

BIOMOLECULES

1. INTRODUCTION

Complex organic compounds which govern the common activities of the living organisms are called biomolecules. Living systems are made up of various complex biomolecules like carbohydrates, proteins, nucleic acids, lipids, etc. In addition, some simple molecules like vitamins and mineral salts also play an important role in the functions of organisms.

2. CARBOHYDRATES

Carbohydrates are primarily produced by plants and form a very large group of naturally occurring organic compounds. Some common examples are cane sugar, glucose, starch etc. Most of them have a general formula, $C_x H_{2y} O_y$ and were considered as hydrates of carbon from where the name carbohydrate was derived. For example, the molecular formula of glucose ($C_6 H_{12} O_6$) fits into this general formula, $C_6 (H_2 O)_6$. But all the compounds which fit into this formula may not be classified as carbohydrates. Rhamnose, $C_6 H_{12} O_5$ is a carbohydrate but does not fit in this definition. Chemically, the carbohydrates may be defined as optically active polyhydroxy aldehydes or ketones or the compounds which produce such units on hydrolysis. Some of the carbohydrates, which are sweet in taste, are also called sugars. The most common sugar, used in our homes is named as sucrose whereas the sugar present in milk is known as lactose.

2.1 Classification of Carbohydrates

Carbohydrates are classified on the basis of their behaviour on hydrolysis. They have been broadly divided into following three groups :

2.1.1 Monosaccharides

A carbohydrate that cannot be hydrolysed further to give simpler units of polyhydroxy aldehyde or ketone is called a **monosaccharide**. Some common examples are glucose, fructose, ribose, etc.

Monosaccharides are further classified on the basis of number of carbon atoms and the functional group present in them. If a monosaccharide contains an aldehyde group, it is known as an aldose and if it contains a keto group, it is known as a ketose. Number of carbon atoms constituting the monosaccharide is also introduced in the name as is evident from the examples given

Different types of Monosaccharides

Carbon Atoms	General Term	Aldehyde	Ketone
3	Triose	Aldotriose	Ketotriose
4	Tetrose	Aldotetrose	Ketotetrose
5	Pentose	Aldopentose	Ketopentose
6	Hexose	Aldohexose	Keto hexose
7	Heptose	Aldoheptose	Ketoheptose

2.1.2 Oligosaccharides

Carbohydrates that yield two to ten monosaccharide units, on hydrolysis, are called oligosaccharides. They are further classified as disaccharides, trisaccharides, tetrasaccharides, etc., depending upon the number of monosaccharides, they provide on hydrolysis. Amongst these the most common are disaccharides. The two monosaccharide units obtained on hydrolysis of a disaccharide may be same or different. For example, sucrose on hydrolysis gives one molecule each of glucose and fructose whereas maltose gives two molecules of glucose only.

2.1.3 Polysaccharides

Carbohydrates which yield a large number of monosaccharide units on hydrolysis are called polysaccharides. Some common examples are starch, cellulose, glycogen, gums, etc. Polysaccharides are not sweet in taste, hence they are also called non-sugars.

2.1.4 Reducing and Non-Reducing Sugars

The carbohydrates may also be classified as either reducing or non-reducing sugars. All those carbohydrates which reduce Fehling's solution and Tollen's reagent are referred to as reducing sugars. **All monosaccharides whether aldose or ketose are reducing sugars.**

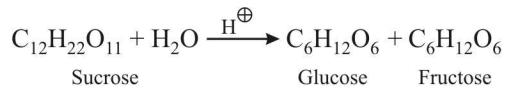
In disaccharides, if the reducing groups of monosaccharides i.e., aldehydic or ketonic groups are bonded, these are non-reducing sugars e.g. sucrose. On the other hand, sugars in which these functional groups are free, are called reducing sugars, for example, maltose and lactose.

3. GLUCOSE (ALDOHEXOSE)

3.1 Preparation of Glucose

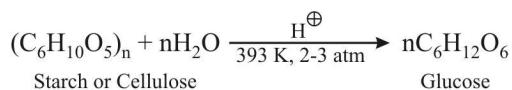
(A) From Sucrose (Cane Sugar)

If sucrose is boiled with dilute HCl or H_2SO_4 in alcoholic solution, glucose and fructose are obtained in equal amounts.



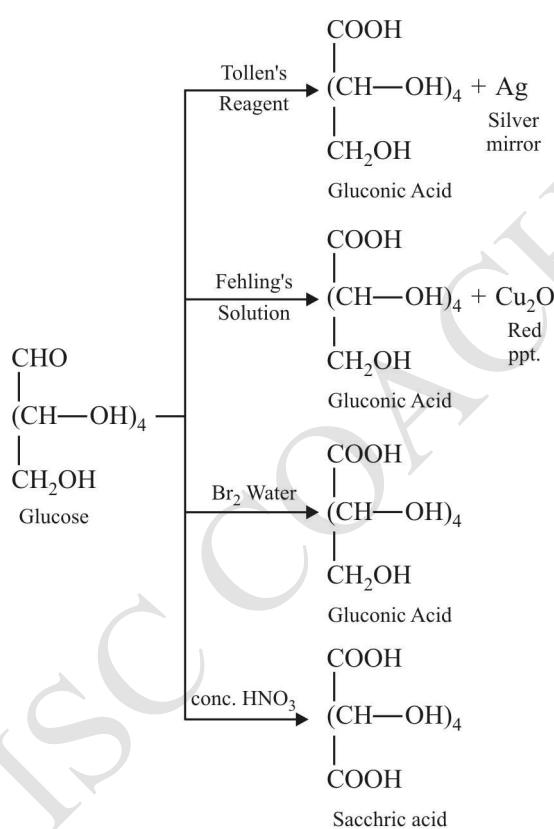
(B) From Starch

Commercially, glucose is obtained by hydrolysis of starch by boiling it with dilute H_2SO_4 at 393 K under pressure.

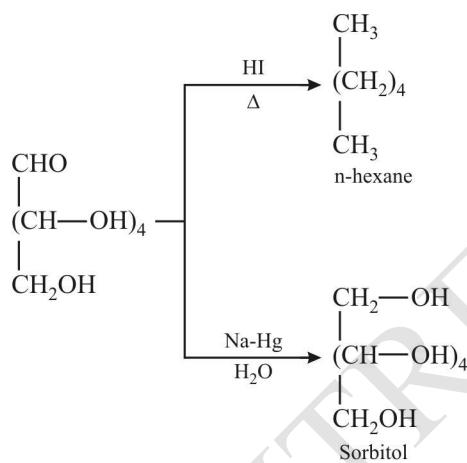


3.2 Reactions

(A) Oxidation

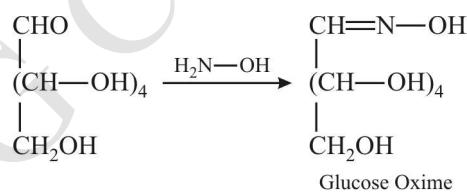


(B) Reduction

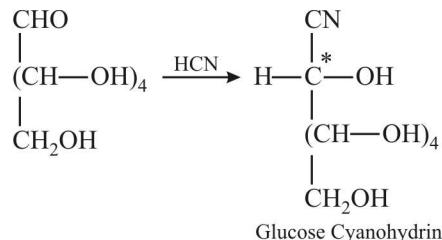


Note... Reduction with HI gives n-hexane which shows that all the 6 carbons of glucose are arranged in straight chain.

