BIOCHEMISTRY

Volume - I

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PREFACE

We are happy to publish “Biochemistry’’ Volume -I to the Undergraduate and Postgraduate students of Science. This book covers basic concepts and theory of biochemistry. The basic concepts in life processes can be understand with the knowledge of biochemistry. Glossary and index is given at the end of the book.

Comments and suggestions for this book from faculty and students for the improvement of this book are always welcome. We request the readers to send your valuable suggestions and comments for the upcoming editions to smcjasbooks@gmail.com

Features of our Publications

- Standard definitions.
- Explanations from references.
- Fulfill the needs of all students.

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Dr. G. Amala Jothi Grace
Dr. P. Subavathy

CONTENTS

1. BASICS OF BIOCHEMISTRY

2. CARBOHYDRATES

3. AMINO ACIDS AND PROTEINS

4. LIPIDS AND FATTY ACIDS

5. ENZYMES

6. NUCLEIC ACIDS

7. VITAMINS

8. NUTRITIONAL BIOCHEMISTRY

9. ANTIBIOTICS

UNIT I

BASICS OF BIOCHEMISTRY

Biochemistry: Introduction, Applications.

Biomolecules: Elements of Life, Atoms, Molecules.

Bonds: Definition, Types - Primary Bonds (Ionic Bond, Covalent Bond), Secondary Bonds (Hydrogen Bond, Van der Waals Bond).

pH: Definition, Measurement - Values of pH and regulation, Henderson and Hasselbalch's equation.

Buffer: Definition, Buffer action, Importance of Buffers, Biological buffer system

Water: Different forms of water, Sources, Water content of organisms, Structure and Properties of water

1

BASICS OF BIOCHEMISTRY

1.1 BIOCHEMISTRY

Biochemistry usually involve the nature of the chemical constituents of living matter, their transformation from one form to another form in the living systems and the energy changes associated with these transformations. Such studies have been conducted both in plant and animal tissues and also in microorganisms like bacteria and viruses.

In earlier, Biochemistry was called as Chemical Physiology since it was originated as an offshoot from human physiology. But, physiology deals with the study of normal functional phenomena of living beings, while biochemistry is concerned with the chemical aspects of those functional phenomena. Under the topic of biochemistry all the biological phenomena are analyzed in terms of chemistry. For this reason, this field is variously named as Biological Chemistry or Chemical Biology. In short, biochemistry is defined as the "Chemistry of living things".

As the knowledge of biochemistry increasing day-by-day, newer disciplines such as Enzymology (study of enzymes), Endocrinology (study of endocrine secretions or hormones), Clinical biochemistry (study of clinical diagnosis of various diseases), Molecular biochemistry (study of genetic materials), Agricultural biochemistry, Drug biochemistry etc., are emerging from the parent biochemistry.

Biochemistry deals with the chemical aspects of the plants and animals and their functions. Biochemistry has two branches

1. **Descriptive biochemistry**: Qualitative and quantitative characterization of various cell compounds.
2. **Dynamic biochemistry**: Elucidation of the nature and mechanism of the reactions involving the cell components.

The term biochemistry was coined by Carl Neuberg in 1903. He was the father of biochemistry. He developed the concept of oxidation and also animal respiration. He equated respiration with combustion.

The characteristic feature of the living organisms are mainly due to the presence of certain organic molecules. Since these organic molecules are present in the living system, they are usually called as **Biomolecules**. These biomolecules generally contain carbon, hydrogen, oxygen etc. Biomolecules are of two types: macro molecules and micro molecules.

Macromolecules are very large, complex, organic molecules with high molecular weights. Examples are carbohydrates, lipids, nucleic acids, proteins etc. All these macromolecules are made up of many simple, smaller building block molecules which are usually called as monomers. Since the macromolecules are formed by the repeating units of monomers they are also named as **Biopolymers**.

Micromolecules are simpler and smaller organic molecules with low molecular weights. They are generally acting as building blocks of macromolecules and are called as monomers or subunits. They can show their activities either individually or in the form of macromolecules by joining together themselves by characteristic linkages.

Examples are

1. Simple sugars which are acting as submits of higher carbohydrates like disaccharides, oligosaccharides and polysaccharides.
2. Amino acids are acting as monomeric units of proteins.
3. Fats are nothing but the esters of fatty acid.
4. Nucleotides are the subunits of the macromolecules – DNA and RNA.

1.2 APPLICATIONS OF BIOCHEMISTRY

Biochemistry is found to have large-scale applications in various areas of industry, agriculture, medicine and pharmacy.

Physiology

Biochemistry helps us to identify the physiological alteration in the body. Any disease can be known by understanding the biochemical changes.

Nutrition Deficiency

In today's scenario, maintaining nutrition in our body is essential. The biochemical changes identified in our body, helps to maintain the essential vitamins and minerals in our body.

Genetic Engineering

By applying biochemical techniques, improved domestic animals and cultivated plants are produced through genetic engineering

Hormonal Deficiency

Hormonal balance is very essential for our body. Deficiency of hormones leads to several major problems.

Agriculture

Biochemistry helps us to enhance the growth of plants. It also helps to get the increased yield. To protect cultivated plants from pests, biological preparations of superior quality that are not harmful to human or animals are currently being manufactured.

Industry

Biological methods are available for the disposal of industrial and domestic wastes. Biochemical processes are widely used in the food industry (in the preparation of bread, cheese, wine etc) and in the leather industry.

Medicine

Biochemical estimations are very essential. Various test such as kidney function test, blood test, liver function test, serum cholesterol test helps to maintain the body requirements. Drug composition, its metabolism, drug transferring reactions in our body can be understood only with the knowledge of biochemistry.

1.3 BIOMOLECULES

Biomolecule refers to a molecule produced by living organisms such as plants and animals. The four major classes of biomolecules are carbohydrates, proteins, lipids and nucleic acids. The chemicals are combined in a particular ratio to form life.

Chemicals present in the environment are nitrogen, hydrogen, carbon and oxygen in the form of gases. They combined together to form ammonia, methane and water.

$N_2 + 3H_2 \longrightarrow 2NH_3$ Ammonia

$C + 2H_2 \longrightarrow CH_4$ Methane

$\frac{1}{2} O_2 + H_2 \longrightarrow H_2O$ Water

Micro molecules like amino acids, fatty acids, monosaccharides, purines, pyrimidines etc are formed from these essential elements. The micro molecules combined together to form macro molecules such as proteins, polysaccharides, lipids, nucleic acids, nucleoprotein etc.

The plants and animals are made up of cells which is composed full of chemicals. The chemicals present in our body constitute inorganic substances like water, minerals, salts, gases etc and organic substances like carbohydrates, proteins, fats, nucleic acids, nucleoproteins etc.

1.4 CHEMICAL COMPOSITION OF LIFE

Cell is the fundamental unit of life. It is the store house of biomolecules which are responsible for various bioactions. The various macro molecules associate together in different proportions to form organelles such as ribosomes, golgi bodies, mitochondria, nucleus etc.

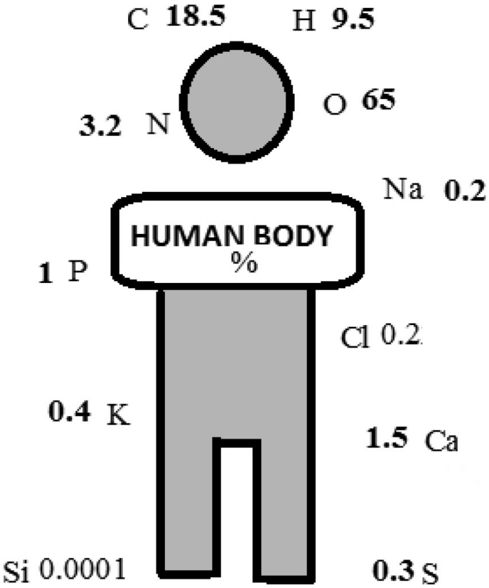


Fig 1.1 Elemental composition of human body

The chemicals making a cell are inorganic compounds and organic compounds. The inorganic substances do not contain C-H groups and they comprise 81% of a cell. The organic compounds constitute 19% of a cell and they contain C-H groups.

Table 1.1 Chemical composition of a cell

Compounds	Percentage
Inorganic Compounds	81.0%
Water	80.0%
Inorganic Salts	1.0%
Organic Compounds	19.0%
Carbohydrates	1.0%
Lipids	3.5%
Proteins	12.0%
Nucleotides	2.0%
Other Compounds	0.5%

Macro biogenic elements are the major elements which make up the living organisms. They constitute 1%. These include 6 elements namely oxygen, carbon, nitrogen, hydrogen, calcium and phosphorous.

Chemical Composition of Earth's Crust and Living Organisms

Table 1.2 Relative contents in % of certain chemical elements on earth's crust and man

Elements	Earth's Crust %	Man %	Elements	Earth's Crust %	Man %
H	1.9	9.5	P	2.6	1
O	47	65	S	0.05	0.3
C	0.08	18.5	K	2.5	0.4
N	0.0001	3.2	Cl	0.017	18.5
Na	2.8	0.2	Si	27.7	0.0001
Ca	3.6	1.5	Al	8.1	0.0001

- Certain elements present in large quantity on earth are represented in higher concentration in the living organisms. Example: Hydrogen.
- Certain elements present in large quantity on earth are represented in very small quantity in living organisms. Example: Silicon.

1.5 ELEMENTS OF LIFE

- All substances in the universe are made up of elements. An element is formed of many similar units called atoms. An atom consists of proton, electron and neutron.

1.5.1 Atoms

Definition

An atom is defined as the smallest unit of an element. It combines with one another by chemical bonding to produce molecules. Atoms are formed of electrons and a nucleus. The nucleus contains protons and neutrons.

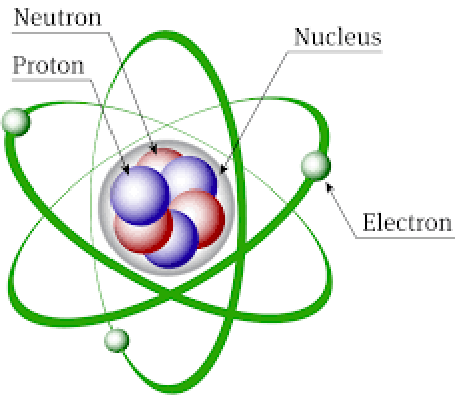


Fig.1.2 Structure of an Atom

1.5.2 Molecules

Definition

Two or more atoms unite together to form a molecule. A molecule may be formed by the union of similar or dissimilar atoms.

Examples

- Oxygen molecule (O_2) is formed by the combination of 2 oxygen atoms.
- Hydrogen (H_2) molecule is formed by the combination of 2 hydrogen atoms.
- Water (H_2O) is a molecule. It is formed by the combination of 2 hydrogen atoms and one oxygen atom.

1.5.3 Stable and Unstable Atoms

Stable atoms: In stable atoms the outer shell is complete by the presence of full number of electrons. It has enough binding energy to hold the nucleus together permanently. They are called stable atoms.

E.g. Helium **-** In helium the outer shell has complete two set of electrons.

Unstable atoms: The atoms which does not have the complete set of electrons in the outer shell are called unstable atoms. An unstable atom does not have enough binding energy to hold the nucleus together permanently.

E.g. Hydrogen has only one electron instead of two in the outer shell.

Oxygen atom has 6 electrons instead of 8 in the outer shell.

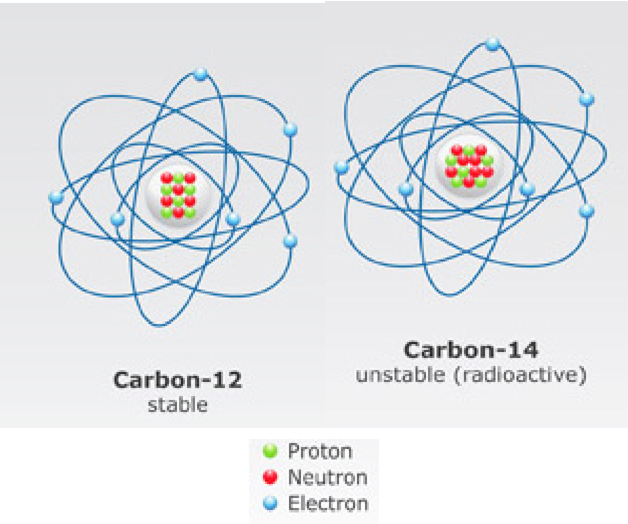


Fig 1.3 Stable and Unstable atoms

1.6 ATOMIC THEORY

Dalton proposed a theory on atoms called atomic theoy. The atomic theory states that each matter is made up of tiny particles called atoms. The main principles of atomic theory are the following

- Each matter is formed of tiny particles called atoms
- Atoms cannot be created or destroyed or divided
- Atoms of the same element are similar and equal in weight
- Atoms of different elements are dissimilar and different in weight and properties

Atoms of different elements have different numbers of electrons, protons and neutrons. For example hydrogen has one electron, one proton and no neutron. Hence the outer shell contains one electron.

Helium atom contains two protons, two neutrons and two electrons. Hence in the helium atom, the outer shell contains two electrons.

Carbon atom has 6 electrons, 6 protons and 6 neutrons. The electrons are arranged in two shells. The first shell contains two electrons and the outer shell contains four electrons.

Oxygen atom contains 8 electrons, 8 protons, 8 neutrons. The electrons are arranged in two shells. The first shell contains two electrons and the outer shell contains 6 electrons.

1.7 ATOMIC WEIGHT

The sum of weights of protons, neutrons and electrons of an atom is called atomic weight. The atomic weight of the atom is approximately equal to the number of its protons and neutrons. The atomic weights range from 1 to 256.

Example

- Hydrogen atom has one proton and no neutron. Hence the atomic weight of hydrogen atom is 1+0 = 1.
- Oxygen atom has 8 protons and 8 neutrons. Hence the atomic weight of oxygen atom is 8 +8 = 16.

1.8 ATOMIC NUMBER

The atomic number or proton number (symbol Z) is the number of protons found in the nucleus of every atom of element. The atomic number uniquely identifies an element. It is similar to the charge number of the nucleus.

Example

Hydrogen atom one proton then the atomic number is 1.
Carbon atom 6 protons and the atomic number of carbon is 6.

1.9 BONDS

Atoms of two or more elements are combined by mutual attraction is called chemical bonds.

The *bond* may result from the electrostatic force of attraction between oppositely charged ions as in ionic *bonds* or through the sharing of electrons as in covalent *bonds*.

1.10 TYPES OF BONDS

The bonds are classified into two types, namely

- **Primary bonds**

  They are strong bonds and hold the atoms together in molecules.

- **Secondary bonds**

  They are weak bonds and they are frequently found in biological molecules. They are found in other organic molecules too.

1.10.1 Primary Bonds

Primary bonds are the strong bonds. They need more energy for the formation of breaking of primary bonds. They bind one atom with another.

The primary bonds are of two types, namely

- Ionic bonds
- Covalent bonds

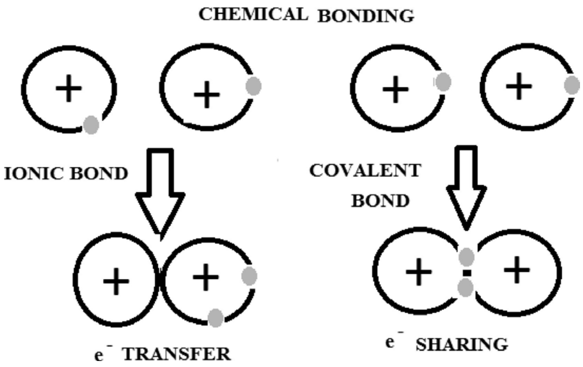


Fig 1.4 Primary Bonds

Ionic Bonds or Electrovalent Bonds

- The bond formed by the transfer of electrons from one atom to another is called ionic bonds.
- The term ‘electrovalent bond’ was proposed by Kossel in 1961.
- Electrovalent bond links two or more atoms in a molecule or compound. The bond is formed by the process of ionization. Hence the bond is called ionic bond and the compound is called ionic compound or electrovalent compound or polar compound.
- Ionic bonds are formed in crystalline inorganic salts.

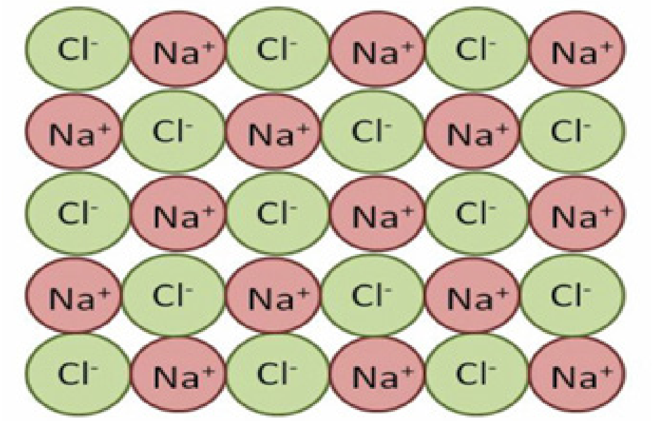


Fig 1.5 Ionic bond of table salt, NaCl

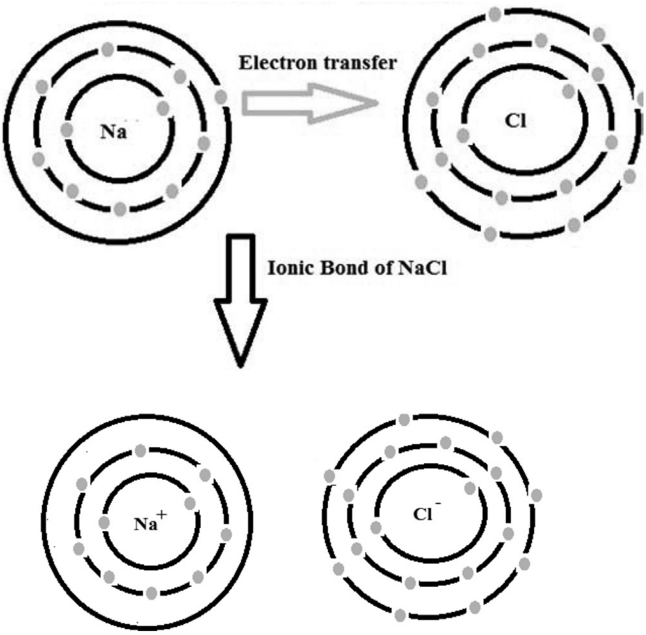


Fig 1.6 Electrovalent bond in Sodium Chloride

Example

Sodium Chloride is an ionic compound. Sodium atom (2, 8, and 1) has one electron in the outermost orbit. Chlorine atom (2, 8 and 7) has 7 electrons in the outermost orbit. The sodium atom transfers one electron to the chlorine atom. Since sodium losses a negatively charged electron, it becomes positively charged or electropositive. As chlorine gains a negatively charged electron, it becomes negatively charged or electronegative. The Na^+ ion and Cl^- ion are held together in NaCl by the electrostatic force of attraction. The valency of an element is the number of electrons an atom gains or losses in order to become stable. So the valency of Na is 1 and that of Chlorine is also 1.

Covalent Bonds

- The term 'covalent bond' was proposed by Lewis in 1966. This bond is very common in organic compound. The atoms also neither lose nor gain electrons. These compounds are called molecular compounds.
- In covalent bonds the atoms are linked together by the sharing of electrons between the atoms.
- The covalent bonds are also called homopolar bonds. They are strong bonds. Covalent bonds are endergonic. i.e., their formation needs energy. 95% of the chemicals in the cells are bounded covalently.

Example

Methane (CH_4)

Carbon combines with 4 hydrogen atoms to form methane. The carbon atom has 4 electrons in the outer shell. It requires 4 electrons to complete its outer shell. It completes its outer shell by sharing electrons with 4 hydrogen atoms.

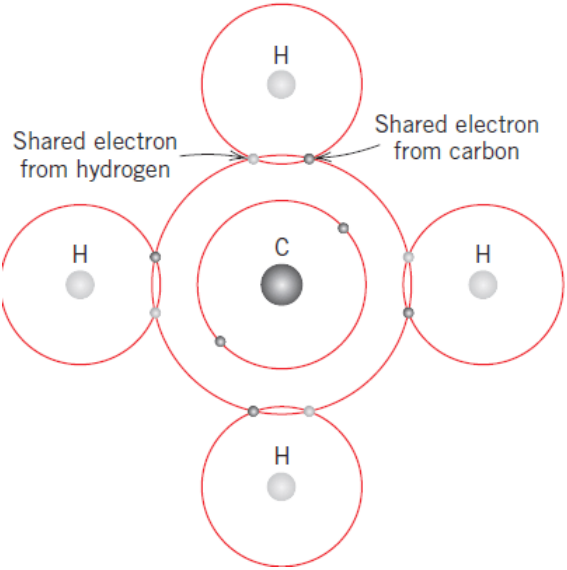


Fig 1.7 Bonding in Methane

1.10.2 Secondary Bonds

Secondary bonds are weaker bonds. They are formed between molecules or within a molecule. They are very important in joining the biochemical compounds. The secondary bonds are easily formed and broken. They need only very little energy for formation or breaking. The important secondary bonds are

- Hydrogen bonds and
- Van der Waals bonds

Hydrogen Bonds

- The term hydrogen bond was proposed by Latimer and Rodenbash.
- The attractive force that binds the hydrogen atom of one molecule with the electronegative atom of another molecule is called hydrogen bond.
- The hydrogen bond is also called proton bonds.
- Hydrogen bonding does not involve transfer or sharing of electrons.
- When a hydrogen atom carrying positive charge, approaches an atom with negative charge an association is formed. This bonding is called hydrogen bond.

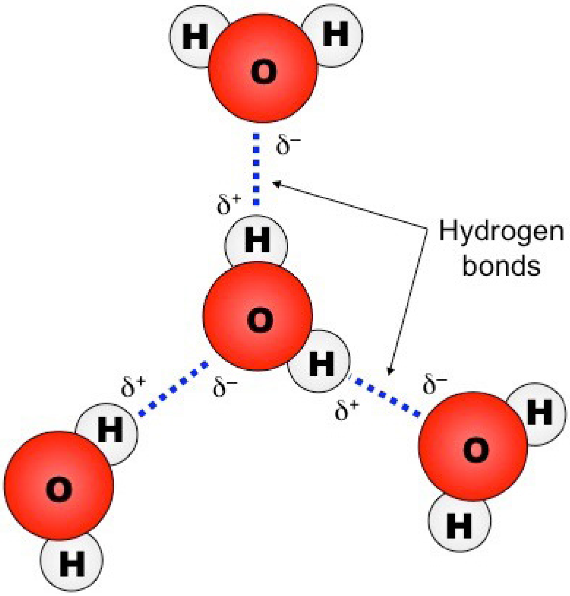


Fig 1.8 Hydrogen Bond

Van der Waals Bond

- Van der Waals bonds are the weakest bonds. They are secondary bonds.
- They act between molecules which are brought close together. These bonds result from the fluctuating charges caused by the nearness of the molecules.
- However, when the molecules are too close, repulsive forces operate because of the overlapping of the outer shells of the atoms involved.
- These bonds are formed between all types of molecules, polar as well as non-polar.

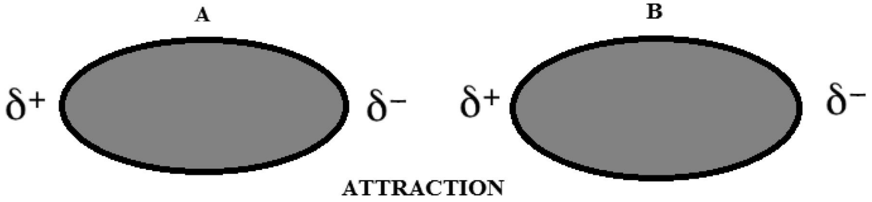


Fig 1.9 Van der Waals bond

1.11 pH

pH is the measure of acidity or alkalinity of a solution.

- The term pH is defined as the negative logarithm of the hydrogen ion concentration in a solution.
- The term pH was introduced by Sorensen in 1909.

$$pH = -\log 10 (H^+)$$

In the expression 'pH',

- p stands for power and
- H stands for the hydrogen ion

- The pH of a neutral solution is said to be 7.
- If the pH is less than 7, the solution is said to be acidic.
- If the pH is greater than 7, the solution is said to be basic or alkaline.

It is also clear that lower the pH, the more acidic is the solution. Similarly, higher the pH the more basic is the solution. A solution having pH = 0 is acidic. pH of a solution decreases when it is heated.

Example

In a litre of pure water, 1/10,000,000 gram of hydrogen ions can be detected.

It can be written in terms of a power, 10^{-7}. In terms of pH scale, it is simply referred to as pH 7.

At pH 7, the concentration of free H^+ and OH^- are exactly the same and thus pure water is neutral.
Water is slightly ionized into H^+ ions and OH^- ions.

$$H_2O \longrightarrow H^+ + OH^-$$

1.11.1 pH Measurement

- pH can be measured for an aqueous solution that can be performed by using indicator dyes such as phenolphthalein, phenol red, litmus etc.
- pH can be measured with the help of pH paper and pH meter.
- In pH meter, pH can be measured with the use of glass electrodes.

Values of pH and Regulation

- For the normal human blood, the pH is close to 7.4. When the pH level decreases below 7.3, it leads to acidosis. If the pH level falls below 7 it is lethal to life.
- The pH of the fluid of the prostatic cells is lower than 5.
- The osteoblastic cells is about 8.0 or even higher.
- In most cells, the pH is found to be nearer to 7.
- The metabolic reactions and enzyme activities require an optimum pH. At the optimum pH, the reaction rate is maximum. When the pH level is altered, the reaction rate also decreases.

1.12 BUFFER

A solution that resists change in pH by addition of a small amount of an acid or a base is called a buffer solution. The capacity of a solution to resist alteration in its pH value is known as buffer capacity. The capacity to resist changes in pH depends upon

i. The actual concentrations of salt and acid present in the buffer and
ii. The salt acid concentration ratio

When a drop of HCl is added to a litre of pure water, the pH of the water changes immediately from 7 to about 2.2. A buffer can be represented by placing the acid or base as the numerator and its salt as the denominator.

$$\text{Acid buffer} = \frac{\text{Acid}}{\text{Salt}}$$

$$\text{Basic buffer} = \frac{\text{Base}}{\text{Salt}}$$

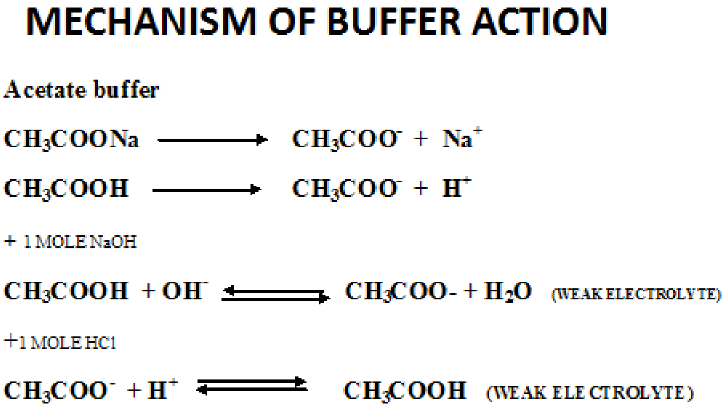
Example

A solution of acetic acid and sodium acetate ($CH_3COOH + CH_3COONa$) is an example of a buffer that consists of a weak acid and its salt.

1.12.1 Buffer Action

The ability of the buffer solution to resist the changes in pH value on the addition of small amount of an acid or a base is known as buffer action.

The buffer action of an acid buffer can be explained by taking an acetate buffer. It is formed of acetic acid (CH_3COOH) and its salt sodium acetate (CH_3COONa). It is represented as follows:



MECHANISM OF BUFFER ACTION

Acetate buffer

$CH_3COONa \longrightarrow CH_3COO^- + Na^+$

$CH_3COOH \longrightarrow CH_3COO^- + H^+$

+ 1 MOLE NaOH

$CH_3COOH + OH^- \rightleftharpoons CH_3COO- + H_2O$ (WEAK ELECTROLYTE)

+1 MOLE HCl

$CH_3COO^- + H^+ \rightleftharpoons CH_3COOH$ (WEAK ELECTROLYTE)

1.12.2 Importance of Buffers

1. It protects the cells and tissues from sudden change in pH.
2. It helps the organisms to carry out the biochemical reactions in a narrow range of pH.

3. It is helpful in many biological experiments.
4. It is able to neutralize small amounts of added acid or base, thus maintaining the pH of the solution relatively stable.

1.13 WATER

Water is the basic molecule of life. It is important for life. It is known that none of the organisms can survive without water. About 70% of our earth is covered with water. Human body also constitutes 70% water. Life originated in the water medium. Water is the most significant molecule which connects the physical world with the biological processes. Therefore, water is described as the mother of life or soul of life.

1.13.1 Different Forms of Water

Water exists in three forms namely,

- **Vapour or steam -** Above 100^{o}C, it occurs in the form of vapour or steam.
- **Solid** - Below 0^{o}C, it becomes solid called ice.
- **Liquid -** Between 0^{o}C and 100^{o}C, it remains in the liquid form.

1.13.2 Sources of Water

Water is available to the biological system from a number of sources such as sea, ponds, pools, lakes, rivers, streams, springs, wells, precipitation etc.

1.13.3 Water Content of Organisms

Plants - The water content of plants is 90% of the total weight.

Animals - In animals, the average water content is more than 50% of their body weight.

Human beings - In human beings, the water content increases and decreases based on age and body. The body water ranges between 45% and 75%. With an increase in age, the total water decreases as if the organism become drier.

Why the water content decreases as age increases?

- **New-borns -** A higher content of total water in new-borns is due to the extracellular water.
- **Infants -** In normal infants the water content is 75% of the total body weight.

- **Adults** - The water content of the body gradually decreases as age increases and it reaches the minimum of 45% in adult (above 55 years).

With increasing age, the total water decreases since the organisms has become drier.

Why a fatty man has less water than lean man?

The average % of total body water ranges around 67%. The variation in body water between normal individuals is caused chiefly by the variable fat content since adipose tissue contains less water. Hence a fatty-man has less water than lean-man. The extracellular water makes up 20% to 26% of the body weight. Of these intercellular fluid 12 to 16%, blood plasma 5%, lymph 2% and intracavitary water 1 to 3%.

In human body, water occurs in two phases, namely

- Intracellular water and
- Extracellular water

Intracellular Water

Water present inside the cell is called intracellular water. It constitutes 35% to 45% of the total body weight. It occurs in two forms, namely free water and bound water. Free water constitutes 95% of the water content of the cell. The bound water constitutes 5% and it occurs in chemical combination with proteins and other constituents of cytoplasm.

Extracellular Water

Extracellular water exists outside the cell. It includes the **intercellular fluid, plasma, lymph** and **intracavitary water** such as cerebrospinal fluid, intraocular fluid, pericardial fluid, synovial fluid and the secretions of salivary, sweat and tear glands.

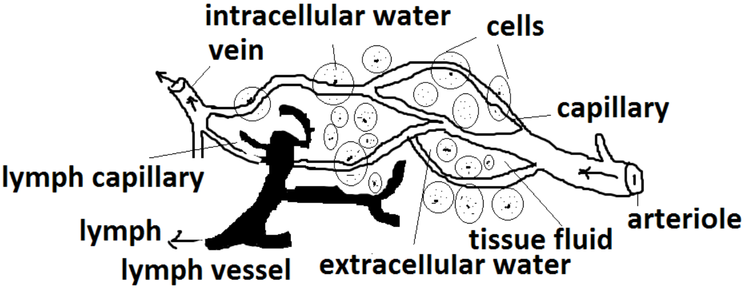


Fig 1.10 Intra and Extracellular water

1.13.4 Structure of Water Molecule

- Water is an inorganic compound.
- The molecular formula of water is H_2O. It contains two hydrogen atoms and one oxygen atom.
- The hydrogen and oxygen atoms are held together by covalent bonds (bonds formed by the sharing of two electrons).
- The three atoms in the water molecule (two hydrogen atoms and one oxygen atom) are not in a line. They are arranged in the form of the letter V, with oxygen atom at the tip and the hydrogen atoms at the ends of the two limbs.
- The bond angle between hydrogen and oxygen atoms is 105^{o}.
- Central Property - Electrical polarity is the central property of water molecule. The oxygen atom is negatively charged and the hydrogen atoms are positively charged. The water molecule is a dipole, as this has two different poles. Water is also called as a polar compound.
- The polar molecules have the property of attracting each other. Owing to this attractive force, water molecules aggregate together. As a result of this force, a water molecule can link with 4 adjacent water molecules. The linking between two water molecules is effected by the formation of a hydrogen bond (O....H) between the oxygen atom of one water molecule and the hydrogen atom of another water molecule. The oxygen atom forms a tetrahedron with the four hydrogen atoms of the neighbouring 4 water molecules.

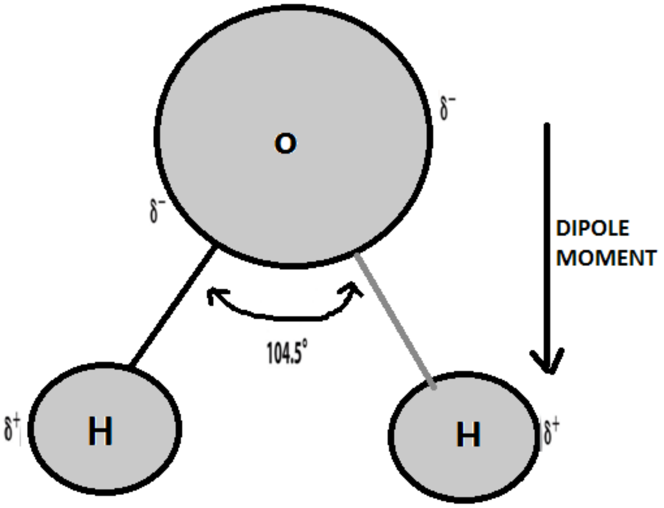


Fig 1.11 Structure of Water Molecule

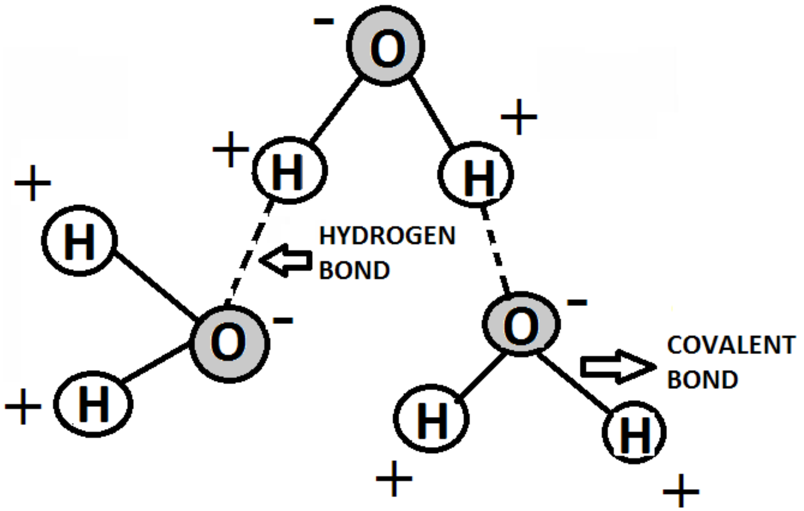


Fig 1.12 Different Bonds in Water Molecule

1.13.5 Properties of Water

The important properties of water are:

- It has the highest boiling point. It is due to the association of water molecules with one another.
- It has the highest melting temperature. This is due to the presence of strong inter molecular forces between multiple water molecules.
- It has the highest specific heat known of any substance. The specific heat of a substance is the amount of heat required to raise its temperature by 1°C. The amount of heat energy (calories) required to raise the temperature of one gram of water from 15°C to 16°C is known as specific heat of water.
- It has a high heat of vaporization. It is defined as the number of calories required to change one gram of liquid into vapour. Vaporization is commonly called evaporation. Vaporization is the change from a liquid to a gas. Water takes more than 500 calories to change a gram of water into vapour.
- Water has a very high latent heat of fusion or melting. It is expressed as the number of calories required to convert one gram of solid at freezing point into liquid at the same temperature. This has important inference because a large amount of heat is removed from water before it freezes.
- Water has a maximum density of 4°C. For this reason, water rarely freezes solid in the sea or in deep lakes even during the coldest weather. When the temperature of the deeper water decreases below 4°C, the water rises up

and ice forms on the surface. This tends to prevent the water below from being cooled down to the freezing point. As a result, the living organisms can continue living below the frozen surface of lakes and oceans. It also facilitates easier melting of the ice exposed to the atmosphere when the environmental temperature raises.

