid when a fatty acid is replaced by one phosphate. A phospholipid molecules has two parts. A phosphate head: It is polar and is therefore soluble in water or hydrophilic (hydro-water; philic-loving) and two hydrocarbon tails they are non polar and are insoluble in water or hydrophobic (hydro-water; phobos-fear). Phospholipids arrange themselves in a double layer in the presence of water in the plasma membrane of the cells.

2.5.3 Waxes

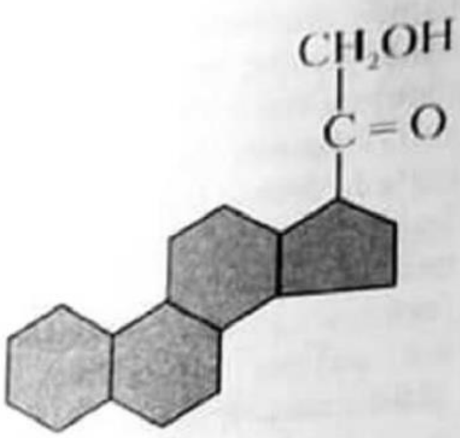
Waxes are formed by long chain fatty acid bonded to long chain alcohol. They are solid at normal temperature because they have a high melting point. They are hydrophobic. They are stable compound and are resistant to degradation. They form a waterproof layer (cuticle) on the surfaces of some plant parts such as leaves, fruits and in this way reduce the rate of water loss. Water barrier waxy layer generally covers bodies of some animals such as sheep and insects.

2.5.4 Steroids

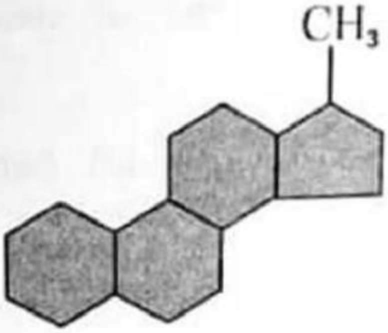
Steroids are lipids that do not contain fatty acids. Each steroid is formed of a backbone of four fused carbon rings containing 17 carbon atoms. They differ from one another by the type of functional group attached. Different steroids have important functions in the bodies of humans and other animals. Cholesterol is a representative example of the steroids. It plays a role as an essential component in animal cell membranes. Cholesterol is also a precursor of all steroid hormones such as aldosterone, sex hormones and vitamin D. Aldosterone helps to regulate the sodium content of the blood. Sex hormones help to maintain male and female characteristics.



a. Cholesterol



b. Aldosterone



c. Testasterone

Fig: 2.14 Some representative examples of the steroids.

2.5.5 Terpenoids

Terpenoids are lipids that like the steroids do not contain fatty acids. They are lipid soluble and water insoluble substances. The terpenoids are formed of units called isoprenoid units. They join by the process of condensation and give rise to different types of compounds such as rubber, carotenoids, etc.

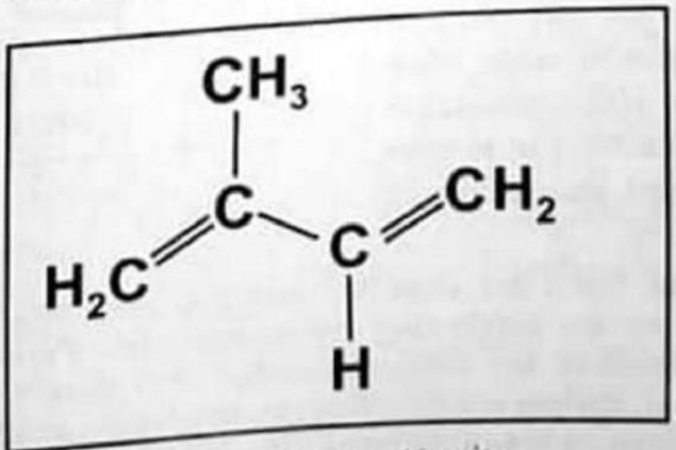


Fig: 2.15 An Isoprenoid units

2.5.6 Functions of lipids

Lipids are long-term energy storage molecules in plants and animals. Plants usually store lipids in seeds as oils (unsaturated fatty acids) while animals store them as fats (saturated fatty acids). Lipids store greater amount of energy than carbohydrates because they contain less oxygen and more C-H bonds than carbohydrates. Lipids are the building materials of the cellular membranes called lipo-protein membranes. Lipids provide insulation to various organs and to the bodies of animals as a whole. Some hormones are lipids that regulate various processes inside the bodies of plants and animals. Examples of plant hormones are auxins, gibberellins, cytokinins while that of animal hormones are aldosterone, testosterone.

2.6 Nucleic Acids

Nucleic acids are polynucleotide chain (polymers) formed by the linkages of units called nucleotides. There are two types of nucleic acids i.e. deoxyribonucleic acids (DNA) and ribonucleic acids (RNA). DNA is formed of deoxyribonucleotides while RNA is formed of ribonucleotides.

2.6.1 Nucleotides

In a typical nucleotide, the nitrogenous base is attached to carbon no. I of pentose sugar while phosphate group is attached to carbon No. 5 of the pentose sugar. The bond formed between phosphoric acids (H_3PO_4) and hydroxyl (OH) groups of pentose sugar is called ester linkage. In a polynucleotide chain one phosphoric acid is attached to the OH group of carbon No 3 of pentose sugar while another phosphoric acid is attached to OH group of carbon No 5 of pentose sugar. This is called phosphodiester linkage.

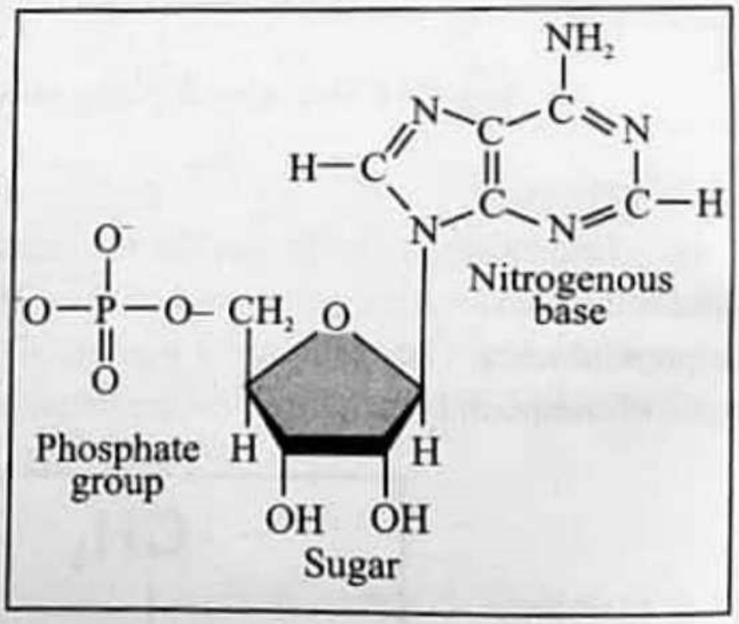
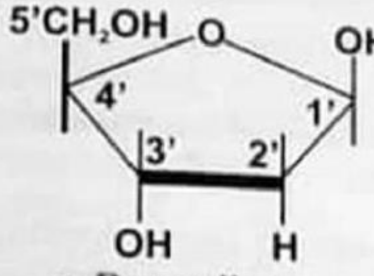
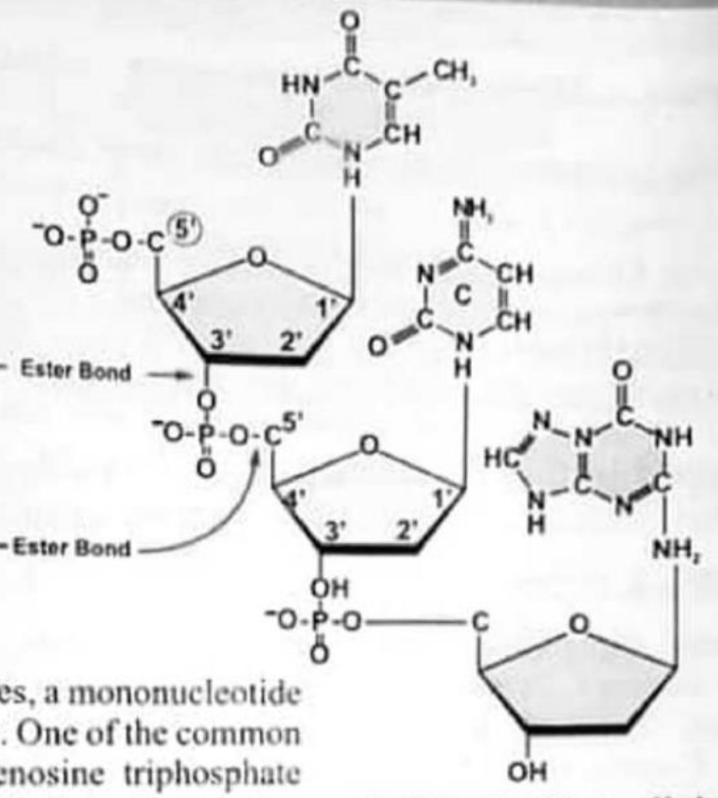