(C) Oxime Formation

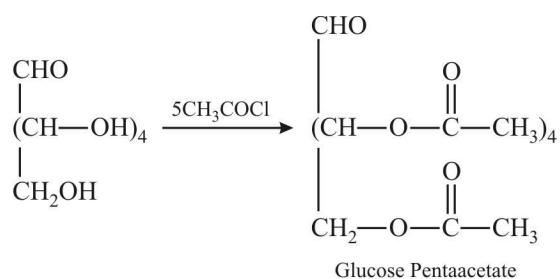


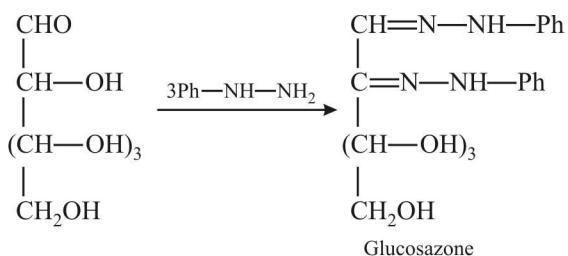
(D) Cyanohydrin Formation



Note  Carbonyl C has become chiral so 2 products are obtained which are diastereomers.

(E) Acetylation



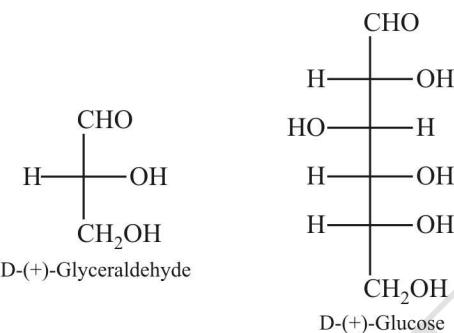
(F) Reaction with phenylhydrazine (formation of osazone)


Note...

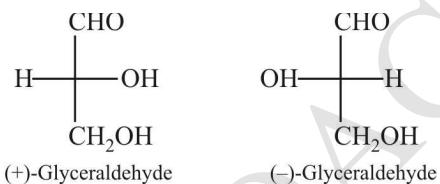


$\text{C}=\text{O}$

One mole consumes three moles of PhNHNH_2 to form osazone. 2 moles give hydrazone group and one is used to oxidise CHOH group to


3.3 Configuration in Monosaccharides

Glucose is correctly named as D $(+)$ -glucose. 'D' before the name of glucose represents the configuration whereas ' $(+)$ ' represents dextrorotatory nature of the molecule. It may be remembered that 'D' and 'L' have no relation with the optical activity of the compound. The meaning of D- and L- notations is given as follows. The letters 'D' or 'L' before the name of any compound indicate the relative configuration of a particular stereoisomer. This refers to their relation with a particular isomer of glyceraldehyde. Glyceraldehyde contains one asymmetric carbon atom and exists in two enantiomeric forms as illustrated.

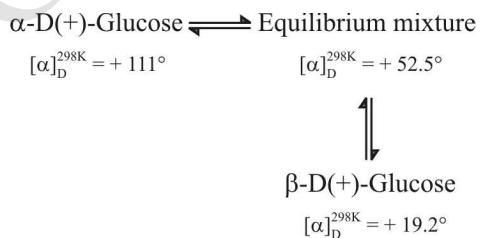


All those compounds which can be chemically correlated to (+) isomer of glyceraldehyde are said to have D-configuration whereas those which can be correlated to (-) isomer of glyceraldehyde are said to have L-configuration. For assigning the configuration of monosaccharides, it is the lowest asymmetric carbon atom (as shown below) which is compared. As in (+) glucose, -OH on the lowest asymmetric carbon is on the right side which is comparable to (+) glyceraldehyde, so it is assigned D-configuration. For this comparison, the structure is written in a way that most oxidised carbon is at the top.

3.4 Cyclic Structure of Glucose

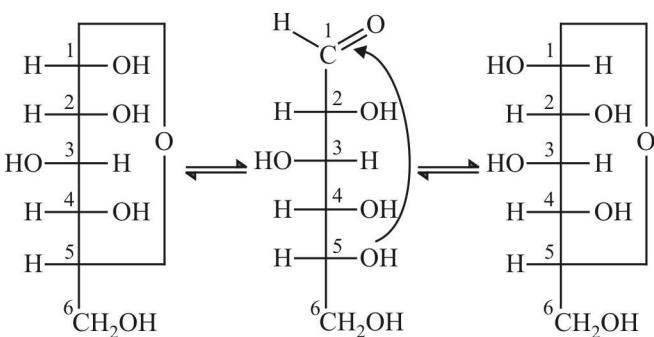
Glucose is found to exist in two different crystalline forms which are named as α and β . The α -form of glucose (m.p. 419 K) is obtained by crystallisation from concentrated solution of glucose at 303 K while the β -form (m.p. 423 K) is obtained by crystallisation from hot and saturated aqueous solution at 371 K.

Both α -D-glucose and β -D-glucose undergo mutarotation in aqueous solution. Although the crystalline forms of α - and β -D (+)-glucose are quite stable in aqueous solution but each form slowly changes into an equilibrium mixture of both. This is evident from the fact that the specific rotation of a freshly prepared aqueous solution of α -D(+)-glucose falls gradually from $+111^\circ$ to $+52.5^\circ$ with time and that of β -D(+)-glucose increases from $+19.2^\circ$ to 52.5° . Thus,

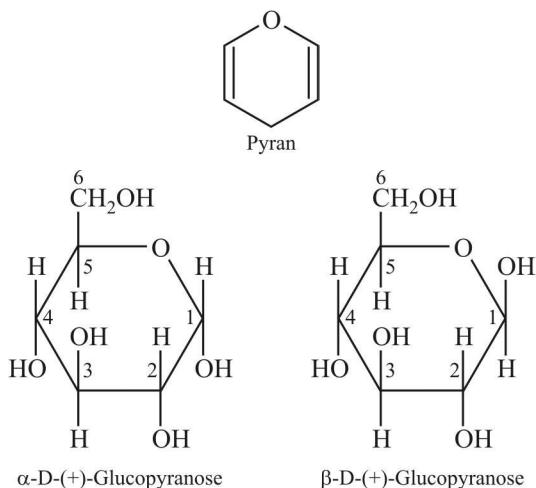


This spontaneous change in specific rotation of an optically active compound with time, to an equilibrium value, is called mutarotation.

It was found that glucose forms a six-membered ring in which -OH at C-5 is involved in ring formation. This explains the absence of -CHO group and also existence of glucose in two forms as shown below. These two cyclic forms exist in equilibrium with open chain structure.

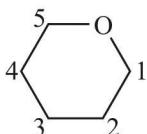


The two cyclic hemiacetal forms of glucose differ only in the configuration of the hydroxyl group at C₁, called anomeric carbon (the aldehyde carbon before cyclisation). Such isomers, i.e., α -form and β -form, are called **anomers**. The six membered cyclic structure of glucose is called **pyranose structure** (α - or β -), in analogy with pyran. Pyran is a cyclic organic compound with one oxygen atom and five carbon atoms in the ring. The cyclic structure of glucose is more correctly represented by Haworth structure.

