# BIOMOLECULES

- Biomolecules are complex organic molecules which forms the basis of life.
- The biomolecules associated with living systems are carbohydrates, proteins, enzymes, lipids, hormones etc.

**CARBOHYDRATES**

- Carbohydrates are a group of naturally occurring organic compounds.
- They contain carbon, hydrogen and oxygen.
- Hydrogen and oxygen are present in the ratio 2:1.
- They have the general formula $C_x(H_2O)_y$.
- They are synthesized by green plants from $CO_2$ and $H_2O$ in the presence of sunlight by a process called photosynthesis.
- Carbohydrates are optically active polyhydroxy aldehydes or ketones or large polymeric substances that can be hydrolysed to polyhydroxy aldehydes or ketones.

**CLASSIFICATION OF CARBOHYDRATES**

- Carbohydrates are classified on the basis of their behaviour on hydrolysis.

**MONOSACCHARIDES**

- These carbohydrates contain a single carbohydrate unit.
- It cannot be hydrolysed further to give asimpler unit of polyhydroxy aldehydes or ketone.
- Eg: Glucose, Fructose, Ribose etc.

**OLIGOSACCHARIDES**

- Carbohydrates which 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.
- Eg: Sucrose, Lactose etc.

**POLYSACCHARIDES**

- Carbohydrates which yield a large number of monosaccharide units on hydrolysis are called polysaccharides
- Eg: Starch, Cellulose, Glycogen etc.
- **The Carbohydrates may also be classified as either reducing or non reducing sugars.**

**REDUCING SUGARS**

- Carbohydrates which reduce Fehling's solution and Tollen's reagent are referred to as reducing sugars.
- All monosaccharides are reducing sugars.

**NON REDUCING SUGARS**

- Carbohydrates which do not have a free aldehyde or ketone are called Non-Reducing Sugars.

- In disaccharides, the reducing groups of monosaccharides i.e., aldehydic or ketonic groups are bonded.
- Hence these are non-reducing sugars.
- Eg: Sucrose.

**MONOSACCHARIDES**

- Monosaccharides, are further classified on the basis of number of carbon atoms and the functional group present in them.
- If a monosaccharide contains an aldehydic group, it is known as an aldose.
- If a monosaccharide contains a keto group, it is known as a ketose.

**GLUCOSE**

- Glucose occurs freely in nature as well as in the combined form.
- It is present in sweet fruits and honey.
- Ripe grapes also contain glucose in large amounts.

**PREPARATION**

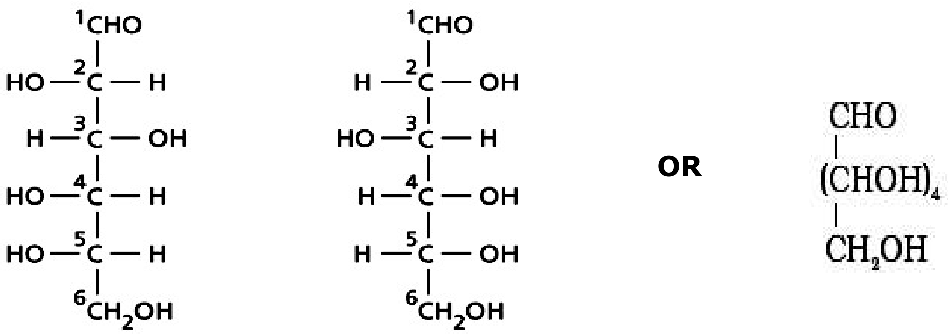
- In the laboratory, glucose is prepared by the hydrolysis of an alcoholic solution of sucrose by boiling with dilute Hydrochloric acid or dilute Sulphuric acid.

$$C_{12}H_{22}O_{11} + H_2O \xrightarrow{H^+} C_6H_{12}O_6 + C_6H_{12}O_6$$

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

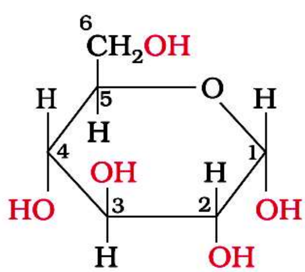
$$C_6H_{10}O_5 + nH_2O \xrightarrow[2\text{-}3\ atm]{H^+/393\ K} nC_6H_{12}O_6$$