- Water has a very high surface tension. It is the force operating on the surface of water. Water will rise due to capillary action in a glass tube of about 0.03mm in diameter to a height of 120cm. This property enables water to move extensively through narrow cavities in the soil and in plant cell walls.
- Water has high viscosity. It helps the water to move through plants.
- Water as a solvent opposes the electrostatic attraction between positive and negative ions that would prevent ionic substances from dissolving. The dielectric constant denotes the ability to oppose attraction of unlike charges.
- Water allows light to penetrate deep into the tissues of leaves.
- Water is a universal solvent. It can dissolve more number of substances. Many substances present within living system occur in solutions of water.
- The polarity of the water molecules is responsible for its use as a solvent. The water molecules cluster around other molecules and so segregate the charged ions. Water molecules have a polar arrangement of oxygen and hydrogen atoms. On one side, (hydrogen) has a positive electrical charge and the other side (oxygen) has a negative charge. This allows the water molecule to become attracted to many other different types of molecules.

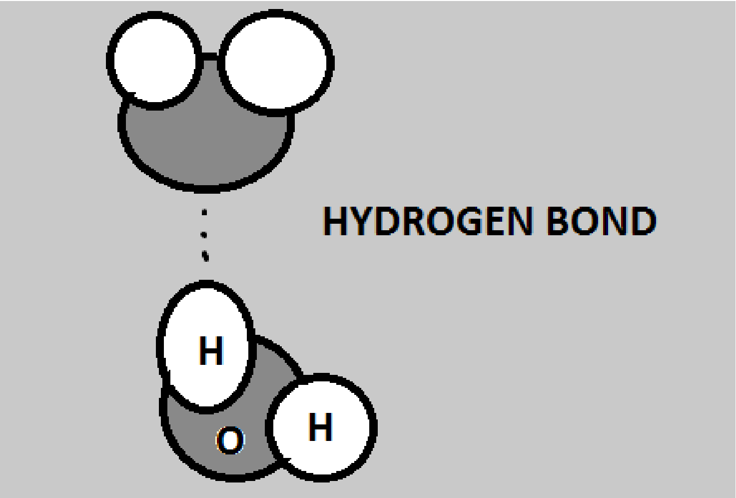


Fig.1.13 Water as a Solvent

1.14 HENDERSON-HASSELBALCH EQUATION

- The Henderson–Hasselbalch equation relates the pH of a solution containing a mixture of the two components to the acid dissociation constant, K_a and the concentrations of the ionic species in solution.
- The Henderson–Hasselbalch equation can be used to estimate the pH of a buffer solution.
- Henderson-Hasselbalch Equation is important for understanding buffer action and acid-base balance in the blood and tissues of the mammalian system.
- The quantitative relationship among pH, buffering action of a mixture of weak and conjugate base and the pK_a of the weak acid is given by a simple expression called Henderson-Hasselbalch equation.
- This equation is simply a useful way of restating the expression dissociation constant of an acid. To derive the equation, a number of simplifying assumptions have to be made.
- We can write the equilibrium reactions for the dissociation of HA in the buffer solution as follows:

$$HA \longrightarrow H^+ + A^-$$

For the dissociation of a weak acid HA into H^+ and A^-, the Henderson-Hasselbalch equation is derived in the following way

$$K_a = \frac{[H^+]\ [A^-]}{[HA]}$$

1. Rearrange the K_a equation to solve for $[H^+]$

$$[H^+] = K_a \frac{[HA]}{[A^-]}$$

2. Convert to logarithmic functions

$$\log\ [H^+] = \log K_a + \log\ \frac{[HA]}{[A^-]}$$

3. Make the expression negative (or multiply by -1)

$$-\log\ [H^+] = -\log K_a - \log\ \frac{[HA]}{[A^-]}$$

4. Substitute pH for $-\log\ [H^+]$ and pK_a for $-\log K_a$

$$pH = pK_a - \log\ \frac{[HA]}{[A^-]}$$

5. Now, to remove the minus sign, invert the last term, i.e., $- \log \frac{[HA]}{[A^-]}$ to obtain Henderson-Hasselbalch equation:

$$pH = pK_a + \log \frac{[A^-]}{[HA]}$$

The equation is expressed more generally as :

$$pH = pK_a + \log \frac{[\text{proton acceptor}]}{[\text{proton donor}]}$$

This equation fits the titration curve of all weak acids and enables one to deduce a number of important quantitative relationships. Henderson-Hasselbalch equation is of great predictive value in protonic equilibria as illustrated below:

A. When $[A^-] = [HA]$ or when an acid is exactly half neutralized: Under these conditions,

$$pH = pK_a + \log \frac{[A^-]}{[HA]} = pK_a + \log \frac{1}{1} = pK_a + 0 = pK_a$$

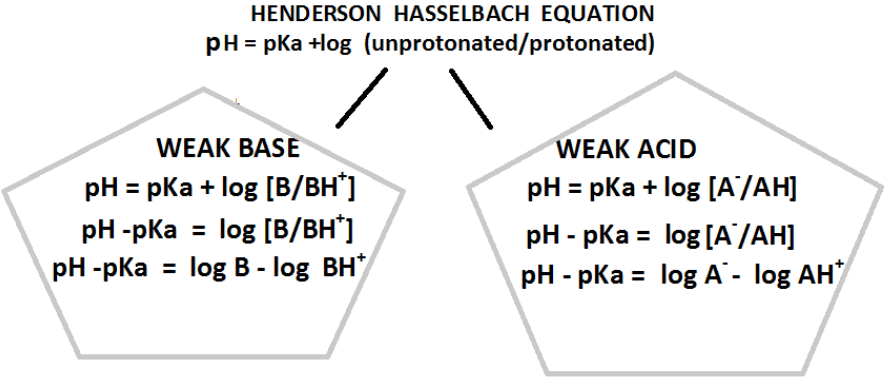
Therefore, at half neutralization pH = pK_a. The equation, thus, shows why the pK_a of a weak acid is equal to the pH of the solution at the midpoint of its titration.

B. When the ratio $[A^-]/[HA]$ = 100 to 1:

$$pH = pK_a + \log \frac{[A^-]}{[HA]} = pK_a + \log \frac{100}{1} = pK_a + 2$$

C. When the ratio $[A^-]/[HA]$ = 1 to 10 :

$$pH = pK_a + \log \frac{[A^-]}{[HA]} = pK_a + \log \frac{1}{10} = pK_a + (-1)$$



HENDERSON HASSELBACH EQUATION

$pH = pKa + \log$ (unprotonated/protonated)

WEAK BASE

$pH = pKa + \log [B/BH^+]$

$pH - pKa = \log [B/BH^+]$

$pH - pKa = \log B - \log BH^+$

WEAK ACID

$pH = pKa + \log [A^-/AH]$

$pH - pKa = \log [A^-/AH]$

$pH - pKa = \log A^- - \log AH^+$

1.15 BIOLOGICAL BUFFER SYSTEMS

Biological buffers are organic substances that maintain a constant pH over a given range by neutralizing the effects of hydrogen ions. In the body, buffers provide a pH environment conducive to critical biochemical processes.

- Almost every biological process is pH dependent. A small change in pH produces large changes in the rate of the process. Cells and organisms maintain a specific and constant cytosolic pH, keeping biomolecules in the optimal ionic state, usually near pH 7.
- In multicellular organisms, the pH of the extracellular fluid is also tightly regulated. Constancy of pH is achieved primarily by biological buffers: mixtures of weak acids and their conjugate bases. There are some important buffer systems of body fluids which helps for maintaining pH. A certain amount of many of these is usually present in the body and cellular fluids and so the maintenance of a constant pH depends on a system.

Body fluids	**Principal Buffers**
Extracellular fluids	Bicarbonate buffer Protein buffer
Intracellular fluids	Phosphate buffer Protein buffer
Erythrocytes	Haemoglobin buffer

1.15.1 The Phosphate Buffer System

- This system which acts in the cytoplasm of all cells, consists of $H_2PO_4^-$ as a proton donor and HPO_4^{2-} as proton acceptor
- $H_2PO_4^- \longrightarrow H^+ + HPO_4^{2-}$
- The phosphate buffer system works exactly like the acetate buffer system, except for the pH range in which it functions.
- The phosphate buffer system is maximally effective at a pH close to its pKa of 6.86 and thus tends to resist pH changes in the ranges between 6.4 and 7.4.
- It is therefore effective in providing buffering power in intracellular fluids.
- In case the ratio of $[HPO_4^{2-}] / [HPO_4^-]$ tends to be changed by the formation of more $H_2PO_4^-$, there occurs the renal elimination of $H_2PO_4^-$ for which the ratio ultimately remains unaltered.

1.15.2 The BicarbonateBuffer System

- This is the main extracellular buffer system which also provide a means for the necessary removal of the CO_2 produced by tissue metabolism.
- The bicarbonate buffer system is the main buffer in blood plasma and consists of carbonic acid as proton donor and bicarbonate as proton acceptor and function as a buffer in the same way as other conjugate acid base pairs.

$$H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

This system has equilibrium constant

$$K_1 = \frac{[H^+][HCO_3^-]}{[H_2CO_3]}$$

- It is unique, however, in that one of its components, carbonic acid, is formed from dissolved carbon dioxide and water, according to the reversible reaction.

$$CO_2\ (d) + H_2O \longleftrightarrow H_2CO_3$$

which has an equilibrium constant given by the expression

$$K_2 = \frac{H_2CO_3^-}{[CO_2\ (d)]\ [H_2O]}$$

Carbon dioxide is a gas under natural conditions and the concentration of dissolved CO_2 is the result of equilibration with CO_2 of the gas phase(g)

$$CO_2\ (g) \longleftrightarrow CO_2\ (d)$$

This process has an equilibrium constant given by:

$$K_3 = \frac{[CO_2\ (d)]}{[CO_2\ (g)]}$$

- The pH of a bicarbonate buffer system depends on the concentration of H_2CO_3 and HCO_3 the proton donor and acceptor components.
- The concentration of H_2CO_3 in turn depends on the concentration of dissolved CO_2 which in turn depends on the concentration or partial pressure of CO_2 in the gas phase.
- With respect to the bicarbonate system a $[HCO_3^-] / [H_2CO_3]$ ratio of 20 to 1 required for the pH of blood plasma to remain 7.40. The concentration of dissolved CO_2 is included in the $[H_2CO_3]$ value i.e.,

$$[H_2CO_3] = [H_2CO_3] + [CO_2 \text{ (dissolved)}]$$

- If there is a change in the ratio in favour of H_2CO_3 acidosis results. This change can result from decrease in $[HCO_3^-]$ or from an increase in $[H_2CO_3]$. Most common forms of acidosis are metabolic or respiratory.
- Metabolic acidosis is caused by a decrease in $[HCO_3^-]$. For example uncontrolled diabetes with ketosis are a result of starvation.
- Respiratory acidosis is brought about when there is an obstruction to respiration or depression in respiration. If acidosis is not treated promptly the patient may go into comma.
- Alkalosis results when $[HCO_3^-]$ becomes favoured in the bicarbonate / carbonic acid rate. Metabolic alkalosis occurs when the HCO_3^- fraction increase with little or no concomitant change in H_2CO_3. Severe vomiting or ingestion of excessive amounts of sodium bicarbonate can produce this condition.
- Respiratory alkalosis is induced by hyperventilation because an excessive removal of CO_2 from the blood result in decrease in H_2CO_3.
- Alkalosis can produce convulsive seizures in children and tetany in adults.
- The pH of blood is maintained at 7.4 when the buffer ratio $[HCO_3^-]/[H_2CO_3]$ becomes 20. If bicarbonate neutralizes any acid or base, there may be change in buffer ratio and the blood value. But the buffer ratio remains by the respiratory elimination of H_2CO_3 as CO_2 or the urine elimination of HCO_3^-.
- Since cells contain much lower amount of HCO_3^- the importance of bicarbonate buffer inside the cell is negligible.

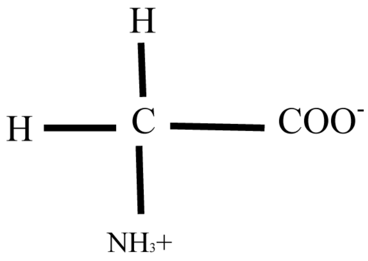
1.15.3 The Protein Buffer System

The protein buffers are very important in the plasma and the intracellular fluids but their concentration is very low in cerebrospinal fluid, lymph and interstitial fluids. The proteins exist as anions serving conjugate base (Pr) at the blood pH 7.4 and form conjugate acids (HPr) accepting H^+. They have the capacity to buffer some H_2CO_3 in the blood.

$$H_2CO_3 + Pr^- \longleftrightarrow HCO_3^- + HPr$$

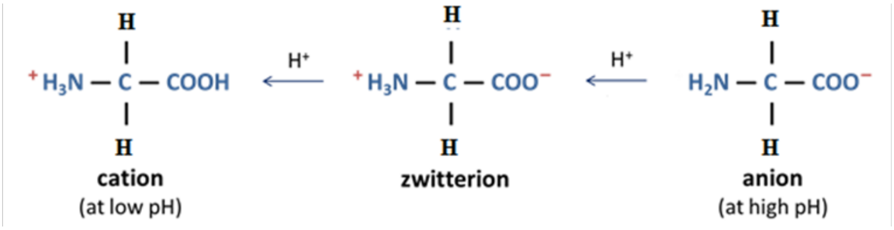
1.15.4 The Amino Acids Buffer System

- Amino acids contain both an acidic (COOH) and a basic ($-NH_2$) group.
- They can be visualized in the form of a neutralize zwitterions in which a hydrogen atom can pass between the carboxyl and amino groups. They may be represented as



$$H-\overset{H}{\underset{NH_3^+}{C}}-COO^-$$

- By the addition or subtraction of a hydrogen ion to form the zwitterions, either the cation or atom form will be produced.



- Thus, when OH ions are added to the solution of amino acid, they take up H^+ from it to form anion. If H^+ ions are added, they are taken up by the zwitterions to produce cation form.
- In practice, if NaOH is added, the salt NH_2 ---- CHR --- COONa would form and the addition of HCl would result in the formation of amino acid hydrochloride, ClH---NH_3---CHR---COOH but these substances would ionize in solution to some extent to form their corresponding ions, haemoglobin and plasma protein act as buffers in a similar way.
- Amino acids differ in the degree to which they will produce the cation or anion form. In other words, a solution of an amino acid is not neutral but is either predominantly acidic or basic, depending on which form is present in greater quantity. For this reason, different amino acids may be used as buffers for different pH values and a mixture of them possesses a wide buffer range.

1.15.5 The Haemoglobin Buffer Systems

- These buffer systems are involved in buffering CO_2 inside erythrocytes. The buffering capacity of haemoglobin depends on its oxygenation and deoxygenation.
- Inside the erythrocytes CO_2 combines with H_2O to form a carbonic acid (H_2CO_3) under the action of carbonic anhydrase. At the blood pH 7.4, H_2CO_3 dissociates into H^+ and HCO_3^- and needs immediate buffering. Oxyhaemoglobin on the other side, losses O_2 to form deoxyhaemoglobin (Hb^-) which remains undissociated (HHb) by accepting H^+ from the ionization of H_2CO_3. Thus, Hb^- buffers H_2CO_3 in erythrocytes.

$$HbO_2^- \longleftrightarrow Hb^- + O_2$$

$$Hb^- + H_2CO_3 \longleftrightarrow HHb + HCO_3^-$$

- Some of the HCO_3^- diffuse out into the plasma to maintain the balance between intracellular and plasma bicarbonates. This causes influx of some Cl^- into erythrocytes along the electrical gradient produced by the HCO_3^- outflow.
- $HHbO_2$, produced in lungs by oxygenation of HHb, immediately ionizes into H^+ and HbO_2^-. The released hydrogen ions (H^+) are buffered by HCO_3^- inside erythrocyte to form H_2CO_3 which is dissociated into H_2O and CO_2 by carbonic anhydrase.
- CO_2 diffuse out of erythrocytes and escapes in the alveolar air. Some HCO_3 return from the plasma to erythrocytes in exchange of Cl and are changed to CO_2

$$HHb + O_2 \longleftrightarrow HHbO_2 \longleftrightarrow HbO_2^- + H^+$$

$$HCO_3^- + H^+ \longleftrightarrow H_2CO_3 \longleftrightarrow H_2O + CO_2$$

UNIT II

CARBOHYDRATES

Isomerism: Definition, Types – Structural isomerism and Stereoisomerism.

Carbohydrates: Introduction - Classification - Monosaccharides: Structure and Properties - Glucose and Fructose. Disaccharides: Structure and Properties – Sucrose, Maltose and Lactose. Polysaccharides: Structure and Properties – Homopolysaccharide: Starch, Cellulose, Glycogen and Chitin. Heteropolysaccharide: Hyaluronic acid, Chondroitin, Agar Agar, Heparin.

2

CARBOHYDRATES

2.1 ISOMERISM

- Isomers are non-identical compounds with the same molecular formula but different arrangements of their atoms.
- Isomers have different physical and chemical properties but the differences may be great or small depending on the type of isomerism.

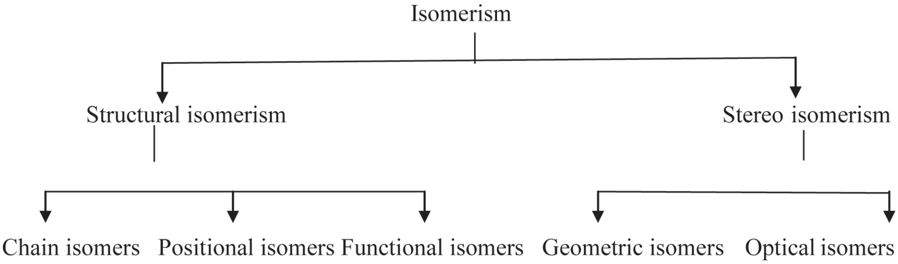


Fig 2.1 Types of isomerism

2.1.1 Structural Isomerism

Structural isomers have the same molecular formula with different structural arrangement of the atoms.

a. **Chain Isomers-** have different arrangements of the carbon chain.

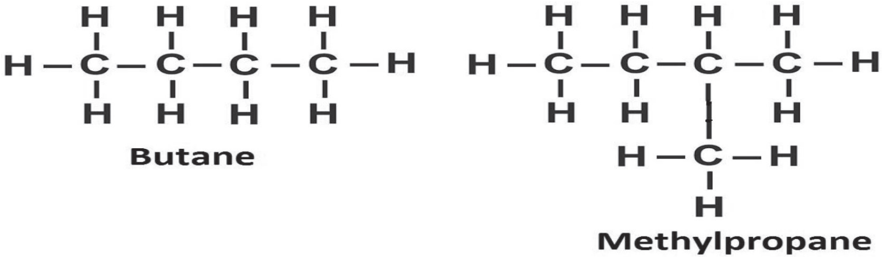


Fig 2.2 Chain isomers - C_4H_{10}

b. **Positional Isomers-** have the same molecular formula but the functional group is in different positions.

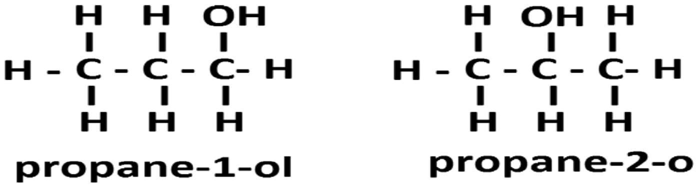


Fig 2.3 Positional isomers - C_3H_8O

c. **Functional Isomers-** have same molecular formula but different functional groups.

$H_3\,C - CH_2$ --CH_2OH H_3C -- $CH_{2\,---}$ O -- CH_3

n- Propanal **Methyl-Ethyl-Ether**

Fig 2.4 Functional isomers - C_3H_8 O

2.1.2 Stereo Isomerism

Stereo isomers have same molecular formula and the same structure but they differ in the arrangement of their atoms in space.

a. Optical Isomers

This type of isomerism occurs when a molecule has one or more asymmetric carbon atoms (i.e) a carbon atom linked to four different atoms or groups. The optical isomers have a chiral centre.

i Aldose and Ketose Isomers

In this type of isomerism, the two isomers have same molecular formula, same structure but differ in the carbonyl carbon. One contain aldehyde (CHO) group and the other contain keto (C=O) group.

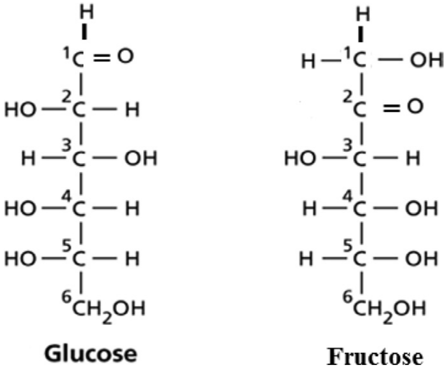
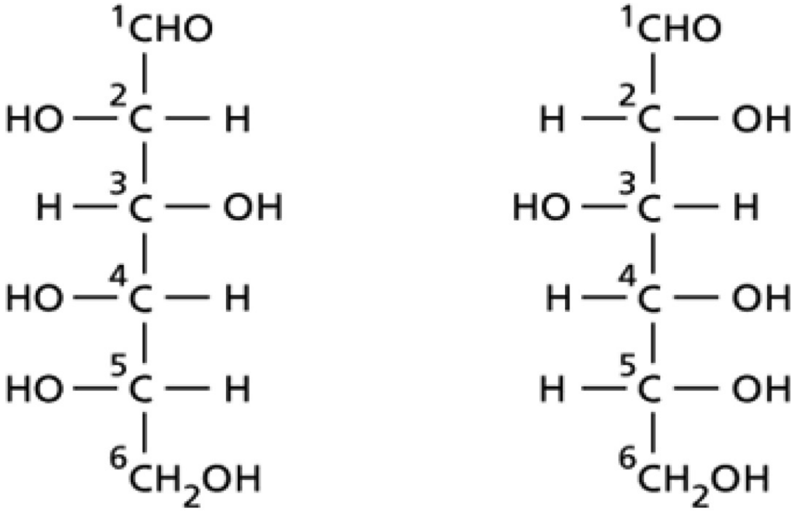

Glucose **Fructose**

Fig 2.5 Aldose and Ketose isomers

ii D and L Isomers

- A monosaccharide can be formed either in D form or L form, In D form. the hydroxyl group at the penultimate carbon (the carbon before the last carbon) is on the right side while in L form, the hydroxyl group at penultimate carbon is on the left side.
- The D and L forms are the mirror images of each other and they are known as **enantiomers.**



L-Glucose **D-Glucose**

Fig 2.6 Enantiomers - $C_6H_{12}O_6$

iii Epimers

- Epimers differ in configuration around 1 carbon atom other than the carbonyl carbon and the penultimate carbon.
- Glucose and galactose have the same molecular formula $C_6H_{12}O_6$ but differ in the position of the hydroxyl group at C_4. Glucose has OH group at C_4 on the right side while galactose has OH group at C_4 on the left side. So glucose and galactose are C_4 epimers.
- Glucose and mannose have the same molecular formula $C_6H_{12}O_6$ but differ in the position of the hydroxyl group at C_2. Glucose has OH group at C_2 on the right side while mannose has OH group at C_2 on the left side. So glucose and mannose are C_2 epimers.

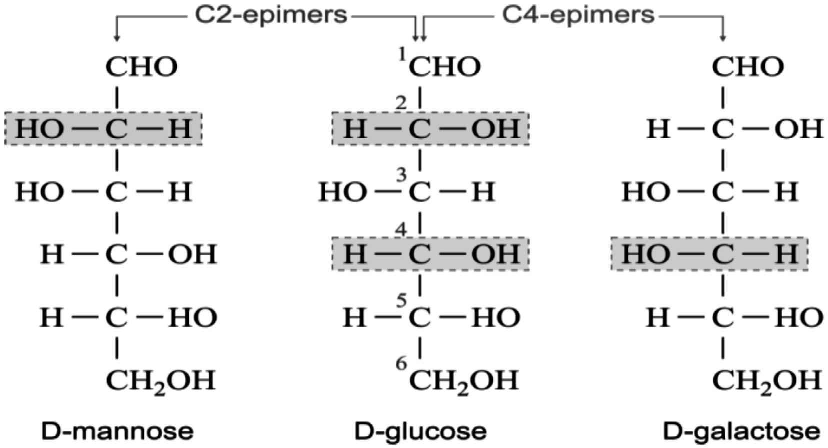


Fig 2.7 Epimers - $C_6H_{12}O_6$

iv α and β Isomers

Monosaccharide that differs in configuration only around the carbonyl carbon in cyclic structure is known as **α and β isomers.** In α form, the hydroxyl group attached to the carbonyl carbon is on the right side. In β form, the hydroxyl group attached to the carbonyl carbon is on the left side.

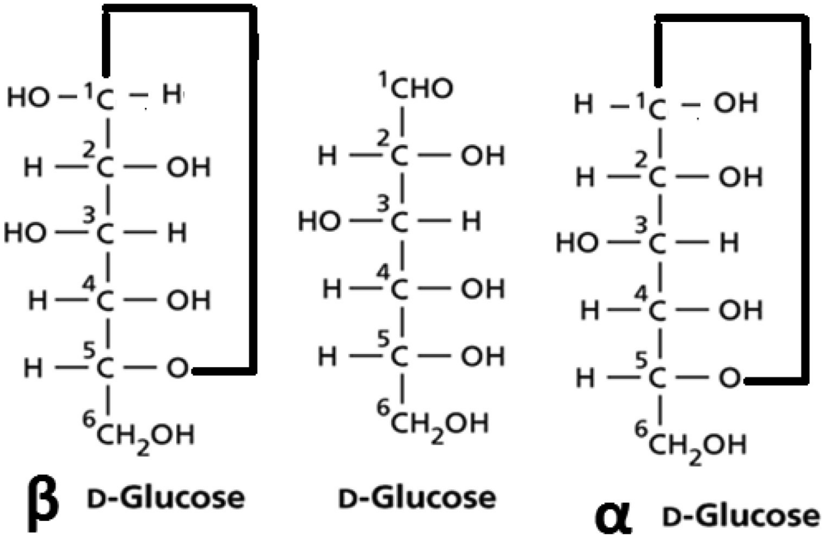
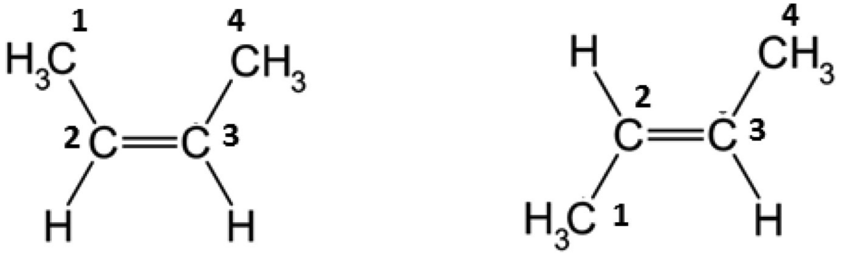


Fig 2.8 α and β isomers - $C_6H_{12}O_6$

b. Geometric Isomers

Geometric or cis-trans isomers exist because of the π band of the C=C bond prevents free rotation.



cis-2-butene

trans-2-butene

Fig 2.9 Geometric isomers - C_4H_8

2.2 CARBOHYDRATES

- Carbohydrates are the most abundant organic molecules in nature.
- They are composed of the elements carbon, hydrogen and oxygen.
- The name carbohydrate literally means “hydrates of carbon”.
- There are several non-carbohydrate compounds (acetic acid, $C_2H_4O_2$; lactic acid, $C_3H_6O_3$) which also appear as hydrates of carbon.
- The general formula for carbohydrate is $(CH_2O)_n$ but, some of the carbohydrate (rhamnohexose, $C_6H_{12}O_5$; deoxyribose $C_5H_{10}O_4$) do not satisfy the general formula.
- Hence, carbohydrates cannot be always considered as hydrates of carbon. The usage of the term carbohydrates is for convenience rather than exactness.
- They are commonly known as saccharides or sugars and are widely distributed in both plants and animals.
- The carbohydrates are defined as polyhydroxy aldehydes or ketones and their derivatives or as substances that yield one of these compounds on hydrolysis.

2.3 CLASSIFICATION OF CARBOHYDRATES

- Carbohydrates are classified into three major groups namely monosaccharides, oligosaccharides and polysaccharides.

2.4 MONOSACCHARIDE

- Monosaccharide is the simplest group of carbohydrates and referred to as simple sugars.
- They have the general formula $C_n(H_2O)_n$.

- They cannot be further hydrolyzed.
- Most of the monosaccharide have the names with suffix as -ose (e.g.) glucose, fructose, mannose etc.

2.4.1 Some Important Monosaccharide

D Glyceraldehyde	-	Simplest sugar
D Glucose	-	Most important in diet
D Fructose	-	Sweetest of all sugar
D Galactose	-	Part of milk sugar
D Ribose	-	Used in RNA

2.4.2 Functional Group

- Monosaccharide contains either a free aldehyde or keto group in their structure. The backbone of monosaccharide is made up of linear single bonded carbon chain. One of the carbon atoms in this backbone contains double bond and an oxygen atom is called as carbonyl carbon atom.
- If the carbonyl carbon is placed at any one end of the backbone, it becomes an aldehyde group.
- If the carbonyl carbon is placed at any other position of the backbone, it becomes a keto group.
- This carbonyl group is acting as functional group of all carbohydrates.

2.4.3 Classification of Monosaccharide

- Based on the functional group and the number of carbon atoms, the monosaccharide are divided into different categories.

Table 2.1 CLASSIFICATION OF MONOSACCHARIDES

Monosaccharides	**No. of carbon atoms**	**Molecular formula**	**Examples**	
			based on aldehyde group	based on ketone group
Trioses	3	$C_3(H_2O)_3$	Glycerose	Dihydroxyacetone
Tetroses	4	$C_4(H_2O)_4$	Erythrose	Erythrulose
Pentoses	5	$C_5(H_2O)_5$	Ribose	Ribulose
Hexoses	6	$C_6(H_2O)_6$	Glucose	Fructose
Heptoses	7	$C_7(H_2O)_7$	Glucoheptulose	Pseudoheptulose

Trioses

- Trioses are monosaccharides containing three carbon atoms.
- The molecular formula of triose is $C_3 H_6O_3$.
- The triose containing an aldehyde group is called aldotriose.

  E.g. Glycerose or Glyceraldehyde.
- The triose containing a ketone group is called ketotriose or triulose.

  E.g. Dihydroxyacetone.

Tetroses

- Tetroses are monosaccharides containing 4 carbon atoms.
- The molecular formula of tetrose is $C_4H_8O_4$.
- The tetrose containing an aldehyde group is called aldotetrose and the tetrose containing a keto group is called ketotetrose.

  E.g. Aldotetrose – Erythrose

  Ketotetrose – Erythulose.

Pentoses

- Pentoses are monosaccharides containing 5 carbon atoms.
- The molecular formula of pentose is $C_5H_{10}O_5$.
- The pentose containing an aldo group is called aldopentose. Eg. Ribose.
- The pentose containing a keto group is called ketopentose or pentulose. Eg. Ribulose.

Hexoses

- Hexoses are monosaccharides containing 6 carbon atoms.
- The molecular formula of hexose is $C_6H_{12}O_6$.
- The hexose containing an aldehyde group is called an aldohexose and hexose containing a ketone group is called a ketohexose or hexulose.