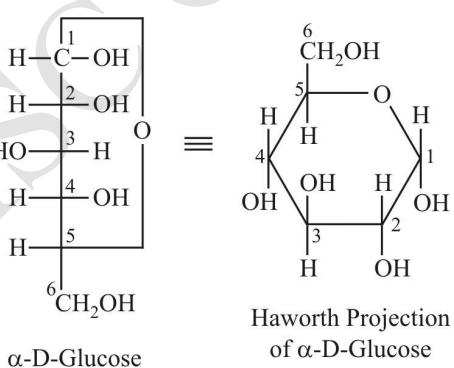


3.4.1 How to draw a Haworth Projection

A ring of 6 atoms (5 'C' and 1 'O') is drawn in which 'O' atom is placed at right hand top corner as shown below

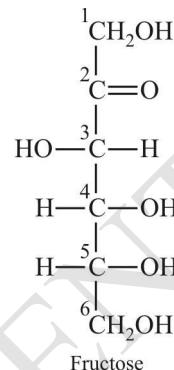


Carbon atom at the right hand side of oxygen is given number 1. Then other carbon atoms are given numbers 2, 3 in a clockwise fashion. Groups attached to a carbon in Fischer projection lying on the right hand side of that carbon are placed below the ring and on the left hand side are placed above the ring. But CH₂OH group of carbon 5 is placed above the plane of ring by convention



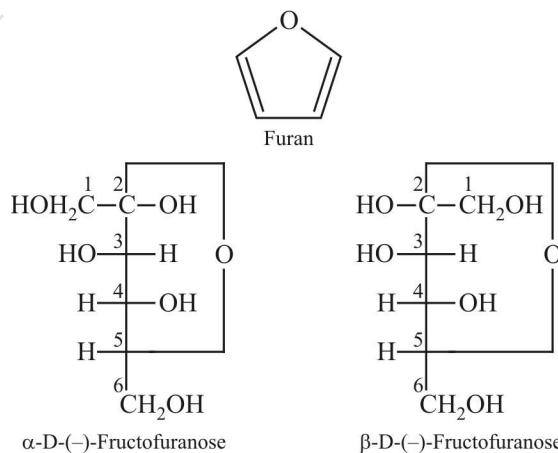
4. FRUCTOSE (KETOHEXOSE)

Fructose also has the molecular formula C₆H₁₂O₆ and on the basis of its reactions it was found to contain a ketonic functional group at carbon number 2 and six carbons in straight chain as in the case of glucose. It belongs to D-series and is a laevorotatory compound. It is appropriately written as D-($-$)-fructose. Its open chain structure is as shown

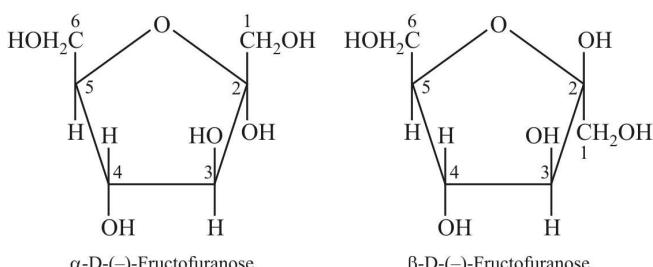


It also exists in two cyclic forms which are obtained by the addition of $-OH$ at C5 to the $(C=O)$ group. The ring,

thus formed is a five membered ring and is named as furanose with analogy to the compound furan. Furan is a five membered cyclic compound with one oxygen and four carbon atoms.



The cyclic structures of two anomers of fructose are represented by Haworth structures as given.



5. COMPARISON OF GLUCOSE AND FRUCTOSE

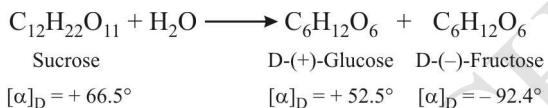
Comparison of Glucose and Fructose			
S.No.	Property	Glucose	Fructose
1.	Molecular formula	$C_6H_{12}O_6$	$C_6H_{12}O_6$
2.	Nature	Polyhydroxy aldehyde	Polyhydroxy ketone
3.	Melting point	146°C	102°C
4.	Optical nature	Dextro rotatory	Laevo rotatory
5.	Tollen's reagent	Silver mirror	Silver mirror
6.	Fehling's solution	Red ppt	Red ppt
7.	Molisch test	Violet colour	Violet colour
8.	Phenyl hydrazine	Forms osazone	Forms osazone
9.	Oxidation by conc. HNO_3	Saccharic acid	Mixture of glycolic acid, Tartaric acid and Trihydroxy Gluteric acid

6. DISACCHARIDES

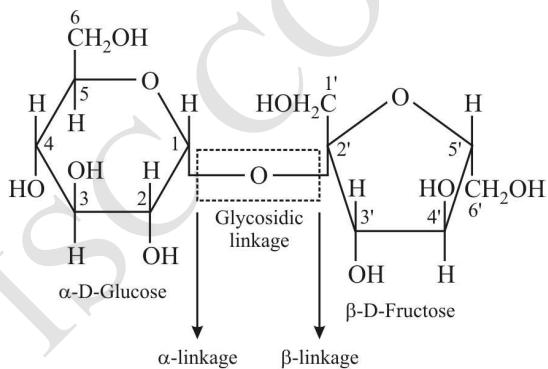
The two monosaccharides are joined together by an oxide linkage formed by the loss of a water molecule. Such a linkage between two monosaccharide units through oxygen atom is called **glycosidic linkage**.

6.1 Sucrose

One of the common disaccharides is **sucrose** which on hydrolysis gives equimolar mixture of D-(+)-glucose and D-(-)-fructose.



These two monosaccharides are held together by a glycosidic linkage between C1 of α -glucose and C2 of β -fructose. Since the reducing groups of glucose and fructose are involved in glycosidic bond formation, sucrose is a non reducing sugar.

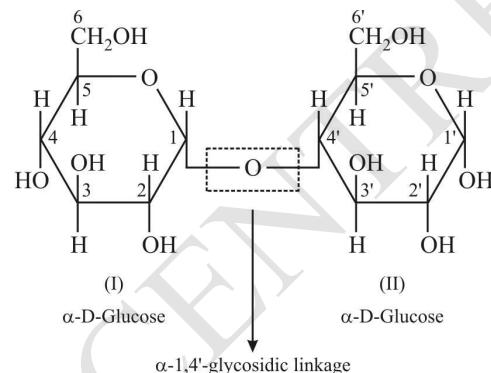


Sucrose is a dextrorotatory compound and its hydrolysis produces an equimolar solution of glucose and fructose. This solution is laevorotatory because laevo rotation of fructose is greater than dextro rotation of glucose.

Thus, hydrolysis of sucrose brings about a change in the sign of rotation, from dextro (+) to laevo (-) and the product is named as invert sugar and this phenomenon is called as inversion of sugar.