**STRUCTURE OF GLUCOSE**

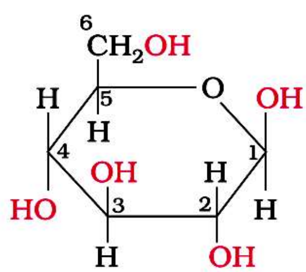



L-Glucose D-Glucose

**CYCLIC STRUCTURE OF GLUCOSE**




α-D-Glucose




β-D-Glucose

**PHYSICAL PROPERTIES**

- Glucose is a colourless crystalline solid.
- It has a sweet taste.
- It is readily soluble in water.
- It is sparingly soluble in alcohol and insoluble in ether.

**CHEMICAL PROPERTIES**

**1. Oxidation**

- Mild oxidising agents like bromine water oxidize glucose to gluconic acid.

$$CH_2OH(CHOH)_4CHO \xrightarrow[H_2O]{Br_2} CH_2OH(CHOH)_4COOH$$

- Strong oxidising agents like $HNO_3$ oxidize glucose to saccharic acid.

$$CH_2OH(CHOH)_4CHO \xrightarrow{HNO_3} HOOC(CHOH)_4COOH$$

**2. Reducing Property**

- Glucose reduces Fehling's solution to a red precipitate of cuprous oxide.

$$CH_2OH(CHOH)_4CHO + 2CuO \longrightarrow CH_2OH(CHOH)_4COOH + Cu_2O$$

- Glucose reduces Tollen's reagent to a shining mirror or black precipitate of silver.

$$CH_2OH(CHOH)_4CHO + Ag_2O \longrightarrow CH_2OH(CHOH)_4COOH + 2Ag$$

**3. Reduction**

- On reduction with Na amalgam and water, glucose gives a hexahydric alcohol called sorbitol.

$$CH_2OH(CHOH)_4CHO \xrightarrow{Na/Hg + H_2O} CH_2OH(CHOH)_4CH_2OH$$

- On reduction with conc. HI and red P, glucose gives n-hexane.

$$CH_2OH(CHOH)_4CHO \xrightarrow{HI + red P} CH_3-(CH_2)_4-CH_3$$

**4. Addition with HCN**

- Glucose reacts with HCN to form glucose cyanohydrin.

$$CH_2OH(CHOH)_4CHO + HCN \longrightarrow CH_2OH(CHOH)_4CH(OH)CN$$

**5. Condensation with Hydroxylamine**

- Glucose condenses with hydroxylamine to form glucose oxime.

$$CH_2OH(CHOH)_4CHO + NH_2OH \longrightarrow CH_2OH(CHOH)_4CH{=}NOH + H_2O$$

**6. Condensation with Phenyl hydrazine**

- Glucose condenses with one molecule of phenyl hydrazine to form glucose phenyl hydrazone.

- It reacts with excess phenyl hydrazine to from glucosazone.

**7. Acylation**

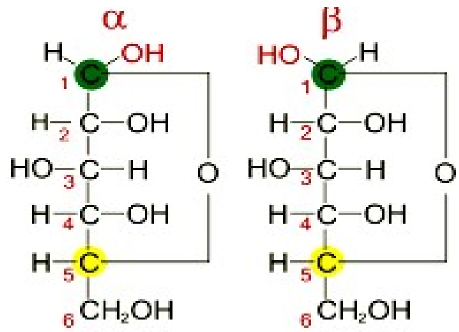
- On heating with acetyl chloride or acetic anhydride, glucose gives glucose penta acetate.

**MUTAROTATION**

- The change in specific rotation of an optically active compound in solution with time is called mutarotation.
- When α-D glucose solution having a specific rotation of +110° is allowed to stand, the specific rotation gradually falls to +52.5°.
- Similarly, when β-D glucose solution having a specific rotation of +19.2° is allowed to stand, its specific rotation gradually increases and remains constant at +52.5°.
- This change in specific rotation with time is called mutarotation.