  E.g. Aldohexose – Glucose
  Ketohexose – Fructose

EXAMPLE OF D-ALDOSES

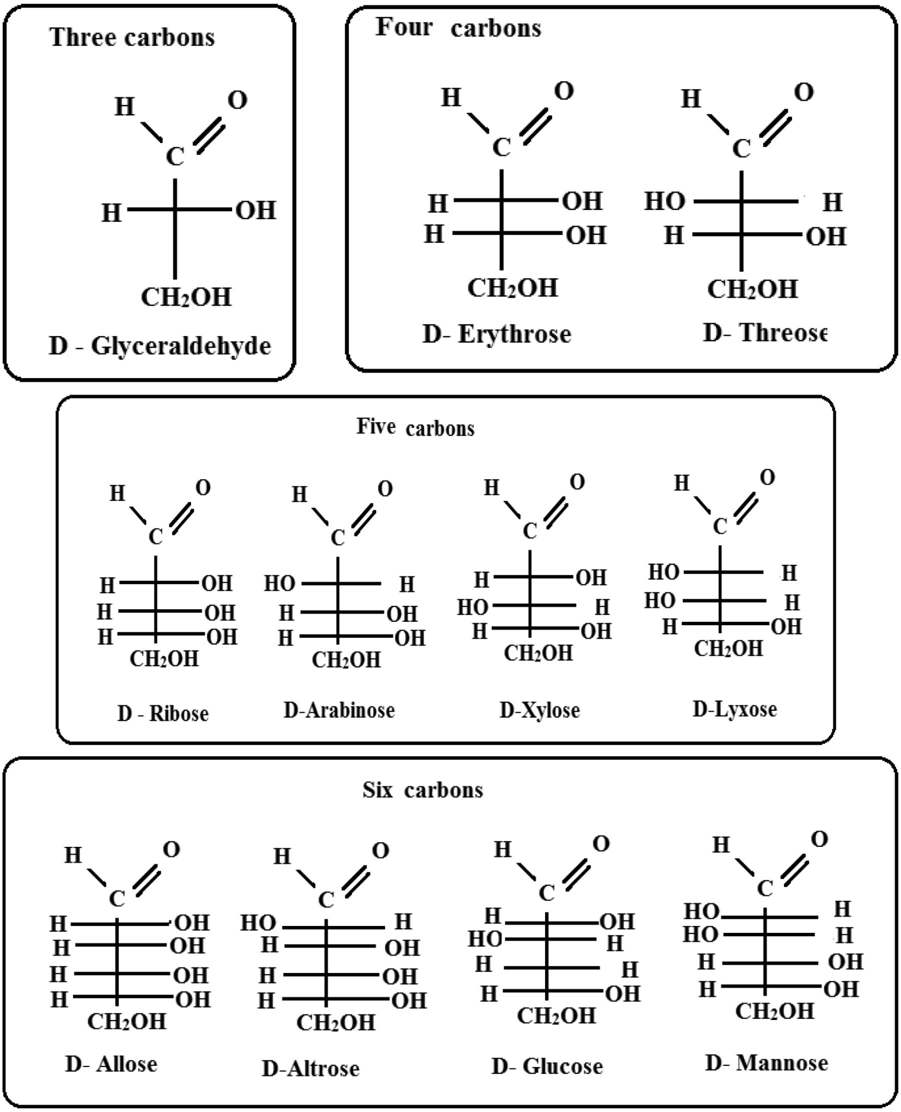


Fig 2.10 Example of D-Aldoses

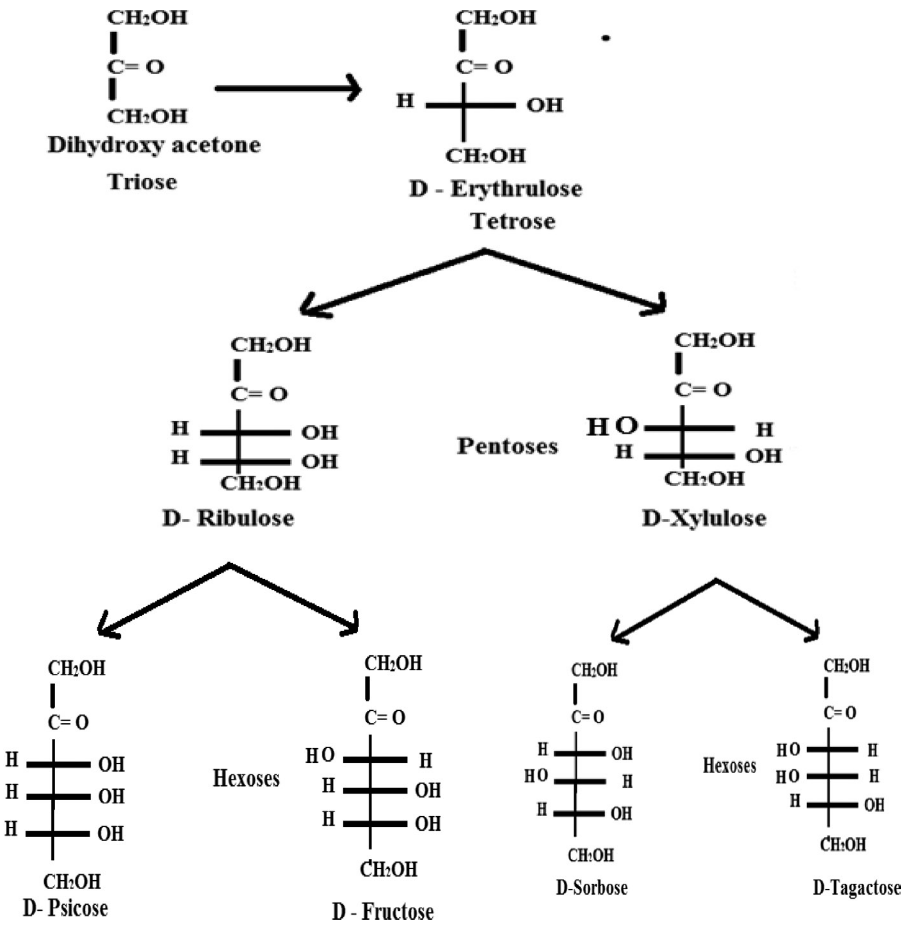


Fig 2.11 Ketoses containing three, four, five, six carbon atoms

2.5 STRUCTURE OF GLUCOSE

Of all the monosaccharide, glucose is an important one. It is the only sugar present in the blood and acts as the source of energy in all living organisms. Structurally glucose exists in two forms.

1. Straight chain structure
2. Ring structure
   a) Hemiacetal ring structure
   b) Haworth projection formula (Pyranose and Furanose Structure)
   c) Chair and boat configurations.

2.5.1 Straight Chain Structure of Glucose

- The molecular formula of glucose ($C_6H_{12}O_6$) was first written by Fitting and Baeyer in 1886.
- This linear form of glucose tells us the presence of an aldehyde group and 5 hydroxyl groups. Later, straight chain structure was demonstrated by Kiliani.
- After 10 years, Emil Fischer succeeded in assigning the spatial relationship of C atoms in the glucose molecule and proved that certain C atoms in glucose molecules are asymmetric.
- Since glucose is a hexose sugar, its structural back bone is made up of 6 carbon atoms which are linked with each other by single bonds.
- In its structure, the first C atom represents aldehyde group and hence glucose is aldohexose. The rest of the C atoms have H and OH groups attached to each other.

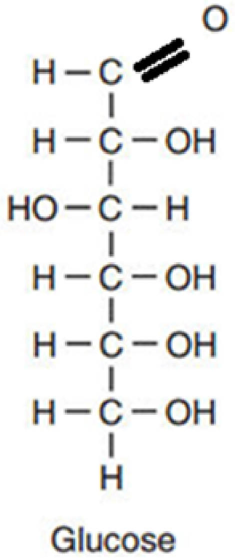


Fig 2.12 structure of glucose

- Of the 6 carbon atoms in the structure of glucose four are asymmetric in nature. C atoms present in positions 2, 3, 4 and 5 are attached with 4 different atoms or groups of atoms at their valency bonds.
- We have already seen that, compounds having asymmetric C atoms are optically active and exist in more than one forms called isomers and the possible number of isomers can be calculated by applying Van 't Hoff rule formula : 2^n=I.

- In glucose, 4 asymmetric C atoms are present at positions 2, 3, 4 and 5. So 16 isomers (2^4=16) are possible for the glucose and of these 16 isomers, 8 belonging to the D series and the rest of the 8 belong to the L series.
- These isomers are called as stereoisomer or space isomers since they differ only in the spatial arrangement of H and OH groups.
- In the D series isomers, the OH group at the fifth C atom is on the right side whereas in the L series isomers, the OH group at the fifth C atom is on the left side. In the glucose structure, fifth C atom is the most distant or farthest C atom from carbonyl group (i.e.) CHO group.

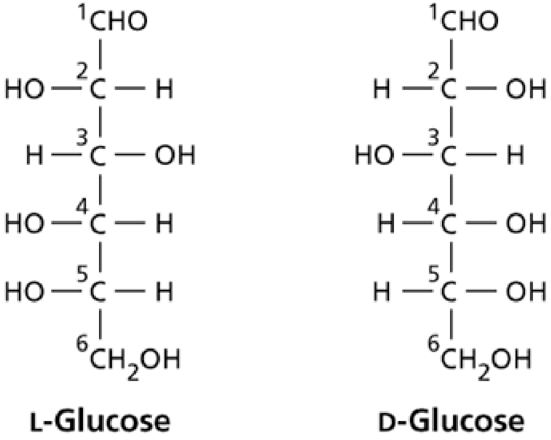


Fig 2.13 Straight Chain Structure of Glucose

2.5.2 Ring Structure of Glucose

- When the straight chain structure of glucose is failed to explain certain other properties Fischer again proposed ring structure of glucose.
- According to him in the solid form glucose is in straight chain structure. But when it is dissolved in solution, it attains ring structure.
- In the natural state, the aldehyde or ketone groups of the monosaccharides with more than five carbon atoms exist in a condensed form such as a hemiacetal or hemiketal.
- This is formed by the condensation of aldehyde group or keto group with any one of the alcoholic groups in the same molecule. This intra molecular hemiacetal formation results in a ring structure called as hemiacetal or hemiketal ring structure.
- Hemiacetal ring structure is either a five membered ring with 4-C atoms and one oxygen atom or a six membered ring with 5-C atom and one oxygen atom.

- There are 2 types of hemi acetal ring structures

  (1) α and (2) β types

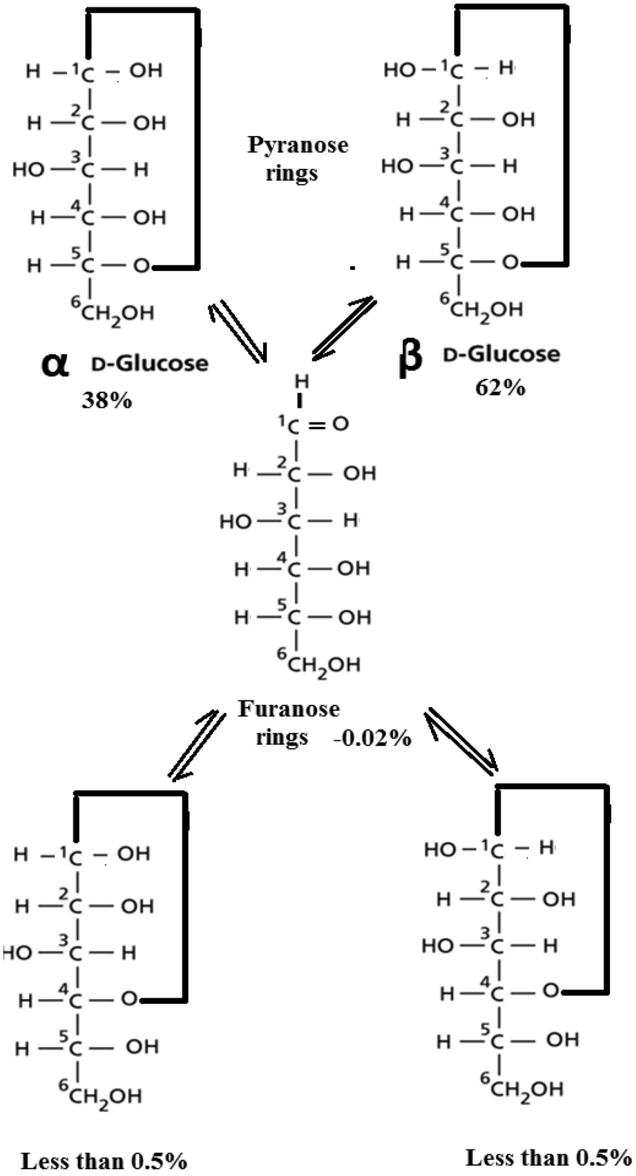


Fig 2.14 Hexoses

- When the H atom of the participating OH group at fifth carbon atom catches the carbonyl oxygen of the rotating aldehyde group and forms the OH group at C-1 at the same side of the ring formation, then it is said to be α form of hemi acetal ring structure of glucose.

- β glucose is formed when the H atom of participating OH at C-5 catches the carbonyl oxygen of the rotating aldehyde group at the opposite side of the ring.
- During this process C-1 of the carbonyl group becomes asymmetric, because now it has four different groups of atoms attached to it. Now the aldehyde group H-C=O is changed to H-C-OH.
- The α and β forms of the sugars are called as "anomers". The α form is called as α anomer and the β form is called as β anomer. The C-1atom which has become asymmetric during the formation of α and β anomers is called as anomeric carbon atom.

2.6 HAWORTH PROJECTION FORMULA OR PYRANOSE AND FURANOSE

- Although Fischer formula are useful in indicating configuration differences among sugars they are difficult to write so, Haworth in 1929 proposed a scheme in which all sugars forming 6-membered rings are called pyranose from their relation to pyran, a chemical compound which possess same 6-membered ring structure composed of 5-carbons and one oxygen.
- The sugars those forming 5 membered rings are called as furanose after furan a chemical compound which possesses similar 5-membered ring with 4-C atoms and one oxygen atom.

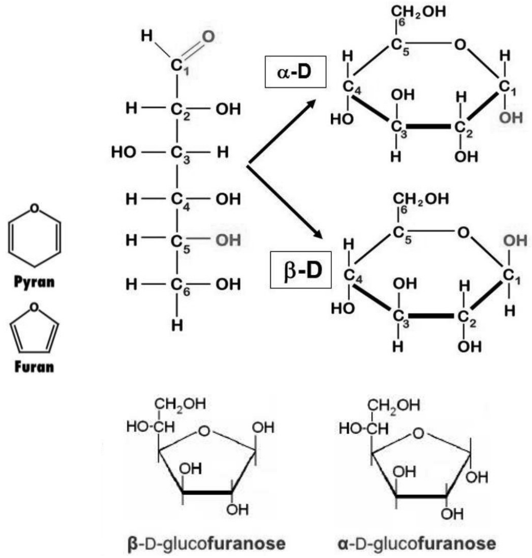


Fig 2.15 Ring Structure of Glucose

- Sugars in pyranose form appear to be most stable than furanose form which is transitory and unstable but the furanose forms are chemically more active than corresponding pyranose forms.
- A pyranose sugar is usually called as hexagon and furanose sugar as pentagon. The ring is considered to be at right angles to the plane of the paper.
- Usually, individual sugars are described by prefixing the main part of their common name to pyranose or furanose.
- For E.g. Glucose in pyranose form is called as glucopyranose and glucose in furanose form is called as glucofuranose.

BOAT AND CHAIR CONFIGURATIONS OF GLUCOSE

- It is otherwise called as "Conformational structures". Even Haworth ring formation does not fully satisfy the requirements for the stability of such molecules.
- The molecules will be more stable if the maximum number of hydroxyl groups is in the equatorial plane, directed outwards, but almost in the same plane as the ring structure.
- This gives the molecule, a structure more resembling "chair" or "boat" configuration. Of these two forms, chair form is more stable.

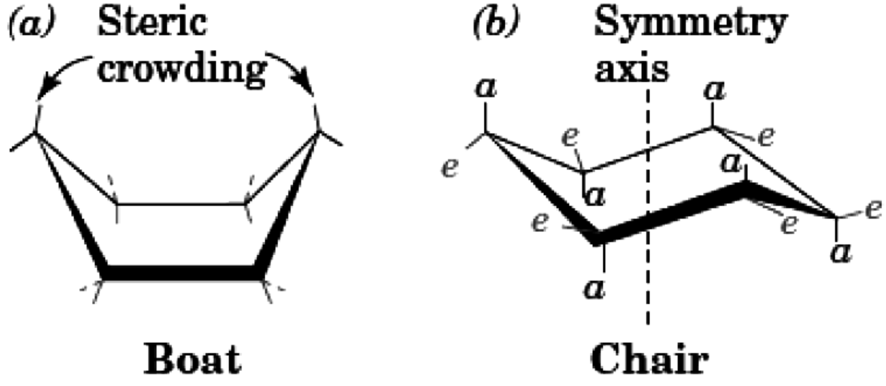


Fig 2.16 Boat and Chair Configurations of Glucose

2.7 PROPERTIES OF MONOSACCHARIDES

2.7.1 Physical Properties

1. **Colour:** Monosaccharides are colourless.
2. **Shape:** They are crystalline compounds.
3. **Solubility:** They are readily soluble in water.
4. **Taste:** They have sweet taste.
5. **Optical Activity:** When an ordinary light beam (which consists of a bundle of electromagnetic waves vibrating in all directions perpendicular to the axis of the beam) is passed through a specially cut crystal of Iceland spar (transparent calcite, $CaCO_3$) or through a special plastic sheet called Polaroid, all vibrations except those in one plane are eliminated. This is called plane polarized light. When such a beam of plane polarized light is passed through a solution exhibiting optical activity, the plane polarized light will be rotated to the right or to the left in accordance with the type of optical isomer present in the solution. This phenomenon is called as optical isomerism. A compound which causes the rotation of plane polarized light to the right is said to be dextrorotatory (d) and a plus (+) sign is used to designate the fact. Rotation of the beam to the left side is said to be levorotatory (l) and is designated by the sign minus (-).When equal amounts of dextrorotatory and levorotatory isomers are present in the solution, the resulting mixture does not show any optical activity, since the activity of each isomer cancel one another. Such a mixture is said to be "racemic" or dl – mixture" or "± mixture".
6. **Mutarotation:** A **change in optical rotation** is called "**Mutarotation**". This is due to the change of one ring form to another ring form (i.e.) α to β form and vice versa. The optical rotation of freshly prepared α - D - glucose is $+ 112^0$. After some time the rotation decreases and finally reaches a steady value of $+ 52.5^0$. Like that, optical rotation of freshly prepared β - D glucose is $+ 19^0$. After some time the optical rotation gradually increases and finally reaches a steady value of $+ 52.5^0$.

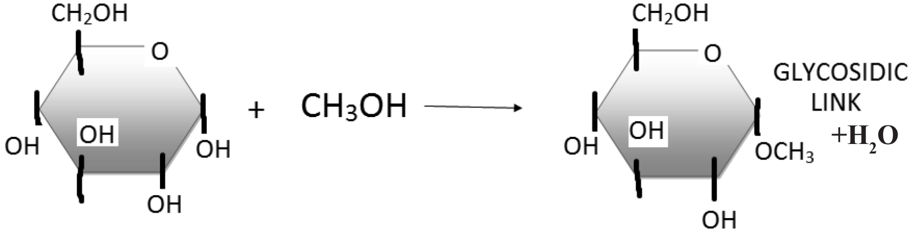
$$\mathbf{+ 112^0 \rightarrow + 52.5^0 \leftarrow + 19^0}$$

α D glucose steady value at equilibrium stage *ß* - D - glucose.

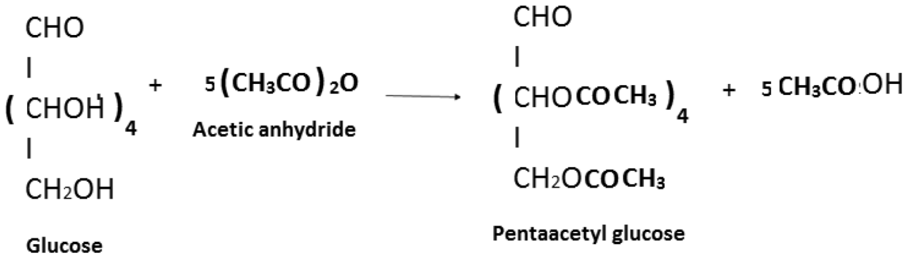
This change in the optical rotation is called as mutarotation and is mainly due to the formation of an equilibrium mixture at 52.5^0 which consists of about one - third of *α*- D glucose, 2/3 of *ß* - D glucose and very small amount of open chain compound. This mechanism shows that all monosaccharides exist in three forms in nature. Those are *α* - form, *ß* - D form and aldehyde form. Of these forms, aldehyde form is unstable. Mutarotation is mainly catalyzed by the addition of hydroxyl or hydrogen ions.

2.7.2 Chemical Properties

7. **Glucoside formation:** Glucose reacts with methyl alcohol in the presence of hydrogen chloride gas to give glucosides. Glucoside formation is due to the reaction of alcohol with the glycosidic OH of monosaccharides. In the same way, fructose forms fructosides.



8. **Acetylation:** Glucose reacts with 5 molecules of acetic anhydride to form penta acetyl derivative. As glucose yields a penta acetate derivative on acetylation, it obviously contains five OH groups.



9. **Reduction:** Monosaccharides can be reduced by various reducing agents. The reduction is due to the presence of CHO or CO group. On reduction, they yield alcohols. When sodium amalgam is used, glucose yields sorbitol (glucitol), mannose yields mannitol, galactose yields dulcitol and fructose yields a mixture of sorbitol and mannitol.

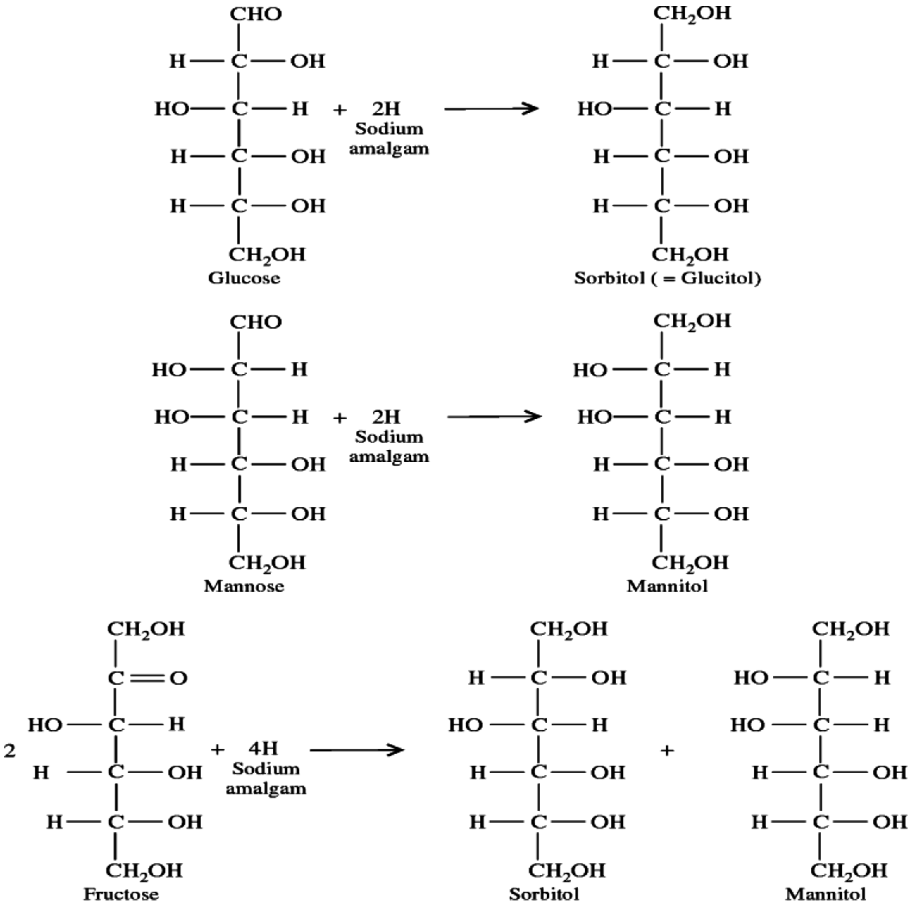
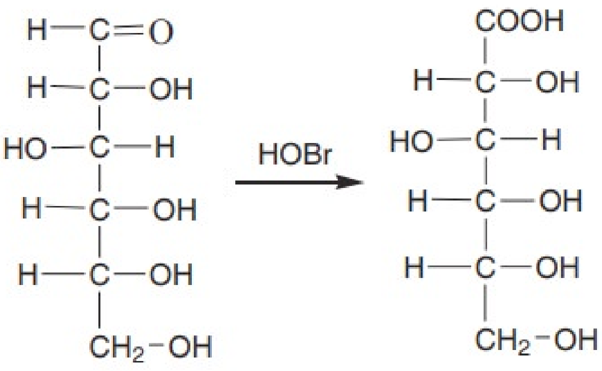


Fig 2.17 α and β D- fructose

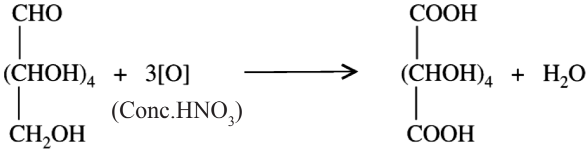
10. **Reducing agents (oxidation):** Monosaccharides act as best reducing agents. They readily reduce oxidizing agents such as ferricyanide, hydrogen peroxide or cupric ion. In such reaction, the sugar is oxidized at the carbonyl group and the oxidizing agent becomes reduced. Glucose and other sugars capable of reducing oxidizing agents are called reducing sugars. This property is useful in the analysis of sugars. Glucose reduces Tollen's reagents Fehling's solution, Benedict's reagents etc. At the same time glucose is oxidized to gluconic acid.

    a) **With mild oxidants (like HOBr):** Only the aldehyde group is oxidized to produce monocarboxylic acids. Ketoses do not respond to this reaction. Hence, this reaction is used to distinguish aldoses from ketoses.



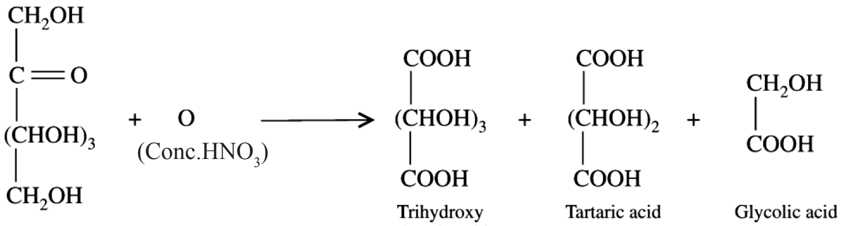
D-Glucose D-Gluconic acid

b) **With strong oxidants (like Conc. HNO3):** Both the aldehyde group (or ketone group) and the primary alcohol group are oxidized to yield dicarboxylic acids.



$$\begin{array}{c}\text{CHO}\\|\\(\text{CHOH})_4\\|\\\text{CH}_2\text{OH}\end{array} + 3[\text{O}] \xrightarrow[(\text{Conc.HNO}_3)]{} \begin{array}{c}\text{COOH}\\|\\(\text{CHOH})_4\\|\\\text{COOH}\end{array} + \text{H}_2\text{O}$$

Glucose (an aldose) Glucaric acid (Saccharic acid)

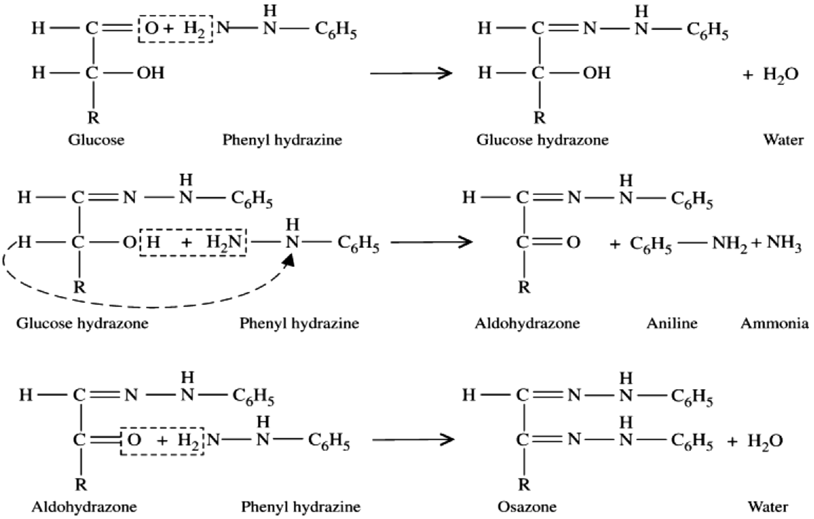


$$\begin{array}{c}\text{CH}_2\text{OH}\\|\\\text{C}=\text{O}\\|\\(\text{CHOH})_3\\|\\\text{CH}_2\text{OH}\end{array} + \text{O} \xrightarrow[(\text{Conc.HNO}_3)]{} \begin{array}{c}\text{COOH}\\|\\(\text{CHOH})_3\\|\\\text{COOH}\end{array} + \begin{array}{c}\text{COOH}\\|\\(\text{CHOH})_2\\|\\\text{COOH}\end{array} + \begin{array}{c}\text{CH}_2\text{OH}\\|\\\text{COOH}\end{array}$$

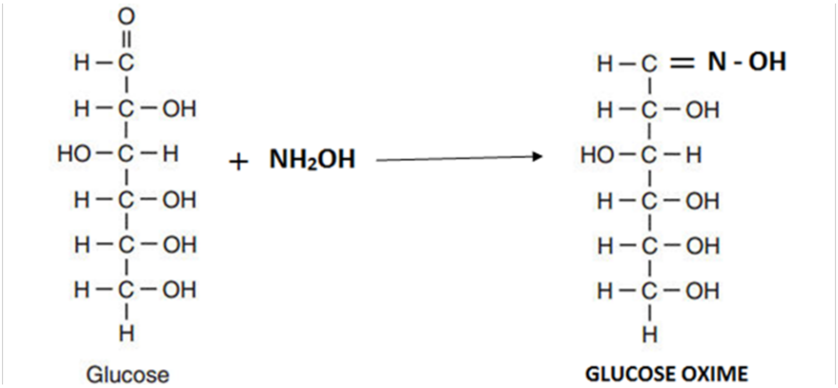
Fructose (a ketose) Trihydroxy glutaric acid Tartaric acid Glycolic acid

11. **Formation of Osazone:** Aldoses and ketoses react with phenylhydrazine. Glucose consumes 3 molecules of phenylhydrazine and produces osazone, aniline and ammonia. Reaction with phenylhydrazine involves only 2 carbon atoms, namely the carbonyl carbon atom (the aldehyde or ketone group) and the adjacent one. First of all, one molecule of phenylhydrazine reacts with one molecule of aldose or ketose to form a molecule of hydrazone. With a second molecule of phenylhydrazine, the hydrazone

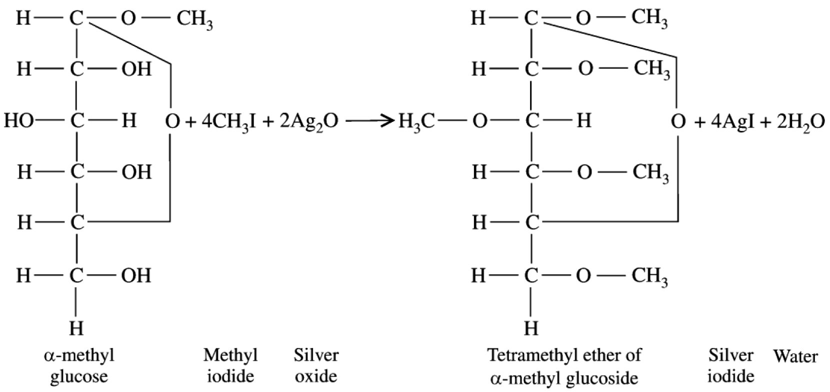
is oxidised to aldohydrazone and the phenylhydrazine itself is reduced to aniline and ammonia. Finally, a third molecule of phenylhydrazine reacts with aldohydrazone to produce Osazone.



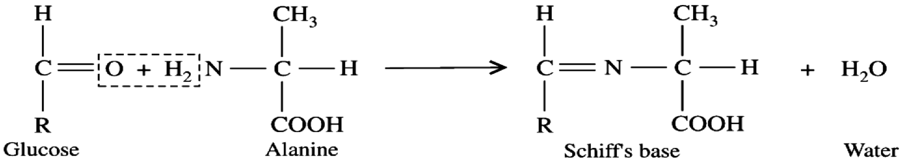
12. **Formation of Oximes:** Aldose and ketose react with hydroxylamine to form oximes.



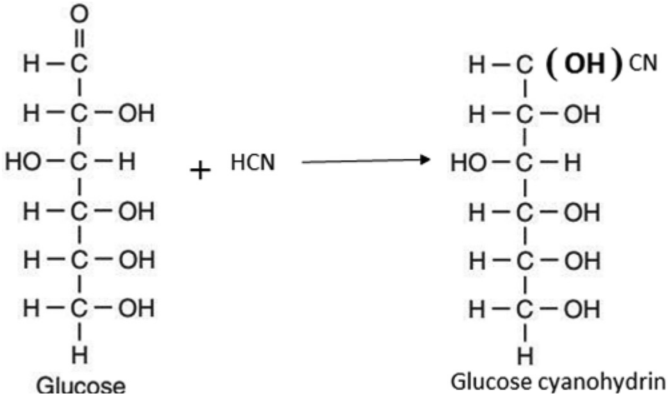
13. **Reaction with methyl iodide (Etherification):** The alcoholic OH groups of monosaccharides are converted to ether groups upon treatment with methylating agents.



14. **Reaction with alanine:** The aldehyde group of carbohydrates condenses with the amino group of alanine to form Schiff's base.



15. **Reaction with Hydrogen cyanide:** When hydrogen cyanide is added to sugars, cyanohydrin is produced.



16. **Caramelization:** When monosaccharide is added with concentrated alkali, it is burnt and this process is called Caramelization.

17. **Fermentation:** Glucose gives ethyl alcohol and CO_2 during fermentation by Zymase.

$$\boxed{\text{Glucose}} \xrightarrow{\textbf{Zymase}} \boxed{\text{Ethyl alcohol}}$$

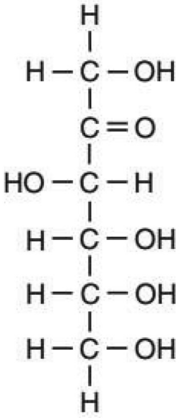
2.8 STRUCTURE OF FRUCTOSE

2.8.1 Occurrence

- Fructose was discovered by French chemist Augustin-Pierre Dubrunfaut in 1847.
- The name Fructose was coined in 1857 by the English chemist William Miller.
- Fructose is found in trees, honey, vine fruits, flowers, berries and most root vegetables.
- It is often bound with Sucrose to form a disaccharide.
- Commercially this sugar has been derived from corn, sugarcane and sugar beets.

2.8.2 Structure

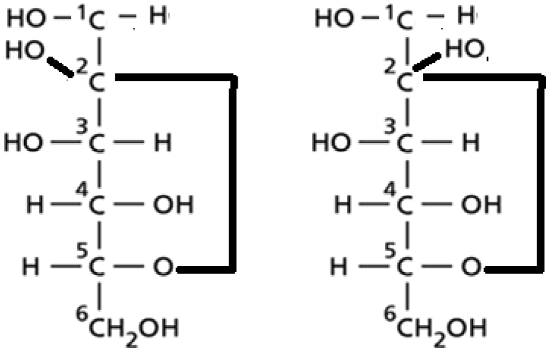
- Fructose (fruit sugar) is a simple, levorotatory monosaccharide (counterclockwise rotation of plane polarized light).
- It has the same molecular formula ($C_6H_{12}O_6$) as glucose but with a different structural arrangement of atoms.
- It is an isomer of glucose.
- Like glucose, fructose is a hexose (six carbons) sugar, but it contains a keto group instead of an aldehyde group, making it a Ketohexose.
- In straight chain structure, six carbon atoms are arranged in a chain. The two end carbons have primary alcoholic groups. The 2nd carbon is a keto group. The other three carbons 3, 4, 5 have secondary alcoholic groups.



Fructose

Fig 2.18 Open Chain Structure of Fructose

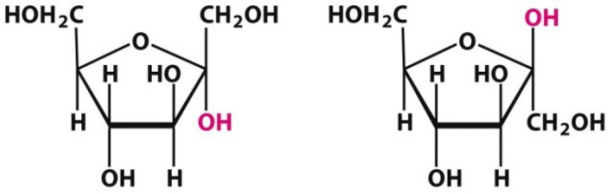
- Fructose can also exist in ring form. Its open-chain structure is able to cyclize (form a ring structure) because a ketone can react with an alcohol to form a hemiketal.
- Specifically, the C-2 keto group of a fructose molecule can react either with its C-6 or C-5 hydroxyl groups to form an intra molecular hemiketal.