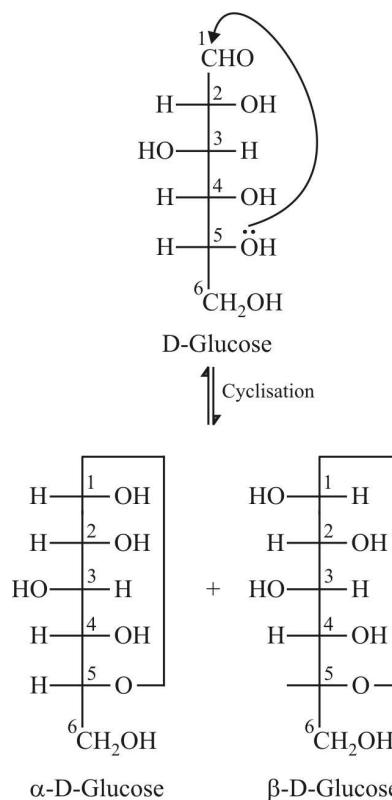
6.2 Maltose

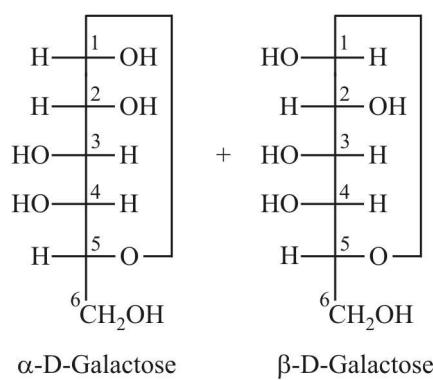
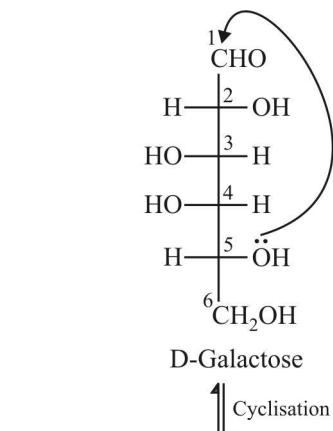
Another disaccharide, maltose is composed of two α -D-glucose units in which C1 of one glucose (I) is linked to C4 of another glucose unit (II). The free aldehyde group can be produced at C1 of second glucose in solution and it shows reducing properties so it is a reducing sugar.



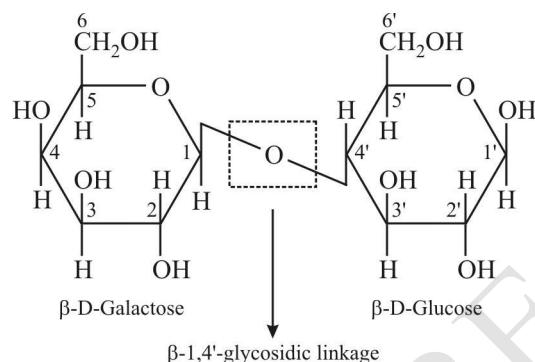
6.3 Lactose

It is more commonly known as milk sugar since this disaccharide is found in milk. It is composed of β -D-galactose and β -D-glucose. Fischer projections of β -D-Glucose and β -D-Galactose are drawn below :





We can see that the configurations of all the carbon atoms in β -D-Glucose and β -D-Galactose is same except at C-4. Such stereoisomers which differ in the configuration at only one carbon other than anomeric carbon are called as epimers and that C atom is called as epimeric carbon atom. Hence we can say that β -D-Glucose and β -D-Galactose are epimers and C-4 is epimeric carbon atom. In lactose, the linkage is between C1 of galactose and C4 of glucose. Hence it is also a reducing sugar.

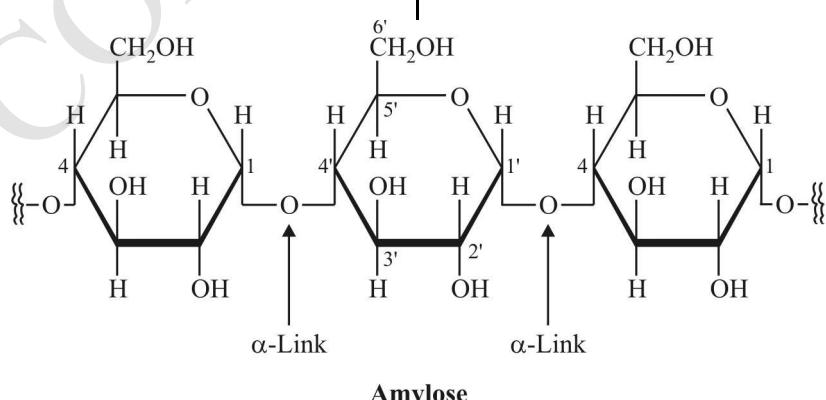


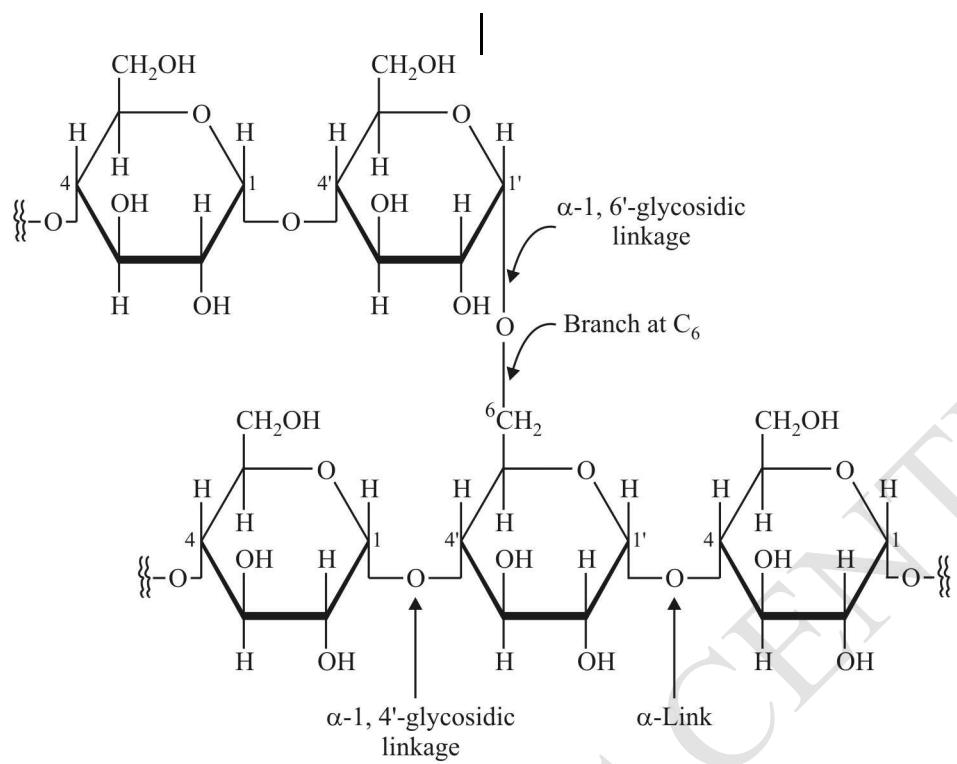
7. POLYSACCHARIDES

Polysaccharides contain a large number of monosaccharide units joined together by glycosidic linkages. They mainly act as the food storage or structural materials.