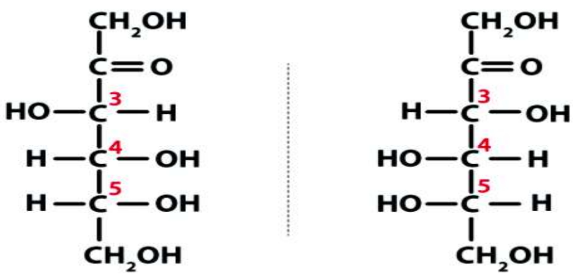
**ANOMER**

- Pair of diastereomers which differ only at carbon-1 are called anomers.
- Carbon-1 is called anomeric carbon.
- α-D glucose and β-D glucose are anomers.




**FRUCTOSE**

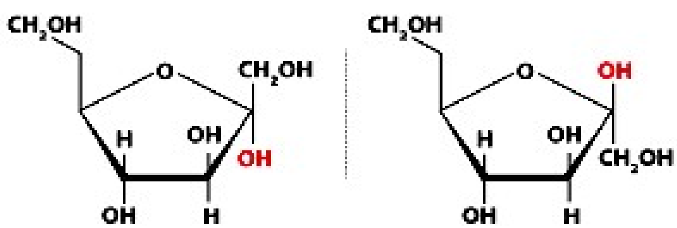
- Fructose has the molecular formula $C_6H_{12}O_6$.
- It contains a ketonic functional group at $C_2$ and six carbon atom in the straight chain as in the case of glucose.
- It belongs to D series and is a leavo rotatory compound.
- It is appropriately written as D−(−) fructose.
- Its open chain structure is as shown below.



D- Fructose

L- Fructose

**CYCLIC STRUCTURE OF FRUCTOSE**



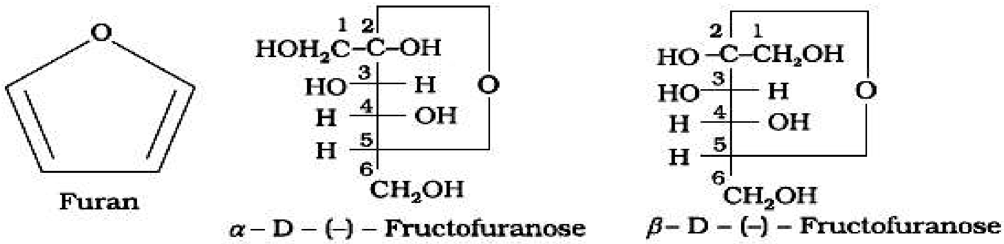
α-D- Fructose

β-D- Fructose

**FURANOSE STRUCTURE**

- Fructose exists in two cyclic forms which are obtained by the addition of −OH at $C_5$ to the (=C=O) group.

- The five membered ring obtained is known as **furanose.**
- Furan is a five membered cyclic compound with one oxygen and four carbon atoms.




**DISACCHARIDES**

- These are carbohydrates with the general formula $C_{12}H_{22}O_{11}$.
- Disaccharides give two molecules of the same or different monosaccharides on hydrolysis.
- The two monosaccharides are joined together by an oxide linkage formed by the loss of a water molecule.
- The linkage formed between two monosaccharide units through oxygen atom is called **glycosidic linkage.**

**SUCROSE**

- Sucrose occurs in sugar cane, beet root etc.
- Sucrose on hydrolysis gives equimolar mixture of D−(+) glucose and D−(−) fructose.

$$C_{12}H_{22}O_{11} + H_2O \xrightarrow{H^+} C_6H_{12}O_6 + C_6H_{12}O_6$$

- The two monosaccharides are held together by a glycosidic linkage between $C_1$ of α – glucose and $C_2$ of β-fructose.
- The reducing groups of glucose and fructose are involved in glycosidic bond formation.
- Therefore, sucrose is a **non reducing sugar.**

**INVERT SUGAR**

- Sucrose is dextrorotatory.
- After hydrolysis, it gives dextrorotatory glucose and laevorotatory fructose.
- Since the laevorotation of fructose (−92.4°) is more than the dextrorotation of glucose (+52.5°), the mixture is laevorotatory.
- Thus, hydrolysis of sucrose brings about a change in the sign of rotation, from dextro (+) to laevo (−).
- The product obtained is known as **Invert Sugar.**

**MALTOSE**

- It is obtained by the partial hydrolysis of starch by the action of the enzyme diastase present in malt extract on starch.
- Maltose is composed of two α-D glucose units in which $C_1$ of one glucose (I) is linked to $C_4$ of another glucose unit (II).
- The free aldehyde group can be produced at $C_1$ of second glucose in solution and it shows reducing properties.
- So it is a reducing sugar.