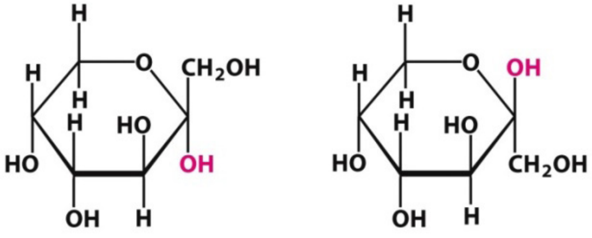
β **D-Fructose** α **D-Fructose**

Fig 2.19 α and β D- fructose

- Fructose may form a six membered ring called a pyranose and five membered ring called a furanose.
- In solution, fructose exists as a mixture of 70% fructopyranose and about 22% fructofuranose.



α-D-Fructofuranose **β-D-Fructofuranose**



α-D-Fructopyranose **β-D-Fructopyranose**

Fig 2.20 Pyranose and Furanose Ring Structure of Fructose

2.8.3 Properties

- It is a sugar with crystalline state and sweet taste. It is highly soluble in water.
- It occurs in plants and honey in the form of oligosaccharides and polysaccharides. It is found in free state in the seminal plasma.
- It is a reducing sugar. It reduces Tollen's reagent and Fehling's solution.
- It is an optically active compound. It is levorotatory. So it is called as levosugar. Its specific rotation is -92^0.
- It plays an important role in cellular metabolism. In the intestine and liver, fructose is converted into glucose and then used by the organs.

2.9 DISACCHARIDES

- Disaccharides are formed by the union of 2 monosaccharides. In other words, disaccharides yield 2 monosaccharides on hydrolysis.
- In general, these are colourless, crystalline substances, sweetish to taste, readily soluble in water and easily hydrolysed by enzymes and dilute mineral acids.
- The common disaccharides have the general formula $C_{12}H_{22}O_{11}$. During hydrolysis, they take up one molecule of H_2O to form 2 hexoses.

$$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$$

- During the formation of disaccharide from 2 molecules of monosaccharides an intermolecular dehydration occurs.

$$C_6H_{12}O_6 + C_6H_{12}O_6 \rightarrow C_{12}H_{22}O_{11} + H_2O$$

Hexose + Hexose Disaccharide + Water

- The 2 monosaccharides are united between the first carbon of one monosaccharide with the second or the fourth carbon of another monosaccharide by a glycosidic linkage. Since C – 1 is the carbonyl carbon atom i.e., functional group, reducing property of at least one hexose unit is lost. Hence disaccharides are considered as glycosides in which both components are sugars. Disaccharides may be of two types, reducing and non – reducing.

GLYCOSIDIC LINKAGE

- A sugar molecule can combine with an identical or a different type of a sugar molecule. The linkage between two monosaccharide sugar molecules is called glycosidic linkage or glycosidic bond.

- A sugar molecule has several reactive hydroxyl groups. The hydroxyl group of number one carbon atom (C-1) is known as the glycosidic hydroxyl group. It is very reactive and readily forms a glycosidic linkage with a hydroxyl group of another sugar molecule.
- When such a linkage occurs, one hydrogen atom and one hydroxyl group are eliminated to form H_2O. This process is dehydration synthesis. The reverse process with the incorporation of the elements of water is called hydrolysis.
- A linkage between C – 1 of one monosaccharide unit and C – 4 of another is called the 1, 4 linkage. Such linkage occurs in disaccharides and in the unbranched chains of polysaccharides.
- The 1, 4 linkage between two hydroxyl groups in the α positions is called α - 1, 4 linkage (e.g., maltose). Similarly a linkage between two β hydroxyl groups is called as β – (1 → 4) linkage (e.g., in lactose).
- Linkage can also takes place between C – 1 of one monosaccharide unit and C – 6 of another. Such a linkage occurs at the point of branching of a chain and is known as (1 → 6) linkage (e.g., in isomaltose, starch and glycogen).

Table 2.1 DIFFERENCE BETWEEN REDUCING AND NON-REDUCING SUGAR

Reducing sugar	Non – Reducing sugar
1. Carbohydrates with a free aldehyde (at C-1) or a free ketone (at C-2) group.	1. Aldehyde or ketone group is not free but instead utilized in bond formation.
2. They are in hemiacetal or hemiketal form.	2. They are in acetal or ketal form.
3. They exhibit mutarotation.	3. They do not exhibit mutarotation.
4. They form osazones with phenyl hydrazine.	4. They do not form osazones
5. They form oximes with hydroxylamine.	5. They do not form oximes
Examples – Glucose, Fructose, Lactose, Maltose, Cellobiose	Examples – Sucrose, Glycogen, Inulin.

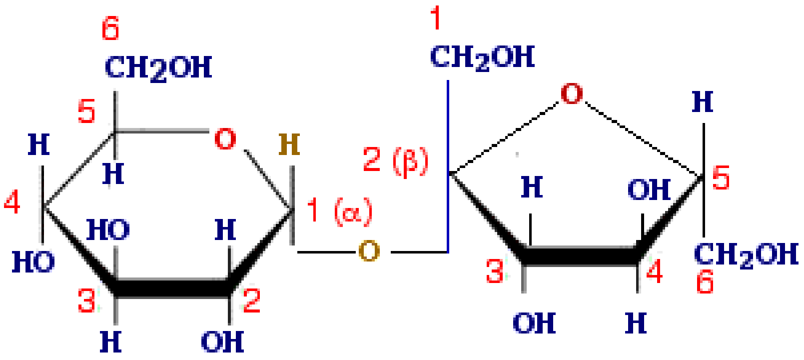
2.10 SUCROSE (CANE SUGAR)

2.10.1 Occurrence

- Sucrose is the common sugar of commerce and kitchen and is widely distributed in all photosynthetic plants.
- It is otherwise called as “table sugar” or “household sugar”.
- It occurs in very large amounts in sugar cane, beet root, pineapple, maple fruits, carrot, sweet potato and honey.
- Nectar of flowers is rich in sucrose.
- It is also present in varying amounts in different plant organs such as fruits, seeds, flowers and roots.

2.10.2 Structure

- It is a disaccharide composed of one molecule of α - D - glucopyranose and one molecule of β - D fructofuranose which are condensed together by α (1 --> 2) glycosidic linkage.
- The linkage exists between aldehyde group of glucose and keto group of fructose. As a result, no reducing group remains free in sucrose molecule.
- Since the functional groups of both glucose and fructose are blocked in the linkage, this disaccharide is called as non- reducing sugar.



α-D-glucopyranosyl (1-->2)-β-D-fructofuranoside
(SUCROSE)

Fig 2.21 Structure of Sucrose

2.10.3 Properties

- It is white crystalline solid, soluble in water with a melting point of 180^0. When heated above its melting point, it forms a brown substance known as Caramel.
- It is the sweetest of 3 common disaccharides (maltose, lactose and sucrose). It is also sweeter than glucose.
- It has no free aldehyde or keto group because the linkage is between aldehyde group of glucose and keto group of fructose. Hence, it is a non-reducing sugar.
- It does not exhibit mutarotation and cannot exist in α and β forms.
- Since it is a non-reducing sugar, it does not reduce Fehling's and Benedict's solutions. It can't reduce Barfoed's solution. It cannot form osazones with phenyl hydrazine.
- Sucrose is dextrorotatory and its specific rotation is $+ 66.7^0$.
- On hydrolysis, it gives one molecule of glucose and one molecule of fructose. Since, fructose is more strongly levorotatory than the dextrorotatory glucose, the mixture (product) after hydrolysis will become levorotatory. This reaction is known as "inversion of sugar". Because the dextrorotatory cane sugar is converted into levorotatory product due to hydrolysis. The mixture of glucose and fructose is called "invert sugar". This invert sugar is sweeter than sucrose. Hydrolysis may be carried out by acids, enzymes (invertase or sucrose) and bacteria.

  $C_{12}H_{22}O_{11} + H_2O$ ---------------> $C_6H_{12}O_6 + C_6H_{12}O_6$

  Sucrose Glucose Fructose

- Sucrose is not fermented directly by yeast.

2.10.4 Functions

- It serves as a nutrient.
- Invert sugars are used in candy both because of its sweetness and do not crystalline.
- It is used to produce artificial sweetener of no nutritive value. e.g. Saccharin. It is developed especially for obese or diabetics. Saccharin is 400 times sweeter than sucrose.

2.11 MALTOSE (MALT SUGAR)

2.11.1 Occurrence

- Maltose does not occur abundantly in nature.
- Sprouting cereal grains are rich in amylase which split the starch to dextrins and maltose.
- Malt (prepared from sprouting barley) is an excellent source of maltose.
- It is the intermediate product in the breakdown of starch by the enzyme amylase in the alimentary canal.

2.11.2 Structure

- It is composed of 2 glucose residues which are condensed together through glycosidic linkage. The linkage exists between the OH group of C-1 of one glucose residue and OH group of C-4 of another glucose residue. This linkage is known as α-(1→4) glycosidic linkage.
- Here, there is a free aldehyde group in the second glucose residue. So, maltose is considered as reducing sugar.

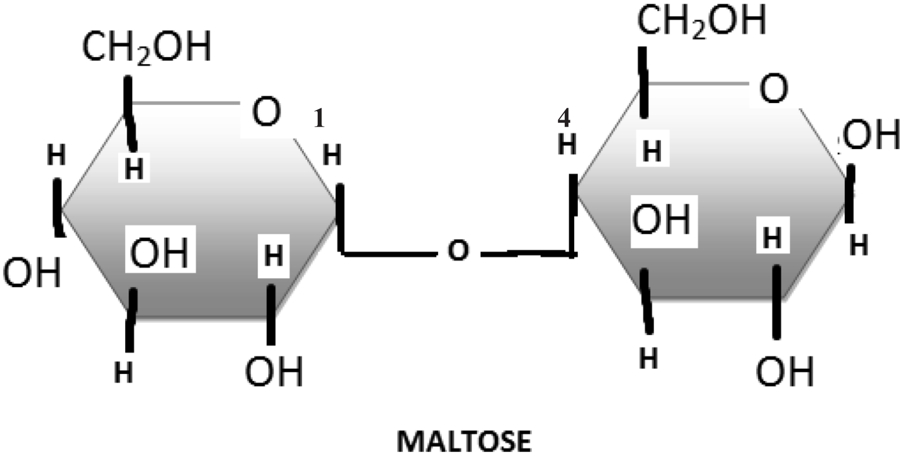


Fig 2.22 Structure of Maltose

2.11.3 Properties

- Maltose is a white crystalline solid, with a melting point 160 - 165^{0}C.
- It is soluble in water and dextrorotatory.
- It is hydrolyzed by the enzyme maltase to glucose and the products are absorbed.

- Since it has free aldehyde group, it shows mutarotation. The final rotation is $+130^0$ and can exist in all the three forms α, β and aldehyde form. In all the three forms, the linkage is α (1→4) glycosidic linkage. Among these three forms, β-form is most common.
- It can reduce Fehling's and Benedict's solution since it is a reducing sugar and cannot reduce Barfoed's solution, since it is a disaccharide.
- It forms osazone with phenyl hydrazine and maltosazone crystals have a characteristic petal like appearance and cluster of them looks like a sunflower and are readily identifiable$_4$when seen under microscope.

2.12 LACTOSE

2.12.1 Occurrence

- Lactose is a disaccharide purely of animal origin. It is commonly called as milk sugar. It is present in the milk of mammals. Lactose is found in the urine of pregnant and lactating women.

2.12.2 Structure

- Lactose is composed of α-D-galactose and α-D-glucose held together by β - 1, 4 glycosidic linkage between glucose and galactose molecules. It exhibits mutarotation due to the presence of a carbonyl group on the carbon atom 1 of glucose unit. The enzyme lactase hydrolysis lactose into glucose and galactose.

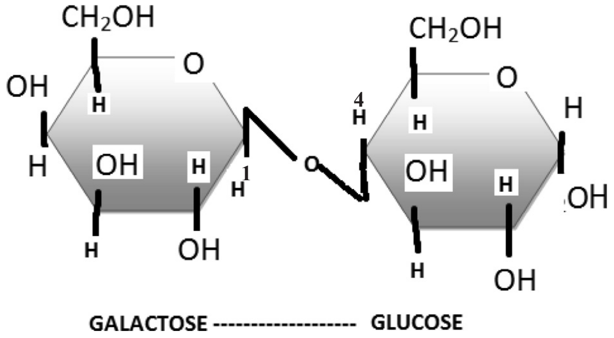


Fig 2.23 Structure of Lactose

2.12.3 Properties

- It is less soluble in water and less sweeter than sucrose.
- Lactose has low calories among sugars.

2.13 PROPERTIES OF OLIGOSACCHARIDES

- Maltose is a reducing sugar. It reduces Fehling's solution and Tollen's reagent. This shows the presence of a free aldehyde group.
- It exhibits mutarotation.
- The anomeric carbon of C_1 glucose is free, hence lactose exhibits reducing property.
- Lactose from ozazones. It also reduces Fehling's solution.
- Lactose is hydrolysed by acids or by the enzyme lactase.
- Sucrose is a non-reducing sugar. The potential aldehyde group of glucose and the ketone group of fructose are blocked in the linkage and has no free reducing group.
- It does not reduce Tollen's and Fehling's solutions and does not form osazone.
- Sucrose on hydrolysis by dilute acids or the enzyme sucrase or invertase gives a mixture of glucose and fructose. It is called as invert sugar.
- Sucrose is dextrorotatory ($+62.5^0$) but its hydrolytic products are levorotatory because fructose has a greater specific levo-rotation than the dextrorotation of glucose. As the hydrolytic products invert the rotation, sucrose is known as invert sugars and the process is called as inversion.

2.14 FUNCTIONS OF OLIGOSACCHARIDES

- Cell recoginition - The oligosaccharides and glycoproteins present on the surface of cell membrane serve as identifiers. That assists the cells in their recognition and cell adhesion.
- Recognition of immunoglobulin - The liver cells recognize immunoglobulin with the help of oligosaccharides.
- Nitrogen fixation - The oligosaccharides present on the wall of nitrogen fixing bacteria help in the binding of bacteria to the root hairs of leguminous plants.

2.15 POLYSACCHARIDES

- Polysaccharides (variously called as glycanes or polyholosides or polyosides) are high molecular weight carbohydrates.
- On hydrolysis, they yield mainly monosaccharides or products related to monosaccharides.

- They may also be regarded as polymeric anhydrides of simple sugars. D – Glucose is the commonest component of polysaccharides.
- The various polysaccharides differ from one another not only in the composition of the constituents of monosaccharides but also in the molecular weight, in the nature of the chain (linear or branched), in the type of glycosidic bond (α or β) and in the type of linkage (1-2 or 1-3 or 1-4 or 1- 6) involved in the respective monosaccharide units.
- Majority of carbohydrates of nature occur as polysaccharides. Chemically, the polysaccharides may be distinguished into homopolysaccharides (homoglycanes) and heteropolysaccharides (heteroglycanes).
- Homopolysaccharides are composed of only one type of monosaccharides. On hydrolysis, they yield only one type of monosaccharides. E.g. Starch, Cellulose, Chitin, Glycogen.
- Heteropolysaccharides are composed of mixture of monosaccharides. On hydrolysis, they yield a mixture of monosaccharides. E.g. Hyaluronic acid, Chondroitin, Heparin, Agar –Agar.
- Based on their functional aspect, the polysaccharides may be grouped into two categories. They are structural (indigestible) polysaccharides (e.g. Cellulose, Pectin and Chitin) and storage (digestible or nutrient) polysaccharides (e.g. Starch, Glycogen and Inulin).

2.15.1 Types of Polysaccharides

Polysaccharides are classified into two main types.

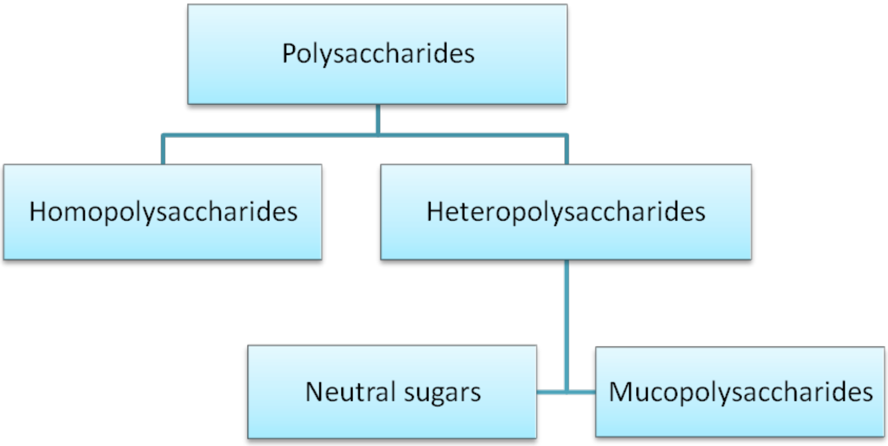


Fig 2.24 Classification of Polysaccharides

2.16 HOMOPOLYSACCHARIDES

Homopolysaccharides are non-sugars composed of only one types of monosaccharides. On hydrolysis they yield only one type of monosaccharides.

E.g. Starch, Glycogen, Inulin, Cellulose, Pectin, Chitin etc.

2.17 STARCH (HOMOPOLYSACCHARIDE AND STORAGE POLYSACCHARIDE)

2.17.1 Occurrence

- It is the most important reserve food material of the higher plants and is found in cereals, legumes, potatoes and other vegetables.
- More than half the carbohydrate ingested by humans is starch.
- Sago starch is obtained from sago palm (*Meteroxylon rumphii*), arrowroot from *Maranta arundinacea* and tapioca from *Manihot utillissima*.
- They usually occur as compact insoluble grains inside the plant cells.
- The bulk of our diet which consists of rice, wheat and vegetables is a good source of starch.

2.17.2 Structure

- Starch may occur either spherical, or oval in shape.
- They differ in size according to their sources.
- Generally, they appear to consist of concentric rings with a hilum in the centre.
- It consists of two components - amylose (15-20%) and amylopectins (80-85%).
- Starch from waxy corn consists of amylopectin component and no amylose.

Amylose Structure

- It has a molecular weight range of 10,000 to 50,000. It is a long unbranched straight chain.
- Amylose forms the inner portion of starch grains and is soluble in water and less viscous.

- It may be formed in plant cells by elimination of water from glycosidic OH group of one α-D-glucose molecule and alcoholic OH group on carbon 4 of the adjacent α-D-glucose molecule. The linkage is α 1-4 glycosidic linkage.

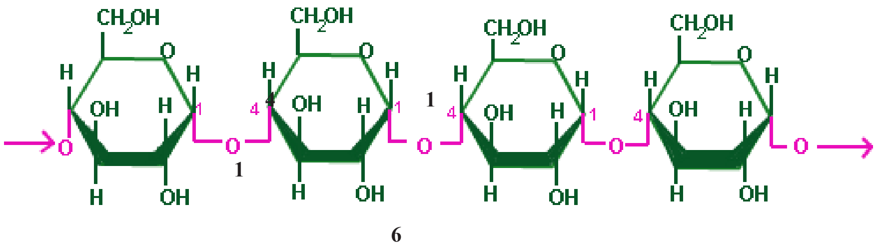


Fig 2.25 Structure of α - amylose

Amylopectin Structure

- In amylopectins, glucose molecules are arranged in highly branched form.
- They have much larger molecular weights of up to 1 million and the chains have at least 80 branches, each branch at interval of 24-30 glucose units.
- Branch point occurs at the 6th carbon atom of glucose molecule. Hence amylopectins have both (1-4) and (1-6) glycosidic linkages.
- Amylopectins form the outer covering of starch grain and is insoluble in H_2O.

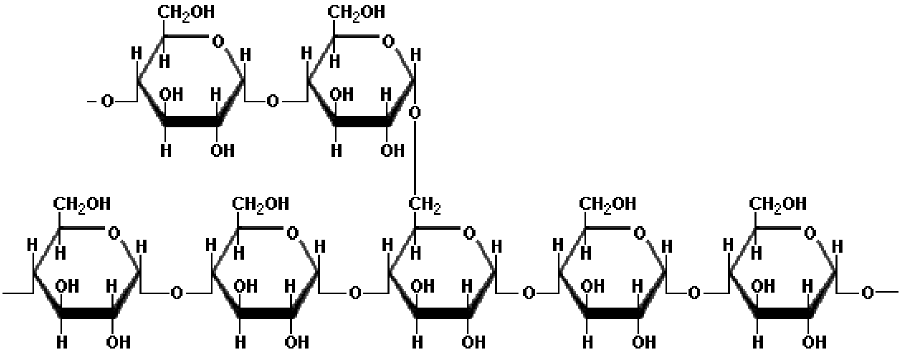


Fig 2.26 Structure of amylopectin

Table 2.2. DIFFERENCES BETWEEN AMYLOSE AND AMYLOPECTIN

Property	Amylose	Amylopectin
1. Molecular Weight	Low, about - 60,000	High, about 1 million
2. Number of glucose units	About 300 units	About 1000 units

3.	Solubility in water	Highly soluble	Sparingly soluble or insoluble
4.	Colour with dilute iodine solution	Blue colour	Violet colour
5.	Branching	Absent	Present
6.	Type of linkage	Only α (1- 4) glycosidic linkage is present.	Both α (1- 4) and α (1- 6) glycosidic linkages are present.

2.17.3 Properties

- Starch is a white, soft, amorphous powder and lacks sweetness.
- It is insoluble in water, alcohol and ether at ordinary temperature.
- The specific rotation of starch is + 196º.
- Starch breaks down into larger fragments called dextrins on heating in the presence of moisture. These dextrins are responsible for the stiffness of clothes which have been starched and ironed. It is called as "Washer Man's Starch". They are also used as adhesives on paper products.
- Since number of exposed OH groups are present in the structure, starch forms turbid colloidal solution when it is extracted from granules with hot water.
- Starch as a whole is insoluble in cold water. When it is heated with water the amylopectin absorbs water, swells up and bursts to form a paste, with amylose, diffusing into the water. This is carried out at a temperature between 60° - 80° C. This mixture of amylose and amylopectin in water is called as starch paste and is used as an adhesive.
- The enzyme amylase from saliva and pancreatic juice can hydrolyse starch to larger units called "dextrin" and finally to maltose. The dextrins give a bluish colour with iodine in the early stages of hydrolysis and later do not give any colour at all. They are accordingly called as

  Amylodextrins - give blue colour with iodine
  Erythrodextrins - give red colour with iodine
  Achrodextrins - give no colour with iodine.

- Hydrolysis of starch can also be brought about by boiling with dilute acids.
- Starch is a glucosan since it yields only glucose molecules on hydrolysis.

2.18 CELLULOSE (HOMOPOLYSACCHARIDE AND STRUCTURAL POLYSACCHARIDE)

2.18.1 Occurrence

- Cellulose is a structural polysaccharide acts as a chief constituent of the fibrous parts of plants and is the most abundant organic material in nature.
- Cellulose is often found associated with other structural substance such as lignin.
- Flax, ramic and cotton contain 97-99% of cellulose. Wood contains 41-53% of cellulose. Cercal straws contain 30-43% of cellulose.
- Cellulose used for experimental studies is prepared from raw cotton by extraction with organic solvents to remove lipids and other soluble impurites.
- It is also present in certain tunicates.

2.18.2 Structure

- Its molecular weight ranges between 2,00,000 and 20,00,000 corresponding to 1,250-12,500 glucose units per molecule.
- It is a linear unbranched structure.
- It is made up of β-D glucose units which are linked by β (1-4) linkages. The linkage involves glycosidic OH group of one β-D-glucose unit and alcoholic OH group at C-4 of the adjacent β-D- glucose molecule.
- It resembles the structure of amylose in starch except that the glucose units here are linked together by β (1-4) linkages where as in amylose it is α (1-4) linkage.
- Due to the difference in chemical structure, cellulose is not acted upon by the enzyme amylase which is present in the digestive juices.

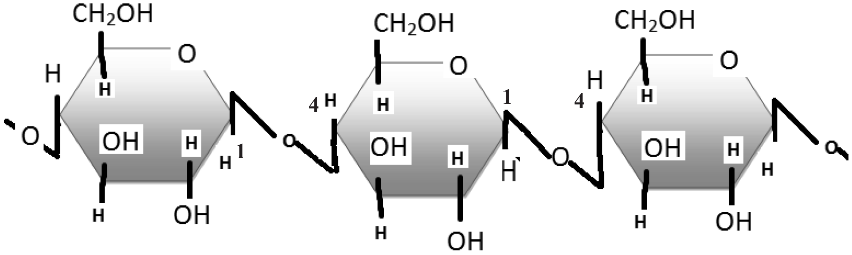


Fig 2.27 Structure of Cellulose

2.18.3 Properties

- It is fibrous, tough, white solid, insoluble in water but soluble in ammoniacal cupric hydroxide solution and in HCl solution of zinc chloride.
- It gives no colour with iodine and lacks sweetness.
- Because of the lack of chemical reactivity, cellulose is of no nutritive value.
- In man, cellulose is not digested because of the absence of appropriate hydrolyzing enzyme (cellulase).Hence it serves as an important source of "bulk" in the diet.
- However, microorganisms such as *Trichonympha* can digest cellulose because these microoranisms secrete an enzyme called cellulase which can break β (1-4) linkages.
- Wood-rot fungi and bacteria also produce cellulase. So that, they can easily digest cellulose.
- Cellulose is a chief food material for ruminants. As they are having cellulase secreting microorganisms in their digestive tract, they can easily digest cellulose.
- On partial hydrolysis, a disaccharide called cellobiose is formed.
- Cellulose is a relatively inert material and it is completely hydrolysed only under most drastic conditions.
- For e.g. it is hydrolysed to glucose when treated with conc. H_2SO_4 or HCl or with conc. NaOH.

2.19 GLYCOGEN

2.19.1 Occurrence

- Glycogen is a homopolysaccharide. It is a glucan because on hydrolysis it yields glucose.It is the major reserve carbohydrate in animals. So it is called as animal starch. It is stored mainly in the liver and muscles of all animals. It is a white powder. It does not dissolve in water. The solution gives reddish brown colour with iodine.

2.19.2 Structure

- It is a branched polymer of glucose with α - 1, 4 and α-1, 6 types of linkages. The external branches of glycogen molecules contain 6 to 7 glucose units. The internal branches contain only 3 glucose units.

- In the main stem, glucose units are linked by α-1, 4 linkage. In the branching points they are linked by α-1, 6 linkage or α-1, 4 linkage. Glycogen resembles amylopectin of starch chemically.
- It is a non reducing sugar.The liver glycogen supplies glucose to all tissues through the blood.
- The blood always contains 1% glucose. When it exceeds 1%, the excess glucose is transported to the liver. This process is called glycogenesis.
- When blood sugar level is below 1% the liver glycogen is changed into blood glucose. This process is called glycogenolysis.
- Muscle glycogen is utilized as the energy source during muscle contraction.

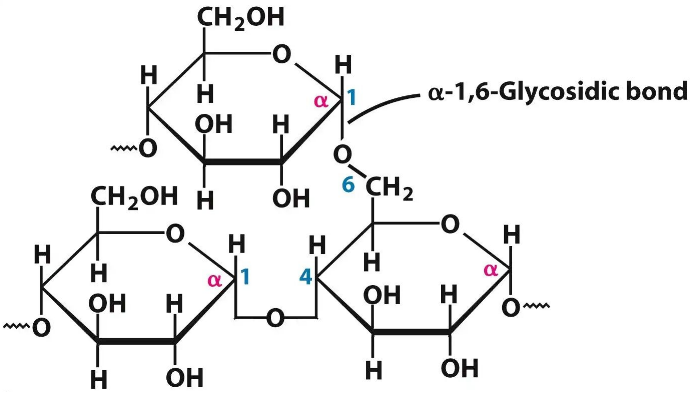


Fig 2.28 Structure of Glycogen

2.19.3 Properties

- Glycogen is a non-osmotic molecule, so it can be used as a solution to store glucose in the cell without disrupting osmotic pressure.

2.20 CHITIN

It is a homopolysaccharide.

It is formed of N-acetyl glucosamine.

It is related to cellulose. The alcoholic OH group on carbon atom 2 of β-D glucose units is replaced by N-acetylamino group.

The N-acetyl glucosamine units are linked by β-1, 4 glycosidic linkage.

It is found in the exoskeleton of insects and crustaceans and in the cell walls of fungi.

On hydrolysis with mineral acid, it gives glucosamine and acetic acid.

Chitin is decomposed to N-acetyl glucosamine by chitinase present in the gastric juice of snails or from bacteria.

2.21 HETEROPOLYSACCHARIDES

Heteropolysaccharides are non-sugars composed of a mixture of monosaccharides. On hydrolysis, they yield a mixture of monosaccharides.

E.g. Neutral sugars such as hemicelluloses, gums etc.

Mucopolysaccharides such as hyaluronic acid, chondroitin, chondroitin sulfate,

keratosulfate, heparin etc.

2.21.1 Classification of Heteropolysaccharides

Heteropolysaccharides are further classified into two types, namely

- Neutral sugars
- Mucopolysaccharides

Neutral sugars - It gives more than one type of sugar units on hydrolysis and sometimes non sugar components also.

Mucopolysaccharides - Mucopolysaccharides are long chain of sugar molecules that are found throughout the body, often in mucus and in fluid around the joints. They are more commonly called glycosaminoglycans. These are gelatinous substances. They are heteropolysaccharides. E.g. Hyaluronic acid, Agar agar, Chondroitin.

2.22 HYALURONIC ACID

It is a heteropolysaccharide and mucopolysaccharide. Hyaluronic acid is also called hyaluronan.

2.22.1 Occurence

It is an anionic, nonsulfate glycosaminoglycans distributed widely throughout connective, epithelial and neural tissues.

2.22.2 Structure

It is a straight chain polymer of disaccharides which form the repeating unit. Each disaccharide unit is formed of D-glucuronic acid an N-acetyl D-glucosamine linked by β-1, 3 linkage.

On Hydrolysis, hyaluronic acid yields an equimolecular mixture of D-glucuronic acid, D-glucosamine and acetic acid.

Hyaluronic acid is split by the enzyme hyaluronidase. The sperm is rich in hyaluronidase and hence can advance better in the cervical canal and finally fertilize the ovum.

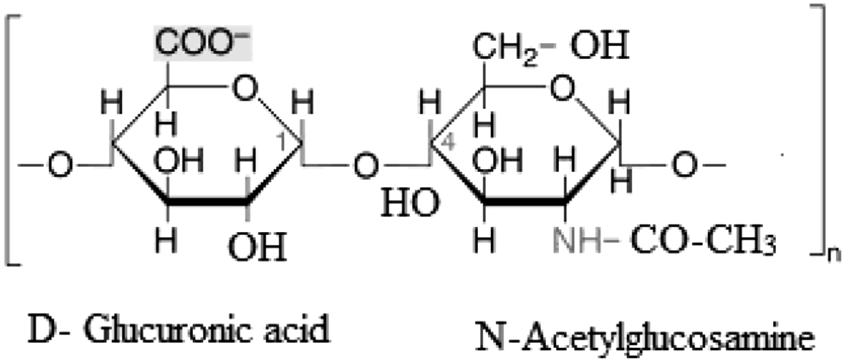


Fig 2.29 Structure of Hyaluronic acid

2.22.3 Properties

- It is highly viscous substances
- It acts as a lubricant and as biological cement in connective tissues.

2.23 CHONDROITIN

Chondroitin is a mucopolysaccharide.

2.23.1 Occurrence

It is found in cartilages and is also component of cell coats.
It is a parent substance for chondroitin sulfate.

2.23.2 Structure

It is a straight chain polymer of disaccharides which form the repeating units. Each disaccharide is linked to the next by β-1, 3 linkages.

Each disaccharide unit is formed of a D-glucuronic acid and N-acetyl D-galactosamine joined by β - 1, 3 linkages.

Thus chondroitin is similar to hyaluronic acid. In chondroitin, galactosamine is present instead of glucosamine.

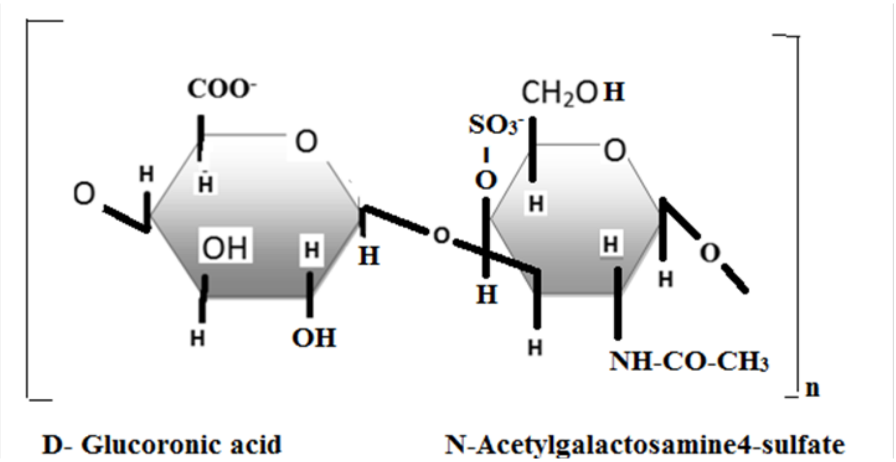


Fig 2.30 Structure of Chondroitin 4-sulfate

2.23.3 Properties

- It provides resistance to compression.
- Along with glucosamine, chondroitin sulfate has become a widely used dietary supplement for treatment of osteoarthritis.

2.24 AGAR-AGAR

2.24.1 Occurrence

Agar- Agar is a commercially important product. It is used extensively in biology laboratories for the production of culture media for bacteria, fungi etc. It is also used in the preparation of medicines and in cosmetics and leather industry.

2.24.2 Structure

Agar-Agar is a heteropolysaccharide because it yields a mixture of monosaccharides on hydrolysis. It has a gel-like consistency.

It consists of D and L galactose in a ratio of 9:1.

It is produced by certain red algae such as Gelidium, Gracilaria, Gigartina, Eucheuma, Campylaephora, Hypner etc.

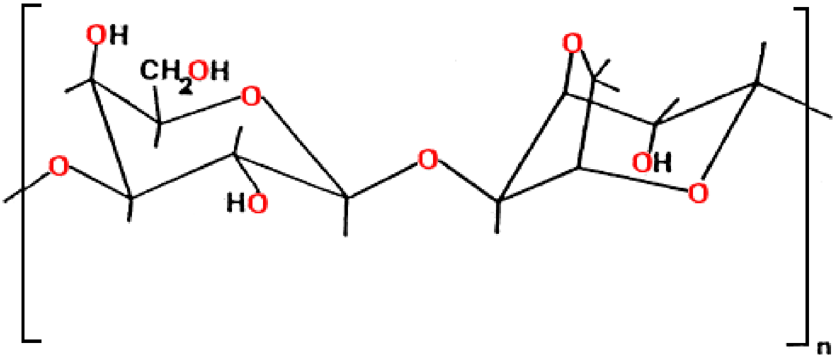


Fig 2.31 Structure of Agar Agar

2.24.3 Properties

It is acidic in nature. Hence it is an acidic heteropolysaccharide. That acidity is due to the presence of sulphuric acid.