7.1 Starch

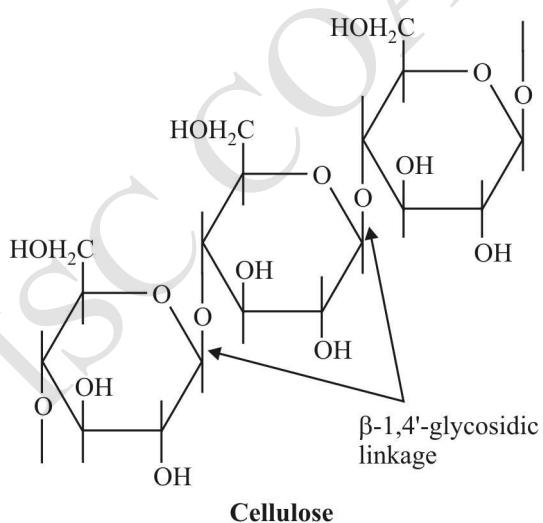
Starch is the main storage polysaccharide of plants. It is the most important dietary source for human beings. High content of starch is found in cereals, roots, tubers and some vegetables. It is a polymer of α -D-glucose and consists of two components - Amylose and Amylopectin. Amylose is water soluble component which constitutes about 15-20% of starch. Chemically amylose is a long unbranched chain with 200-1000 α -D-(+)-glucose units held by C1-C4 glycosidic linkage. Amylopectin is insoluble in water and constitutes about 80-85% of starch. It is a branched chain polymer of α -D-glucose units in which chain is formed by C1-C4 glycosidic linkage whereas branching occurs by C1-C6 glycosidic linkage.





7.2 Cellulose

Cellulose occurs exclusively in plants and it is the most abundant organic substance in plant kingdom. It is a predominant constituent of cell wall of plant cells. Cellulose is a straight chain polysaccharide composed only of β -D-glucose units which are joined by glycosidic linkage between C1 of one glucose unit and C4 of the next glucose unit.



7.3 Glycogen

The carbohydrates are stored in animal body as glycogen. It is also known as animal starch because its structure is similar to amylopectin and is rather more highly branched. It is present in liver, muscles and brain. When the body needs glucose, enzymes break the glycogen down to glucose. Glycogen is also found in yeast and fungi.

7.4 Summary

Carbohydrates	Type	Reducing/ Non Reducing	Units	Linkage
Glucose	Monosaccharide	Reducing	Glucose	—
Fructose	Monosaccharide	Reducing	Fructose	—
Sucrose	Disaccharide	Non Reducing	α -D-Glucose and β -D-Fructose	C1 of Glucose and C2 of Fructose
Lactose	Disaccharide	Reducing	β -D-Glucose and β -D-Galactose	β -1, 4' glycosidic linkage
Maltose	Disaccharide	Reducing	Both are α -D-Glucose	α -1, 4' glycosidic linkage
Starch	Polysaccharide	Non Reducing	Amylose + Amylopectin	α -1, 4' and α -1, 6' glycosidic linkages
Glycogen	Polysaccharide	Non Reducing	Amylopectin	α -1, 4' and α -1, 6' glycosidic
Cellulose	Polysaccharide	Non Reducing	β -D-Glucose	β -1, 4' glycosidic linkage

Note...

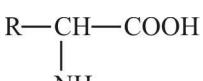
1. All the carbohydrates containing CHO group or α -Hydroxy ketonic group or hemiacetal group are reducing sugars.
2. All reducing sugars show the phenomenon of mutarotation.

8. PROTEINS

The word protein is derived from Greek word, “**proteios**” which means primary or of prime importance. All proteins are polymers of α -amino acids.

8.1 Amino Acids

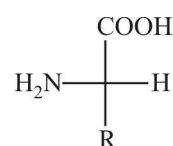
Amino acids contain amino ($-\text{NH}_2$) and carboxyl ($-\text{COOH}$) functional groups. Depending upon the relative position of amino group with respect to carboxyl group, the amino acids can be classified as α , β , γ , δ and so on. Only α -amino acids are obtained on hydrolysis of proteins. They may contain other functional groups also.

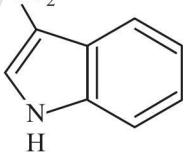
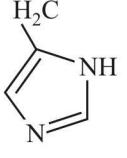
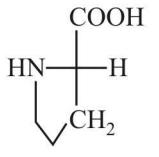


α - amino acid
(R = side chain)

All α -amino acids have trivial names, which usually reflect the property of that compound or its source. Glycine is so named since it has sweet taste (in Greek glykos means sweet) and tyrosine was first obtained from cheese (in Greek, tyros means cheese.)

8.2 Natural Amino Acids



Name of the Amino Acids	Characteristic feature of side chain. R	Three letter symbol	One letter of code
1. Glycine (N)	H	Gly	G
2. Alanine (N)	—CH ₃	Ala	A
3. Valine* (N)	(H ₃ C) ₂ CH—	Val	V
4. Leucine* (N)	(H ₃ C) ₂ CH—CH ₂ —	Leu	L
5. Isoleucine* (N)	H ₃ C—CH—CH— CH ₃	Ile	I
6. Arginine* (B)	HN=C—NH—(CH ₂) ₃ — NH ₂	Arg	R
7. Lysine* (B)	H ₂ N—(CH ₂) ₄ —	Lys	K
8. Glutamic acid (A)	HOOC—CH ₂ —CH ₂ —	Glu	E
9. Aspartic acid (A)	HOOC—CH ₂ —	Asp	D
10. Glutamine (N)	H ₂ N—C(=O)—CH ₂ —CH ₂ — O	Gln	Q
11. Asparagine (A)	H ₂ N—C(=O)—CH ₂ —	Asn	N
12. Threonine* (N)	H ₃ C—CHOH—	Thr	T
13. Serine (N)	HO—CH ₂ —	Ser	S
14. Cysteine (N)	HS—CH ₂ —	Cys	C
15. Methionine* (N)	H ₃ C—S—CH ₂ —CH ₂ —	Met	M
16. Phenylalanine* (N)	C ₆ H ₅ —CH ₂ —	Phe	F
17. Tyrosine (N)	(p)HO—C ₆ H ₄ —CH ₂ — —CH ₂	Tyr	Y
18. Tryptophan* (N)		Trp	W
19. Histidine* (B)		His	H
20. Proline (N)		Pro	P

N = Neutral

B = Basic

A = Acidic

Note...

1. *Essential amino acids.
2. Arginine has highest isoelectric point i.e. 10.8.
3. Cysteine has lowest isoelectric point i.e. 5.1.

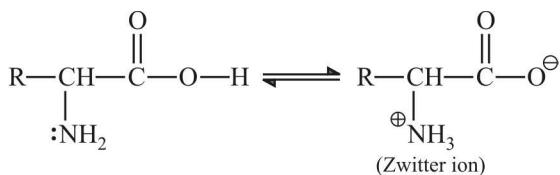
8.3 Classification of Amino Acids

Amino acids are classified as acidic, basic or neutral depending upon the relative number of amino and carboxyl groups in their molecule.

The amino acids, which can be synthesised in the body, are known as **non-essential amino acids**. On the other hand, those which cannot be synthesised in the body and must be obtained through diet, are known as **essential amino acids**.