**LACTOSE**

- Lactose occurs in the milk of all animals and is also known as milk sugar.
- Cow's milk contains about 4% and human milk contains about 7% lactose.
- This sugar is not present in plants.
- It undergoes hydrolysis by the enzyme called emulsin which specially hydrolyses β-glycosidic linkages.
- Lactose is composed of β-D galactose and β-D glucose.
- The linkage is between $C_1$ of galactose and $C_4$ of glucose.
- Hence it is also a reducing sugar.

**POLYSACCHARIDES**

- Carbohydrates which give a large number of monosaccharide molecules on hydrolysis.
- They have the general formula $(C_6H_{10}O_5)_n$.
- Polysaccharides contain a large number of monosaccharide units joined together by glycosidic linkages.
- Polysaccharides mainly act as the food storage or structural materials.
- Two important polysaccharides of plant origin are starch and cellulose.

**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.
- Starch is a polymer of α-glucose and consists of two components.
- Amylose and amylopectin.

**AMYLOSE**

- Amylose is a water soluble component which consists of 15-20% of starch.
- Chemically amylase is a long unbranched chain with 200-1000 α-D+ glucose units held by $C_1-C_4$ glycosidic linkage.

**AMYLOPECTIN**

- Amylopectin is insoluble in water and constitutes about 80 - 85% starch.
- It is a branched chain polymer of α-D glucose units in which chain is formed by $C_1-C_4$ glycosidic linkage whereas branching occurs by $C_1-C_6$ glycosidic linkage.

**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.
- It is composed of only β−D−glucose units which are joined by glycosidic linkage between $C_1$ of one glucose unit and $C_4$ of the next glucose unit.

**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.

**IMPORTANCE OF CARBOHYDRATE**

- Carbohydrates are essential for life in both plants and animals.
- They work as body fuels and act as the main source of energy.
- It acts as storage of energy for the functioning of living organisms.
- Carbohydrate like cellulose form structural material for cells.
- Some carbohydrates such as sugar and starch serve as food.

## CARBOHYDRATES AT A GLANCE

| No. | SUGAR | REDUCING CHARACTER | MONO SACCHARIDES | GLYCOSIDIC LINKAGE |
|---|---|---|---|---|
| 1 | Sucrose | Non-reducing | α-D glucose + β-D-fructose | C1 of α -glucose and C2 of β-fructose (C1 – C2) |
| 2 | Maltose | Reducing | α -D glucose + α -D-glucose | C1 of one α -glucose and C4 of another α - glucose (C1 – C4) |
| 3 | Lactose | Non-reducing | β-D-glucose + β-D-galactose | C1 of galactose and C4 of glucose |
| 4 | Starch Amylose | Non-reducing | α -D-glucose | 1. **Amylose** is a linear polymer of α -D-glucose (C1-C4) |
| 5 | Starch Amylopectin | Non-reducing | α -D-glucose | 2. **Amylopectin** is a branched chain polymer of -D-glucose (C1-C4 & C1-C6) |
| 6 | Cellulose | Non-reducing | β-D-glucose | C1 of one glucose and C4 of another glucose |
| 7 | Glycogen | Non-reducing | α-D-glucose | It is a branched chain polymer of α -D-glucose (C1-C4 & C1-C6) |

**AMINO ACIDS**

- Amino acids are organic compounds containing both amino group and a carboxyl group.
- They can be represented by the general formula

$$R-\underset{\displaystyle NH_2}{\underset{|}{CH}}-COOH$$

- They are very important because they are the building blocks of proteins.