2.25 HEPARIN

Heparin is a heteropolysaccharide because it yields mixtures of monosaccharides and their derivates.

It is a mucopolysaccharide because it has gel- like consistency.

It contains uronic acid and sulfuric acid and is acidic in nature.

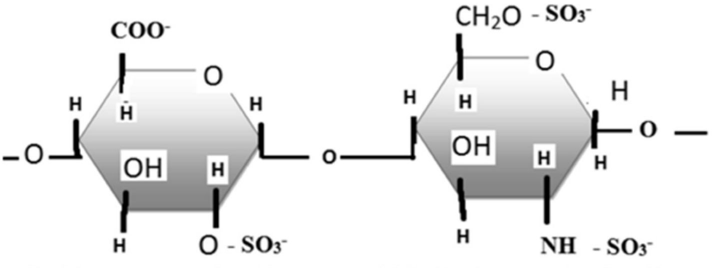
Hence it is also called acidic heteropolysaccharide.

It functions as an anticoagulant because it prevents coagulation or clotting of blood.

It is a straight chain polymer composed of D-glucuronic acid and D-glucosamine-N-sulfate. It contains an additional O-sulfate group at C_6.

The two molecules are linked by 1 → 4 linkages only and 1 → 3 linkages is absent.

The D-glucuronic acid is esterified at carbon atom number 2.



D-Glucouronate-2-sulfate **N-Sulfoglucosamine6- sulfate**

Fig 2.32 Structure of Heparin

2.26 FUNCTIONS OF CARBOHYDRATES

- Carbohydrates provide energy for body functions and for doing work.
- They are structural components of many organisms.
- They exert a sparing action on protein.
- They provide the carbon skeleton for the synthesis of some non essential amino acids and fats.
- Some carbohydrates are present as tissue constituents.
- Starch forms the main source of carbohydrates in the diet.
- Glycogen is the major reserve carbohydrate in animals and is often called animal starch. It is stored in liver and muscle of animals.
- Cellulose is widely distributed in plant sources. It occurs in the cell walls of plants where it contributes to the structure. It is the main constituents of the supporting tissues of plants and forms a considerable part of vegetables.
- Pectin and hemicelluloses are present in fruits of many plants and serve as jelling agents.
- Hyaluronic acid occurs in synovial fluid in skin and in tissues. It acts as cementing substances in tissues and also acts as a lubricant. It is also present in vitreous humor.
- Heparin is used in medicine as an anticoagulant and prevents blood clotting.
- Keratan sulphate is an important component of cartilage and cornea.
- Lactose is otherwise called as milk sugar. It is present in milk and is made up of monosaccharides (i.e.) glucose and galactose.

$$\text{Glucose} + \text{Galactose} \longrightarrow \text{Lactose}$$

- Maltose is otherwise known as malt sugar and is present in germinating cereals, malt etc. It is the intermediate product in the hydrolysis of starch by amylase in the alimentary canal. It is made up of 2 molecules of glucose.

$$\text{Glucose} + \text{Glucose} \longrightarrow \text{Maltose}$$

- Sucrose is otherwise called as table sugar or cane sugar. It is the common sugar and is widely distributed in all photosynthesis plants. It does not exist in the body but occurs in sugarcane, pineapple, sweet potato and honey. It is made up of glucose and fructose.

UNIT III

AMINO ACIDS AND PROTEINS

Aminoacids: Structure, Specific rotation, Distribution and location in proteins, Classification: Based on Composition, Number of Amino and Carboxylic groups, Polarity of R group, Metabolism, Nutritional requirements, Non standard protein amino acids, Non protein amino acids, Physical and Chemical properties.

Proteins: Biologically important proteins, Sources, Nutritive value, Biological functions, Elemental composition, Classification – Based on solubility and shape, Structure complexity. Ramachandran plot. Structural organization of proteins: primary, secondary, tertiary and quaternary structure. Bonds involved in protein structure, Properties, Tests for proteins.

3

AMINO ACIDS AND PROTEINS

3.1 STRUCTURE OF AMINO ACIDS

- Each amino acid is a nitrogenous compound having both an acidic carboxyl (COOH) group and a basic amino (NH_2) group.
- The amino acids are regarded as building blocks of proteins.
- The general formula of an amino acid is presented below

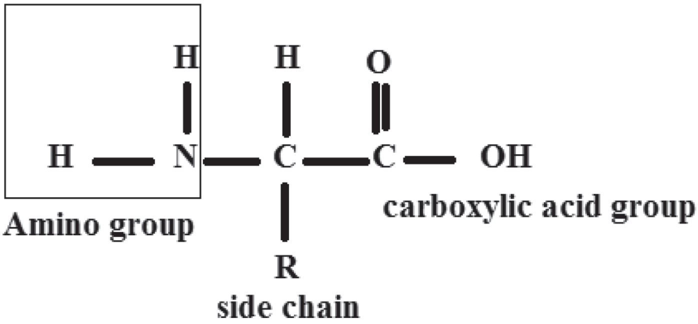


Fig 3.1 Structure of Amino acid

- **"**R" stands for the side chains that are different for each amino acid. "R" can be as simple as a hydrogen atom (H) or a methyl group (CH_3) or a more complex structure.
- The first carbon is the part of the carboxyl group. The second carbon, to which the amino group is attached, is called the α carbon.
- The α carbon of most of the amino acids is joined by covalent bonds to four different groups of atoms.
- Thus, the α carbon atom in all amino acids is asymmetric except in glycine, where the α carbon is symmetric.
- Amino acids (except glycine) exist in two optically active forms due to the presence of asymmetrical carbon atom: those having - NH_2 group to the right are designated as D-forms and those having - NH_2 group to the left as L-forms.

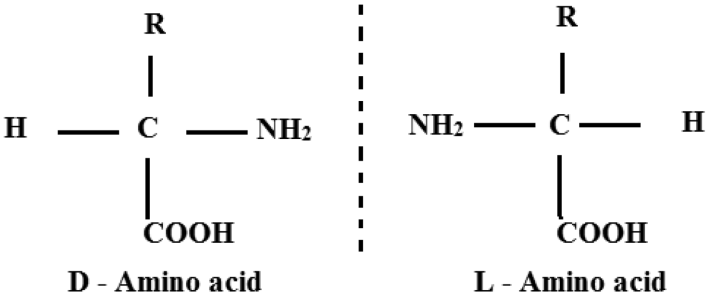


Fig 3.2 D and L forms of Amino acid

- However, the two amino acids, threonine and isoleucine have two asymmetric carbon atoms each and thus have $2^n = 2^2 = 4$ optical isomers.
- At pH 7.0, both the carboxyl and amino groups are ionized. The amino acids found in the proteins belong to the L- series.

3.1.1 Specific Rotation

- It is interesting to note that the amino acids found in the proteins belong to the L-series.
- Many of the naturally occurring L-amino acids rotate the plane of polarized light to the left (i.e., they are levorotatory) while others rotate the plane of polarized light to the right (i.e., they are dextrorotatory).
- Thus, it is evident that the symbols D and L do not identify the property of light rotation, i.e. D-isomers can be either dextrorotatory (d) or levorotatory (l); similarly, L-isomers can be either dextrorotatory (d) or levorotatory (l).
- However, to minimize confusion, the symbols d and l are usually not used nowadays. Moreover, the DL nomenclature has limitations because it describes the asymmetry of only one carbon atom in a compound and many biomolecules contain two or more asymmetric carbon atoms.
- The R and S classification or RS notation of isomers, introduced in 1956 by Robert Cahen, Christopher Ingold and Vladimir Prelog are currently being used in chemistry. This is more useful for defining the asymmetry of biomolecules because it accounts for all asymmetric carbons in an isomer.
- If any atom (other than H) or group on the asymmetric carbon is on the right side, that asymmetric carbon is designated as R (from *rectus*^{L} = right); conversely, if any atom (other than H) or group is on the left side, the asymmetric carbon is then designated as S (from *sinister*^{L} =left).

3.1.2 Distribution in Proteins

- The distribution of the 20 amino acids is not uniform in all proteins. Nearly 40% by weight of fibroin and 25% by weight of collagen are accounted for glycine.
- Fibroin is all rich in alanine (30% by weight). Serine and threonine predominate in casein and phosvitin.
- Collagen (in connective tissue), gliadin (in wheat) and zein (in corn) are rich in proline. Human serum albumin with 585 amino acid residues has only one tryptophan moiety.
- The pulse is notable as it lacks S-containing amino acid, methionine (Met) but contain good amount of the basic amino acid, lysine (Lys); whereas cereals lack lysine but have sufficient quantity of methionine. When combined, these alter the deficiency of each other through mutual supplementation and are better utilized in human body.

3.1.3 Location of Proteins

- Amino acids with uncharged polar side chains are relatively hydrophilic and are usually on the outside of the proteins, while the side chains on non polar amino acids tend to cluster together on the inside.
- Amino acids with acidic or basic side chains are very polar and they are nearly always found on the outside of the protein molecules.

3.2 CLASSIFICATION OF AMINO ACIDS

3.2.1 On the Basis of the Composition of the Side Chain or R Group

Based on the composition of the side chain, the twenty amino acids may be grouped into following 8 categories.

- **Simple amino acids**: These have no functional groups in the side chain, e.g. Glycine, Alanine, Valine, Leucine and Isoleucine.
- **Hydroxy amino acids**: These contain a hydroxyl group in their side chain, e.g. Serine and Threonine.
- **Sulfur-containing amino acids:** These possess a sulfur atom in the side chain, e.g. Cysteine and Methionine.
- **Acidic amino acids**: These have a carboxyl group in the side chain, e.g. Aspartic acid and Glutamic acid.

- **Amino acid amides**: These are derivatives of acidic amino acids in which one of the carboxyl group has been transformed into an amide group (-CO.NH2), e.g. Asparagine and Glutamine.
- **Basic amino acids**: These possess an amino group in the side chain, e.g. Lysine and Arginine.
- **Heterocyclic amino acids**: These amino acids have a ring in their side chain which possess at least one atom other than the carbon, e.g. Tryptophan, Histidine and Proline.
- **Aromatic amino acids**: These have a benzene ring in the side chain, e.g. Phenylalanine and Tyrosine.

3.2.2 On the Basis of the Number of Amino and Carboxylic Groups

McGilvery and Goldstein (1979) have classified twenty amino acids as follows:

- **Monoamino-monocarboxylic amino acids:**
    - ♦ **Unsubstituted** – Glycine, Alanine, Valine, Leucine, Isoleucine
    - ♦ **Heterocyclic** – Proline, Histidine
    - ♦ **Aromatic** – Phenylalanine, Tyrosine, Tryptophan
    - ♦ **Thioether** – Methionine
    - ♦ **Hydroxyl** – Serine, Threonine
    - ♦ **Mercapto** – Cysteine
    - ♦ **Carboxamide** **–** Asparagine, Glutamine
- **Monoamino-dicarboxylic amino acids**: Aspartic acid, Glutamic acid
- **Diamino-monocarboxylic amino acids**: Lysine, Arginine,

3.2.3 On the Basis of Polarity of the Side Chain or "R" Group

Amino acids is based on the polarity of the R groups present in their molecules, it is classified as follows.

- **Amino acids with non polar R groups:**
  The R groups in this category of amino acids are hydrocarbon in nature and thus hydrophobic. This group includes five amino acids with aliphatic R groups (alanine, valine, leucine, isoleucine, proline), two with aromatic rings (phenylalanine, tryptophan) and one containing sulfur (methionine).

- **Amino acids with polar but uncharged R groups:**
  The R groups of these amino acids are more soluble in water i.e. more hydrophilic than those of the non polar amino acids because they contain functional groups that form hydrogen bonds with water. This category includes 7 amino acids, viz., glycine, serine, threonine, tyrosine, cysteine, asparagine and glutamine. The polarity of these amino acids may be due to either a hydroxyl group (serine, threonine, tyrosine) or a sulfhydryl group (cysteine) or an amide group (asparagines, glutamine).
- **Amino acids with negatively charged (=acidic) R groups:**
  These are monoamino-dicarboxylic acids. In other words, their side chain contains an extra carboxyl group with a dissociable proton. The resulting additional negative charge accounts for the electrochemical behaviour of proteins. The two amino acids which belong to this category are aspartic and glutamic acid.
- **Amino acids with positively charged (=basic) R groups:**
  These are diamino-monocarboxylic acids. In other words, their side chain contains an extra amino group which imparts basic properties to them. Lysine, arginine and histidine belong to this category.

3.2.4 Based on Metabolism

- Purely Ketogenic: Leucine is purely ketogenic because it is converted to ketone bodies.
- Ketogenic and Glucogenic: Lysine, Isoleucine, Phenylalanine, Tyrosine and Tryptophan are partially ketogenic and partially glucogenic. During metabolism, part of the carbon skeleton of these amino acids will enter the ketogenic pathway and the other part to glucogenic pathway.
- Purely glucogenic: All the remaining 14 amino acids are purely glucogenic as they enter only into the glucogenic pathway.

3.2.5 Based on Nutritional Requirements

The amino acids may further be classified according to their essential nature for growth.

- **Essential or indispensible amino acids:**
  - ♦ Isoleucine, Leucine, Threonine, Lysine, Methionine, Phenylalanine, Tryptophan and Valine are essential amino acids.

- **Partially essential or semi-essential amino acids**
  - ♦ Histidine and Arginine are semi essential amino acids.
- **Non essential or Dispensable amino acids**
  - ♦ The remaining 10 amino acids are non-essential, because their carbon skeleton can be synthesized by the body. The non essential amino acids are alanine, aspargine, aspartic acid, cysteine, glutamine, glutamic acid, glycine, proline, serine, tyrosine.

3.3 NON STANDARD PROTEIN AMINO ACIDS

- In addition to the above-mentioned twenty standard amino acids, several other amino acids exist.
- As an example, hydroxyproline has a limited distribution in nature but constitutes as much as 12% of the composition of collagen, an important structural protein of animals.
- Similarly, hydroxylysine is also a component of collagen, where it accounts for about 1% of the total amino acids.
- N-methyl lysine is found in myosin, a contractile protein of muscle. Another important nonstandard or less common amino acid is γ-carboxyglutamate, which is found in the blood clotting protein, prothrombin as well as in certain other proteins that bind Ca^{2+} in their biological function.

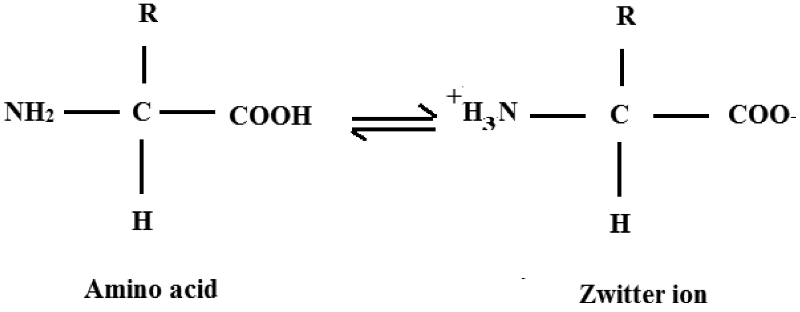
3.4 NON PROTEIN AMINO ACIDS

- There are some 300 additional amino acids which are never found as constituents of proteins but which either play metabolic roles or occur as natural products.
- Non protein amino acids are L-ornithine, L-citrulline, β-alanine, creatine and γ-amino butyrate (play metabolic role).
- L-ornithine and L-citrulline occur in free State in the animal tissues and are metabolic intermediates in the urea cycle.
- Higher plants are especially rich in non protein amino acids. These non protein amino acids are usually related to the protein amino acids as homologues or substituted derivatives. They have a limited distribution, sometimes to a single species even.
- L-azetidine-2-carboxylic acid, a homologue of proline, accounts for 50% of the nitrogen present in the rhizome of Solomon's seal, *Polygonatum multiflorum*.

- Orcylalanine is found in the seed of cornocockle, *Agrostemma githago*. It may be considered as a substituted phenylalanine.
- Furthermore, in the toxic polypeptides of *Amanita phalloides*, in addition to hydroxyleucine, allo-threonine is also found.

3.5 PHYSICAL PROPERTIES OF AMINO ACIDS

- Amino acids are colourless crystalline substance.
- They are generally soluble in H_2O, acids, alkalies, but sparingly soluble in organic solvents.
- They have melting points ranging between 200°C to 300°C or even more. Many of the amino acids undergo more or less decomposition at or near the melting point.
- Amino acids are usually sweet, tasteless or bitter.
  - ♦ For example glycine, alanine, valine, proline, hydroxyl proline, serine, tryptophan and histidine are sweet.
  - ♦ Leucine is tasteless.
  - ♦ Isoleucine and arginine are bitter and sodium glutamate acts as valuable flavouring agent for the preparation of certain sauces and dishes.
- All amino acids except glycine are optically active since they contain asymmetric carbon atoms.
- Amino acids contain acidic and basic groups. They can both donate and accept protons, hence they are said to be amphoteric in nature. The name zwitter is derived from the German word which means "hybrid". Zwitterion (or) dipolar ion is a hybrid molecule containing positive and negatively ionic groups. Basically the proton shifts from carboxyl group to amino group of the self molecule at normal pH cellular levels.



$$NH_2-CH(R)-COOH \rightleftharpoons {}^{+}H_3N-CH(R)-COO^{-}$$

Fig 3.3 Zwitterion formation

- According to zwitter ion theory, amino acid possessing double charges (both +ve and –ve) are called zwitter ions which are electrically netural. It has been found out that in an acid solution (low pH), amino acids carry positive charge and hence they move towards cathode in an electric field.
- In alkaline solution (high pH), the amino acids carry negative charge and therefore move towards anode in electric field. But at around neutrality, the amino acids exist as inner salts or zwitter ions which do not migrate to either electrode in an electric field.

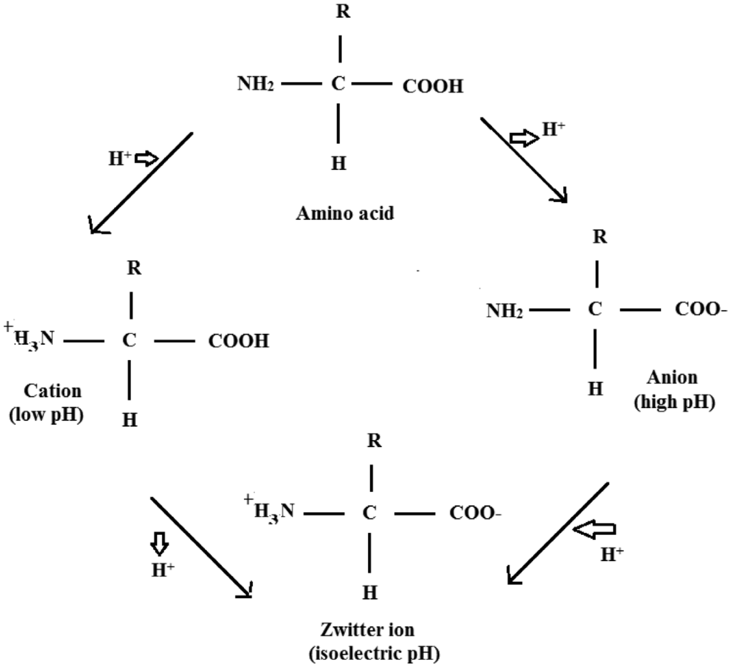


Fig 3.4 Existence of Amino acid as Cation, Anion and zwitter ion

- **Isoelectric pH:** At particular pH, amino acids do not migrate towards cathode (or) anode under the influence of electric field, is simply called "**Isoelectric point**". Isoelectric pH is defined as the pH at which a molecule exists as a Zwitter ion (or) dipolar ion and carries no net charge. Thus, the molecule is electrically neutral, but the charge will cancel each other. This is symbolized by pI. Individual amino acids have their own constant isoelectric points.

3.6 CHEMICAL PROPERTIES OF AMINO ACIDS

Chemical reactions of amino acids due to carboxyl and amino groups:

3.6.1 Due to Carboxyl Group

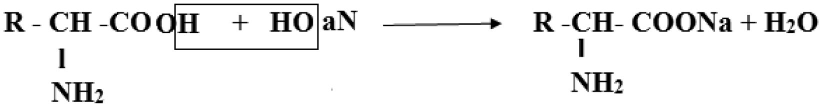
a) Decarboxylation

The amino acids will undergo alpha decarboxylation to form the corresponding "amines". Thus important amines are produced from amino acids.

- **Histidine** → Histamine + CO_2
- **Tyrosine** → Tyramine + CO_2
- **Tryptophan** → Tryptamine + CO_2
- **Lysine** → Cadaverine + CO_2
- **Glutamic acid** → Gamma Amino Butyric Acid (GABA) + CO_2

b) Reaction with Alkalies (Salt formation):

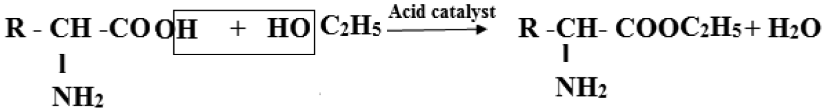
The carboxyl group of amino acids releases a H^+ ion with the formation of carboxylate (COO^-) ions. These may be neutralized by cations like Na^+ and Ca^{+2} to form salts. Thus amino acids react with alkalies to form "Salts".



$$R-\underset{\substack{|\\ NH_2}}{CH}-COO\boxed{H\ +\ HO}aN \longrightarrow R-\underset{\substack{|\\ NH_2}}{CH}-COONa + H_2O$$

c) Reaction with Alcohols (Esterification):

The amino acids react with alcohol to form "Ester".

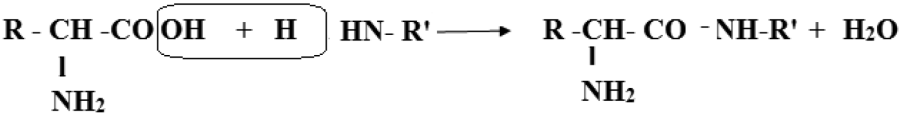


$$R-\underset{\substack{|\\ NH_2}}{CH}-COO\boxed{H\ +\ HO}C_2H_5 \xrightarrow{\text{Acid catalyst}} R-\underset{\substack{|\\ NH_2}}{CH}-COOC_2H_5 + H_2O$$

Ethyl ester
of amino acid

d) Reaction with Amines:

Amino acid reacts with Amines to form "Amides".



$$R-\underset{\substack{|\\ NH_2}}{CH}-CO\boxed{OH\ +\ H}HN-R' \longrightarrow R-\underset{\substack{|\\ NH_2}}{CH}-CO-NH-R' + H_2O$$

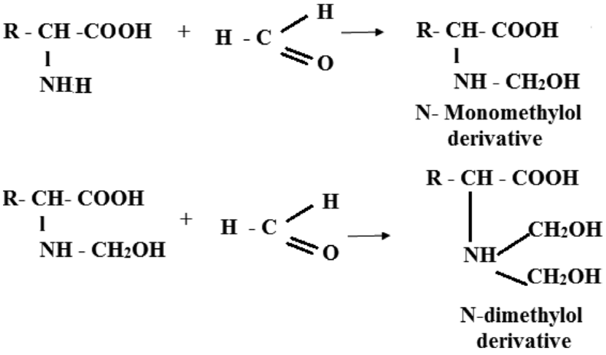
3.6.2 Due to Amino Group

a) Reaction with Mineral acids (Salt formation)

- When the amino acids are treated with mineral acids (like HCl), they form "Acid Salts".

b) Reaction with Formaldehyde

- When the amino acid reacts with two molecules of formaldehyde it forms "N-dimethylol derivative" (Hydroxy-methyl derivative). This reaction is done in two steps. These derivatives are insoluble in water and resistant to attack by microorganisms.

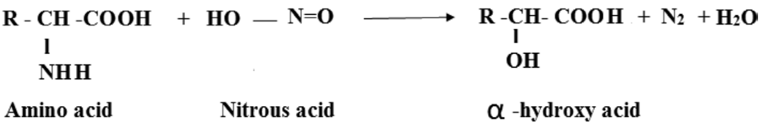


c) Reaction with Benzaldehyde:

- The amino acid reacts with benzaldehyde it gives "Schiff's base".

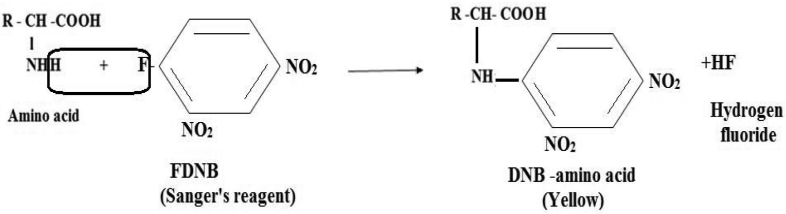
d) Reaction with Nitrous acid (Van Slyke reaction):

- When the amino acids react with nitrous acid (HNO_2) to liberate N_2 gas, it produce the corresponding "α-hydroxyl acid". The imino acids Proline and Hydroxyproline do not respond to this reaction.



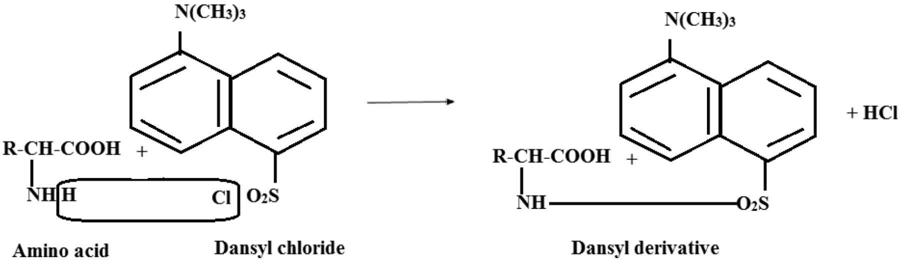
e) Reaction with Sanger's reagent:

- "1-Fluoro-2, 4-dinitrobenzene" is called Sanger's reagent (FDNB). In mildly alkaline solution, Sanger's reagent reacts with α-amino acid to produce a yellow coloured derivative, DNB-amino acid.



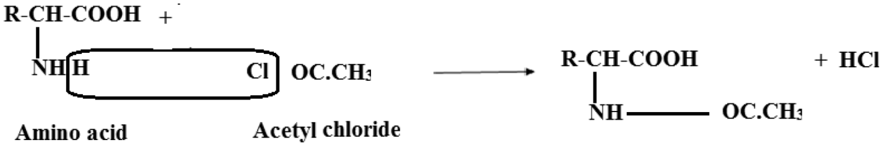
f) Reaction with DANSYl Chloride

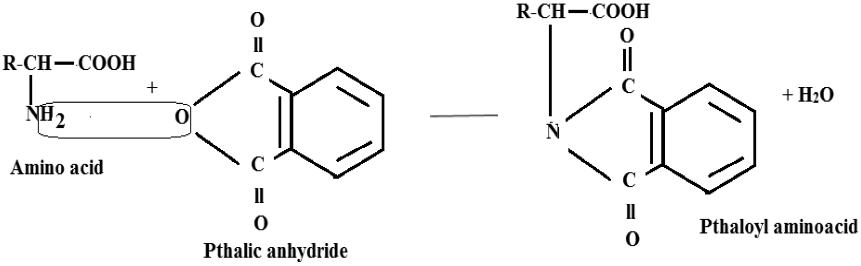
- DANSYl chloride means “Dimethyl Amino Naphtha Sulphonyl Chloride”. When the amino acid reacts with DANSYl chloride reagent, it gives a “Fluorescent DANSYl derivative”.



g) Reaction with acylating agents (Acylation):

- When the amino acids react with “Acid chloride” and acid anhydride (Pthalic anhydride) in alkaline medium it gives “pthaloyl amino acid”.



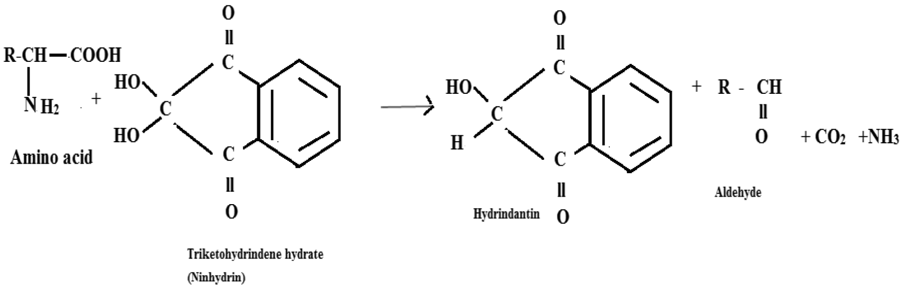


3.6.3 Due to Amino & Carboxyl Group

Ninhydrin Reaction

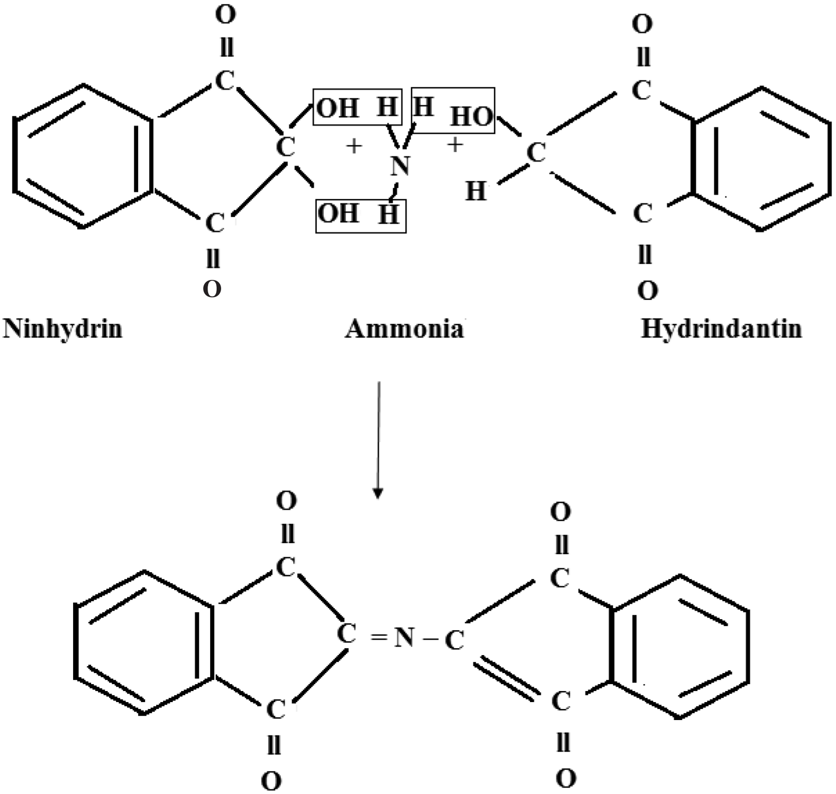
Step1

- Ninhydrin (=indane 1,2,3-trione hydrate) is a powerful oxidizing agent and causes oxidative decarboxylation of α-amino acids producing CO_2, NH_3 and an aldehyde with one less carbon atom than the parent amino acid.



Step2

- The reduced ninhydrin then reacts with the liberated NH_3 and a molecule of ninhydrin, forming Blue-colored Ruheman's complex.



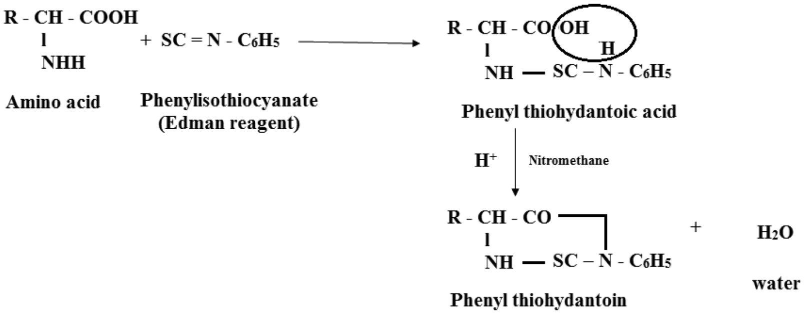
Diketohydrindylidene diketohydrindamine (Ruheman's purple)

This reaction is a very sensitive reaction and it is used for amino acid and imino acid identification. When amino acids (or) imino acid react with Ninhydrin molecule it gives colour. When it gives **Purple colour Ruheman's complex** –

the unknown sample is amino acids (which have primary amine $-NH_2$) or it gives yellow colour – the unknown sample is imino acid (**-NH-**).

Reaction with Edmann's degradation:

- Edmann's reagent is **"phenylisothiocyanate"**. When amino acids react with Edmann's reagent it gives "*phenyl thiohydantoic acid*" and finally it turns into cyclized form "*Phenyl thiohydantoin*" (Edmann's derivative).



3.7 PROTEINS

Protein is a macromolecule composed of one or more polypeptide chains possessing a characteristic amino acid sequence. It is a polymer of amino acids. Protein is the essential constituents of living cells. Proteins make up 12 % of the protoplasm. They are the body-builders. The term protein is derived from Greek: Proteuo = Primary or holding first place.

- The term protein was first proposed by **Berzelius.**
- They contain carbon, nitrogen, hydrogen, oxygen and sometimes sulphur. They are constructed largely of **amino acids.**

3.8 BIOLOGICALLY IMPORTANT PROTEINS

Thousand of proteins exist in the biological system. A few commonly available proteins are given below.

1. Plasma albumin
2. Ovalbumin in egg
3. Lactalbumin in milk
4. Plasma globulin
5. Serum globulin
6. Ovaglobulin in egg
7. Myosin in muscles

8. Edestin in hempseed
9. Glutenin in wheat
10. Oryzenin in rice
11. Zein in corn
12. Hordein in barley
13. Secalin in rye
14. Keratin in hair
15. Collagen in tendons
16. Elastin in ligaments
17. Fibroin in silk
18. Histones in nucleus
19. Sturin in sperm
20. Salmin in sperm
21. Mucin in saliva
22. Casein in milk
23. Vitelline in egg
24. Lipoprotein of blood
25. Nucleoproteins
26. Haemoglobulin
27. Myoglobulin
28. Cytochromes
29. Flavoproteins
30. Insulin
31. Oxytocin
32. Lactic dehydrogenase
33. Isozyme
34. Chymotrypsin

3.9 SOURCES OF PROTEIN

- Proteins are obtained from both animal and plant sources. The animal sources of proteins include milk, egg, meat, fish, liver etc. Plant sources of proteins are pulses, nuts and cereals.