Fig: 2.16 Skeleton of a nucleotide

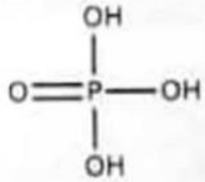
Nitrogenous bases are classified into two main types, Pyrimidines and Purines. Pyrimidines are single ring compounds while Purines are double ring compounds. Pyrimidines are further classified into three types, i.e. Thymine, Cytosine and Uracil. Purines are classified into two types i.e. Adenine and Guanine. Nucleotides are classified in to three types. These are mononucleotides dinucleotides and polynuceotides.



a. Deoxyribose



b. Phosphodiester linkage



c. Phosphoric acid

2.6.2 Mononucleotides

As the name indicates, a mononucleotide exists as a single nucleotide. One of the common mononucleotide is the adenosine triphosphate (ATP). It is a nucleotide with three phosphates. Adenine base linked to pentose sugar (ribose) forms a structure called adenosine. When adenosine is bonded to a single phosphate it will form a nucleotide called adenosine monophosphate. This reaction needs energy.

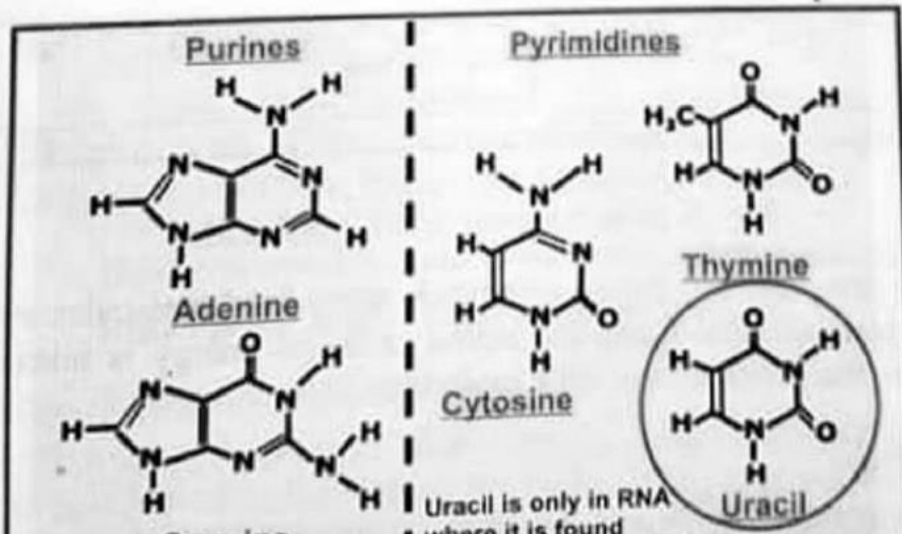


Fig: 2.17 Chemical structures

Adenine + Ribose (pentose sugar) $\longrightarrow$ Adenine-Ribose (Adenosine)

Adenosine (Adenine-Ribose) + phosphate $\longrightarrow$ Adenosine Monophosphate (AMP)

Adenosine Monophosphate is a nucleotide with one phosphate group. Another phosphate is bonded to this molecule when energy is supplied; it forms **adenosine diphosphate (ADP).** With the addition of a third phosphate and energy to it, **adenosime triphosphate (ATP)** molecule is formed.

AMP + Phosphate $\longrightarrow$ Adenosine Diphosphate (ADP) " A-P~P "
(A- stands for adenosine; P for phosphate)

ADP + P $\longrightarrow$ ATP (Adenosine Triphosphate) " A-P~P~P "

Adenosine triphosphate is an energy rich molecule and is commonly called energy currency. It provides energy to cells of all living organisms for their functions. The wavy bonds between the phosphate groups indicate high-energy bonds. Usually the bond between the second and third phosphate breaks up releasing the energy used by the cell. An ATP molecule is hydrolyzed into ADP and P and almost 7 Kcal energy is produced.

$$\mathbf{ATP + H_2O \longrightarrow ADP + P + 7.0\ K\ Cal}$$

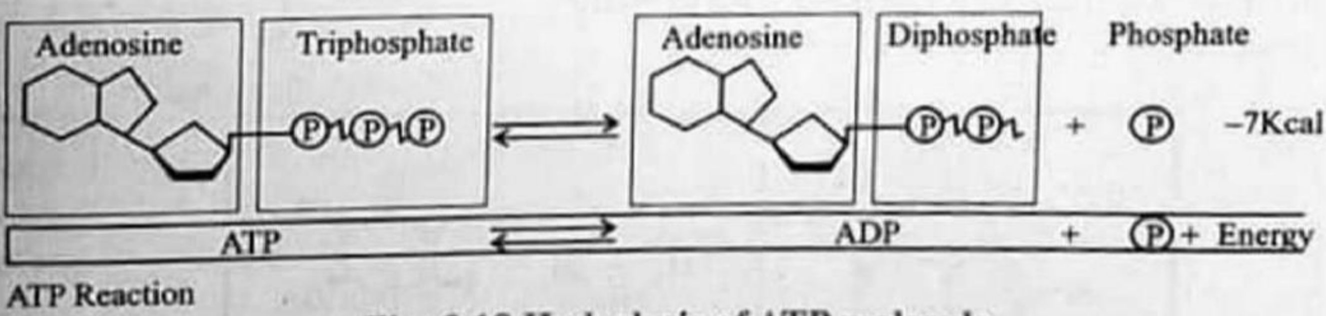


Fig: 2.18 Hydrolysis of ATP molecule.

ATP molecules are produced during respiration when food molecules are broken down into simpler substances and the stored chemical energy is released. This energy is used in the generation of ATP molecules.

2.6.3 Dinucleotides

When two nucleotides are linked together, a structure called dinucleotide is formed. If the dinucleotide contains adenine as nitrogenous base, then it will be called adenine dinucleotide.

For your information

Nicotinamide is a vitamin called nicotinic acid (niacin). Flavin is also a vitamin called riboflavin (Vitamin B2).

The adenine dinucleotide in combination with different vitamins form important compounds called co-enzymes. Three important co-enzymes are NAD (Nicotinamide Adenine Dinucleotide), NADP (Nicotinamide Adenine Dinucleotide Phosphate) and FAD (Flavin Adenine Dinucleotide).
These coenzymes can exist in two forms; a reduced and oxidized form. In the oxidized state they function as hydrogen acceptor. NAD and FAD are both active in the electron transport chain of respiration where they act as electron carriers. In the process they are alternately reduced and oxidized.

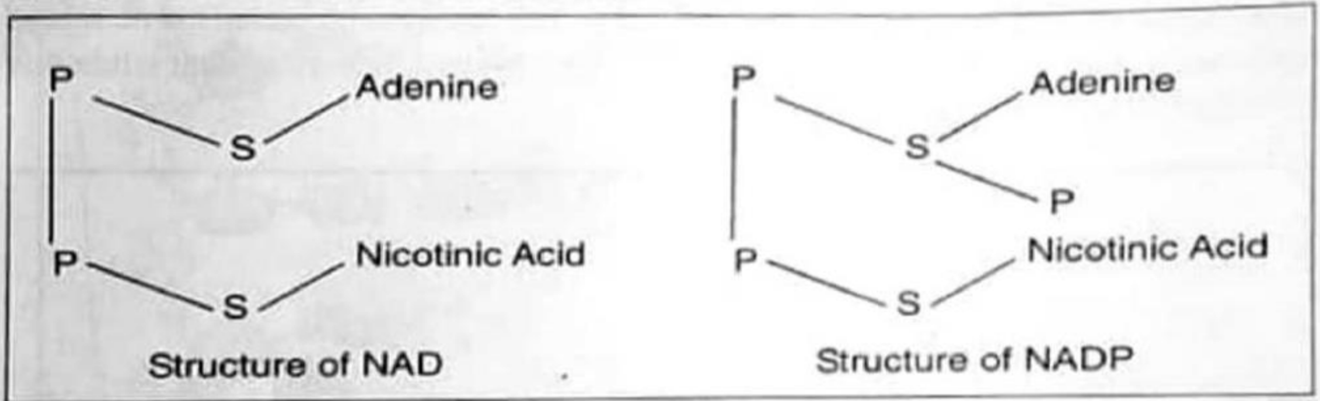


Fig: 2.19 Some examples of co-enzymes.