- Human body can synthesize 10 out of 20 amino acids.
- Therefore, others must be supplied through our diet.
- The amino acids which can be synthesized in the body are known as **Non-Essential Amino Acids (NEAA)**.
- The amino acids which cannot be synthesized in the body and must be obtained through diet are known as **Essential Amino Acids (EAA).**

**CLASSIFICATION OF AMINO ACIDS**

- Amino acids can be classified as α, β, γ and δ depending upon the relative position of amino group with respect to carboxyl group.
- Of these, α amino acids are important because they are building block of proteins.
- Amino acids are classified as neutral, basic and acidic depending upon the relative number of amino group and carboxyl group in their molecule.

**1. NEUTRAL AMINO ACIDS**

- Neutral Amino acids have equal number of $-NH_2$ and $-COOH$ group.
- Eg: $H_2N-CH_2-COOH$

**2. BASIC AMINO ACIDS**

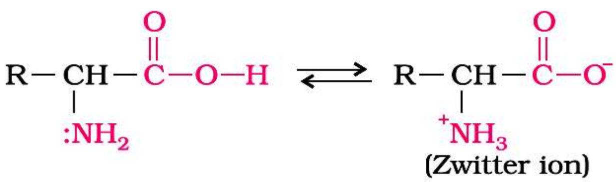
- Basic Amino Acids have more $-NH_2$ group than carboxyl group.
- Eg: Lysine

**3. ACIDIC AMINO ACIDS**

- Acidic Amino acids have more carboxyl group than amino group.
- Eg: Aspartic acid.

**ZWITTER ION**

- Amino acid does not contain free amino and free carboxyl groups.
- Since one is acidic and the other is basic, it undergoes an internal neutralization and produces an internal salt known as zwitter ion.




- In acid medium, zwitter ion is acting as a cation and it move towards the cathode during electrolysis.
- In basic medium, zwitter ion is acting as an anion and it move towards the anode during electrolysis.

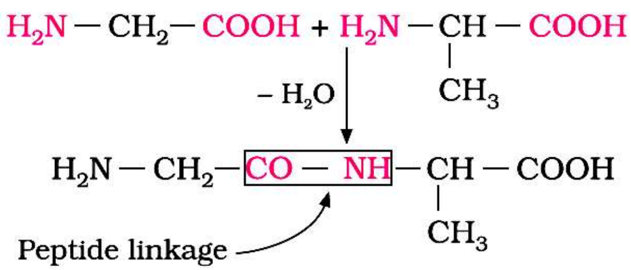
**ISOELECTRIC POINT**

- It is a particular pH where the number of cations is exactly balanced by the number of anions.
- At this pH there is no resultant migration of ions either towards the cathode or anode.
- This point is called isoelectric point.

**PEPTIDES AND POLYPEPTIDES**

- Compounds formed by the condensation of two or more same or different α-amino acids.

- The condensation occurs between amino acids with the elimination of water.
- Here condensation takes place between carboxyl group of one amino acid and amino group of another amino acid with the elimination of a water molecule. The resulting −CO−NH− linkage is called a peptide linkage.




- Depending upon the number of amino acid residues per molecule, the peptides are classified into dipeptide, tripeptide, polypeptide etc.
- A peptide having molecular mass up to 10,000 u is called a poly peptide.

**PROTEINS**

- Proteins are highly complex nitrogenous molecules which are essential for the growth and maintenance of life.
- They are composed of a large number of different amino acids and are having a molecular mass above 10,000 u.
- Proteins are the chief constituent of protoplasm in all living cells.

**CLASSIFICATION OF PROTEINS**

- Based on the molecular structure proteins can be classified into two types. They are:

**1. Fibrous Proteins**

- It consists of linear molecules which are placed side by side to form fibres.
- The molecules are held together by hydrogen bonds.
- These are usually insoluble in water.
- Eg: Keratin, Myosin, Collagen, Fibroin etc.

**2. Globular Proteins**

- In this, the molecules are folded together to form a spherical shape.
- The peptide chains in globular proteins are held together by hydrogen bonds.
- These are soluble in water, acids, bases and salts.
- Eg: Insulin, Albumins, Enzymes, Hormones etc.

**STRUCTURE OF PROTEINS**

- The structure is divided into 1°, 2°, 3° and Quaternary structure.