8.4 Properties of Amino Acids

Amino acids are usually colourless, crystalline solids. These are water-soluble, high melting solids and behave like salts rather than simple amines or carboxylic acids. This behaviour is due to the presence of both acidic (carboxyl group) and basic (amino group) groups in the same molecule.



In aqueous solution, the carboxyl group can lose a proton and amino group can accept a proton, giving rise to a dipolar ion known as **zwitter ion**. This is neutral but contains both positive and negative charges. In zwitter ionic form, amino acids show amphoteric behaviour as they react both with acids and bases.

Except glycine, all other naturally occurring α -amino acids are optically active, since the α -carbon atom is asymmetric. These exist both in 'D' and 'L' forms. Most naturally occurring amino acids have L-configuration. L-Amino acids are represented by writing the $-\text{NH}_2$ group on left hand side.

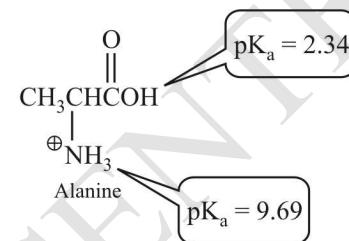
8.4.1 Isoelectric Point

The **isoelectric point** (pI) of an amino acid is the pH at which it has no net charge. In other words, it is the pH at which the amount of negative charge on an amino acid exactly balances the amount of positive charge.

pI (isoelectric point) = pH at which there is no net charge

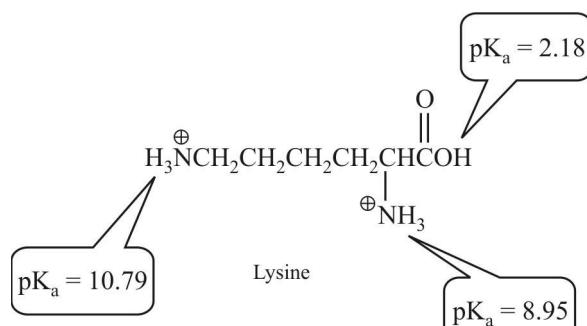
The pI of an amino acid that does not have an ionizable side chain—such as alanine—is midway between its two pK_a values. This is because at pH = 2.34, half the molecules

have a negatively charged carboxyl group and half have an uncharged carboxyl group, and at pH = 9.69, half the molecules have a positively charged amino group and half have an uncharged amino group. As the pH increases from 2.34, the carboxyl group of more molecules becomes negatively charged; as the pH decreases from 9.69, the amino group of more molecules becomes positively charged. Therefore at the average of the two pK_a values, the number of negatively charged groups equals the number of positively charged groups.

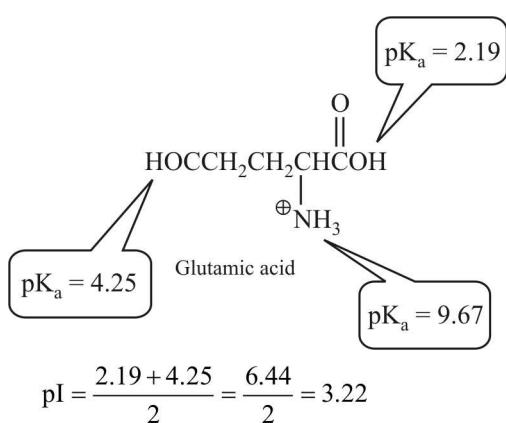


$$\text{pI} = \frac{2.34 + 9.69}{2} = \frac{12.03}{2} = 6.02$$

If an amino acid has an ionizable side chain, its pI is the average of the pK_a values of the similarly ionizing groups (positive ionizing to uncharged, or uncharged ionizing to negative). For example, the pI of lysine is the average of the pK_a values of the two groups that are positively charged in their acidic form and uncharged in their basic form. The pI of glutamate, on the other hand, is the average of the pK_a values of the two groups that are uncharged in their acidic form and negatively charged in their basic form.

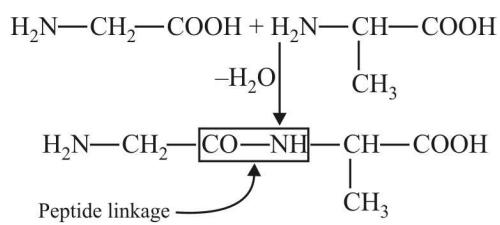


$$\text{pI} = \frac{8.95 + 10.79}{2} = \frac{19.74}{2} = 9.87$$



8.5 Structure of Proteins – Peptide Bond

Proteins are the polymers of α -amino acids and they are connected to each other by **peptide bond** or **peptide linkage**. Chemically, peptide linkage is an amide formed between –COOH group and –NH₂ group.



The reaction between two molecules of similar or different amino acids, proceeds through the combination of the amino group of one molecule with the carboxyl group of the other. This results in the elimination of a water molecule and formation of a peptide bond –CO–NH–.

8.6 Classification of Proteins

Proteins can be classified into two types on the basis of their molecular shape.

(A) Fibrous Proteins

When the polypeptide chains run parallel and are held together by hydrogen and disulphide bonds, then fibre-like structure is formed. Such proteins are generally insoluble in water.

Some common examples are **keratin** (present in hair, wool, silk) and **myosin** (present in muscles), etc.

(B) Globular Proteins

This structure results when the chains of polypeptides coil around to give a spherical shape. These are usually soluble in water. **Insulin** and **albumins** are the common examples of globular proteins. Structure and shape of proteins can be

studied at four different levels, i.e., primary, secondary, tertiary and quaternary.

(i) Primary Structure

Proteins may have one or more polypeptide chains. Each polypeptide in a protein has amino acids linked with each other in a specific sequence and it is this sequence of amino acids that is said to be the primary structure of that protein. Any change in this primary structure i.e., the sequence of amino acids creates a different protein.

(ii) Secondary Structure

The secondary structure of protein refers to the shape in which a long polypeptide chain can exist. They are found to exist in two different types of structures viz. α -helix and β -pleated sheet structure. These structures arise due to the regular folding of the backbone of the polypeptide chain due to hydrogen bonding between C = O and –NH– groups of the peptide bond.

α -Helix is one of the most common ways in which a polypeptide chain forms all possible hydrogen bonds by twisting into a right handed screw (helix) with the –NH group of each amino acid residue hydrogen bonded to the C = O of an adjacent turn of the helix.

In β -structure all peptide chains are stretched out to nearly maximum extension and then laid side by side which are held together by intermolecular hydrogen bonds.

(iii) Tertiary Structure

The tertiary structure of proteins represents overall folding of the polypeptide chains i.e., further folding of the secondary structure. It gives rise to two major molecular shapes viz. fibrous and globular. The main forces which stabilise the 2° and 3° structures of proteins are hydrogen bonds, disulphide linkages, van der Waals and electrostatic forces of attraction.

(iv) Quaternary Structure

Some of the proteins are composed of two or more polypeptide chains referred to as sub-units. Subunits with respect to each other is known as quaternary structure.