2.6.2 Polynucleotides (Poly:many)

When many nucleotides are linked together they form a structure called polynucleotide. DNA and RNA molecules are polynucleotide chains (strand). There are different types of RNA molecules, each type performs specific function under the instructions of DNA. Nucleic acids are of two types:

1. **DNA:** **Deoxyribonucleic Acid** – made of deoxyribonucleotides
2. **RNA:** **Ribonucleic Acid** - made of ribonucleotides

1. Deoxyribonucleic Acid (DNA)

In 1962 James Watson (b. 1928), Francis Crick (1916–2004), and Maurice Wilkins (1916–2004) jointly received the Nobel Prize in physiology or medicine for their 1953 determination of the structure of deoxyribonucleic acid (DNA). According to this model the DNA molecule is double helix. The double helix can be visualized as spiral stair case wound around a central axis. Watson and Crick suggested that base pair always consists of purine pointing toward pyrimidines, keeping the molecule diameter at a constant 2nm. The base pair are flat with a distance of 0.34 nm between them.

DNA contains pentose sugar as deoxyribose. It is formed of four different types of nucleotides. These nucleotides are named after the base present in them they are: Adenine deoxyribonucleotide, Guanine deoxyribonucleotide, Thymine deoxyribonucleotide and Cytosine deoxyribonucleotide.

These four types of nucleotides are used as building blocks of DNA molecule. The nucleotides in the DNA molecule are bonded to one another in such a manner that the sugar of one nucleotide is linked to the phosphate group of the next one. In this way the nucleotides form a linear molecule called a strand in which the backbone is made up of sugar alternating with the phosphate group. The bases are projected to one side of the strand. The sequence of the nucleotide in one type of DNA is constant while it is different from other type of DNA molecule.

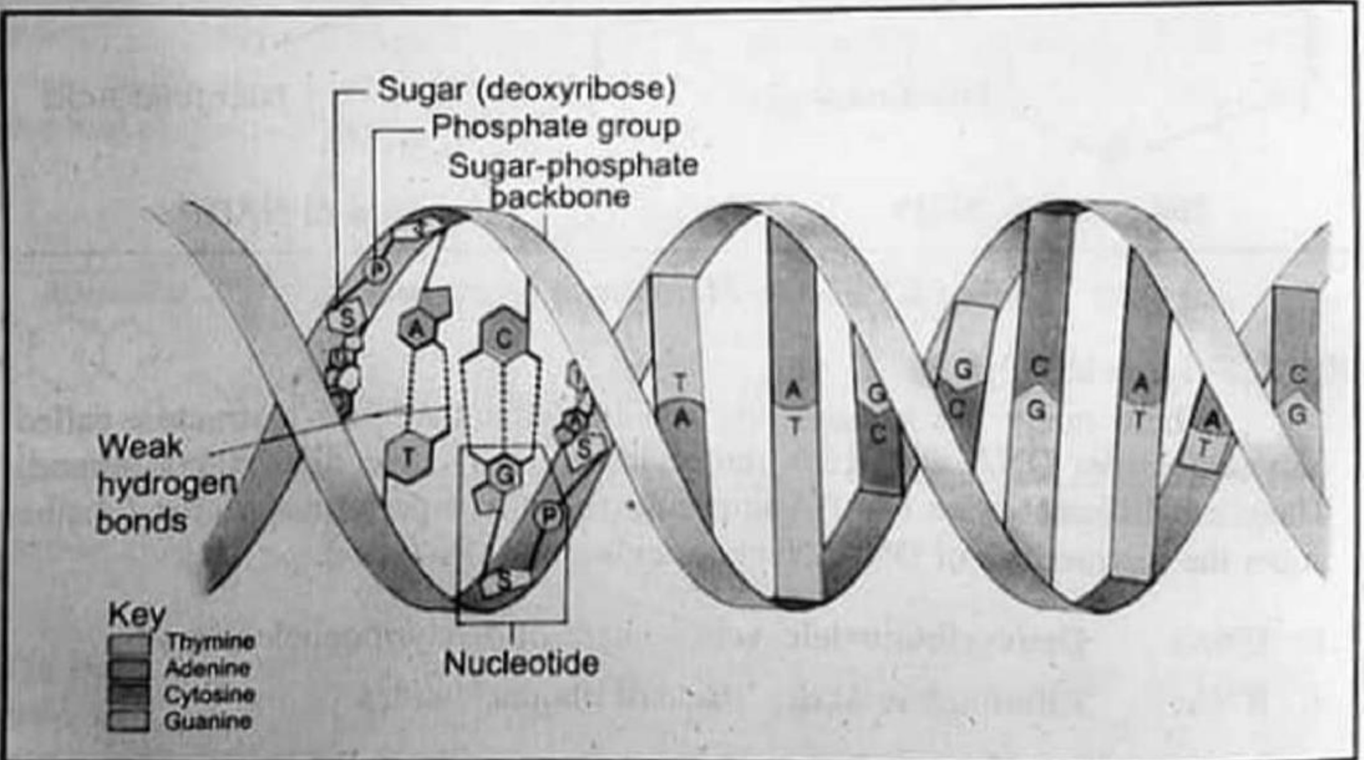


Fig: 2.20 Structure of DNA

DNA molecule consists of two strands. The two strands twist about one another in the form of a double helix. The two strands run in opposite direction to each other in the double helix. They are held together by hydrogen bonds between purine and pyrimidine bases. Thymine in one strand is always paired with ademnine in the opposite strand and guanine is always paired with cytosine.

There are two hydrogen bonds between adenine and thymine and three hydrogen bonds between guanine and cytosine.

2. Ribonucleic Acid

Ribonucleic acid is also a polymer of the nucleotides. Ribonucleic acid called RNA contains pentose sugar as Ribose. It is also formed of four different types of nucleotides. These nucleotides are named after the base present in them they are: adenine ribonucleotide, guanine ribonucleotide, cytosine ribonucleotide, uracil ribonucleotide.The nucleotides in the RNA molecule are linked in the same manner as in the DNA molecule. RNA is a single polynucleotide strand. In RNA the base uracil occurs instead of the base thymine.