3.10 NUTRITIVE VALUE

- The nutritive value of protein is based on two factors, namely amino acid composition and digestibility.
- All proteins do not contain all the essential amino acids. Only a few types of proteins contain the complete set of essential amino acids. Such proteins are called first class proteins and their nutritive value is high.
- Almost all the animal proteins contain all the essential amino acids. Eg. milk, milk products, meat, fish, kidney, liver, shell fish, soya beans etc.

3.11 BIOLOGICAL FUNCTIONS OF PROTEIN

- **Enzyme catalysts** – The chemical reactions in the biological system are catalyzed by enzymes. They exhibit enormous catalytic power. Thousands of enzymes have been identified in the biological system. The striking fact is that all the enzymes are nothing but proteins.
- **Transport -** Proteins transport ions and small molecules. Haemoglobin, a conjugated protein of blood, transport oxygen. Myoglobin, a muscle protein, transports oxygen in the muscles. Transferrin carries iron in the plasma of blood. The lipoproteins of plasma carry lipids from the liver to other organs. The membrane proteins transport glucose, amino acids and other nutrients across the membrane into the cell.
- **Storage -** Certain proteins function as a storage molecule. Ferritin, a protein stores iron in the liver. Seeds store nutrient proteins. Eg. Wheat, corn, rice etc.
- **Nutrients -** Certain proteins function as nutrients. The egg contains ovalbumin. The milk contains casein.
- **Contraction and Movement -** The contraction of muscle is brought about by two fibrous protein called actin and myosin. The microtubules of flagella and cilia are built on tubulin, a protein.
- **Mechanical Support -** Many proteins serve as supporting filaments, cables or sheets to give biological structures, strength, support and protection. Collagen, a fibrous protein is the major component of tendons, cartilage and leather. Ligaments contain elastin, a structural protein. Keratin, an insoluble protein, is the main component of hair, finger nails and feathers. Fibroin is the major component of silk fibres and spider web.
- **Immune Protection -** Many proteins defend organisms against invasion by other species. Invading bacteria virus, etc. elicit the production of

antibodies by lymphocytes. Antibodies neutralize the foreign germs. Antibodies are protein and immunoglobulins.

- **Blood Clotting -** Bleeding is stopped by the formation of clot. Clotting is brought about by blood clotting proteins such as fibrinogen and thrombin.
- **Transmission of Nerve Impulse -** The nerve impulse is transmitted through synapse with the help of receptor proteins. Receptor proteins at the synapse are triggered by acetylcholine.
- **Gene Expression -** In a cell, all the genes are not functioning at a time. Only a few genes are active and the other genes remain in an inactive condition. The inactivation of genes is brought about by repressor proteins especially in bacteria.
- **Hormonal Action -** Many hormones are proteins. Eg. Insulin, growth hormone, parathyroid hormone etc.
- **Thermoregulation -** The blood plasma of some antartic fish contains antifreeze proteins, which protect the blood from freezing.

3.12 ELEMENTAL COMPOSITION OF PROTEINS

All proteins contain C, H, O, N and generally S. Many proteins contain P also. Elements such as I, Fe, Cu and Zn are also occasionally present. Proteins are made up of amino acids.

Proteins are polymers of amino acids. The amino acids are the building blocks or monomers of proteins. An amino acid consists of five components namely

1. An amino group (NH_2)
2. A carboxyl group (COOH)
3. A hydrogen atom
4. An R group or a side chain or alkyl
5. A carbon atom.

There are more than 100 amino acids. All proteins of the biological system from bacteria to man are constructed out of 20 amino acid only. This is just like the 26 letters of English alphabet can make up many thousands of words. Similarly, the 20 amino acids make up thousands of proteins. For example, a bacterial cell contains 1000 to 2000 proteins and the human cell contains as many as 100000 protein molecules.

3.13 CLASSIFICATION OF PROTEINS

Proteins are macromolecules made up of amino acids. They are classified in two ways.

1. On the basis of their solubility or shape.
2. On the basis of increasing complexity of structure.

3.13.1 Classification of Proteins on the Basis of Solubility or Shape

Proteins are classified into two groups on the basis of their solubility or shape. They are globular proteins and fibrous proteins.

1. GLOBULAR PROTEINS

- Globular proteins are spherical in shape.
- They are soluble in water
- They are highly branched
- The polypeptide chains are cross linked by the usual peptide bonds.
- The globular protein molecules are tightly folded into spherical or globular shapes

Example: Enzymes, Protein hormones, Antibodies, Haemoglobin and Myoglobin

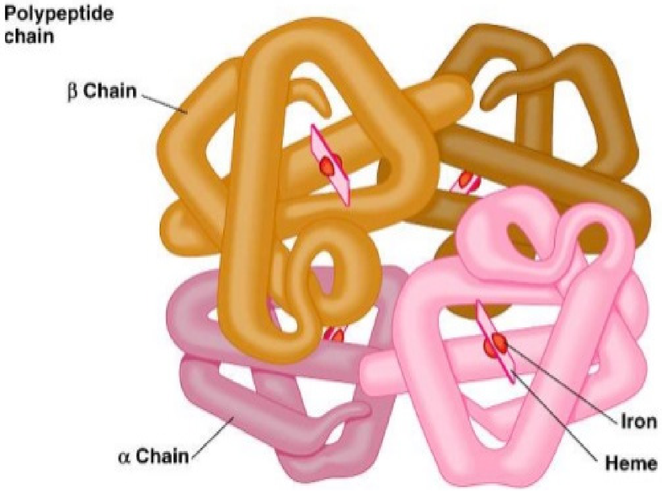


Fig 3.5 Globular proteins

2. FIBROUS PROTEINS

- Fibrous proteins are insoluble in water.
- They are in the form of fibres.
- They are highly resistant to digestion by proteolytic enzymes.
- They are unbranched.
- They are linear molecules.
- The long linear protein chains are held together by intermolecular hydrogen bonds.
- They are not folded into globular molecules.
- They serve as structural proteins.

Example : Collagen of tendons, Elastin of connective tissue, Fibroin of silk, Keratin of hair, Actin and Myosin.

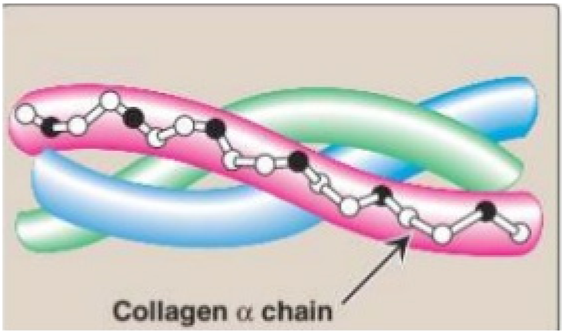


Fig 3.6 Fibrous proteins

3.13.2 Classification of Proteins Based on the Increasing Complexity of Structure

On the basis of increasing complexity of structure, proteins are classified into three groups. They are:

1. Simple proteins
2. Conjugated proteins
3. Derived proteins

SIMPLE PROTEINS

The proteins which yield amino acids or their derivatives on hydrolysis are called simple proteins. Simple proteins are further classified into 7 subtypes on the basis of the decreasing solubility.

1. Albumins

Albumins are simple proteins soluble in water. They are coagulated by heat. They are precipitated by saturated ammonium sulphate salt solution. They are deficient in glycine.

Eg: Plasma albumin, serum albumin of egg, ovalbumin of egg, white lacatalbumin of milk.

2. Globulins

Globulins are insoluble in water, but soluble in dilute solution of neutral salts. They are coagulated by heat. They are precipated by lower concentrations of salts such as ammonium sulphate or sodium sulphate. Globulins are precipated by saturated NaCl solution. They are glycine.

Eg: Plasma globulin, ovaglobulin in egg white, myosin in muscles and edestin in hemp seed.

3. Glutelins

Glutelins are insoluble in water and dilute solutions of neutral salts. But they are soluble in acids and bases. They are coagulated by heat. They are rich in arginine, proline and glutamic acid.

Eg: Glutenin in wheat, oryzenin in rice.

4. Prolamines

Prolamines are soluble in 70 to 80% ethyl alcohol. But they are insoluble in water, absolute alcohol and other neutral solvents. They are not coagulated by heat. They contain large amount of protein. They are deficient of lysine.

Eg: Zein from maize, glaidin from wheat, ordain from barley.

5. Albuminoids or Scleroproteins

These proteins are insoluble in water, dilute solutions of neutral salts, acid, bases and 60 to 80% ethyl alcohol. But they are soluble in long boiling concentration acid solutions.

Eg. Keratin in hair, feathers, nails and horn, collagen in tendons, skin and bone, elastin in ligaments and fibroin in silk.

6. Histones

Histones are simple proteins soluble in water and dilute acids, but insoluble in ammonia. They are not coagulated by heat. Histones are rich in basic amino acids like histidine and arginine, but deficient in tryptophan and contain little cystine or methionine. Histones are combined with nucleic acids and haemoglobulin.

7. Protamines

Protamines are soluble in water and ammonium hydroxide. They are not coagulated by heat. They are more basic than histones. They contain large quantities of arginine. Tyrosine and tryptophan are absent.

Eg. Salmine from salmon sperm, clupeine from hering, sturine from sturgeon.

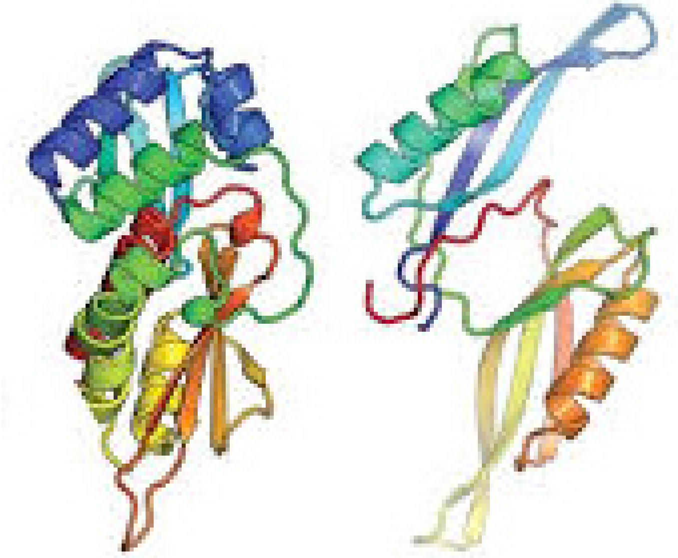


Fig 3.7 Protamines

CONJUGATED PROTEIN

Conjugated proteins are proteins united with non-protein substances. The non-protein substances linked to proteins are referred to as prosthetic group.

The protein part is called apoprotein. The prosthetic group and apoprotein are together called holoprotein. So conjugated protein, on hydrolysis yield non-protein substances in addition to amino acids.

The conjugated proteins are further classified into 5 sub types.

1. Glycoprotein or Mucoproteins

Glycoproteins contain carbohydrates as the prosthetic group. On hydrolysis, they yield amino sugars. E.g. Mucin in saliva, egg albumin, serum albumins and serum globulins.

2. Phosphoproteins

Phosphoproteins contain phosphoric acid as the prosthetic group. The phosphoric acid is attached to the hydroxyl group of protein by an ester linkage. E.g. Casein in milk and vitelline in egg yolk.

3. Lipoprotein

Lipoproteins contain phospholipids or cholesterol as the prosthetic group. E.g. Lipoproteins of blood serum.

4. Nucleoprotein

Nucleoproteins contain nucleic acid as the prosthetic group. E.g. Nuclein, nucleohistone etc.

5. Chromoproteins

Chromoproteins are coloured proteins. These are simple proteins linked to a metallic prosthetic group which gives the colour to the protein. Eg. Haemoglobin, haemocyanin, cytochromes, flavoproteins, chlorophyll etc.

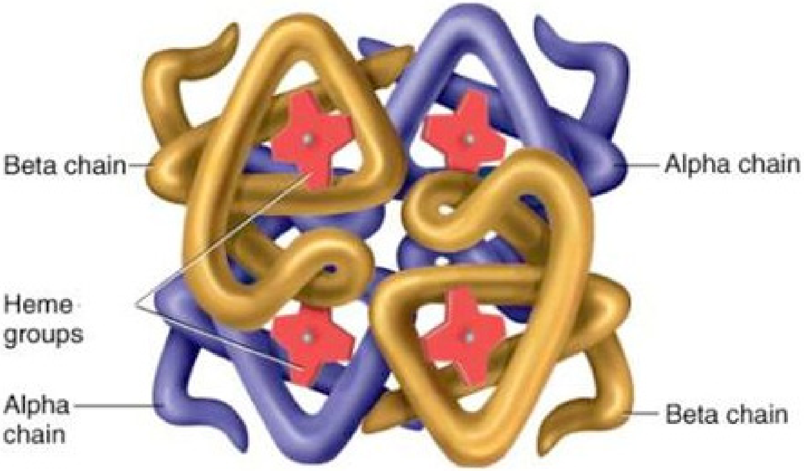


Fig 3.8 Chromoproteins

DERIVED PROTEINS

Derived proteins are the intermediate products formed from natural proteins when they are hydrolyzed by heat, acids, alkalies or enzymes. The derived proteins are of two types. They are primary derived proteins and secondary derived proteins.

a. Primary Derived proteins:

Primary derived proteins are the derivatives of proteins in which the size of the protein molecule is not materially altered. There are 3 types of primary derived proteins.

1. PROTEANS

Proteans are denatured proteins. They are the first products produced by the action of acids, enzymes or water on proteins. They are insoluble in water.

Eg. Edestan derived from edestin, Fibrin derived from fibrinogen, Myosan derived from myosin.

2. METAPROTEINS

Metaproteins are derived by the further action of acid or alkali on proteins. These are insoluble in water, but soluble in dilute acid or alkali.

3. COAGULATED PROTEINS

Coagulated proteins are insoluble protein products produced by the action of heat or alcohol on protein. Coagulated egg white is an example of this type.

a. Secondary Derived Proteins:

Secondary derived proteins are the products of proteins in which definite hydrolysis has taken place. The molecules are smaller than those of the original protein. They may be mainly of three types, namely proteases, peptones, polypeptides.

1. **Proteoses:** Proteoses are soluble in water. They are not coagulated by heat. They are precipitated by saturating their solutions with ammonium sulphate.
2. **Peptones:** Peptones are soluble in water. They are not coagulated by heat. They are also not precipitated by saturating their solutions with ammonium sulphate.
3. **Polypeptides:** Polypeptides are the derivates of proteins containing many amino acid units.

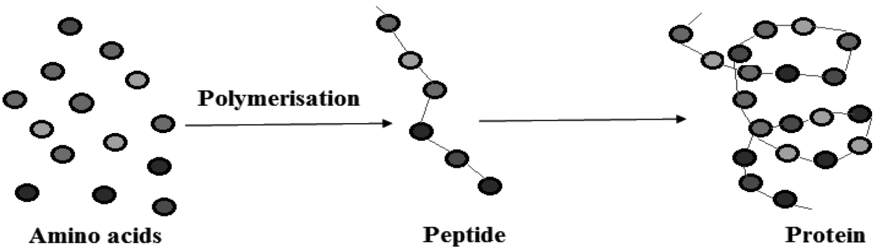


Fig 3.9 Aminoacids to Proteins

3.14 RAMACHANDRAN PLOT

- The secondary structure of proteins can be determined with the help of Ramachandran plot.
- The dihedral angles ψ against φ of amino acid residues in protein structure can be known with the help of Ramachandran plot.
- The two torsion angles of the polypeptide chain, also called Ramachandran angles.
- It describe the rotations of the polypeptide backbone around the bonds between N-Cα (called Phi, φ) and Cα-C (called Psi, ψ).

3.15 STRUCTURE OF PROTEIN

- The structure of protein depends upon its molecular size and shape. Four levels of structural organisation are primary, secondary, tertiary and quaternary structures.
- Some proteins have only first level and some other proteins have first and second levels and so on.
- These structures were first worked out by two American Scientists L. Pauling and Corey by using X- ray crystallography and later by Linderstrom – Lang.

3.15.1 Primary Structure (1°)

- This refers to the number, nature and sequence of amino acids along the peptide chain. The amino acids are linked with each other by peptide bonds only.
- The formation of disulfide bridges is also included in this organisation. The primary structure of proteins may consist of one or more peptide chains.

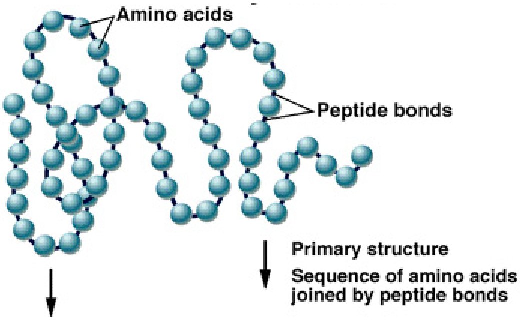
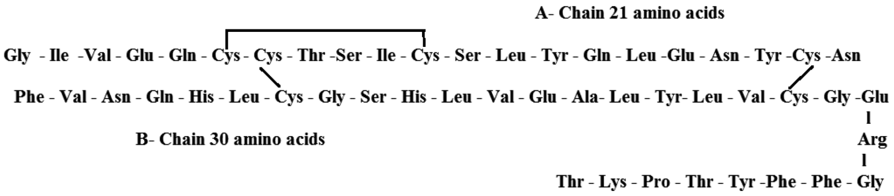


Fig 3.10 Primary Protein Structure

Examples

- Insulin is an excellent example where two peptide chains are linked together by two disulfide bonds. Both peptide and disulfide bonds are stable and individually or collectively they maintain the linear form of the protein molecule.



- **Oxytocin** – a hormone stimulating the contraction of smooth muscles especially during child birth is another example. Here, the intra-disulfide bond occurs between two cysteine units which are separated from each other in the peptide chain by four different amino acids.

Oxytocin

3.15.2 Secondary (2°) Structure (Helix Formation)

- If the peptide and disulfide bonds alone present in proteins, these molecules would have behaved as irregularly coiled peptide chains of considerable length.
- But the native proteins show regularly coiled structure which involves the formation of hydrogen bonds between the folding of the peptide chain. This brings the second level of organisation called secondary structures.
- Due to the folding and hydrogen bonding between neighbouring amino acids results in the formation of a rigid and tubular structure called as helix.
- Two types of helix conformations have been recognised. They are α type – and β type.

α HELIX

Some structural proteins are found to be in a coiled form. Details of the α– helix have been furnished by Nobel prize winner Lineaus Pauling and his co-workers in 1951.

- The α - helix is a spiral, formed by coiling of the linear polypeptide chain around the fibre axis.
- Each turn of the helix is 5.4 A° long and contains 3.6 amino acid residues, length of each residue being 1.5A°.
- This helical structure is stabilized by non - covalent hydrogen bonds linking the amide nitrogen with the carbonyl oxygen.
- The side chains of the residues project outwards. But the amino acids proline and hydroxy proline do not fit into the normal α-helix. So, they disrupt the α helical structure and cause sharp bends or changes in the direction of the chain. Because of this characteristic feature, proline and hydroxy proline along with glycine, serine and asparagine are called as "helix breaker".
- The α– helix may be either right handed or left handed. The right handed α–helix is favoured for L amino acids. Best example for α helix is α keratin which makes up the protein of hair, wool, fur, claws, hooves and feathers. The α helix is found in both fibrous and globular proteins.

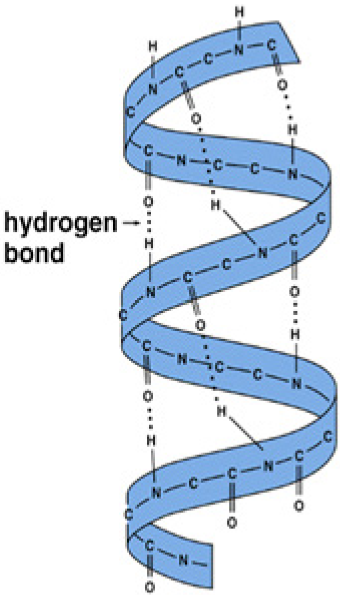
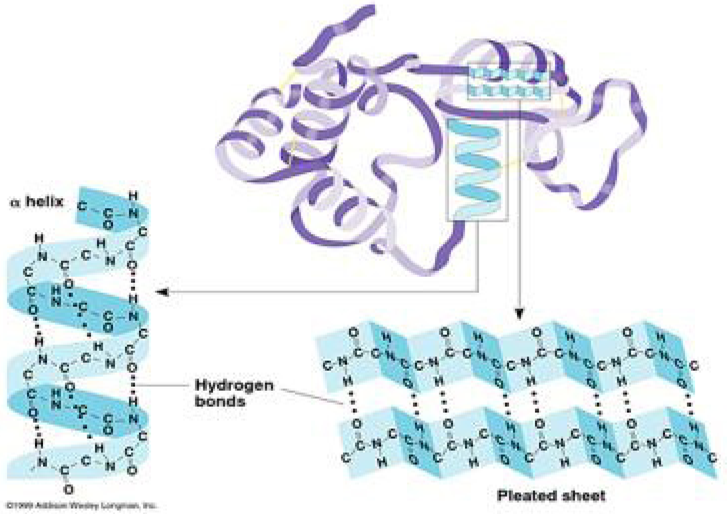


Fig 3.11 Secondary Structure of Proteins

β - PLEATED SHEET

- Pauling and Corey proposed another arrangement of protein, the β-pleated sheet structure. In α helix, the polypeptide chain is condensed whereas, in β-pleated sheet structure it is almost fully extended.

- In the β - pleated sheet structure, 2 or more peptide chains are linked together laterally by hydrogen bonds.
- The chains may be parallel or anti-parallel. In a β- pleated sheet, when the adjacent polypeptide chains run in opposite directions, the structure is termed as anti-parallel whereas, if the chains run in the same direction, it is termed as parallel.
- The anti-parallel structure permits more number of hydrogen bonding than parallel chain structure.
- Most heat treatment and stretching of α keratin convert it into β - keratin by breaking the stabilising hydrogen bonds.
- β helix is found in silk, muscle and contractile fibres. Anti-parallel structure is found in silk fibroin.



Parallel β Sheet

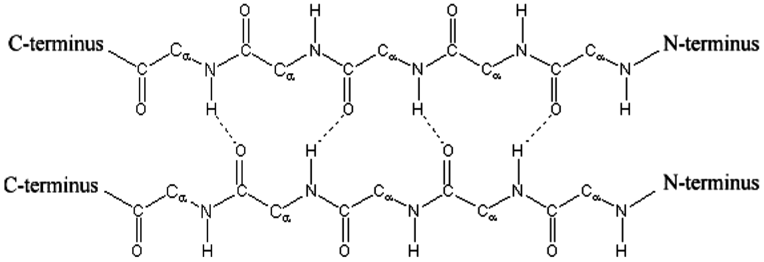
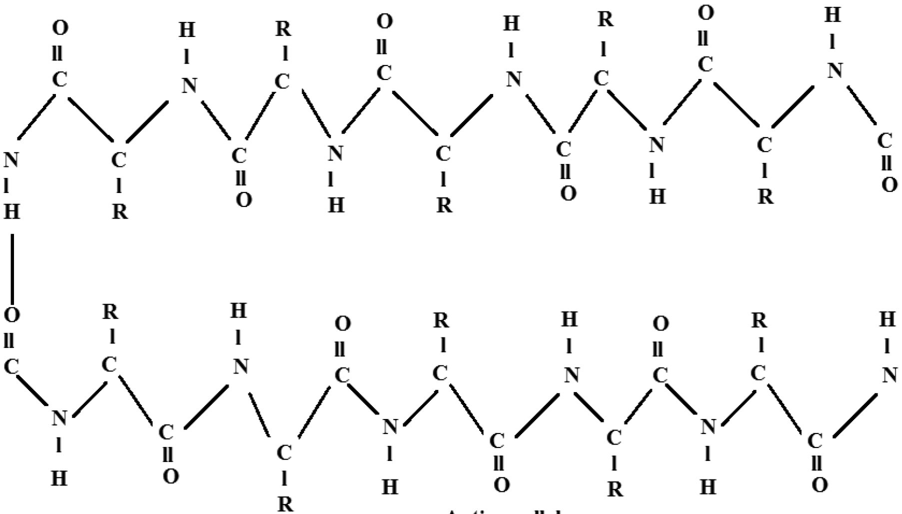


Fig 3.12 β - Pleated Sheet



Anti parallel

3.15.3 Tertiary Structure of Protein

- When a protein chain is folded in a three dimensional arrangement, a compact and tightly folded structure is formed and designated as tertiary structure.
- Most of the native proteins occur in this state and the shape is stabilized by intermolecular bonds like
    - ♦ Interpeptide hydrogen bonds
    - ♦ Side chain hydrogen bonds
    - ♦ Ionic bonds and
    - ♦ Hydrophobic interactions, so that the distant regions of the chain are brought closer.
- The folded proteins may be spherical, globular or ellipsoidal. The tertiary structure refers the folding of the helices of globular proteins. X-ray crystallography studies reveals the 3D structure.
- The tertiary structure describes the conformation of the entire protein. Example is myoglobin.
- Myoglobin is the first protein whose tertiary structure was established by Kendrew using X-ray diffraction technique.
    - ♦ Molecular weight of myoglobin is 16,700.
    - ♦ It is an iron containing protein acting as storehouse of oxygen in the muscle.
    - ♦ In contains a single polypeptide chain of 153 amino acids.

- ♦ There are no SH groups, hence no disulfide bonds.
- ♦ The myoglobin chain is folded back on itself in a complex arrangement without any symmetry within the molecule.
- ♦ The backbone of the molecule is made up of 8 more or less straight helical segments interrupted or alternated by non – helical bends which twist to produce the characteristic folding. The longest helical segment has 23 amino acids and the shortest has only seven residues.
- ♦ All the helical segments are right handed α – helix.
- ♦ The tertiary structure gives the myoglobin a very compact structure with little space which can accommodate only four water molecules.
- ♦ All the polar R – groups except two are located on its outer surface and all of them are hydrated whereas, non polar R – groups are located in the interior of the molecule.
- ♦ Each of the 4 proline residues occurs at a turn. Other turns and bends are occupied by serine, threonine and asparagines.

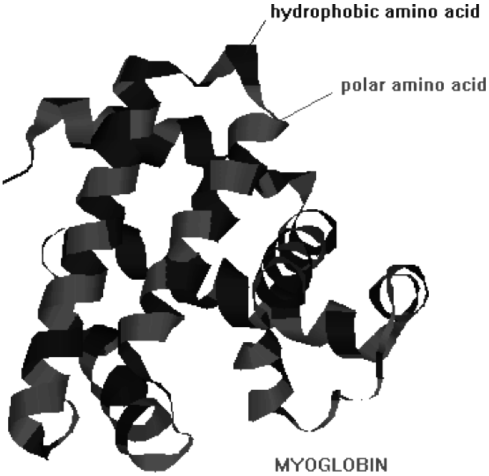


Fig 3.13 Tertiary Structure of Protein

3.15.4 Quaternary Structure (protein – protein interaction)

- This is the fourth level of organisation in the protein structure shown by proteins containing more than one polypeptide chain.
- These chains may be identical (homogenous quaternary structures) in their primary structure.

- The specific association of number of sub units into a complex, large – sized molecules is called as quaternary structure.
- Again the same forces which are involved in maintaining the tertiary structure are also involved in the formation of quaternary structure to link the various polypeptide chains which are otherwise called as subunits or monomers or promoters.
- Each of the subunits is characterised by its own secondary and tertiary structures.

E.g. Haemoglobin

- Haemoglobin is a protein consists of 4 polypeptide chains of 2 types; two alpha chain and two beta chain.
- The alpha chain has valine at N – terminal and arginine at the C terminal and contains 141 amino acid residues.
- The beta chain has valine at N- terminal and histidine at the C-terminal and contains 146 amino acid residues. So, the protein has the total of 574 amino acid residues in its structure.
- Each of the 4 chains has its own characteristic 2^0 and 3^0 structure.
- Like myoglobin, this protein also contains number of straight chain segments of alpha helix interrupted by non – helical chains.
- The alpha and beta subunits are held together as a pair by ionic and hydrogen bonds. The 2 pairs are then joined with each other by additional ionic (salt) bonds, hydrogen and hydrophobic bonds.
- Thus the four subunits fit together almost tetrahedrally to produce the characteristic quaternary structure of haemoglobin.

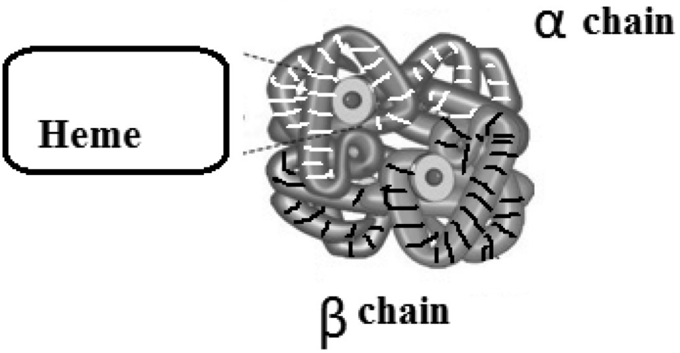


Fig 3.14 Haemoglobin

3.16 BONDS INVOLVED IN PROTEIN STRUCTURE

Proteins are the polymers of amino acids monomers. Any two amino acids monomers are linked together by a chemical bond. There are five types of bonds which occur in proteins. They are the following:

1. Peptide bond
2. Disulfide bond
3. Hydrogen bond
4. Non polar or hydrophobic bond
5. Ionic bond

3.16.1 Peptide Bond

Peptide bond is an amide bond when the CO group of COOH group of the amino acids linked with the NH group of NH_2 group of the adjacent amino acid [-CO-NH-]. The peptide bond produces linear primary structure of proteins.

3.16.2 Disulfide Bond [-s-s-]

Disulfide bond is a covalent bond formed between two polypeptide chains by a cystine residue. The disulfide bond is formed by the oxidation of thiol [-SH] group of two cysteine molecules. This result in the formation of molecules of cysteine an amino acid with a disulfide bridge. Oxytocin, a hormone of pituitary gland has a disulfide bond. Here the disulfide bond links two cysteine unit of the same polypeptide chain. Insulin is another example for disulfide bond. In insulin, two polypeptide chains are linked together by 2 disulfide bonds. Another disulfide bond connects the amino acid 6 and 11 in A chain. The disulfide bond produces a linear form and gives the primary structure of protein

3.16.3 Hydrogen Bond [>O….HN<]

Hydrogen bond is a weak electrostatic attraction between one electronegative atom and a hydrogen atom covalently linked to a second electronegative atom. The formation of a hydrogen bond is due to the tendency of hydrogen atom to share electrons with two neighbouring atoms, especially O and N. For example the carbonyl O of one peptide bond shares its electrons with the hydrogen atom of another peptide bond. An interaction set in between a C=O group and the proton of an NH or OH group if these groups come within a distance of about 2.8A°. This secondary valence bond is symbolized by a dotted line CO….H-N. Silk fibroin is an example of the presence of hydrogen bond involving the imide

(>NH) and carbonyl (C=O) groups of the peptide bond. Here the hydrogen bonds link the vicinal peptide chains. In keratin of wool, the hydrogen bonds link the side chain so that a single peptide chain is held in a coiled or helical nature and produce secondary structure of protein.

3.16.4 Non Polar or Hydrophobic Bond

The association of non polar groups with each other in aqueous systems because of the tendency of the surrounding water molecules to seek their most stable is called non polar or hydrophobic bond. Many amino acids like alanine, leucine, isoleucine, methionine, tryptophan, phenylalanine and tyrosine have little attraction for water molecules in comparison to the strong hydrogen bonding between water molecules. Such R groups can unite among themselves with the elimination of water to form linkages between various segments of a chain or between different chains. This is very much like the coalescence of oil droplets suspended in water.

3.16.5 Ionic or Electrostatic Bond

Ionic bonds are formed by ionization. The bond is formed by the transfer of electrons (ions) from one atom to another. Ions possessing similar charge repel each other whereas the ions having dissimilar charge attract each other. For example, divalent cations like magnesium may form electrostatic bonds with 2 acidic side chains. Another instance of ionic bonding may be the interaction between the acidic and basic groups of the constituents' amino acids. Ionic bonds occur between positively charged groups and negatively charged groups. The ionic bonds maintain a folded nature of proteins and procedure tertiary structure.

3.17 PROPERTIES OF PROTEIN

Proteins have the following properties

- Most of the proteins are hydrophilic colloids. A few proteins such as insulin, tobacco mosaic viruses etc are crystalline in nature.
- Proteins have no characteristic colour except chromoproteins. Chromoproteins are coloured and the colour is imparted by the metallic prosthetic group.
- A pure protein is tasteless and odourless.
- Proteins are highly viscous in nature. Generally fibrous proteins are more viscous than globular protein.
- The molecular weight of proteins varies from 30,000 to a few million. Protein molecules are much smaller. In fact, the molecular weight of a typical protein is comparable to that of the smallest nucleic acid molecule,

the tRNA. Typical polypeptide chains have molecular weights ranging from 15,000 to 70,000. The average molecular weight of an amino acids is 110, which means that typical polypeptide chains contain some 135 to 635 amino acids. The molecular weight is determined by ultracentrifuge.

- All the proteins are levorotatory. The property is due to the presence of α-amino acids, which are the building blocks of proteins.
- Peptides and proteins undergo hydrolysis by means of dilute HCl or H_2SO_4, alkali or enzyme into their constituent amino acids.
- When proteins are brought into contact with water, protein molecules absorb water and swell up. The polar group likes –COOH, $-NH_2$ and OH become hydrated. Electrolytes, alcohols or sugars in high concentration will complete for the water of hydration, dehydrate the protein and precipitate from solution.
- Most of the proteins are hydrophilic colloids. They are precipitated or coagulated in solutions alkaline to the isoelectric pH by positive ions such as Zn^{2+}, Cd^{2+}, Pb^{2+}, Hg^{2+}. At this pH the protein has a negative charge.
- Negative ions combine with proteins in solutions more acidic than the isoelectric pH to form salts. The common precipitants in this group are trichloracetic acid, tungstic acids, phosphotungstic acid, sulphosalicylic acid and tannic acids.
- The solubility of many proteins is increased in the presence of small concentrations of various neutral salts. This is referred to as salting in of proteins. Salting in protein is caused by forces of attraction between salt and protein at low salt concentrations leading to increased solubility.
- As the concentration of the neutral salt is increased, the solubility increases to maximum and then starts decreasing and finally the protein is precipitated. This is referred to as salting out. The salting out of proteins is caused by the competition between the protein and the salt at high concentrations. The salting out of proteins is an effective method of purification of proteins.
- Proteins are oxidized by putrefaction processes to form the products such as amino nitrogen compounds, CO_2 and water. The bad smell of the dead and decaying bodies is due to the putrefaction of the protein.
- In proteins there are several free $– NH_2$ groups from basic amino acids and –COOH groups from acidic amino acids. The groups can ionize in solution producing both anions and cations. Thus the protein molecules exist as zwitterions in solution. It can combine with both acids and bases. Thus proteins are Amphoteric compounds.