8.7 Denaturation of Proteins

Protein found in a biological system with a unique three-dimensional structure and biological activity is called a native protein. When a protein in its native form, is subjected to physical change like change in temperature or chemical change like change in pH, the hydrogen bonds are disturbed. Due to this, globules unfold and helix get uncoiled and protein loses its biological activity. This is called **denaturation** of protein. The coagulation of egg white on boiling is a common example of denaturation. Another

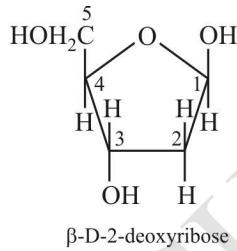
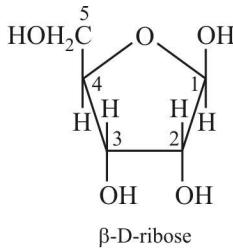
example is curdling of milk which is caused due to the formation of lactic acid by the bacteria present in milk.

9. NUCLEIC ACIDS

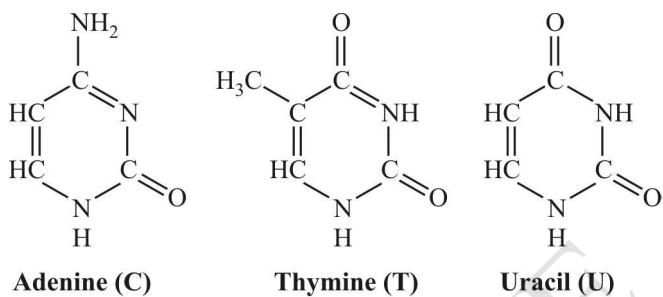
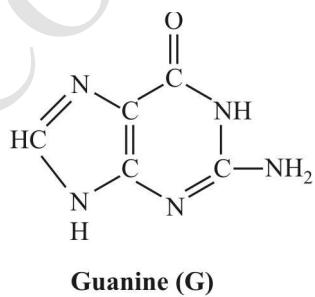
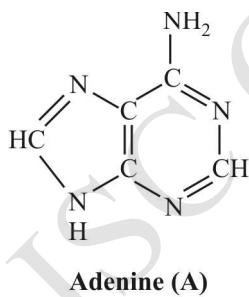
Every generation of each and every species resembles its **ancestors** in many ways. How are these characteristics transmitted from one generation to the next? It has been observed that nucleus of a living cell is responsible for this transmission of inherent characters, also called **heredity**. The particles in nucleus of the cell, responsible for heredity, are called chromosomes which are made up of proteins and another type of biomolecules called **nucleic acids**. These are mainly of two types, the **deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)**. Since nucleic acids are long chain polymers of **nucleotides**, so they are also called polynucleotides.

9.1 Chemical Composition of Nucleic Acids

Complete hydrolysis of DNA (or RNA) yields a pentose sugar, phosphoric acid and nitrogen containing heterocyclic compounds (called bases). In DNA molecules, the sugar moiety is β -D-2-deoxyribose whereas in RNA molecule, it is β -D-ribose.

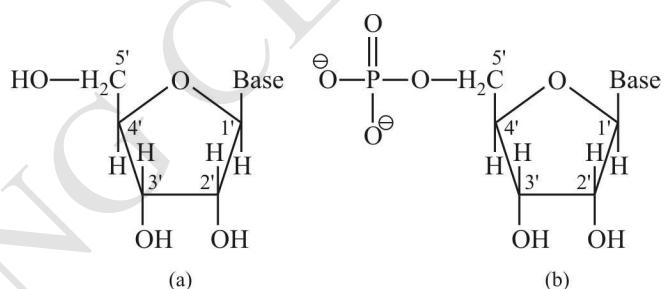


DNA contains four bases viz. **adenine** (A), **guanine** (G), **cytosine** (C) and **thymine** (T). RNA also contains four bases, the first three bases are same as in DNA but the fourth one is uracil (U).



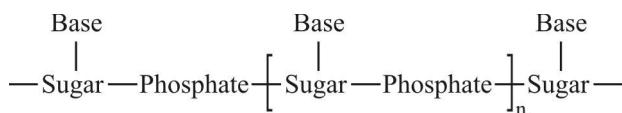
9.2 Structure of Nucleic Acids

A unit formed by the attachment of a base to 1' position of sugar is known as **nucleoside**. In nucleosides, the sugar carbons are numbered as 1', 2', 3', etc. In order to distinguish these from the bases. When nucleoside is linked to phosphoric acid at 5'-position of sugar moiety, we get a nucleotide.



Structure of (a) a nucleoside and (b) a nucleotide

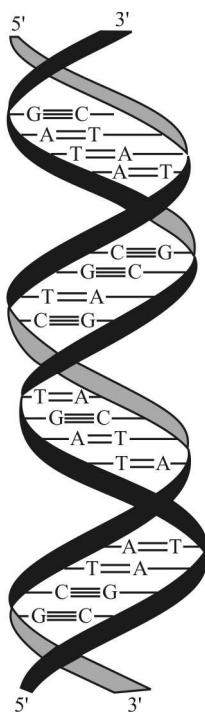
Nucleotides are joined together by phosphodiester linkage between 5' and 3' carbon atoms of the pentose sugar. A simplified version of nucleic acid chain is as shown below



Information regarding the sequence of nucleotides in the chain of a nucleic acid is called its primary structure. Nucleic acids have a secondary structure also. James Watson and Francis Crick gave a double strand helix structure for DNA. Two nucleic acid chains are wound about each other and held together by hydrogen bonds between pairs of bases. The two strands are complementary to each other because the hydrogen bonds are formed between specific pairs of bases. Adenine forms hydrogen bonds with thymine whereas cytosine forms hydrogen bonds with guanine.

In secondary structure of RNA, helices are present which are only single stranded. Sometimes they fold back on themselves to form a double helix structure. RNA molecules

are of three types and they perform different functions. They are named as **messenger RNA (m-RNA)**, **ribosomal RNA (r-RNA)** and **transfer RNA (t-RNA)**.



Double strand helix structure for DNA

9.3 DNA Vs RNA

	Deoxyribonucleic Acid (DNA)	Ribonucleic Acid (RNA)
1.	DNA occurs in the nucleus of the cell.	RNA occurs in the cytoplasm of the cell.
2.	The sugar present in DNA is D-(-)-2-deoxyribose.	The sugar present in RNA is D(-)-ribose.
3.	DNA contains cytosine and thymine as pyrimidine bases and guanine and adenine as purine bases.	RNA contains cytosine and uracil as pyrimidine bases and guanine and adenine as purine bases.
4.	DNA has double-stranded α -helix structure.	RNA has single stranded α -helix structure.
5.	DNA undergoes replication.	RNA usually does not undergo replication.
6.	DNA controls the transmission of hereditary effects.	RNA controls the synthesis of proteins.

9.4 Biological Functions of Nucleic Acids

DNA is the chemical basis of heredity and may be regarded as the reserve of genetic information. DNA is exclusively responsible for maintaining the identity of different species of organisms over millions of years. A DNA molecule is capable of self duplication during cell division and identical DNA strands are transferred to daughter cells. Another important function of nucleic acids is the protein synthesis in the cell. Actually, the proteins are synthesised by various RNA molecules in the cell but the message for the synthesis of a particular protein is present in DNA.