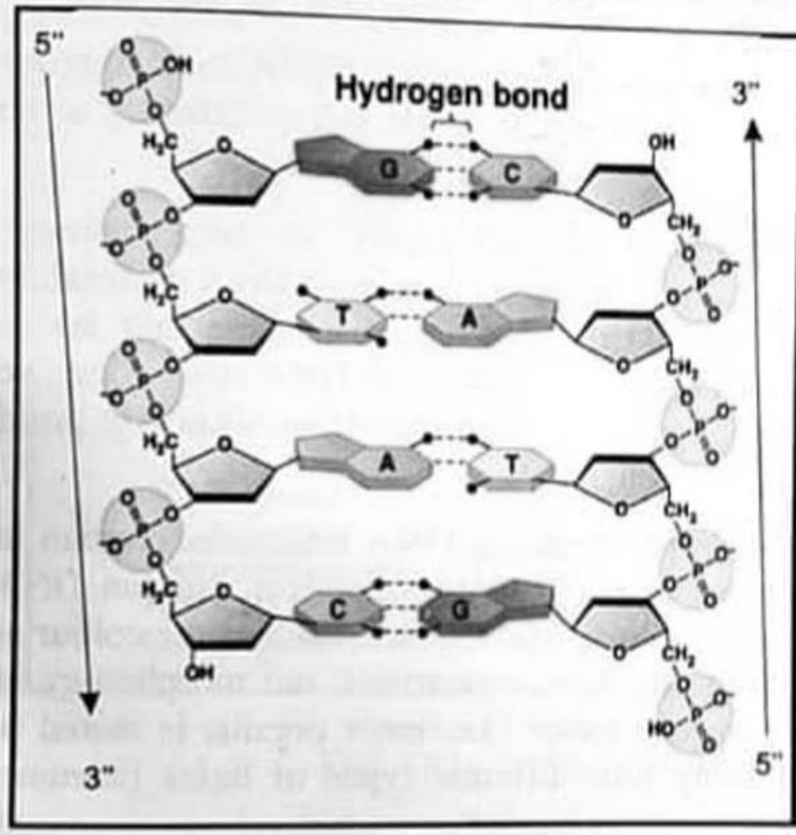


Fig: 2.21 Chemical structure of DNA

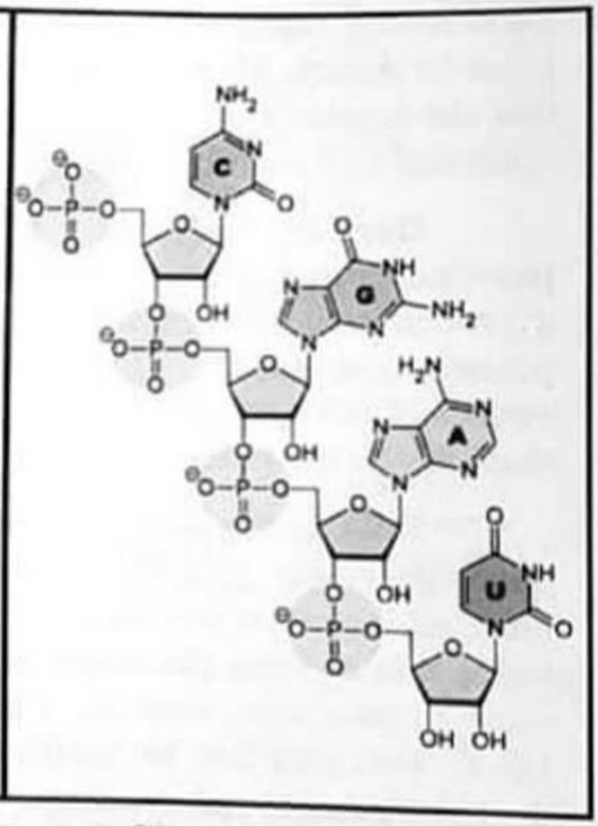


Fig: 2.22 Chemical structure of RNA

There are three types of RNA molecules; messenger RNA (mRNA), transfer RNA (tRNA) and ribosomal RNA (rRNA).

a. Messenger RNA (mRNA)

Messenger RNA carries messages from the DNA to the ribosome for protein synthesis.

b. Transfer RNA (tRNA)

Transfer RNA transfers the specific amino acid from the cytoplasm to the ribosome for protein synthesis.

c. Ribosomal RNA (rRNA)

Ribosomal RNA in combination with protein forms the body of the ribosome.

2.6.3 DNA as Hereditary Material

Chromosome is composed of DNA and proteins. Biologists conducted experiments and proved that DNA is the genetic material and is responsible for the transfer of genetic information from parents to offspring.

In 1928 Griffith conducted experiments using bacteria that causing pneumonia in mice. He used two types of bacteria; pathogenic and non-pathogenic bacteria. He observed that the non-pathogenic bacteria have absorbed genetic material (DNA) from the pathogenic bacteria. As a result they have been transformed (changed) to pathogenic form.
Later on **Avery, Mcleod and McCarty** provided experimental evidence to prove that the virulence of *Pneumococcus*, which is due to its outer surface, can be transmitted through DNA to bacteria that have lost their virulence.

Hershey and Chase who studied the life history of bacteriophages provided further conclusive evidence. Bacteriophages consist of DNA enclosed in a protein coat. The bacteriophage injects its DNA into bacterium and leaves protein coat outside. Under the instructions of the viral DNA new complete viruses (DNA and proteins) are made inside the host bacterium. This is a proof that DNA is the genetic (hereditary) material.

DNA is the data bank of living organisms. DNA molecules contain in them the master plan of all characters of every living organism. Human DNA holds all the information about the human body. All the data, such as the colour of hairs, skin or eyes, the height of body, the size, appearance and morphology of nose, fingers, ears, eyes etc. the way one looks like, inner organs, is stored in DNA. This data can be encoded using four different types of bases (adenine, thymine, guanine and cytosine).

2.6.4 Genetic Code

All genetic information is encoded in the DNA molecule in the form of gene. A gene is a unit of heredity in a living organism. All living things depend on genes, as they specify all proteins and functional RNA chains. These information are transferred to the next generation through DNA. Nucleotides are arranged in a specific way in a polynucleotide chain of DNA. A code is a sequence of three nitrogenous bases (triplet) along one sugar-phosphate strand of DNA molecule. A code specifies the way in which an amino acid is to be bonded in polypeptide chain of protein molecule.

First position (5'end)

	U		C		A		G		
U	UUU	Phe	UCU		UAU	Tyr	UGU	Cys	U
	UUC		UCC	Ser	UAC		UGC		C
	UUA	Leu	UCA		UAA	Stop	UGA	Stop	A
	UUG		UCG		UAG	Stop	UGG	Trp	G
C	CUU		CCU		CAU	His	CGU		U
	CUC	Leu	CCC	Pro	CAC		CGC	Arg	C
	CUA		CCA		CAA	Gln	CGA		A
	CUG		CCG		CAG		CGG		G
A	AUU		ACU		AAU	Asn	AGU	Ser	U
	AUC	Ile	ACC	Thr	AAC		AGC		C
	AUA		ACA		AAA	Lys	AGA	Arg	A
	AUG		ACG		AAG		AGG		G
G	GUU		GCU		GAU	Asp	GGU		U
	GUC	Val	GCC	Ala	GAC		GGC	Gly	C
	GUA		GCA		GAA	Glu	GGA		A
	GUG		GCG		GAG		GGG		G

Third position (3'end)

Amino acids names

Ala = alanine
Arg = arginine
Asn = asparagine
Asp = aspartate
Cys = cysteine
Gln = glutamine
Glu = glutamate
Gly = glycine
His = histidine
Ile = Isoleucine
Leu = leucine
Lys = lysine
Met = methionine
Phe = phenylalanine
Pro = proline
Ser = serine
Thr = threonine
Trp = tryptophan
Tyr = tyrosine
Val = valine

Fig: 2.23 Various combination of Genetic Codes

For your information

There is a lot of information stored in the DNA. If we had to write down all the information in the DNA, it would make 900 volumes, each of 500 pages. All this knowledge has been fitted into a tiny molecule that we cannot see with our naked eye. Who has fitted all this information in DNA. Certainly this is the work of **supreme intelligence, He is Allah with His supreme intelligence,** limitless knowledge and eternal power, Who created the universe.

There are four nitrogenous bases involved in the formation of many codes; adenine, guanine, thymine and cytosine. These four nitrogenous bases make sufficient codes for the 20 different amino acids which synthesize a large number of different protein molecules.

2.6.5 RNA as a carrier of genetic information

Three types of RNA molecules, mentioned earlier, are involved in the transfer of genetic information from DNA to synthesize proteins. This transfer of genetic information takes place in two steps:

1. Transcription

This is the transfer of genetic code from DNA molecule to RNA molecule.

2. Translation

This is the transfer of the genetic code from a mRNA to a sequence of amino acids in a polypeptide.

2.7 Conjugated Molecules

A conjugated molecule is defined as a molecule that is formed by the combination of two different molecules belonging to different categories. For example when a carbohydrate molecule combines with protein, a conjugated molecule called glycoprotein is formed. Other examples are nucleoproteins, glycolipids and lipoproteins.

1. Lipoproteins

Lipoprotein are formed by the combination of lipids and proteins. Lipoproteins are the basic structural framework of plasma membrane and all other types of membranes in the cell.

2. Nucleoproteins

Nucleoproteins are formed by the combination of nucleic acids with proteins. A eukaryotic chromosome is basically a nucleoprotein that is formed by the DNA and protein. These are slightly acidic and soluble in water.

3. Glycolipids

Glycolipids are formed by the combination of carbohydrates and lipids. Glycolipids are important component of brain and plasma membrane.

4. Glycoproteins

Glycoproteins are formed by the combination of carbohydrates and proteins. Glycoproteins are integral component of the plasma membrane. They are also present in egg albumin.