**PRIMARY STRUCTURE (1°)**

- **1° structure** shows how the atoms of protein molecules are joined to one another by covalent bonds.
- Proteins are made up of peptide chains i.e., amino acid residues are joined by amide linkages.

- Primary structure of proteins gives the number, nature and sequence of amino acid residues along the peptide chains.

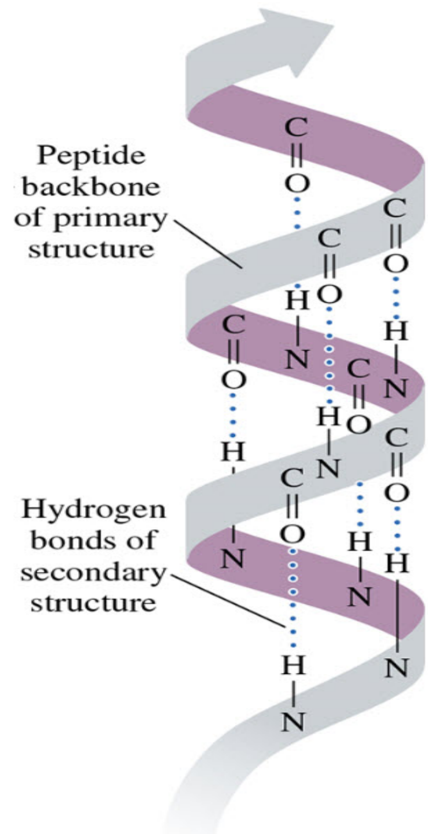
**SECONDARY STRUCTURE (2°)**

- **2° structure** shows the way in which the polypeptide chains are coiled to give a helical structure.
- The secondary structure deals with the conformation of the peptide chain present in the protein molecule.
- In order to explain the secondary structure two models were proposed by Pauling and Corey.
- They are: 1. α-helix

  2. β-Pleated structure.

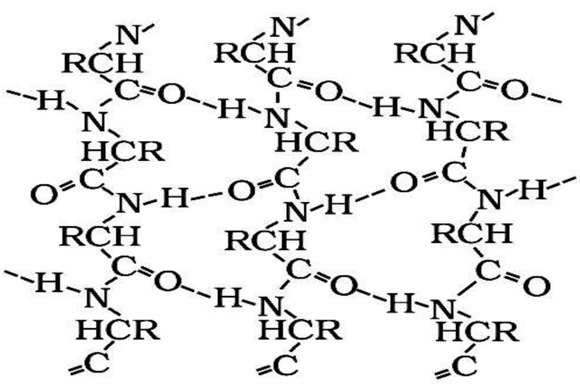
**α-Helix**

- It is a spiral arrangement of poly peptide chain, winding around a central axis in a spiral manner.
- There are 3.7 amino acid residues in one complete turn of the helix.
- The minimum distance between the two successive turns is 5.4Å.
- The diameter of the helix is 10Å.
- Intramolecular hydrogen bonds are formed between the C=O of one amino acid residue and the N−H of the fourth amino acid residue in the chain.
- The hydrogen bonding prevents the free rotation and so the helix is rigid.
- The α-helix may be either left or right handed.
- The right handed helix is more stable.
- Eg:- Hair, horn, nail, wool etc.




**β-PLEATED STRUCTURE**

- In this, the long peptide chains lie side by side to form a flat sheet.
- Each chain is held to the neighbouring chains by hydrogen bond.
- These sheets are then stacked one above the other to form a 3 dimensional structure called the β-Pleated structure.



**TERTIARY STRUCTURE (3°)**

- **3° structure** refers to the three dimensional structure.
- This arises due to folding, coiling and bending of polypeptide chain producing three dimensional structures.

- This structure describes the overall spatial arrangements of the polypeptide chain and gives exact molecular shape.
- Eg: Globular Protein

**QUATERNARY STRUCTURE**

- Some of the proteins are composed of two or more polypeptide chains known as sub units.
- These sub units are held together by non-covalent interactions like hydrogen bonding or Vander Waals forces.
- The spatial arrangement of the poly peptide sub units with respect to each other is known as quaternary structure.