- As each protein contain one free NH_2 group and another free carboxyl group, the protein has an ionizing property. Due to these ionisable groups in the protein chains, the proteins also have some definite isoelectric pH at which they do not migrate in an electric field. At the isoelectric pH, the number of positive charges is equal to the number of negative charges, giving a net charge of zero.
- The isoelectric pH of the proteins has been found to depend upon the relative number of acidic or basic groups, which are rendered by amino acids. Serum albumin, which has many acidic amino acids, has an isoelectric pH of 4.7. Giladin with many basic amino acids has 9.0 isoelectric pH.
- Swelling capacity, viscosity and solubility are minimal at the isoelectric pH.
- Proteins are cations at pH values lower than the isoelectric pH and anions at pH values higher than the isoelectric pH.
- Proteins undergo remarkable changes in their solubility, optical rotation and biological properties, when they are treated with heat, X-rays, ultra violet rays, light, alcohol, acetone, aqueous potassium iodide, urea, detergents, etc. These changes occurring in proteins are called denaturation. The changed proteins are called denatured proteins and the unchanged proteins are called native proteins.

3.18 TESTS FOR PROTEINS

Proteins give characteristic colours on treatment with specific reagents. These reactions help to identify proteins. Hence they are called tests for proteins. There are 6 tests to identify proteins. They are the following.

- Biuret test
- Millon’s test
- Ninhydrin test
- Xanthoproteic test
- Heller’s test
- Nitroprusside test

3.18.1 Biuret Test

The protein solution is warmed gently with 10% solution of sodium hydroxide and then a drop of very dilute copper sulphate solution is added. The formation of reddish violet colour indicates the presence of peptide link –CO-NH. This test is answered by all proteins, peptones and peptides except dipeptide.

The name biuret is derived from the fact that the test is also positive for the compound biuret, H_2N. CONH. $CONH_2$ obtained from urea by heating.

Dipeptides do not answer the biuret test, while all other peptides answer the test. Hence biuret test is important to know whether hydrolysis of proteins is complete or not. If the biuret test is negative, hydrolysis is complete atleast to the dipeptide stage.

3.18.2 Millon's Test

Millon's reagent is a solution of mercuric and mercurous nitrates in nitric acid containing a little nitrous acid. Proteins on adding Millon's reagent followed by heating the solution give a red precipitate or red colour. The test is responded by the proteins having tyrosine. The hydroxyphenyl group of tyrosine is the structure responsible for this test. The non proteinous material having phenolic group, also responds the test.

3.18.3 Ninhydrin Test

When ninhydrin is added to protein solution and the mixture is heated to boil, a blue to violet colour appears. It is a test used to test the presence of amino acids.

3.18.4 Xanthoproteic Test

When a few drops of nitric acid is added to the protein solution, yellow precipitate appears. Xanthoproteic reactions are due to the presence of amino acids namely tyrosine, phenylalanine and tryptophan. The yellow precipitate is due to the formation of metaproteins insoluble in nitric acid.

3.18.5 Heller's Test

In a test tube containing concentrated nitric acid, small quantity of protein solution is slowly added. The two solutions are mixed slowly by rotating on the palm. A white ring appears at the junction of the two solutions.

3.18.6 Nitroprusside Test

Proteins containing free –SH groups (of cysteine) give a reddish colour with sodium nitroprusside in ammoniacal solution.

UNIT IV

LIPIDS AND FATTY ACIDS

Structure, classification, properties and biological significance of lipids. Simple lipids –Monoglycerides, Diglycerides, Triglycerides and Wax - Compound lipids - phospholipids and glycolipids and derived lipids – steroids- cholesterol, ergosterol, lanosterol - terpenes and carotenoids). Fatty acids - saturated, unsaturated fatty acids, hydroxy or oxygenated, cyclic, essential, non-essential fatty acids.

4

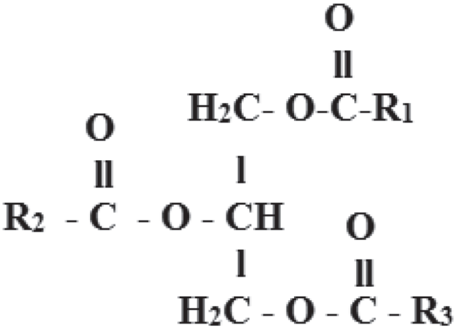
LIPIDS

The lipids are a heterogeneous group of compounds related to fatty acids. They are formed of 3 fatty acids joined to an alcohol. Fatty acids and alcohol are the building block components of lipids. Chemically, lipids are defined as the esters of alcohol and fatty acids. The term lipid was first introduced by the German Biochemist Bloor in 1943.

E.g. Fats, Oils, Waxes etc.

4.1 STRUCTURE OF LIPIDS

- Lipids are esters (ester is a compound formed by the combination of an acid with a glycerol with the removal of water) of glycerol and fatty acids.
- Lipid is made up of a glycerol and three fatty acids. Such a lipid is called a triglyceride or a neutral fat.



$$\begin{array}{lcl} & & H_2C-O-\overset{\overset{\large O}{\|}}{C}-R_1 \\ & & \quad | \\ R_2-\overset{\overset{\large O}{\|}}{C}-O- & CH & \\ & & \quad | \\ & & H_2C-O-\overset{\overset{\large O}{\|}}{C}-R_3 \end{array}$$

Fig 4.1 Structure of a Simple Lipid

4.2 CLASSIFICATION OF LIPIDS

Lipids are generally classified into three types. They are

1. Simple lipids or homolipids
2. Compound lipids or heterolipids
3. Derived lipids

4.2.1 Simple Lipids or Homolipids

- These are the esters of fatty acids with alcohols like glycerol (in neutral fats) and cetyl alcohol (in waxes).
- Example - fats, oils and waxes.

4.2.2 Compound Lipids

- Compound lipids are the lipids linked to non-lipids. They are also called heterolipids.
- The compound lipid consists of three components namely glycerol, fatty acid and a nonlipid. The non-lipid may be a phosphoric acid or a carbohydrate.
- Compound lipids are of two types. They are phospholipids (phosphatids) and glycolipids (cerebrosides).

4.2.3 Derived Lipids

- Derived lipids are the products of hydrolysis of simple lipids and compound lipids
- Example - steroids, terpenes, fatty acids, alcohols, aldehydes and ketones.

4.3 PROPERTIES OF LIPIDS

Lipids have the following important properties.

- Lipids are insoluble in water but soluble in non-polar organic solvents, such as acetone, alcohol, chloroform, benzene and ether.
- They contain a large proportion of carbon and hydrogen bonds and release large amount of energy on breakdown.
- Fats on hydrolysis with the enzyme lipase, yield fatty acids and glycerol.
- Fats containing saturated fatty acids are solids. Example - animal fats.
- Fats containing unsaturated fatty acids are liquids. Example - plant fats.
- Lipids are greasy to touch and they leave an oil impression on paper.
- Pure fats are colourless and odourless.
- Fats are sparingly soluble in water, i.e. fats are hydrophobic. They are highly soluble in organic solvents like alcohol, ether etc.
- Melting point of fatty acids increases with increase in molecular weight. Saturated fatty acids having higher melting points than fatty acids with unsaturated bonds.

- Specific gravity is less than water. So they are floating on the water surface. Solid fats are lighter than liquid fats (oil).
- Due to the presence of double bonds in unsaturated fatty acids, geometrical isomerism (cis-trans) is possible.
- Fats are bad conductors of heat.
- In water, fats are broken into minute droplets and dispersed. This process is called emulsification. Emulsion is a mixture of lipids and water.
- When a liquid fat is placed on water, it spreads uniformly over the surface of water to form a thin layer. This phenomenon is called spreading.
- The conversion of a fat into glycerol and 3 molecule of sodium salt of higher fatty acids (soap) by boiling with sodium hydroxide is called saponification.
- Rancidity is ill-smelling of fat. It is caused by rancidification. Rancidification is due to auto-oxidation of fats. The fat which has become rancid has a disagreeable odour and taste and is unfit for consumption. Rancidity occurs in two ways. They are hydrolytic rancidity and oxidative rancidity.

    a. **Hydrolytic Rancidity:** When butter or other fats are stored, they become rancid and unpalatable. This is due to the activity of microorganisms. Micro-organisms secrete enzymes like lipase. Lipase hydrolyses the fat into fatty acid and glycerol. The fatty acid gives unpalatable smell. This is known as rancidity. Rancidity may be prevented by refrigeration or by excluding water.

    b. **Oxidative Rancidity:** Oils and unsaturated fatty acids are easily oxidized at the double bonds by atmospheric air at room temperature to yield short chain fatty acids (with C_4 to C_{10}) and aldehydes. Rancid taste and odour of the fats are due to the atmospheric oxidation. This is called oxidative rancidity.

- The unsaturated fatty acids are saturated by the reaction with H_2 in the presence of nickel or platinum or palladium as catalyst. If there is one double bond, one molecule of H_2 will be taken. If two bonds are present, 2 hydrogen molecules will be taken. Thus for saturation, the number of hydrogen molecule taken will be equal to the number of double bonds.
- Unsaturated fatty acids and esters are giving addition reactions with halogens in the presence of acetic acid or methanol at room temperature.

- Fatty acids with unsaturated bonds are oxidized by ozone or potassium permanganate. Reaction with ozone is called ozonolysis and the product is an ozonide. The ozonides on hydrolysis give two molecules of aldehydes.
- When fats are heated with $NaHSO_4$ (sodium bisulphate) or potassium hydrogen sulphate, acrolein (unsaturated aldehyde) having a pungent odour is formed. This is a test for a fat containing glycerol.

4.4 BIOLOGICAL SIGNIFICANCE OF LIPIDS

Lipids constitute an essential component of cell. So it has enormous biological importance.

- Lipid contains large amount of energy. One gram of lipid on oxidation releases 9.3 kilocalories of heat. But the same amount of carbohydrate releases 4.5 kilocalories only.
- Lipids are insoluble in water. So they are readily stored in the body as a food reserve. Eg.Triacylglycerol is a food reserve. It is used as a substrate for oxidation.
- Lipids constitute an important component of cell membrane.
- Phospholipids transport cations across the lipid layer of biomembranes.
- Lipids serve as an electro insulating material in the myelin sheath of neurons.
- Subcutaneous fats of mammals act as an insulator against excessive heat loss to the environment.
- Amphipathic lipids are emulsifiers. The process of emulsification is of great metabolic significance. In fact, the fats have to be emulsified before they can be absorbed by the intestinal wall. This process is accomplished by the bile juice secreted by the liver.
- Lipids of connective tissue of internal organs protect them from eventual damage on exposure to mechanical action. E.g.Triacylglycerides subcutaneous fat deposits act as an insulator against mechanical trauma.
- Under physiological conditions, certain lipids function as solvents to dissolve other lipids. E.g. Bile acids are solvents for insoluble vitamins in the intestine.
- The major group of hormones is formed of steroids. They regulate a large variety of physiological functions. E.g. Sex hormones and adreno corticoids.
- Prostaglandins are modulators of hormones, derived from fatty acids.

- Vitamin – D, calciferol is a steroid derivative. It possesses a steroid structure. It is synthesized from cholesterol.
- Lipids act as carrier of natural fat soluble vitamins such as A, D and E.
- Lipids are essential for the activation of enzymes. Eg. Glucose-6-phosphatase, β – hydroxybutyric dehydrogenase.

4.5 SIMPLE LIPIDS (HOMOLIPIDS)

- A simple lipid is formed when three molecules of fatty acids combine with one molecule of glycerol. In this process, three molecules of water are released. They are further classified into fats and waxes.

Fats - They are esters of fatty acids with a trihydroxy alcohol, glycerol. A fat is solid at room temperature.

Waxes - They are esters of fatty acids with high molecular weight of monohydroxy alcohols.

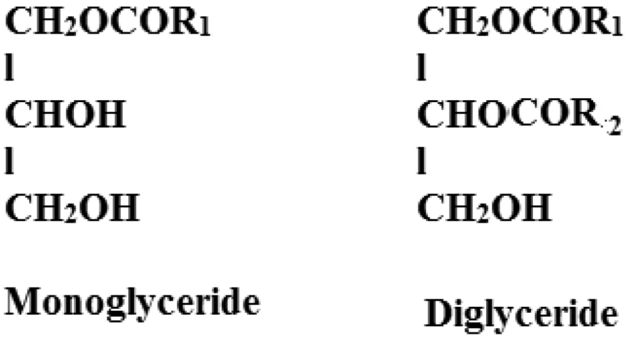
- When three palmitic acids are combined to glycerol, it is called tripalmitin.
- When three stearic acids are combined to glycerol, it is called tristearin.
- When three oleic acids are combined to glycerol, it is called triolein.
- When three fatty acids of a lipid are similar, the fat is called a neutral fat. Eg. Tripalmitin, tristearin, triolein etc.
- When the three fatty acids in a fat are different, the fat is called a mixed fat.
- When the mixed fat contains two palmitic acids and one stearic acid, the fat is called dipalmito stearin.

4.5.1 Monoglycerides

- When only one fatty acid is combined to a glycerol, it is called monoglyceride.
- When the fatty acid is palmitic acid, then it is called monopalmitin.
- When the palmitic acid is attached to the first carbon atom of glycerol, then the monopalmitin is named as 1-monopalmitin. If it is attached to the second carbon, it is called 2-monopalmitin.

4.5.2 Diglycerides

- When two fatty acids are combined to a glycerol, the fat is called a diglyceride. When the fatty acid is palmitic acid, the diglyceride is called a dipalmitin.
- When the palmitic acids are attached to first and second carbon atoms of glycerol, the fat is called 1,2 dipalmitin. Similarly, there are 1,3 dipalmitin and 2,3 dipalmitin etc.



$$\begin{array}{l} \mathrm{CH_2OCOR_1} \\ | \\ \mathrm{CHOH} \\ | \\ \mathrm{CH_2OH} \end{array} \qquad \begin{array}{l} \mathrm{CH_2OCOR_1} \\ | \\ \mathrm{CHOCOR_{2}} \\ | \\ \mathrm{CH_2OH} \end{array}$$

Monoglyceride Diglyceride

Fig 4.2 Monoglyceride and Diglyceride

4.5.3 Triglyceride

- Triglyceride is a simple and most abundant lipid. It is often referred to as fat or neutral fat.
- Glycerol reacts with 3 molecules of fatty acids to give a molecule of triglyceride with 3 water molecules.
- There are many different types of triglyceride, with the main division between saturated and unsaturated types. Saturated fats are “saturated” with hydrogen — all available places where hydrogen atoms could be bonded to carbon atoms are occupied. These have a higher melting point and are more likely to be solid at room temperature. Unsaturated fats have double bonds between some of the carbon atoms, reducing the number of places where hydrogen atoms can bond to carbon atoms. These have a lower melting point and are more likely to be liquid at room temperature.
- A glycerol reacts with three palmitic acids to form tripalmitin.
- A glycerol reacts with three oleic acids to form triolein.
- A glycerol reacts with three stearic acids to form tristearin.

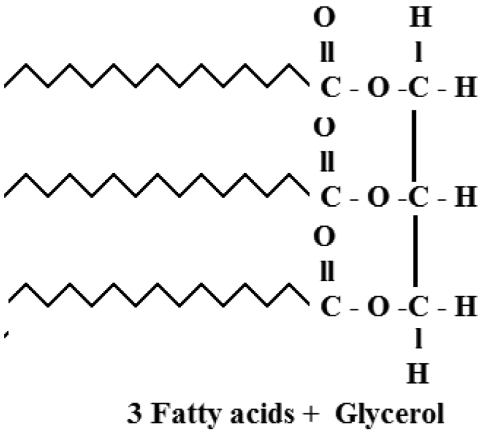


Fig 4.3 Triglyceride

4.5.4 Waxes

- Waxes are simple lipids. They are solid lipids. Wax means the material of honey comb.
- They are esters of fatty acids with monohydric alcohols of higher molecular weight.
- The fatty acids of waxes have 14C atoms to 36C atoms.
- Alcohols have 16C atoms to 36C atoms.
- Waxes are secreted by bees, cutaneous glands and plants.
- Hair, wool and fur are coated with wax.
- Waxes are acting as a protective coating to keep the skin pliable, lubricated and water proof.
- Due to the deposition of waxes on the leaves of certain plants, they are shiny.
- Waxes are the chief storage form of fuel in plankton.
- Waxes act as major food and store lipids in them.
- The common fats are

  i. Sperm whale wax (Spermaceti)
  ii. Bees wax
  iii. Carnauba wax
  iv. Ambretolide

- The bees-wax contains palmitic acid and myricyl alcohol and it is called myricyl palmitate.
- The sperm whale wax contains palmitic acid and cetyl alcohol and it is called cetyl palmitate.

$$\text{Palmitic acid} + \text{Myricyl alcohol} \longrightarrow \text{Myricyl palmitate}$$

$$\text{Palmitic acid} + \text{Cetyl alcohol} \longrightarrow \text{Cetyl palmitate}$$

- Carnauba wax is the hardest known wax. It contains fatty acids esterified with tetracosanol and tetratriacontanol.

Ambretolide is composed of hydroxy fatty acid and alcohol.

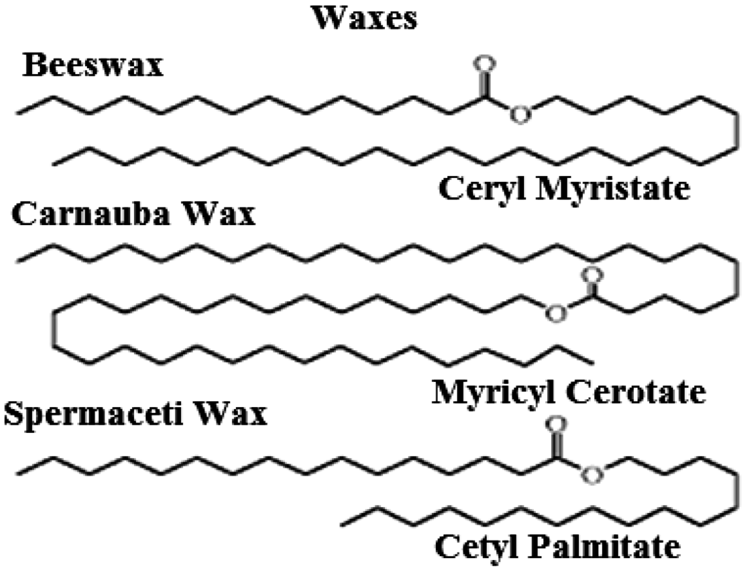


Fig 4.4 Common Fats

Properties of Waxes

- They have fully reduced hydrocarbon chain.
- They are insoluble in water.
- They are resistant to atmospheric oxidation.
- They have high melting points.
- They are chemically inert.
- They are not digested by enzymes but may be split by hot alcoholic KOH.
- Bees wax is used in sealing the honey comb cells to store the food for the winter season.

- Waxes provide water barrier quality for aquatic animals, insects and birds.
- Waxes serve as protective coatings on fruits and leaves.

4.6 COMPOUND LIPIDS

- Compound lipids are the lipids linked to non-lipids. They are also called heterolipids.
- The compound lipid consists of 3 components, namely glycerol, fatty acid and a non-lipid. The non-lipid may be a phosphoric acid or a carbohydrate.
- Compound lipids are of two types. They are phospholipids (phosphatids) and glycolipids (cerebrosides).

4.6.1 Phospholipids

- Phospholipids are compound lipids. They are formed by glycerol, phosphoric acid and fatty acids. They are also called phosphatids.
- They are the structural component of membranes and so are abundant in brain, kidney etc.
- Due to the presence of phosphoric acid group, phospholipids behave as polar lipids.
- They are hydrophilic in nature.
- Phospholipids are amphipathic.
- Phospholipids are further classified into
  1. Lecithins
  2. Cephalins
  3. Plasmologens
  4. Phosphoinositides
  5. Phosphingosides

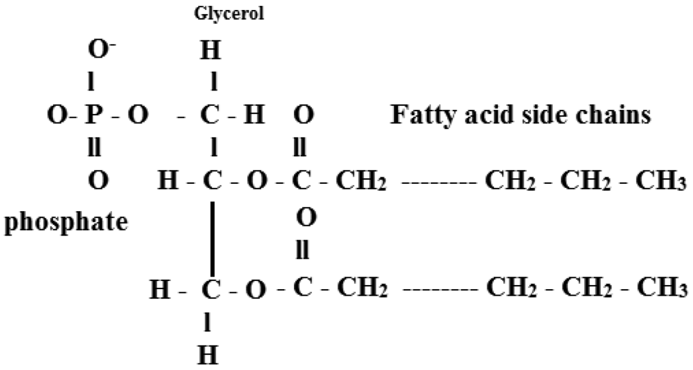


Fig 4.5 Phospholipid

4.6.1.1 Lecithins

- Lecithins are compound lipids. They are phospholipids.
- Lecithins are the esters of glycerol with fatty acids.
- Two hydroxyl groups of glycerol are linked to two fatty acid molecules.
- The third hydroxyl group of glycerol is linked to a phosphoric acid molecule.
- The phosphoric acid group links with choline. Choline is a nitrogenous base.
- It is found in all animals and plants. In animals, it is found in the brain, nerve tissues, sperm and egg yolk. In plants it is abundant, in seeds and sprouts. Soya bean is the main source.
- Lecithins are yellowish grey solids, soluble in ether, alcohol etc.
- Lecithins are required for normal transport and utilization of other lipids particularly in the liver.
- They swell in water and form colloidal solutions.
- They are dextrorotatory.
- Lecithins on hydrolysis yield choline and two molecules of fatty acids. On partial hydrolysis by lecithinase, (found in snake venoms) only one fatty acid molecule is removed. The product without one fatty acid molecule is called lysolecithin.
- When lysolecithin is injected into the blood stream either by snake bite or by syringe, rapid rupture of red blood corpuscles takes place. This is called hemolysis.
- It has an important role in fat metabolism in liver.
- There are twenty forms of lecithins in human red blood corpuscles.

Functions of Lecithin

- It is a component of plasma membrane.
- It transports fats and oils through the plasma membrane.
- It brings about cell communication.
- It is an emulsifier. Hence it helps to absorb fats and oils from the digested food.
- It is a source of B vitamins such as choline and inositol.
- Lecithin improves memory.
- Daily intake of lecithin improves brain chemical activity.
- It improves learning.

- Lecithin is essential for liver metabolism.
- It supports regeneration of liver cells.
- It helps to heal liver from hepatitis.
- It needs for healthy gall bladder and heart.
- It helps to reduce cholesterol.
- It is used to treat treat anxiety and eczema.
- It acts as moisturizer on the skin.
- It relieves arthritis.
- It is an ingredient in eye medicines.
- It is used as food additive.

4.6.1.2 Cephalins

- Cephalins are compound lipids. They are phospholipids. They are otherwise called phosphatidyl ethanolamine.
- They resemble lecithins except that the choline is replaced by ethanolamine or serine. Cephalin consists of 4 components, namely glycerol, fatty acids, phosphoric acid and ethanolamine.
- Cephalin is the ester of glycerol and fatty acids.
- The two hydroxyl groups of glycerol are linked to two fatty acids.
- The third hydroxyl group of glycerol is linked to a phosphoric acid.
- The phosphoric acid is linked to ethanolamine.
- There are two types of cephalins. They are α-phosphatidyl ethanolamine and α-phosphatidyl serine.
- Cephalins are more acidic than lecithins.
- Cephalins are less soluble in alcohols than lecithins.
- Venoms containing lecithinase split off the fatty acids from cephalins leaving hemolytic lysocephalins.
- Cephalin occurs in all cells, soyabean oil etc. It is abundant in brain cells. The important fatty acid constituents of cephalin are stearic, oleic, linoleic and arachidonic acids.

Functions of Cephalins

- Cephalin is a component of plasma membrane.
- It is found in the inner lipid layer of plasma membrane.
- It maintains the fluidity of the plasma membrane.

- The brain cells contain 45% of cephalins.
- It is involved in membrane fusion in cytokinesis.
- It helps for the secretion of lipoprotein in the liver.
- It propagates infectious prions without the help of nucleic acids.
- It improves blood clotting.
- It causes deterioration of processed foods such as chocolate, soyabean milk, infant formula etc.
- It causes vascular diseases, diabetes and cancer.

4.6.1.3 Plasmologens

- Plasmologens are phospholipids.
- These are found in brain, muscle and seeds of higher plants.
- These are not significantly found in plant tissues.
- Structurally, plasmologens resemble lecithins and cephalins except in having one unsaturated ether group in the place of fatty acid groups.
- It is soluble in all lipid solvents. Since the base is a nitrogen base it may be choline, ethanolamine or serine. Due to this, plasmologens are of three types.

Serine cephalin - This compound contains amino acid serine instead of ethanolamine.

Phosphatidyl inositol - This cephalin contains inositol instead of serine. On hydrolysis, the phosphoinositides yield 1 mole of glycerol, two moles of fatty acid, 1 mole of inositol and 1,2 or 3 moles of phosphoric acid.

Accordingly mono, di or tri phosphoinositides are formed.

4.6.1.4 Phosphoinositides

- In these phospholipids a cyclic hexahydroxy alcohol inositol replaces the base. So these lipids are otherwise known as lipoinositol.
- Occurrence - Phospholipids of brain tissues, soyabeans and also in nervous tissue.
- They play an important role in transport processes in cells.

4.6.1.5 Phosphingosides (Sphingomyelins)

- These are phospholipids. Sphingomyelins differ radically from cephalin in composition.

They contain fatty acid, phosphoric acid, choline and a complete amino alcohol sphingosine. The fatty acid is attached to amino group of sphingosine by amide linkage. The phosphoric acid is attached to one of the hydroxyl group of sphingosine.

- On hydrolysis, the phosphingosides yield equimolecular mixture of fatty acid, phosphoric acid, choline and sphingosine or dihydrosphingosine (sphinganine). No glycerol is formed.
- It is commonly found in nerve tissue especially in the myelin sheath of the nerve. So the name is sphingomyelins. It is found in brain and spinal cord and in plant seeds.
- Sphingomyelins are electrically charged molecules. They contain phosphocholine as their polar head groups.
- Sphingosine carries the phosphoric acid on its primary alcohol group and the fatty acid by amide linkage on its primary amino group.
- It is absent in plants and micro-organisms.
- In a syndrome called Niemann-Pick disease, a rare genetic disorder (inherited as an autosomal recessive condition) the sphingomyelins are stored in the brain in large quantities. The disease is due to the deficiency of the enzyme sphingomyelinase.

4.6.2 Glycolipids

- Glycolipids are compound lipids containing sugar and high molecular weight fatty acids.
- It is found in the brain, adrenals, kidney, spleen, liver, leucocytes, thymus, lungs, retina, egg-yolk and fish sperm.
- Cerebrosides and gangliosides are important glycolipids.
- Cerebroside is relatively abundant in liver, spleen and medullated nerve fibres.
- Cerebroside is made up of 3 components namely,

  i. Sphingosine
  ii. Fatty acid
  iii. Carbohydrate

4.6.2.1 Sphingosine

The sphingosine is an amino alcohol with a long unsaturated hydrocarbon chain.

The molecular formula is $C_{16}H_{37}NO_2$.

It is a nitrogen containing base.

4.6.2.2 Fatty acid

The fatty acid is linked to the amino group of sphingosine by an amide linkage.

The sphingosine and fatty acid together form a waxy substance called ceramide.

4.6.2.3 Carbohydrate

The carbohydrate is linked to the primary alcoholic group of sphingosine through a glycosidic linkage.

The carbohydrate may be glucose or galactose.

If the carbohydrate is a glucose unit, then the cerebroside is called glucocerebroside.

If the carbohydrate is a galactose unit, then the cerebroside is called galactocerebroside.

4.7 SULFUR CONTAINING GLYCOLIPIDS

Glycolipids containing sulfur are called sulfolipids and sulfatides.

4.7.1 Sulfolipids

- Sulfolipids are widely distributed in plants.
- It is localised in chloroplasts.
- It is also found in the chromatophores of photosynthetic bacteria.
- The sulfur in this lipid is in the sulfonic group with a hexose. So it is called as sulfolipids.

4.7.2 Sulfatide

- It is a sulfur containing glycolipid. It is a sulfate ester analogue to phrenosin.
- It is present in the white matter of brain.
- The sulfate is present in the ester linkage at C_3 of galactose portion of the molecule.
- Members of this cerebroside sulfuric esters are called as sulfatide.

4.8 DERIVED LIPIDS

- Derived lipids are the substances produced from simple and compound lipids through the process of hydrolysis. There are many different types of derived lipids, including alcohols, monoglycerides, diglycerides, fatty acids, steroids, terpenes and carotenoids, with the last three groups being the most common.
- Steroids are derived lipids that are found in almost every species of animal and do not contain fatty acids. Terpenes are found mainly in plants and this group includes substances such as natural rubber and many essential oils. Carotenoids are a type of tetraterpene produced only by plants, although they are widespread in both plants and animals as they remain in the body after carotenoid producing plants are eaten.

4.8.1 Steroids

- The steroids are often found in association with fat. Since they contain no fatty acids, they are non-saponifiable, i.e., cannot be hydrolyzed by heating with alkali to yield soaps of their fatty acid components.
- All steroids may be considered as derivatives of a fused and fully saturated ring system called cyclopentanoperhydrophenanthrene or sterane.
- This system consists of 3 cyclohexane rings (A, B and C) fused in nonlinear or phenanthrene manner and a terminal cyclopentane ring (D).

Steroids may be divided in the following manner

- Sterols: Cholesterol, Ergosterol, Coprosterol; Bile acids: Glycocholic acid and Taurocholic acid; Sex hormones: Testosterone, Estradiol; Vitamin D: Vitamin D_2 and D_3; Adrenocortical hormones: Corticosterone; Cardiac glycosides: Stropanthin; Saponins: Digitonin. Some common steroids are: Cholesterol

4.8.2 Cholesterol

- Cholesterol has a molecular formula, $C_{27}H_{45}OH$.
- In addition to an OH group at C_3, there is a double bond at C_5.
- The hydroxyl group constitutes its polar head and the rest of the molecule is hydrophobic.

- It is a white crystalline solid and is optically active, [α] D 39°.
- It has a melting point of 149°C.
- Cholesterol is generally believed to be notorious as a major cause of heart disease.
- There are 2 types of cholesterol, the low density lipoprotein cholesterol (LDL-C) and the high-density lipoprotein cholesterol (HDL-C).
- It is the principal sterol of higher animals and is especially abundant in nerve tissues and in gallstones.
- It occurs either free or as fatty esters in all animal cells.
- It was first isolated in 1784, from human gallstones which consist almost entirely of cholesterol and hence so named (cholesterol literally means ‘solid alcohol from bile’).
- Its main sources are fish liver oils and the brain and spinal cord of cattle.
- Cholesterol is not found in plant fats.

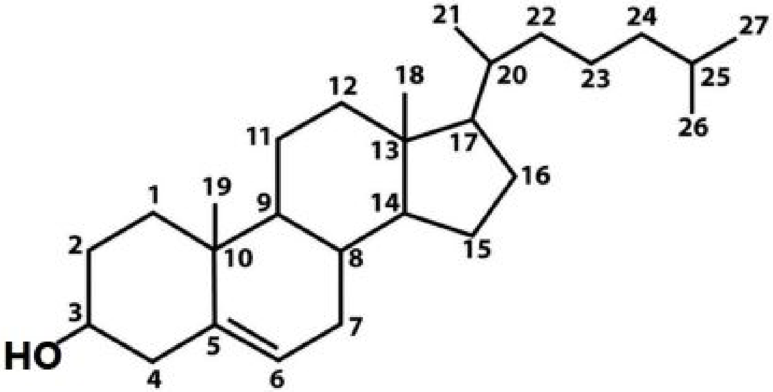


Fig 4.6 Structure of Cholesterol

4.8.3 Ergosterol

- It is present in ergot (hence its nomenclature), yeast and the mould Neurospora.
- Its parent hydrocarbon is ergostane, $C_{28}H_{50}$.
- Ergosterol has a molecular formula, $C_{28}H_{43}OH$ with one **OH group at C_3** and **3 double bonds at C_5, C_7 and C_{22}**.
- It is also **optically active**, [α] D -135°.

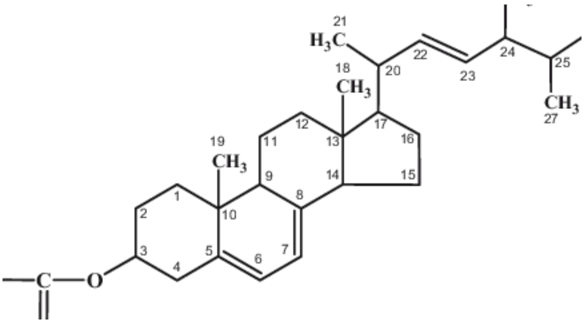


Fig 4.7 Structure of Ergosterol

4.8.4 Lanosterol

- It is a major constituent of wool fat and is also present in minor quantities in liver and yeast.
- Lanosterol is a C30 compound with twin methyl groups at C_4 and a third angular methyl group on C_{14}.
- There are 2 double bonds at C_8 and C_{24}.
- It is an intermediate in the biosynthesis of cholesterol.

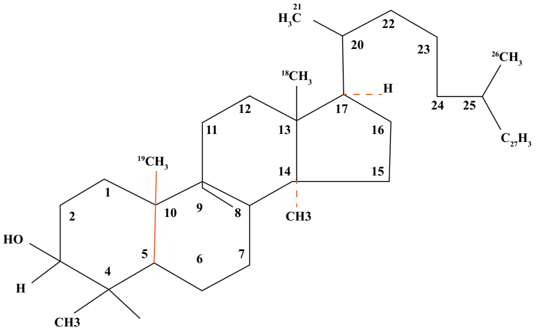
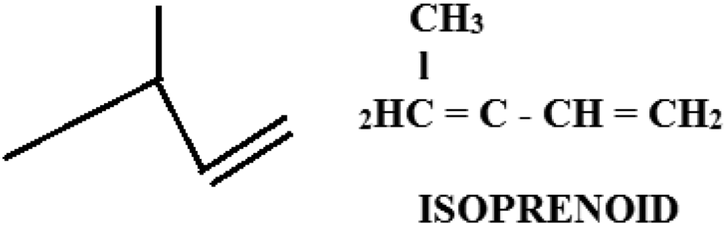


Fig 4.8 Structure of Lanosterol

4.9 TERPENES

1. Terpenes are a group of derived lipids.
2. They are non-saponifiable lipids found in plants.
3. They cannot yield soap on hydrolysis.
4. Chemically, terpenes are hydrocarbons**.**
5. They have less than 40 carbon atoms.
6. Terpenes belong to isoprenoid groups.



$$ {}_2HC = \overset{\displaystyle CH_3}{\overset{|}{C}} - CH = CH_2 $$

Fig 4.9 Isoprenoid

7. Terpenes are constructed out of isoprene units. Each isoprene unit has two ends, namely a head and a tail. The head is the branched end and the tail is the unbranched end.

8. Each terpene has two or more isoprene units. The isoprene units are joined in a head to tail fashion. That is, the tail end of one isoprene unit is joined to the head end of another isoprene units.