KEY POINTS

- Biochemistry is the branch of biology that deals with biochemical basis of life.
- In higher plants inorganic compounds are obtained from the environment and are used to make different organic compounds.
- Water is one of the best solvents, regulate temperature of the body and has high absorbing capacity to absorb different materials.
- Condensation is a process in which large organic molecules are synthesized and water molecules is removed.
- Hydrolysis is a process in which large organic molecules is broken down and involves the addition of water molecules.
- Carbon is present in all organic compounds with a covalent bonding capacity of four.
- Carbohydrates are generally the hydrated carbons which are composed of carbon ,hydrogen and oxygen.
- Carbohydrates are classified into monosaccharides, oligosaccharides and polysaccharides.
- Starch is a common storage product in plants and glycogen in animals.
- Cellulose is a common polysaccharides found in plants.
- Carbohydrates provide energy, a building material of different body structure and are storage molecules.
- Proteins contain carbon, hydrogen, oxygen and nitrogen as four essential elements.
- Proteins are made up of amino acids.
- The amino acids bond together by peptide bonds which produce polypeptides chains.
- Protein molecules may be fibrous e.g. keratins or globular .e.g. haemoglobin.
- Globular proteins may be primary ,secondary, tertiary and quaternary depending on their different levels of structural organization.
- Lipids are mainly composed of carbon, hydrogen and oxygen and some other elements particularly phosphorous and nitrogen and include animal fats, vegetables oils, waxes, steroids etc.

KEY POINTS

- Vegetable oils and animals fat are called triglyecrides.
- Triglycerides are with three fatty acid chains bonded to one molecules of glycerol.
- Fatty acid may be saturated or unsaturated.
- Lipids are important as storage molecules ,building material, insulators and help in the fat digestion and speeding up of vital activities.
- The two nucleic acids are Deoxyribonucleic acid (DNA) and ribonucleic acids (RNA).
- DNA has four nitrogenous bases namely ,adenine, guanine, cytosine and thymine. RNA has the nitrogenous base uracil instead of thymine.
- RNA molecule are of three types messenger RNA (m RNA) ,ribosomal (r RNA) and transfer RNA (t RNA).
- Mononucleotides may have single phosphate group .e . g. Adenosine (AMP), two phosphate groups .e .g . Adenosine diphosphate (ADP) and three phosphate group e.g. Adenosine triphosphate (ATP).
- When more than two nucleotides join together they form polynucleotides e.g. DNA and RNA.
- Example of conjugate molecules are glycoproteins, nucleoproteins, glycolipids and lipoproteins.

EXERCISE ?

A. Choose the correct answers for the following questions.

1. Which of the following is a disaccharide?
   a. Glucose
   b. Lactose
   c. Fructose
   d. Galactose

2. Which of the following has the greatest number of glycosidic bonds?
   a. Glucose
   b. Sucrose
   c. Cellulose
   d. Maltose

3. The main component of cellular membrane is:
   a. nucleic acid
   b. cellulose
   c. carbohydrates
   d. protein

4. The kinds of amino acids which are involved in the synthesis of proteins are :
   a. 20
   b. 30
   c. 40
   d. 50

5. Amino acids mainly differ from each other by the difference in their:
   a. R –group
   b. carboxyl group
   c. amino group
   d. alpha group

6. Keratin is a type of protein found in:
   a. silk fiber
   b. nails
   c. blood cells
   d. muscle cells

7. DNA is more or less present in all of the following EXCEPT:
   a. nucleus
   b. chromosomes
   c. ribosome
   d. mitochondrion

8. In saturated fatty acids more hydrogen are not accommodated because of
   a. Presence of single bonds between carbon atoms
   b. Presence of double bonds between carbon atoms
   c. Presence of triple bonds between carbon atoms
   d. Absence of bond between carbon atoms

EXERCISE

9. Lipid molecules have the capacity to store double amount of energy as compared to same amount of carbohydrate because of high number of:
   a. C-C bonds b. C-H bonds
   c. C-N bonds d. C-O bonds
10. The "tails" of the hydrocarbons in the phospholipids molecules orient away from water. Which of the following describes the tail's movement away from water?
   a. Polar b. Adhesive
   c. Hydrophilic d. Hydrophobic
11. Lactose is a disaccharide formed by the formation of a glycosidic bond between glucose and________.
   a. glyucose b. galactose
   c. Sucrose d. fructose
12. Ester linkage is a bond which involves a chemical reaction between:
   a. H_3PO_4 and COH b. H_3PO_4 and CH
   c. H_3PO_4 and COOH d. H_3PO_4 and OH
13. How many nitrogenous bases are involved in the formation genetic codes?
   a. 2 b. 3
   c. 4 d. 5

B. Write short answers to the following questions.

1. Define the following:
   (a) condensation
   (b) hydrolysis
2. What are different kinds of carbohydrates? Give two example of each.
3. Compare the isomers and stereoisomers of glucose.
4. Give the chemical nature of the glycosidic bond.
5. How dehydration-synthesis and hydrolysis reactions are used for the making and breaking of macromolecule polymers.
6. Outline the synthesis and breakage of peptide linkages.
7. Evaluate the role of steroids in human body.
8. Illustrate the formation of phosphodiester bond.
9. List some examples of structural proteins.

C. Write detailed answers to the following questions.

1. Explain how the properties of water make it important for life?
2. Describe the properties and roles of disaccharides.
3. Classify proteins. List examples and roles of structural and functional proteins.
4. Describe the properties and roles of acylglycerol, terpenes and phospholipids.
5. Define conjugated molecule and describe the roles of common conjugated molecules.
6. Explain the double helical structure of DNA as proposed by the Watson and Crick.

Projects:

- Make a model exhibiting the hydrogen bonding.
- Make a simple model of ring forms of alpha and beta glucose.
- Create a 3-Dimensional model of Watson - Crick Model of DNA.

Introduction

Recall from your pervious classes that enzymes are biological catalyst which increase the rate of chemical reaction in living cells without being used in the process. Nearly every chemical process that takes place in living things is facilitated by an enzyme. The sum of all the chemical reactions that a cell or larger living thing carries out is its metabolism. Many activities in living things are controlled by metabolic pathways in which a series of interrelated steps are involved each one of them facilitated by an enzyme.

3.1 Enzyme Structure

Enzymes are proteins, and their function is determined by their complex structure. The reaction takes place in a small part of the enzyme called the active site, while the rest of the protein acts as "framework". The amino acids around the active site attach to the substrate molecule and hold it in position while the reaction takes place. This makes the enzyme specific for one reaction only, as other molecules would not fit into the active site.

3.2 Mode of Enzyme Action

Following two hypotheses explains mode of enzyme action

3.2.1 Lock and Key Hypothesis

Fischer in 1890 suggested that each enzyme had a particular shape into which the substrate fit exactly. This was known as the lock and key hypothesis. According to this hypothesis the substrate is imagined like a lock while the enzyme is imagined like a key. As one specific key can open only a specific lock, similarly a specific enzyme can break up only one specific substrate. The active site is regarded as rigid structure that does not modify or change during the reaction process. However later studies did not support this hypothesis in all type of reactions and therefore the hypothesis was modified into Induced fit hypothesis.

3.2.2 Induced-Fit Hypothesis

The attraction of the substrate and enzyme form an enzyme-substrate complex. It was originally referred to as the Lock and Key Enzyme Theory. The current theory suggests that the enzyme molecules are in an inactive form. To become active they must undergo a slight change in structure to more specifically accommodate the substrate(s). It is said to be "induced to fit" the substrate.

Think of way your hand changes shape slightly when you shake a person's hand. There are three ways of thinking about enzyme catalysis. They all describe the same process, though in different ways, and you should know about each of them.