**DENATURATION OF PROTEINS**

- The disruption of 3 dimensional structure of proteins by changes in pH, temperature and presence of chemical agents is called denaturation.
- As a result, globules unfold and helix gets uncoiled and protein loses its biological activity.
- During denaturation 2° and 3° structures are destroyed but 1° structure remains intact.

**ENZYMES**

- Enzymes are biological catalysts produced by living cells which catalyse the biochemical reactions in living organisms.
- Almost all the enzymes are globular proteins.
- Enzymes are highly specific in nature.
- Eg:- The enzyme that catalyses hydrolysis of maltose into glucose is named as maltase.

$$C_{12}H_{22}O_{11} \xrightarrow{\text{Maltase}} 2C_6H_{12}O_6$$

**NUCLEIC ACIDS**

- Nucleic acids are biologically important polymers which are present in the nuclei of all living cells.
- It plays an important role in the growth and development of all forms of life.
- Nucleic acids are polymers of certain monomeric units called nucleotides.
- They are polynucleotides.

**CHEMICAL COMPOSITION OF NUCLEIC ACIDS**

**NUCLEOTIDE**

- A nucleotide is a complex molecule made up of one unit of phosphate, a pentose sugar and nitrogen containing heterocyclic base.
- Each nucleotide has three components-a nitrogen containing heterocyclic base, a pentose sugar and a phosphate group.
- The heterocyclic nitrogenous base may be purines (adenine and guanine) of pyramidines (thymine, cytosine and uracil).
- The sugar unit present in nucleotides is either ribose or deoxyribose.

Nucleoside + Phosphoric Acid ⟶ Nucleotide

**NUCLEOSIDE**

- Nucleosides are the fundamental units in nucleic acids in which the heterocyclic nitrogenous base is joined to a sugar unit.

Pentose sugar + Heterocyclic nitrogenous base ⟶ Nucleoside

**CLASSIFICATION OF NUCLEIC ACIDS**

- Nucleic acids are of two types:

**DEOXYRIBO NUCLEIC ACID (DNA)**

- This nucleic acid contains 2-deoxyribose.
- The heterocyclic nitrogenous bases present are the purines-adenine and guanine, pyramidines-thymine and cytosine.

**RIBONUCLEIC ACID (RNA)**

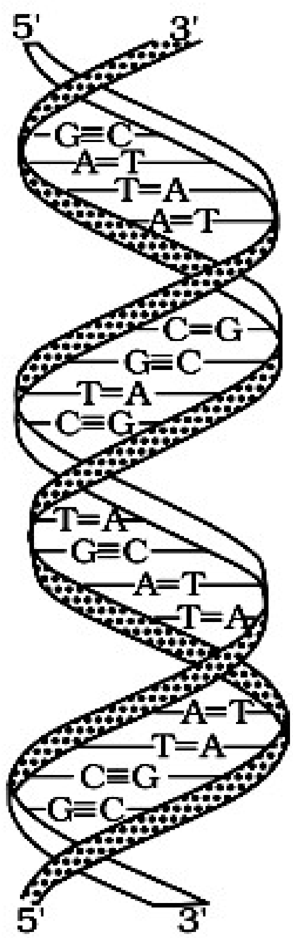
- This nucleic acid contains ribose.
- The bases present in RNA are the purines-adenine and guanine and the pyramidines-cytosine and uracil.

**TYPES OF RNA**

- **Messenger RNA (m-RNA)**
- It carries the message of DNA for specific protein synthesis.
- **Ribosomal RNA (R-RNA)**
- It provides the site for protein synthesis in the cytoplasm.
- **Transfer RNA (t-RNA):**
- It transfers amino acids to the site of protein synthesis.

**STRUCTURE OF NUCLEIC ACIDS**

- Watson and Crick in 1953 proposed a structural model of DNA.
- A DNA molecule consists of two strands twisted in the form of a double helix.
- The DNA molecule looks like a spiral stair case.
- The two strands of the polynucleotide chains coiled around each other in the form of a double helix.
- The strands are made up of nitrogenous base pairs connected by hydrogen bonds.
- The long strands are made up of pentose sugar and phosphate alternating with each other.
- The base pairs have one nitrogenous base from the purine and another from the pyramidine group.
- The pairing between nitrogenous bases is always Adenine-Thymine and Guanine-Cytosine.