10. ENZYMES

Enzymes are biological catalysts. Chemically all enzymes are globular proteins. Some important enzymes and their functions are given

	Enzyme	Reaction Catalysed	
(i)	Invertase or sucrase	Sucrose	\rightarrow Glucose + Fructose
(ii)	Maltase	Maltose	\rightarrow Glucose + Glucose
(iii)	Lactase	Lactose	\rightarrow Glucose + Galactose
(iv)	α -Amylase	Starch	\rightarrow n \times Glucose
(v)	Emulsin	Cellulose	\rightarrow n \times Glucose
(vi)	Urease	NH_2CONH_2	\rightarrow $\text{CO}_2 + 2\text{NH}_3$
(vii)	Carbonic anhydrase	H_2CO_3	\rightarrow $\text{CO}_2 + \text{H}_2\text{O}$
(viii)	Pepsin	Proteins	\rightarrow α -Amino acids
(ix)	Trypsin	Proteins	\rightarrow α -Amino acids
(x)	Nucleases	DNA or RNA	\rightarrow Nucleotides
(xi)	DNA polymerase	Deoxynucleotide triphosphates	\rightarrow DNA
(xii)	RNA polymerase	Ribonucleotide triphosphates	\rightarrow RNA

11. VITAMINS

	Vitamin	Sources	Deficiency diseases
(i)	Vitamin-A (Retinol or eye vitamin)	Milk, cod liver oil, butter, carrots, green leaves, tomatoes, eggs, etc.	Night blindness, xerophthalmia (i.e. hardening of cornea of eye) and xerosis.
(ii)	Vitamin-B ₁ Thiamine or Aneurin	Pulses, nuts, green vegetables, Polished rice, yeast and egg yolk.	Beriberi (a disease of nervous system) and loss of appetite.
(iii)	Vitamin-B ₂ or Riboflavin or Lactoflavin	Milk, meat, green vegetables and yeast.	Inflammation of tongue or dark red tongue (glossitis), and cheilosis (cracking or fissuring of the lips and corners of the mouth)
(iv)	Vitamin-B ₆ or Pyridoxine or Adermine	Rice, bran, yeast, meat, fish, egg, yolk, maize, spinach and lettuce.	Specific dermatitis called acrodynia, pellagra (shriveled skin) anaemia and convulsions.
(v)	Vitamin-B ₁₂ or Cyanocobalamin	Milk, liver, kidney and eggs.	Inflammation of tongue, mouth etc. and pernicious anaemia.
(vi)	Vitamin-C or L-Ascorbic acid	Citrus fruits, amla, (oranges, lemons), sprouted pulses, germinated.	Scurvy and brittleness of bones, swelling and bleeding of gums and loosening of teeth.
(vii)	Vitamin D or Ergocalciferol (or antirachitic Vitamin of sunshine vitamin)	Fish liver oil, cod liver oil, milk and eggs.	Rickets (softening and bending of bones) in children, controls Ca and P metabolism.
(viii)	Vitamin-E or Tocopherols (α , β and γ) or Antisterility factor	Eggs, milk, fish, wheat germ, oil, cotton seed oil etc.	Sterility (loss of sexual power and reproduction)
(ix)	Vitamin-H (Biotin)	Yeast, liver, Kidney and milk.	Dermatitis, loss of hair and paralysis.
(x)	Vitamin-K or Phylloquinones or Antihaemorrhagic vitamin	Cabbage, alfalfa, spinach and carrot tops.	Haemorrhage and lengthens time of blood clotting.
(xi)	Coenzyme Q ₁₀	Chloroplasts of green plants and mitochondria of animals.	Low order of immunity of body against many diseases.

12. HORMONES

Hormones are biomolecules which are produced in the ductless (endocrine) glands and are carried to different parts of the body by the blood stream where they control various metabolic processes. These are required in minute quantities and unlike fats and carbohydrates these are not stored in the body but are continuously produced.

12.1 Steroidal Hormones

	Name	Organ of Secretion	Functions
A.	Sex hormones (a) Androgens (Testosterone)	Testes	Control the development and normal functioning of Androsterone and male sex organs.
	(b) Estrogens (Estrone, Estradiol, Estriol)	Ovary	Control the development and normal functioning of female sex organs.
	(c) Gestogens (Progesterone)	Corpus luteum	Control the development and maintenance of pregnancy.
B.	Adrenal cortex hormones or corticoids (Cortisone, Corticosterone Aldosterone etc.)	Adrenal cortex	Regulate the metabolism of fats, proteins and carbohydrates; control the balance of water and minerals in the body.

12.2 Peptide Hormones

	Name	Organ of Secretion	Functions
(i)	Oxytocin	Posterior pituitary gland	Controls the contraction of the uterus after child birth and releases milk from the mammary glands.
(ii)	Vasopressin	Posterior pituitary gland	Controls the reabsorption of water in the kidney.
(iii)	Angiotensin II	Blood Plasma of persons	Potent vasoconstrictor i.e. contracts the blood vessels with high blood pressure.
(iv)	Insulin	Pancreas	Controls the metabolism of glucose, maintains glucose level in the blood.

12.3 Amine Hormones

Name	Organ of Secretion	Functions
(i) Adrenaline or Epinephrine	Adrenal medulla	It is an amine compound and was the first hormone to be isolated. Prepares animals and humans for emergency in many ways by raising the pulse rate, blood pressure etc. stimulates the breakdown of liver glycogen into blood glucose and fats into fatty acids during emergency. These properties make adrenaline as one of the most valuable drugs used in medicine.
(ii) Thyroxine	Thyroid gland	Controls metabolism of carbohydrates, lipids and proteins.

13. TEST FOR BIOMOLECULES
13.1 Test of Carbohydrates
13.1.1 Molish Test

Molish test is used for detection of all types of carbohydrates, i.e. monosaccharides, disaccharides and polysaccharides. Molisch reagent (1% alcoholic solution of α -naphthol) is added to the aqueous solution of a carbohydrate followed by conc. H_2SO_4 along the sides of the test tube. A violet ring is formed at the junction of the two layers.

13.2 Test for Proteins
13.2.1 Biuret Test

An alkaline solution of a protein when treated with a few drops of 1% $CuSO_4$ solution, produces a violet colouration. The colour is due to the formation of a coordination complex of Cu^{+2} with $\text{C}=\text{O}$ and $-\text{NH}-$ groups of the peptide linkages.

13.2.2 Xanthoproteic Test

When a protein is treated with conc. HNO_3 a yellow colour is produced. This test is given by a protein which consists of α -amino acids containing a benzene ring such as tyrosine, phenylalanine etc. and the yellow colour is due to the

nitration of the benzene ring. An important example of this test is that when conc. HNO_3 is spilled on your hands, the skin turns yellow due to nitration of benzene ring of the amino acids of the proteins present in your skin.

13.2.3 Millon's Test

Millon's reagent is a solution of mercurous nitrate and mercuric nitrate in nitric acid containing little nitrous acid. When Millon's reagent is added to aqueous solution of protein, a white ppt. is formed. This test is given by all

proteins containing phenolic α -amino acids i.e. tyrosine. As such gelatin which does not contain phenolic α -amino acids does not give this test.

13.2.4 Ninhydrin Test

When proteins are boiled with a dilute aqueous solution of ninhydrin (2, 2-dihydroxyindane-1,3-dione), a blue-violet colour is produced. This test is actually given by all α -amino acids. Since proteins on hydrolysis give α -amino acids, therefore, proteins and peptides also give this test.