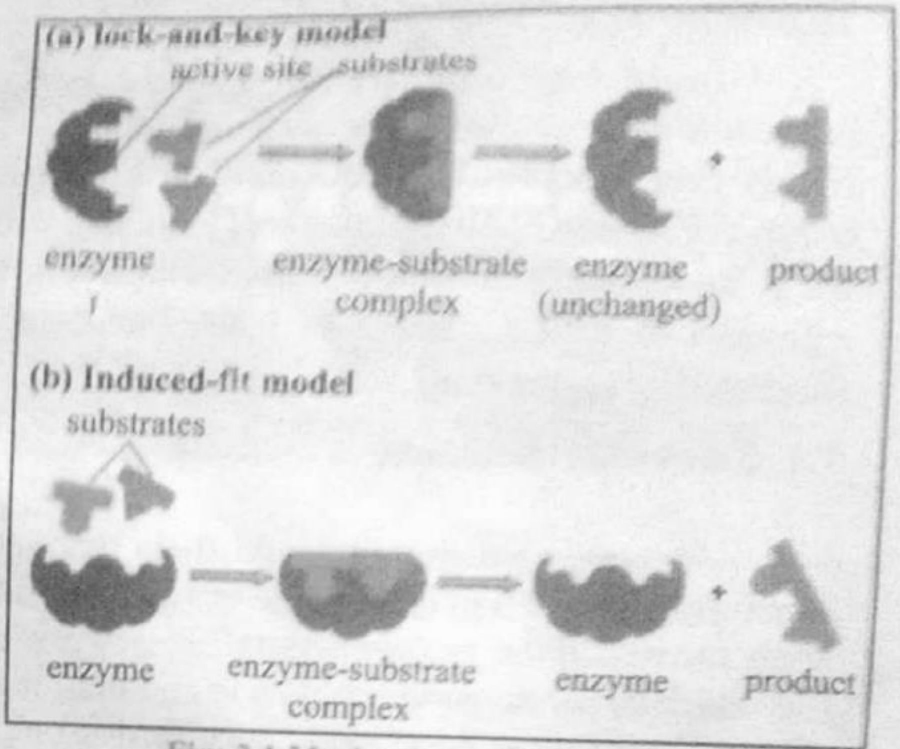


Fig: 3.1 Mechanism of Enzyme Action

A. Reaction Mechanism

In any chemical reaction, a substrate (S) is converted into a product (P):

$$S \sim P$$

There may be more than one substrate and more than one product, but that doesn't matter here. In an enzyme-catalyzed reaction, the substrate first binds to the active site of the enzyme to form an enzyme-substrate (ES) complex, then the substrate is converted into product while attached to the enzyme, and finally the product is released. This mechanism can be shown as in the Fig 3.2. The enzyme is then free to start again.

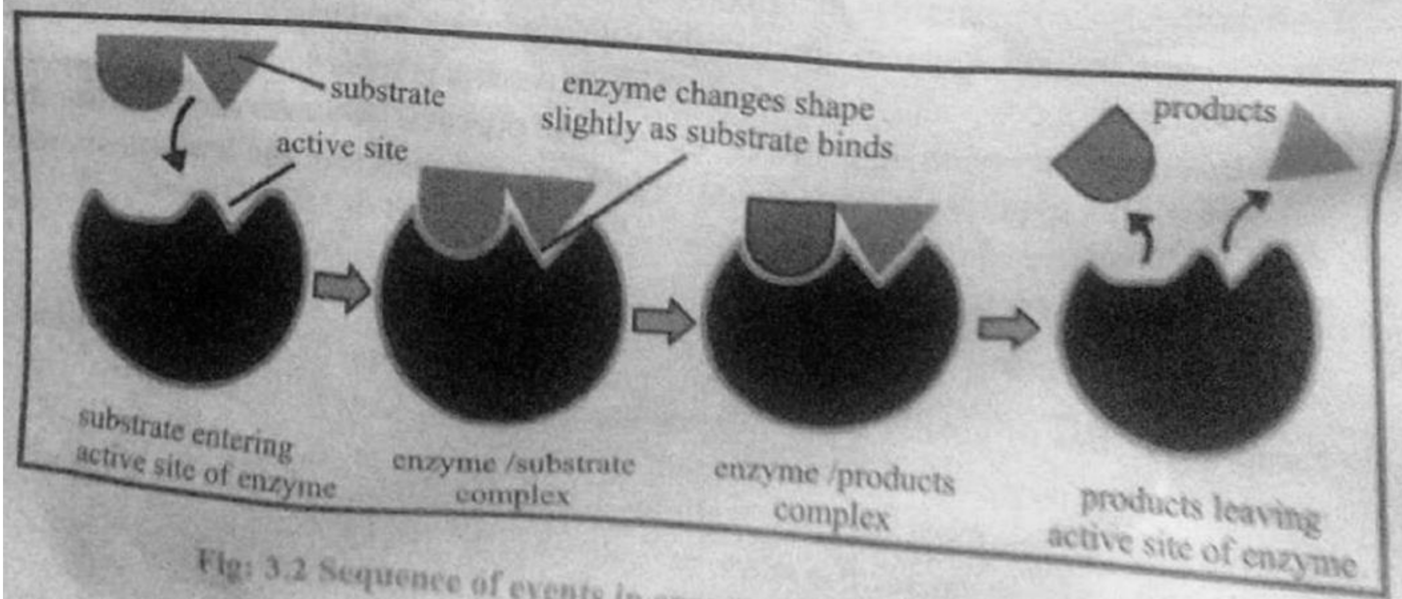


Fig: 3.2 Sequence of events in enzyme controlled reaction

B. Molecule Geometry

The substrate molecule fits into the active site of the enzyme molecule like a key fitting into a lock. Once there, the enzyme changes shape slightly, distorting the molecule in the active site, and making it more likely to change into the product. For example if a bond in the substrate is to be broken, that bond might be stretched by the enzyme, making it more likely to break. Alternatively the enzyme can make the local conditions inside the active site quite different from those outside (such as pH, water concentration, charge), so that the reaction is more likely to happen.

C. Energy Changes

The way enzymes work can also be shown by considering the energy changes that take place during a chemical reaction. We shall consider a reaction where the product has a lower energy than the substrate, so the substrate naturally turns into product (in other words the equilibrium lies in the direction of the product). Before it can change into product, the substrate must overcome an "energy barrier" called the activation energy (E_A). The larger the activation energy, the slower the reaction will be because only a few substrate molecules will by chance have sufficient energy to overcome the activation energy barrier. Enzymes dramatically reduce the activation energy of a reaction, so that most molecules can easily get over the activation energy barrier and quickly turn into product. For example, for the following reaction

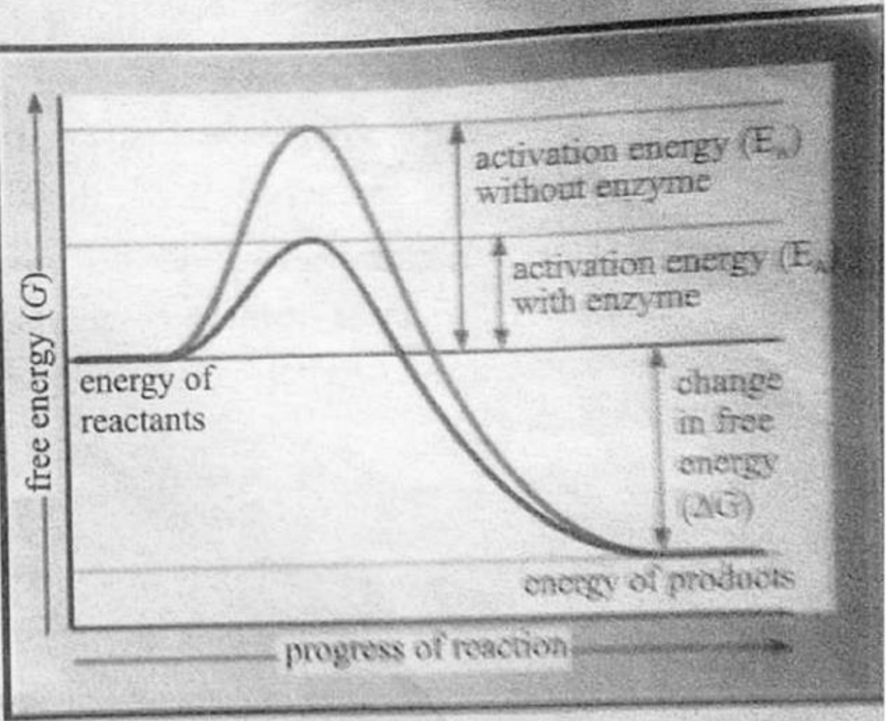


Fig: 3.3 Energy changes during chemical reaction.

$$2H_2O_2 \longrightarrow 2H_2O + O_2$$

The activation energy is 86 kJ mol^{-1} with no catalyst and just 1 kJ mol^{-1} in the presence of the enzyme catalase.

The activation energy is actually the energy required to form the transition state, so enzymes lower the activation energy by stabilising the transition state, and they do this by changing the conditions within the active site of the enzyme.