- The nitrogenous bases are complementary to each other.
- The nucleotides making up each strand of DNA are connected by phosphodiester bonds.
- This forms the back bone of each DNA strand.
- Adenine pairs with thymine by two hydrogen bonds (A=T) and guanine pairs with cytosine by three hydrogen bonds (G ≡ C).

**STRUCTURAL DIFFERENCE BETWEEN DNA AND RNA**

| DNA | RNA |
|---|---|
| It is double stranded | It is single stranded |
| 2-Deoxyribose sugar is present | Ribose sugar is present |
| Bases present are adenine, guanine, cytosine and thymine. | Bases present are adenine, guanine, cytosine and uracil |
| Present mainly in the nuclei of the cell | Present throughout the cell |

**BIOLOGICAL FUNCTIONS OF NUCLEIC ACIDS**

- DNA is responsible for maintaining the identity of different species of organisms.
- A DNA molecule is capable of self duplication during cell division.
- Protein Synthesis by RNA molecules.
- Message for protein synthesis of a particular protein is present in DNA.

**VITAMINS**

- Vitamins are complex organic compounds which are required for the normal health, growth and maintenance of the body.
- These substances are vital for the body.
- Vitamins cannot be produced by the body.
- Vitamins are provided through diet.

**CLASSIFICATION OF VITAMINS**

**Fat Soluble Vitamins**

- Vitamins which are soluble in fat and oils but insoluble in water are called fat soluble vitamins.
- These include vitamin A, D, E and K.
- They are stored in liver and adipose (fat storing) tissues.

**Water Soluble Vitamins**

- Vitamins which are soluble in water are called water soluble vitamins.
- These include vitamin B and C.
- Water soluble vitamins must be supplied regularly in the diet.
- Because they are readily excreted in urine and cannot be stored in our body.

## VITAMINS AND DEFICIENCY DISEASES

| No. | NAME OF VITAMIN | SOURCES | DEFICIENCY DISEASES |
|---|---|---|---|
| 1 | Vitamin A (Retinol) | Fish liver oil, carrots, butter and milk | Xerophthalmia, Night blindness |
| 2 | Vitamin B1 (Thiamine) | Yeast, milk, green vegetables and cereals. | Beri beri |
| 3 | Vitamin B2 (Riboflavin) | Milk, egg white, liver, kidney | Cheilosis, digestive disorders and burning sensation of the skin. |
| 4 | Vitamin B6 (Pyridoxine) | Yeast, milk, egg yolk, cereals and grams. | Convulsions |
| 5 | Vitamin B12 (Cyanocobalamine) | Meat, fish, egg and curd | Pernicious anaemia |
| 6 | Vitamin C (Ascorbic Acid) | Citrus fruits, amla and green leafy vegetables. | Scurvy |
| 7 | Vitamin D (Ergocalciferol) | Exposure to sunlight, fish and egg yolk. | Rickets, and osteomalacia |
| 8 | Vitamin E (Tocopherol) | Vegetable oils like wheat germ oil, sunflower oil. | Increased fragility of RBCs and muscular weakness |
| 9 | Vitamin K (Phylloquinone) | Green leafy vegetables | Increased blood clotting time |

**NOTE**

**XEROPHTHALMIA:** Hardening of cornea of eye due to the deficiency of vitamin A.

**BERI BERI:** Inflammation of the nerves and heart failure, ascribed to a deficiency of vitamin $B_1$.

**CHIELOSIS**: Fissuring at corners of mouth and lips due to the deficiency of vitamin B2.

**PERNICIOUS ANEMIA**: Deficiency of RBC in haemoglobin due to the deficiency of vitamin B12.

**SCURVY**: Bleeding of gums due to the deficiency of vitamin C.

**RICKETS**: Imperfect calcification, softening, and distortion of the bones typically resulting in bow legs in children due to the deficiency of vitamin D.

**OSTEOMALACIA**: Joint Pains and softening of the bones caused by impaired bone metabolism due to the deficiency of Vitamin D.