3.3 Cofactors

Cofactors - *are atoms, groups of atoms and molecules that join with enzymes altering their shape and making them functional.* One can think of these cofactors as an" *on-off" switch* for activating an enzyme. If the cofactor is a non-protein like a *metallic ion* (i.e. zinc, copper, or iron) it is referred to as a prosthetic group. Some *cofactors* are small organic molecules called coenzymes. Like enzymes they are not *permanently* altered in the reactions.

Many of these coenzymes are derived from vitamins and minerals that are essential for life. The absence of these cofactors can lead to vitamin and mineral deficiency diseases e.g lack of Vitamin B produces beriberi . Examples of coenzymes are NAD^+, FAD^+, NADP.

3.4 Enzyme nomenclature

Many enzymes but not all end in the suffix "ase". (exceptions: pepsin, trypsin). They are named for the substrate they act on or the action they perform.

The following are the six major enzyme categories.

1. **Oxidoreductases**

These enzymes catalyze various types of oxidation-reduction reactions. Subclasses of this group contain oxidases, oxygenases and peroxidases.

2. **Transferases**

These enzymes catalyze reactions that involve the transfer of groups from one molecule to another. Examples of such groups include amino, carboxyl, methyl and carbonyl. Transcarboxylases and transmethylases are examples of transferases.

3. **Hydrolases**

These enzymes catalyze the reactions in which the cleavage of bonds is accomplished by the addition of water. The hydro lases include the esterases, phosphatases and peptidases

Table 3.1 Enzyme Nomenclature by Substrate

Substrate	Enzyme
Lipid	Lipase
Urea	Urease
Maltose	. Maltase
Ribonucleic Acid (RNA)	RNAase
A TP	ATPase
Dextrose	Dextrase
Protein	Proteinase

4. Lyases

Lyases catalyze reactions in which groups (e.g. H_2O, CO_2 and NH_3) are removed to form a double bond or added to a double bond .Decarboxylases, deaminases and synthases are examples of Lyases.

5. Isomerases

This is a heterogeneous group of enzymes which catalyze several types of intermolecular rearrangements. Epimerases and mutases are the examples.

6. Ligases

Ligases catalyze bond formation between two substrate molecules. The energy for these reactions is always supplied by ATP hydrolysis.

3.5 Factors that Affect the Rate of Enzyme Reactions

Rate of enzyme reactions depend on the following factors.

A. Temperature

Enzymes works best at an optimum temperature. Enzymes present in mammals works best at about 40°C. Animals present in different environments are adopted to range of temperature. for example, enzymes of the arctic snow flea work at -10°C whereas in thermophilic bacteria enzymes work at a temperature of 90°C.Upto the optimum temperature the rate increases geometrically with temperature (i.e. it's a curve, not a straight line). The rate increases because the enzyme and substrate molecules both have more kinetic energy so collide more often and also because more molecules have sufficient energy to overcome the (greatly reduced) activation energy. The increase in rate with temperature can be quantified as a Q IO, which is the relative increase for a 10°C rise in temperature.

The rate is not zero at 0°C, so enzymes still work in the refrigerator (and food still goes off), but they work slowly. Enzymes can even work in ice, though the rate is extremely slow due to the very slow diffusion of enzyme and substrate molecules through the ice lattice.

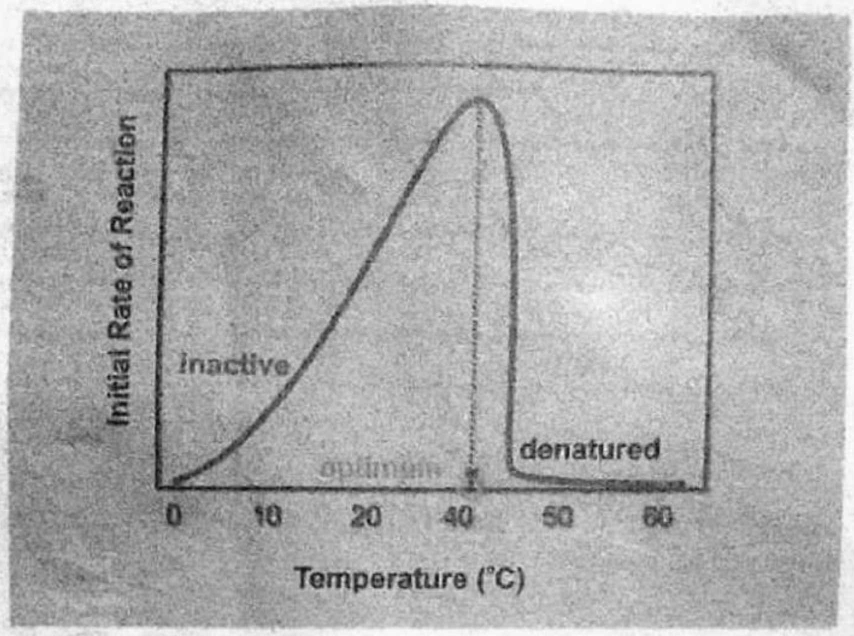


Fig: 3.4 Influence of temperature on the rate of enzyme-catalyzed reactions.

B. pH

Enzymes have an optimum pH at which they work fastest. For most enzymes this is about pH 7-8 (physiological pH of most cells), but a few enzymes can work at extreme pH, such as protease enzymes in animal stomachs, which have an optimum pH 1. The pH affects the charge of the amino acids at the active site more specifically, changes in pH ionizes amino acids forming an enzyme so the properties of the active site change and the substrate can no longer bind.

For your information

Enyzme	pH Optimum
Lipase (Pancreas)	8.0
Lipase (Stomach)	4.0-5.0
Lipase (Castor oil)	4.7
Pepsin	1.5-1.6
Trypsin	7.8-8.7
Urease	7.0
Invertase	4.5
Maltase	6.1-6.8
Amylase (Pancreas)	6.7-7.0
Amylase (malt)	4.6-5.2
Catalase	7.0

C. Enzyme concentration

As the enzyme concentration increases the rate of the reaction increases linearly, because there are more enzyme molecules available to catalyze the reaction. At very high enzyme concentration the substrate concentration may become rate-limiting, so the rate stops increasing. Normally enzymes are present in cells in rather low concentrations.

D. Substrate concentration

The rate of an enzyme-catalyzed reaction shows a curved dependence on substrate concentration. As the substrate concentration increases, the rate increases because more substrate molecules can collide with enzyme molecules, so more reactions will take place. At higher concentrations the enzyme molecules become saturated with substrate, so there are few free enzyme molecules, so adding more substrate doesn't make much difference.

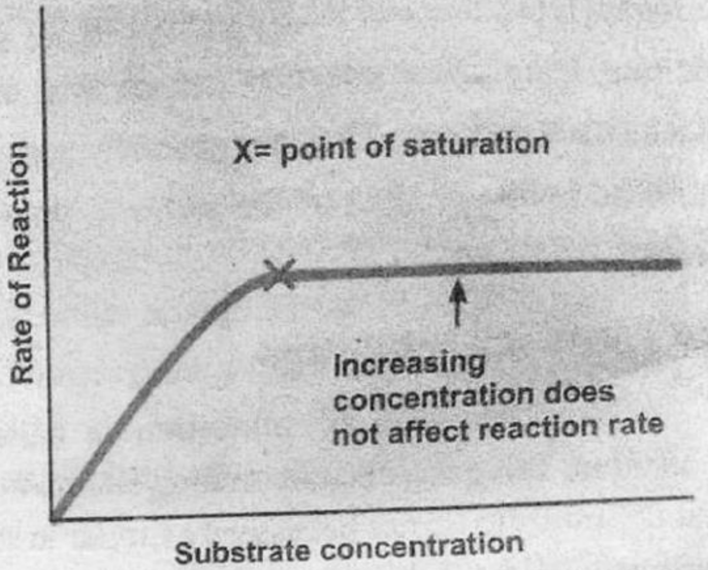


Fig: 3.5 Effect of substrate concentration on rate of reaction.

E. Inhibitors

Inhibitors inhibit the activity of enzymes, reducing the rate of their reactions. They are found naturally, but are also used artificially as drugs, pesticides and research tools. There are two kinds of inhibitors.

(a) **A competitive inhibitor molecule** has a similar structure to the normal substrate molecule, and it can fit into the active site of the enzyme. It therefore competes with the substrate for the active site, so the reaction is slower e.g the sulphonamide to an antibacterial drugs which act as competitive inhibitors.

(b) **A non-competitive inhibitor molecule** is quite different in structure from the substrate molecule and does not fit into the active site. It binds to another part of the enzyme molecule, changing the shape of the whole enzyme, including the active site, so that it can no longer bind substrate molecules. Inhibitors that bind weakly and can be removed out easily are sometimes called reversible inhibitors, while those that bind tightly and cannot be removed out are called irreversible inhibitors. Poisons like cyanide, heavy metal ions and some insecticides are all non-competitive inhibitors.

The activity of some enzymes is controlled by certain molecules binding to a specific regulatory (or allosteric) site on the enzyme, distinct from the active site. Different molecules can inhibit or activate the enzyme, allowing sophisticated control of the rate. Only a few enzymes can do this, and they are often at the start of a long biochemical pathway. They are generally activated by the substrate of the pathway and inhibited by the product of the pathway, thus only turning the pathway on when it is needed.

3.6 Feedback Inhibition

Another kind of inhibition is called feedback inhibition. In feedback inhibition, there is a second binding site on the enzyme where the inhibitor binds, so that the inhibitor is not necessarily similar in structure to the substrate. The absence or presence of the inhibitor at this second binding site activates or deactivates the enzyme, by changing the conformation of the enzyme so that the active site is made available or unavailable to the substrate. The inhibitor is usually the product of a reaction formed during the metabolic pathway.

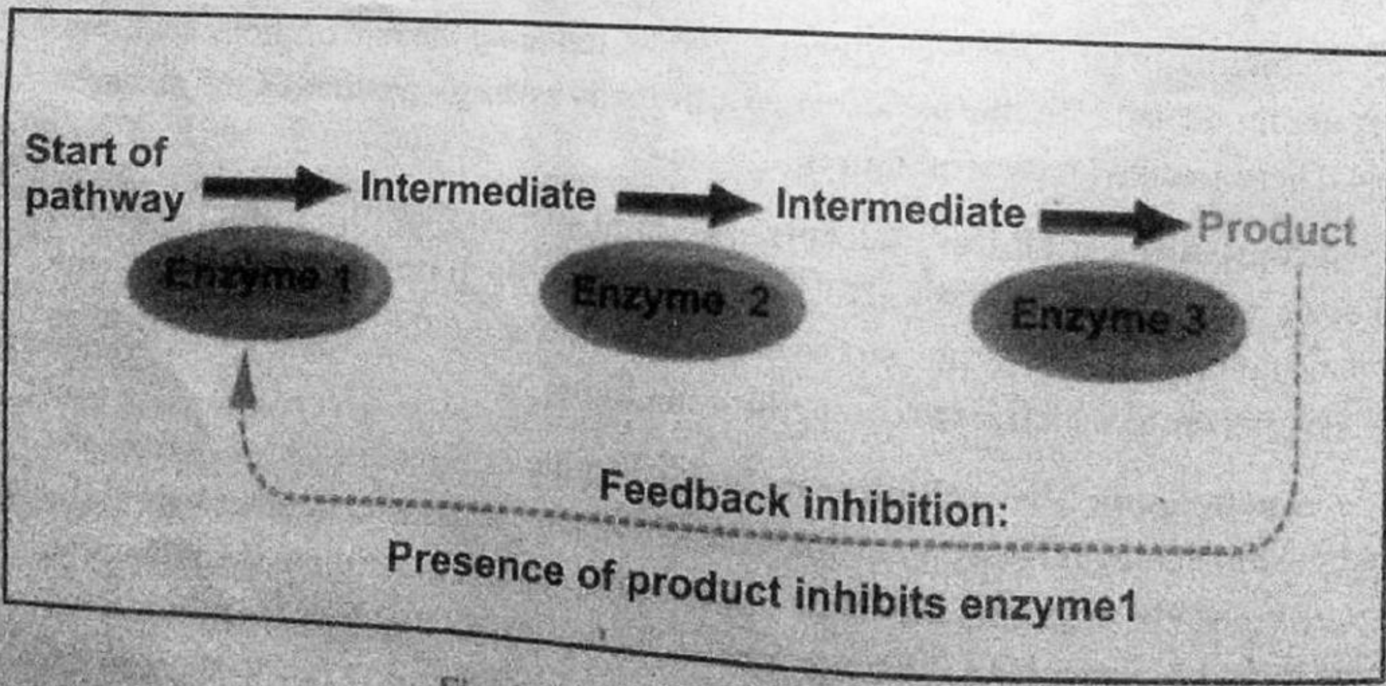


Fig: 3.6 Feedback inhibition.

KEY POINTS

Enzymes are organic chemical substances produced by the living organisms to speed up a particular reaction, but during this process these remain unchanged.

Enzymes are very specific in their action acting on a specific substrate.

When an enzymes acts on a specific substrate, enzymes substrates complex is formed.

When enzyme's shapes are disrupted it loses its characteristics biological activity.

The non protein part or prosthetic group of an enzyme is called cofactor.

According to lock and key model of enzyme the active site of an enzyme is a rigid structure.

Modification to the lock and key model suggests that since enzymes are rather flexible structures, the active site is continually reshaped by interactions with the substrate as the substrate interacts with the enzyme.

An inhibitor is a chemical substance which can block the active site of an enzyme temporarily or permanently by stopping the activity of the enzyme.

The factors that affect the rate of enzyme action are: enzymes concentration, substrate concentration, temperature, pH of the medium.

A cellular control mechanism in which an enzyme that catalyzes the production of a particular substance in the cell is inhibited when that substance has accumulated to a certain level, thereby balancing the amount provided with the amount needed.

EXERCISE ?

A. Choose the correct answers in the following questions.

1. Which one enzyme catalyzes the oxidation-reduction reaction?
   a. Oxygenases b. Transmethylases
   c. Lyases d. Peptidases
2. Enzyme catalyzing rearrangement of atomic groupings without altering molecular weight or number of atoms is:
   a. ligase b. isomerase
   c. oxidoreductase d. hydrolase
3. Enzymes are polymers of:
   a. hexose sugar b. amino acids
   c. fatty acids d. inorganic molecules
4. Which one forms the raw material for coenzymes?
   a. Vitamins b. Carbohydrates
   c. Proteins d. Metals
5. What will happen to reaction if enzyme is added?
   a. Rate of reaction decreases b. Rate of reaction increase
   c. No effect on the rate of reaction d. Reaction is reversed
6. What is induced fit hypothesis?
   a. When enzyme change shape due to absence of substrate
   b. When enzyme do not change shape due to absence of substrate
   c. When enzyme change shape due to presence of substrate
   d. When enzyme do not change shape due to presence of substrate
7. Which enzyme digest` egg albumin into peptides and amino acids best in alkaline conditions?
   a. Catalase b. Lipase
   c. Pepsin d. Trypsin
8. Sometimes enzyme and substrate are held together by the kind of bonds called:
   a. Ionic b. hydrogen
   c. hydrophobic d. covalent
9. Which one of the following refers to non competitive inhibitors:
   a. Bind to the active site.
   b. Similar to the normal substrate with which energy interact
   c. Destroy the globular conformation of enzyme
   d. Bind to the binding site other than active site

EXERCISE

10. Which one of the following factors does not affect the rate of enzyme action?
   a. Enzymes concentration
   b. Substrate concentration
   c. Water concentration
   d. Temperature

11. The optimum pH value for pepsin to work is :
   a. 6.8
   b. 4.5
   c. 5.5
   d. 1.5

B. Write short answers to the following questions.

1. What is a cofactor? Give examples.
2. What are metal activators? Give three examples.
3. Differentiate the key difference between the Lock and Key Model and Induced Fit Hypothesis/model?
4. How pH of a cell affects the enzyme activity?

C. Write detailed answers to the following questions.

1. Describe the characteristics of enzymes.
2. Explain the process of enzyme inhibition. Make a list of some common enzymes inhibitors.
3. Write briefly the mode of action of an enzyme.
4. How do the enzyme and substrate concentrations affect the rate of enzyme action?

Projects

- Search and make a list of enzymes which are used for diagnostic purposes in your local diagnostic laboratory.
- List down some common venoms which can act as enzyme inhibitors.
- Enzymes are three-dimensional, create a unique three-dimensional enzyme model using low cost no cost material. Identify your model in terms of the name of enzyme and substrate, active site, enzyme substrate complex, products.