9. Terpenes are classified into 6 types based on the number of isoprene units present in them. They are the following:

Type of Terpene	Number of Carbon atoms	Isoprene Units
Hemiterpene (half)	C5	1
Monoterpene	C10	2
Sesquiterpene (one and a half)	C15	3
Diterpene	C 20	4
Sesterterpene	C25	5
Triterpene	C30	6
Tetraterpene	C40	8
Rubber	>500	>100

- **Monoterpenes:** Monoterpenes contain 2 units of isoprene E.g. *Myrcene* from oil of bay, *geraniol* from rose oil, *limonene* from lemon oil and *menthol* from pepper mint oil. The fragrances of many plants arise from these terpenes. The monoterpenes are used as perfumes.
- **Sesquiterpenes:** Sesquiterpenes contain 3 units of isoprene. They are also used as perfumes. E.g. *Farnesol* found in essential oils.
- **Diterpenes:** Diterpenes contain 4 units of isoprene. They are found as substituent of the resins and balsams.
- **Triterpenes:** Triterpenes contain 6 isoprene units. They do not occur in nature. But they are produced as intermediate products during the biosynthesis of cholesterol.

- **Tetraterpenes:** Tetraterpenes contain 8 isoprene units. E.g. Carotenoids.
- **Polyterpenes:** Polyterpenes contain more than 8 units of isoprene units. E.g. Rubber. It is present in the latex of many tropical plants. A molecule of rubber is composed of about 500 to 5000 isoprene units.

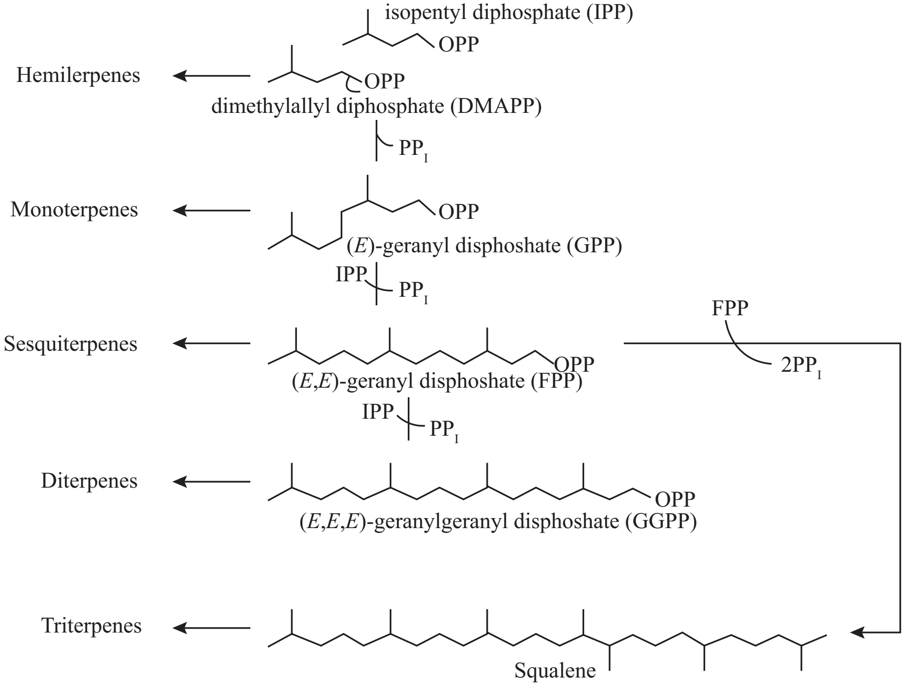


Fig 4.10 Terpenes

4.10 CAROTENOIDS: (CHROMOLIPIDS)

- Carotenoids are a group of derived lipids. They are also called chromolipids or lipochromes.
- They are non saponifiable lipids.
- They cannot yield soap on hydrolysis.
- They are exclusively of plant origin, but are distributed both in plants and animals. They are found in tomato, carrots and leaves.
- Chemically, carotenoids are hydrocarbon.
- They have 40 carbon atoms.
- They are isoprene derivatives.
- They are tetraterpenes containing 8 isoprene units.

- They have high degree of unsaturation containing many conjugated double bonds.
- They are coloured red or yellow.
- They exhibit isomerism and exist in many forms. Examples: Lycopene found in tomato, Alpha and beta carotene found in carrot, Xanthophylls.

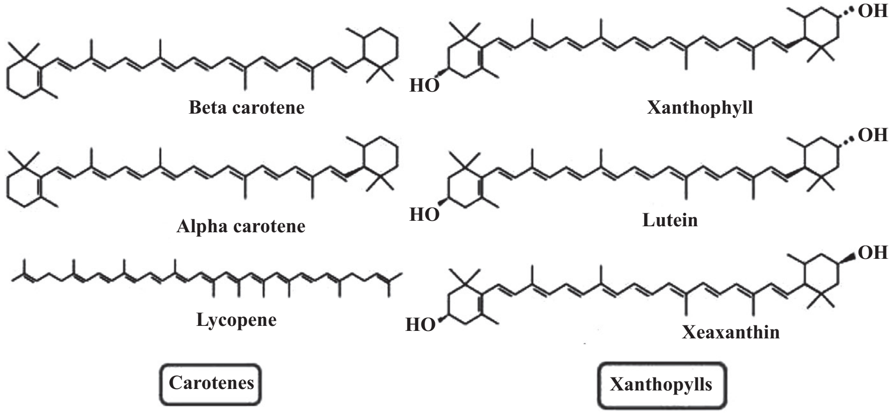


Fig 4.11 Carotenoids

4.10.1 Lycopene

Lycopene is a carotenoid found in tomato and other fruits. It is a tetra terpene. It is a highly unsaturated, unbranched, long chain hydrocarbon (polytene). It is composed of two identical units (C_{20} H_{28}) joined by a double bond between C_{15} and C^1_{15}. Each of these two units, in turn is derived from 4 isoprene units (C_5 H_8). A molecule of lycopene contains 13 double bonds of which 11 are conjugated.

4.10.2 Carotene

Carotene is a carotenoid found in carrots. Carotene was first isolated from carrot by Wackenroder. As it was isolated from carrot, it was named as carotene. Alfalfa is another source of carotene. Carotene is a tetraterpene. It is a highly unsaturated, unbranched long chain hydrocarbon (polytene). It exists in three forms, namely alpha- carotene, beta- carotene and gamma- carotene. Alpha carotene is a violet crystal, beta carotene is a red crystal and gamma carotene is a dark red crystal. Beta – carotene is the precursor of vitamin A. The carotene has the molecular formula like that of lycopene ($C_{40}H_{56}$). It is a derivative of isoprenoid. Carotene is formed of two identical units and each unit is formed of $C_{20}H_{28}$. The two units are joined by a double bond between C_{15} and C^1_{15}. Each of these units is derived from 4 isoprene units, namely C_5 H_8. Alpha and Beta- carotene have two rings one at each end. Each is formed by the closing of the end of lycopene chain by the disappearance of double bonds. The ring is structurally related to ionone alpha and beta- carotene differs in the position of double bonds in the rings.

4.10.3 Xanthophylls

Xanthophylls is a yellow carotenoid pigment. Xanthophylls are found in leaves corn and crustaceans. The Xanthophylls of leaf are called lutein, that of corn is called Zeaxanthine and that of crustaceans is called as taxanthine. Lutein is derived from alpha- carotene while Zeaxanthine is derived from beta-carotene. Xanthophylls are characterized by the presence of hydroxyl groups (OH) in ionone rings of carotenes, in the para position to the long chain.

4.11 FATTY ACIDS

- Fatty acids are aliphatic straight chain hydrocarbon compounds with a terminal carboxyl group.
- They are the building blocks of lipids.
- There are about 200 fatty acids.

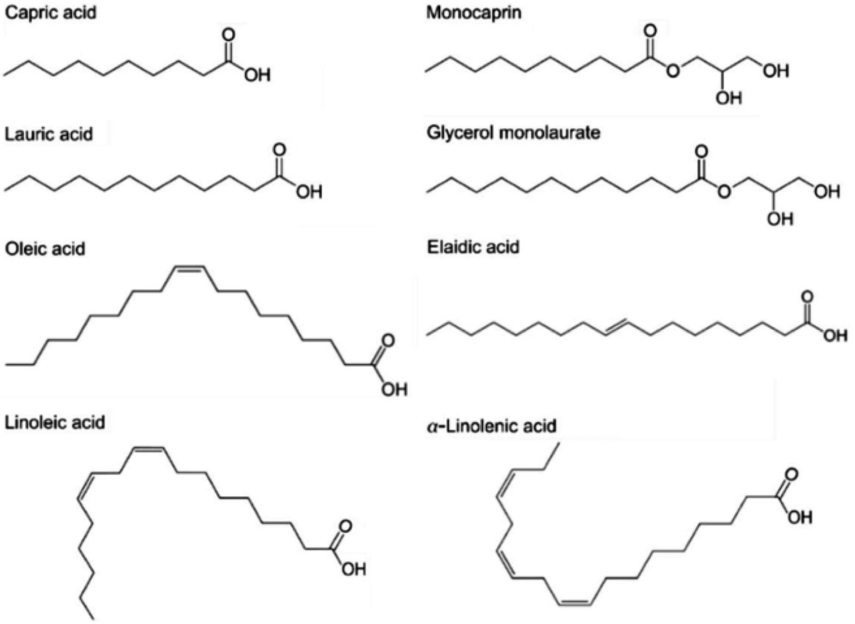


Fig 4.12 Structure of Fatty acids

- Fatty acids are long chain organic compounds containing even number of carbon atoms from 4 to 24.

- They have a single carboxyl group and a long non-polar hydrocarbon tail. The non-polar tail gives most lipids their water insoluble and oily or greasy nature.
- In fatty acid, carbon atoms are numbered starting at the carboxyl terminus.
- Carbon atoms 2 and 3 are often referred to as α and β respectively. The methyl carbon atom at the distal end of the chain is called ω carbon.
- Fatty acids do not occur in free or unbound form in cells or tissues. They are bound in lipids through covalent bonds. However, they are released on hydrolysis.
- The hydrocarbon chain is almost unbranched very rarely it is branched.
- Fatty acids with 16 and 18 carbon atoms are most abundant in nature.
- The fatty acid, containing a single bond, is called saturated fatty acid. The suffix ***–anoic*** indicates a fully saturated fatty acid.
- The fatty acid containing one or more double bonds is called unsaturated fatty acid. The suffix ***enoic***, ***dienoic*** and ***trienoic*** suggest the presence of one, two and three double bonds in the molecule.
- A C_{18} fatty acid without double bond is called octadecanoic acid; A C18 fatty acid with one double bond is called octadecenoic acid, with two double bonds is called octadecadienoic acid and with three double bonds is called octadecatrienoic acid.

4.11.1 Classification of Fatty Acids

Fatty acids are classified into two types based on the absence or presence of double bonds. They are

- Saturated fatty acids – without double bonds
- Unsaturated fatty acids – with one or more double bonds

The fatty acids containing hydroxyl groups are called hydroxy fatty acids or oxygenated fatty acids. The fatty acids containing ring structure are called cyclic fatty acids. Again, based on their requirement in the diet, fatty acids are classified into two types, namely

- Essential fatty acids
- Non-essential fatty acids

Thus fatty acids are classified into 6 types. They are the following:

1. Saturated fatty acids
2. Unsaturated fatty acids

3. Hydroxy fatty acids or oxygenated fatty acids
4. Cyclic fatty acids
5. Essential fatty acids
6. Non-essential fatty acids

4.12 SATURATED FATTY ACIDS

- The saturated fatty acids have single bonds. They have maximum possible number of hydrogen atoms. At one end, there will be an acid group (COOH). At the other end, there will be a methyl group (CH_3). In between these two groups, there will be CH_2 groups. The saturated fatty acids end with the suffix *–anoic*. Eg. *Octanoic acid*, *Decanoic acid*, *Butanoic acid* etc.
- The saturated fatty acids are straight chain acids. In addition to these straight chain acids, there are some branched chain acids, with odd or even number of carbon atoms. But these are the minor components of natural fats and oils. Isopalmitic acid, ante-isopalmitic acid, tuberculo-stearic acids are some examples of branched chain fatty acids identified in fats.

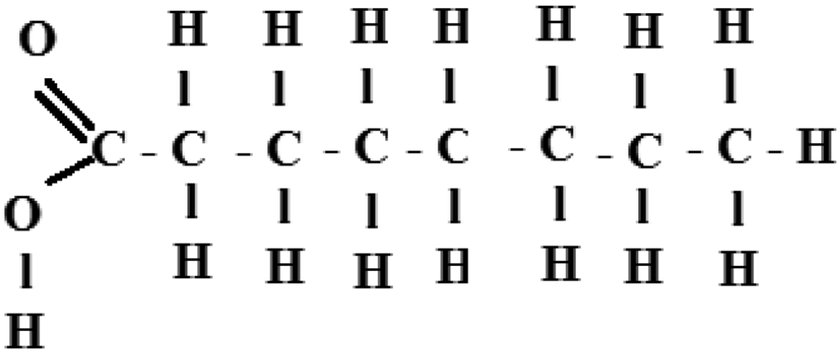


Fig 4.13 Saturated Fatty acids

4.13 UNSATURATED FATTY ACIDS

- The unsaturated fatty acids have one or more double bonds, i.e. 1 to 6 double bonds. These double bonds may occur after 9,12,15,18 etc carbon atoms. The unsaturated fatty acids are named with the suffix – enoic. Based on the number of double bonds, unsaturated fatty acids may be called as monoenoic (one =), dienoic (two =), trienoic (three =), tetraenoic (four =) and pentaenoic acids etc.

- In most of the unsaturated fatty acids, there is a single double bond lying between carbon atom 9 and 10. This is designated as δ^9. The symbol δ with the superscript number 9 indicates the position of double bond. When there are more than one double bonds, the additional, bonds occur between the δ^9 double bond and the methyl terminal end of the chain.
- The symbol 18:0 denotes a C_{18} fatty acid with no double bonds. The number 18:2 signifies that there are two double bonds. Similarly, the symbol 18:2, 9, 12 is used to denote an 18 carbon fatty acid with two double bonds in the 9 and 12 positions. When two or more double bonds are present in a fatty acid, the double bonds are never conjugated. But the double bonds are separated by a methylene group.
- Unsaturated fatty acid containing more than one double bond is called polyunsaturated fatty acid. The unsaturated fatty acids are common in living organism.
- Nemotinic acid is one of the few naturally occurring compounds containing allene group along with single, double and triple carbon-carbon linkages. It is excreted in the growth medium by Citrivorium mould. Santalbic acid, a major component of seed oil of sandal wood contains one acetylene group.
- Due to the presence of C=C in unsaturated fatty acids, geometrical isomerism is possible. Depending on the spatial arrangements of groups or atoms around the C=C two isomers are possible. They are cis and trans isomers. In cis isomers, identical groups are on the same side of the C=C. In trans isomers, identical groups are occupying opposite sides of C=C. Examples: Oleic acid and elaidic acid.
- In unsaturated fatty acid, if the double bonds are in alternate carbon atoms then it is said to be a conjugated unsaturated fatty acid. Example: α – eleostearic acid.
- If the double bonds are not in alternate positions, unsaturated fatty acid is called non conjugated fatty acid. Example : Linoleic acid
- The hydro carbon chain of saturated fatty acid is in a zig-zag manner. The zig-zag configuration is a stable configuration. Eg. Stearic acid.
- When a cis double bond is inserted into a stearic acid, an oleic acid is formed. Oleic acid has got the bent structure.

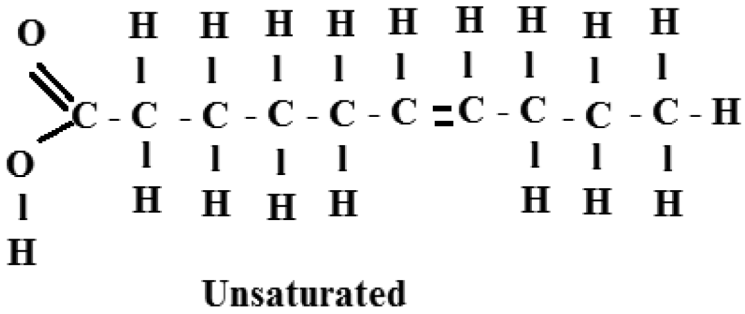
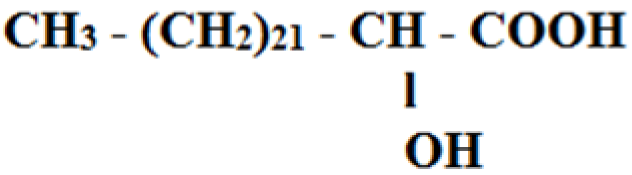


Fig 4.14 Unsaturated Fatty Acids

- Fatty acids containing hydroxyl groups are called hydroxy fatty acids.
- **Ricinoleic Acid -** It is a C_{18} acid. A double bond is present at C_9 carbon atom and hydroxyl group on C_{12}.
- **Cerebronic Acid -** It is obtained from animal lipid. It is also a hydroxy acid. The hydroxyl group is present at the C_2 carbon atom.



$$CH_3 - (CH_2)_{21} - \underset{\displaystyle OH}{\underset{|}{CH}} - COOH$$

Fig 4.15 Cerebronic acid

4.14 CYCLIC FATTY ACIDS

- Fatty acids with cyclic structures are rare occurrence. Chaulmoogric acid, hydnocarpic acid, lactobacillic acid and sterculic acids are examples of cyclic fatty acids.
- **Chaulmoogric Acid -** It is present in chaulmoogra oil used in the treatment of leprosy. It has a cyclopentenyl ring in its structure.
- **Hydnocarpic Acid -** It is present in chaulmoogra oil.

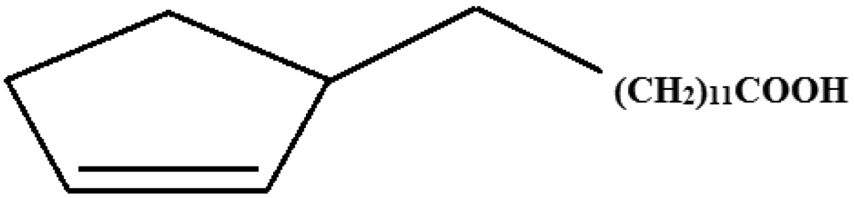


Fig 4.16 Cyclic Fatty Acids

4.15 ESSENTIAL FATTY ACIDS

Man cannot synthesize in his body certain fatty acids. These fatty acids must be included in the diet. Such, fatty acids which are not synthesized by man, but they must be included in the diet are called essential fatty acids. There are 3 essential fatty acids. They are linoleic acid, linolenic acid and arachidonic acid.

Essential fatty acids cannot be synthesized in the body of human beings.

- They must be included in the diet for maintaining normal health.
- The essential fatty acids are linoleic acid, linolenic acid and arachidonic acid.
- Most of the animal systems can interconvert these three essential fatty acids. Therefore, the diet should contain atleast any one of these essential fatty acids.
- The essential fatty acids are unsaturated fatty acids with one or more double bonds.
- Linoleic acid has 2 double bonds, linolenic acid has 3 double bonds and arachidonic acid has 4 double bonds.
- The essential fatty acids are present in vegetable oils. The best known source is the safflower oil.
- They are essential for active promotion of growth and for the maintenance of dermal integrity.
- Essential fatty acids are the important constituents of structural lipids of plasma membrane and mitochondrial membrane.
- They are found in high concentrations in reproductive organs.
- They are also present in the phospholipids.
- Arachidonic acids give rise to prostaglandins.
- They are involved in the genesis of fatty livers.
- They are essential for the metabolism of cholesterol.
- In infants, eczema is cured by feeding fats containing essential fatty acids.
- Deficiency of essential fatty acids, does not occur in man because the amount required is very less and absolutely fat free diet is practically unknown.

$CH_3 - (CH_2)_4\ CH = CH - CH_2 - CH = CH - (CH_2)_7 - COOH$

LINOLEIC ACID

$CH_3 - (CH_2)_4\ CH = CH - CH_2 - CH = CH - CH_2 - CH = CH - (CH_2)_7 - COOH$

LINOLENIC ACID

$CH_3 - (CH_2)_4\ CH = CH - CH_2 - CH = CH - CH_2 - CH = CH - CH_2 - CH = CH - (CH_2)_3 - COOH$

Arachidonic acid

Fig 4.17 Essential Fatty Acids

4.16 NON-ESSENTIAL FATTY ACIDS

- Certain fatty acids can be synthesized in the tissues from other fatty acids. These fatty acids need not be included in the diet. Hence they are also called as non-essential fatty acids.
- Example - palmitoleic acid and oleic acid.
- They are unsaturated fatty acids each containing one double bond.
- Non-essential fatty acids are synthesized from their corresponding (stearic acid) saturated fatty acids by the introduction of a single double bond. They are synthesized in the liver.
- An enzyme system in liver microsomes catalyzes the conversion of stearic acid to oleic acid.

UNIT V

ENZYMES

Chemistry of enzymes, Prosthetic group (coenzymes), Nomenclature, Classification, Properties, Mechanism of enzyme action (lock and key hypothesis, induced fit theory) and its regulation, Coenzymes: Salient features and functions, Mechanism of Coenzyme action, Classification, Common coenzymes NAD, FAD, CoA, ATP, TPP, Co Q. Factors affecting enzyme activity.

5

ENZYMES

Enzymes are defined as the biocatalysts. Enzymes are catalysts for biochemical reactions in living cells. They are proteins. They are soluble and colloidal. They accelerate the rate of reactions without being lost in the process. Enzymes are located in the cells, cytoplasm, mitochondria, tissue and body fluids.

- Enzymes help to speed up reactions of digestion and metabolism.
- Cells cannot exist without enzymes.

The term enzyme was derived from Greek meaning “in yeast”, because the yeast cells were the first to reveal enzyme activity in living organisms. It was first introduced by W. KUHNE in 1878. The study of enzyme is known as enzymology.

5.1 NOMENCLATURE OF ENZYMES

- The naming of enzymes is called as nomenclature of enzymes.
- Enzymes are named based on the substrate, the reaction, synthesis, chemical nature, etc.

1. Nomenclature based on substrate

Substrate is the substance on which an enzyme acts. Many enzymes are named by adding the suffix –ase to the name of substrate.

- The enzymes acting on carbohydrates are named as carbohydrases.
- The enzymes acting on proteins are named as proteases.
- The enzymes acting on lipids are named as lipases.
- The enzymes acting on nuclei acid are named as nuclease.
- The enzymes acting on maltose are named as maltase.
- The enzymes acting on lactose are named as lactase.
- The enzymes acting on sucrose are named as sucrase.
- The enzymes acting on urea are named as ureases.

2. Nomenclature based on reaction

The enzyme are highly specific to the reaction they catalyze. Hence this had necessitated their naming by adding the suffix –ase in the name of the reaction.

- The enzyme catalyzing hydrolysis is named as hydrolase.
- The enzyme catalyzing oxidation is named as oxidase.
- The enzyme catalyzing reduction is named as reductase.
- The enzyme catalyzing dehydrogenation is named as dehydrogenase.
- The enzyme catalyzing phosphorylation is named phosphorylase.
- The enzyme catalyzing transamination is named as transaminase.
- The enzyme catalyzing isomerization is named as isomerase.

3. Based on substrate and reaction

Some enzymes are named based on the substrate utilized and the type of reaction catalyzed.

- The enzyme removing CO_2 from pyruvic acid is named as pyruvic decarboxylase.
- The enzyme removing hydrogen from isocitric acid is named as isocitric dehydrogenase.

4. Based on synthesis

Enzymes are also named by adding suffix –ase to the substance to be synthesized.

The enzyme synthesizing citric acid is named as citric acid synthetase.

5. Based on discoverer

Certain enzymes are named by the discoverers of enzymes. Eg. Pepsin, Trypsin, Ptyalin, etc.

6. Based on enzyme commission

Commission on enzymes named the enzymes into 6 groups based on the chemical reaction catalyzed. They are

- Oxidoreductases
- Transferases
- Hydrolases
- Lyases
- Isomerases
- Ligases

Oxidoreductase: The enzymes catalyzing oxidation-reduction reactions are named as oxidoreductases E.g. Oxidase, Oxygenases, Dehydrogenases.

Transferases: The enzymes which catalyze the transfer of a group between two substances are called transferases.

E.g. Transaminase transfer amino group from one amino acid to another.

Hydrolase: The enzymes which catalyze the substrate by adding water across the bond they split are called hydrolases. E.g. Proteases, Esterases, Carbohydrases.

Lyases: The enzymes which remove the groups from substrates by mechanisms other than hydrolysis are named as lyases. E.g. Aldolase, Enolase, Fumarase etc.

Isomerase: The enzymes which interconvert isomers by rearrangement of atoms are named as isomerases. E.g. Phosphohexo isomerase

Ligases: The enzymes which link two substrate are called ligases. They are called synthetases. E.g. Acetyl CoA synthetase, Glutamine synthetase etc.

7. Based on E.C. Number

The commission on enzymes named the enzymes by a code number called enzyme commission number. Accordingly each enzyme is named by 4 digit number. E.g. 5. 2. 1. 3

The first number 5 represent the 5th class of enzyme Isomerase. The second number represents the sub-class, the third number represent the sub- sub class and the final number represents the enzyme.

5.2 CHEMISTRY OF ENZYMES

1. Proteins

Enzymes are the most specialized large protein molecules. They are made up of one or more polypeptide chains.

2. Simple enzymes

Some enzymes are simple proteins. On hydrolysis, they yield amino acid only.

Eg. Amylase, Urease etc.

3. Holoenzymes

Chemically enzymes are proteins. Some enzymes are simple proteins and others are conjugated proteins. The conjugated protein enzymes are made up of two components, namely a protein part called apoenzyme and a non-protein part. The two components together form a holoenzyme.

5.3 PROSTHETIC GROUP

The non-protein part of the enzyme may be firmly bond to the enzyme and cannot be separated by dialysis. This tightly bound non-protein part of the enzyme is called prosthetic group.

Co-enzyme

In the co-enzyme, the cofactor component is not firmly attached to the enzyme protein. Here the co-factor exist in free state in the solution. It makes a contact with the enzyme protein only at the instant of enzyme action.

5.4 PROPERTIES OF ENZYMES

- Most of the enzymes are simple or conjugated proteins. They exhibit all the properties of proteins.
- Enzymes are colloidal in nature.
- Denaturation is the change in structure and loss of activity. Enzymes are subject to denaturation by changing pH or increases in the temperature.
- Enzymes accelerate the speed of reactions.
- The enzymes promote a given reaction, but itself remains unchanged at the end of the reaction.
- Only a small amount of enzyme is required by a biological system for a complete reaction. A simple enzyme can act upon 5 lakhs substrate molecules per minute. This value is known as Turn-over number. The number of substrate molecules catalyzed by an enzyme is called turn-over number.
- Enzymes are sensitive to heat. They are destroyed by high temperature. Above 60°C the enzymes coagulate and become inactivated.
- Every enzyme has an optimum temperature at which the rate of activity is maximum. The enzyme is most active at the optimum temperature. The optimum temperature ranges between 30°C to 40°C for most of the enzymes. The optimum temperature for catalyst is 30°C.
- The rate of activity decreases when the temperature goes up or goes down from the optimum temperature.
- The activity of the enzyme steadily increases when the temperature is raised to the optimum level. The reaction velocity doubles for every rise in 10°C. This is called Q_{10} or temperature coefficient or temperature quotient.
- Most of the enzymes are characterized by the reversibility of their actions. That is, the enzymes act in either direction.

- Each enzyme will react with only one type of substrate or a group of related substrates. This property of enzyme is called specificity of enzymes.

5.5 CLASSIFICATION OF ENZYMES

In 1961, the enzyme commission of the International Union of Biochemistry proposed a comprehensive system for the classification of enzymes. According to this system, enzymes are classified into six major classes. They are follows:

- Oxidoreductases
- Transferases
- Hydrolases
- Lyases
- Isomerases
- Ligases

- Oxidoreductases are the enzymes catalyzing oxidation- reduction reactions are named as oxidoreductases. Oxidation means addition of oxygen or removal of hydrogen. Reduction means addition of hydrogen or removal of oxygen. The important sub classes are
- Dehydrogenases are enzymes that catalyze the removal of hydrogen from one substrate and pass it on to second substrate.

$$AH_2 + B \xrightarrow{\text{Dehydrogenase}} BH_2 + A$$

E.g. Alcohol dehydrogenase enzyme

- Oxidases are enzyme which catalyze the removal of hydrogen from a substrate and pass it to oxygen.

  E.g. Cytochrome oxidase enzyme

- Oxygenases are enzymes which catalyze the incorporation of oxygen directly into the substrate.
- Transferases are enzymes which catalyze the transfer of a group between two substances are called transferases.

$$AX + B \xrightarrow{\text{Transferase}} A + BX$$

eg. Transaminase transfer amino group from one amino acid to another.

- Transaminase is an enzyme which transfers amino group from alanine to oxaloacetic acid. The enzyme creatine phosphoryl transferase transfers phosphate group from creatine phosphate or adenine diphosphate.

- Hydrolase are the enzymes which catalyze the substrate by adding water across the bond they are called hydrolases. E.g. Proteases, esterases, carbohydrases.
- Proteases are enzymes that attack the peptide bonds on proteins and peptides. It is sub divided into peptidase and proteinases. It is otherwise known as exopeptidases.
- Carboxypeptidases require a free carboxyl group in the substrate and split the peptide bond adjacent to this group, liberating a free amino acid.
- Peptidases are the enzymes which act on peptide bonds adjacent to a free amino or carboxyl group.

1. **Esterases:** These enzymes catalyses hydrolysis of ester linkages. Eg. Liver esterase, Lipase, Nuclease etc.
2. **Carbohydrases:** These enzymes hydrolyze the glycosidic linkages of simple glycosides, oligosaccharides and polysaccharides.
   - Lyases are the enzymes which remove the groups of atoms from substrates leaving the double bond or add groups to double bond without hydrolysis, oxidation or reduction are named as lyases. E.g. Aldolase, Enolase, Fumarase etc.
   - Isomerases are the enzymes which interconvert isomers by rearrangement of atoms are named as isomerases.
   - These enzymes catalyze intra molecular rearrangements. The Phosphohexose isomerase catalyze the following interconversion

$$\text{Glucose-6-phosphate} \xrightarrow{\text{Phosphohexose isomerase}} \text{Fructose-6- phosphate}$$

   - Ligases are the enzymes catalyze synthesis reactions by joining two molecules coupled with that breakdown of a pyrophosphate bond of ATP $\longrightarrow$ ADP. The common Ligases are DNA Ligases, RNA synthetase, Glutamine synthetase.

5.6 MECHANISMS OF ENZYME ACTION

- The breaking of substrate into end product by an enzyme is called enzyme action. The compound on which the enzyme acts is called the substrate.
- Michaelis and Menton proposed a hypothesis for enzyme action. The enzyme action involves the following steps.

1. The enzyme molecule (E) combines with a substrate molecule (S) to form an enzyme-substrate complex. It is also called as Michaelis complex.
2. The enzyme contain specific sites for the attachment of substrates. These sites are called active sites or catalytic centres. They are made up of amino acid residues.
3. The active sites loosen the chemical bonds in the substrate and this leads to the breaking of substrates into end products.
4. Finally, the enzymes dissociates from the end product.
5. The enzyme is now free to combine with another molecule of substrate.

There are two hypothesis to explain the mechanism of the formation of enzyme-substrate complex.

1. Lock and Key hypothesis
2. Induced fit hypothesis.

5.6.1 Lock and Key Hypothesis

- This hypothesis was proposed by Emil Fisher (1914)
- This theory explains the mechanisms of the formation of enzyme substrate complex. According to this hypothesis, the enzyme molecule has one or more specific points. These points are called active sites or active centers.
- The active sites exist in the enzyme in a rigid and proper conformation even in the absence of substrate.
- During enzyme action the substrate fits into the active site of the enzyme as a key fits into the lock.

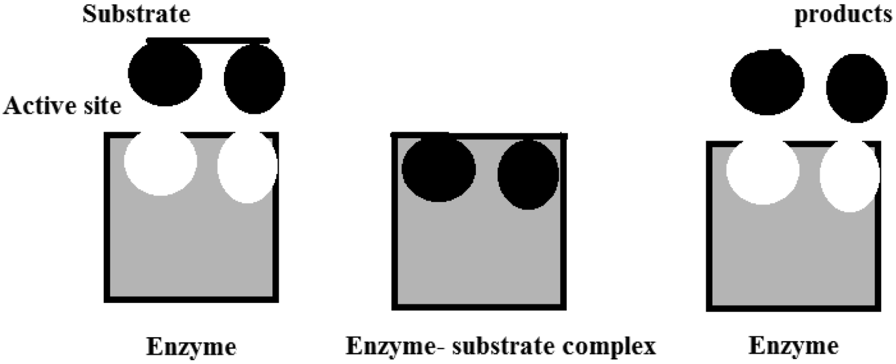


Fig 5.1 Lock and Key hypothesis

5.6.2 Induced Fit Hypothesis

- This hypothesis was proposed by Koshland (1963). It explains the mechanism of the formation of enzyme-substrate complex.
- This theory says that the active site does not possess a rigid and performed structure. The region of the active site is flexible.
- When the enzyme reacts with the substrate, the substrate induces a conformational change in the active site of the enzyme.
- This change results in the development of attraction between enzyme and the substrate so that an enzyme - substrate complex is formed.
- It leads to the loosening of the chemical bonds linking the components of the substrate.
- As the reaction is completed the substrate is split into end product and enzyme is released.

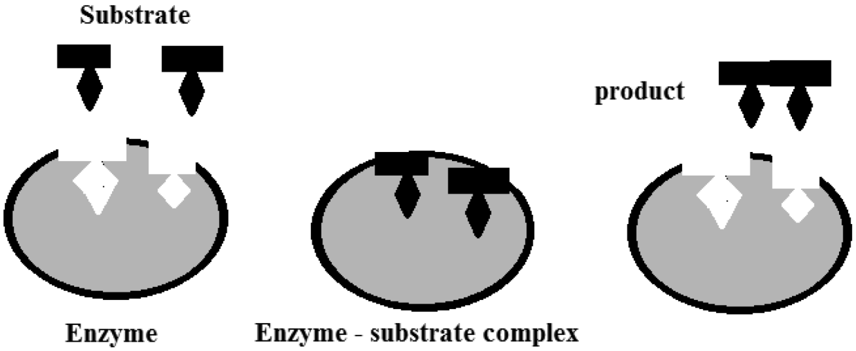


Fig 5.2 Induced Fit hypothesis

5.7 COENZYMES

- Coenzymes may be defined as non-protein organic substance loosely attached to the enzyme and can be separated by dialysis and is essential for enzyme action. E.g. NAD, NADP, ATP, UDP, CoA, TPP, FAD, FMN, Ubiquinone (CoQ), etc.
- Chemically enzymes are proteins. Some enzymes are simple proteins and others are conjugated proteins. The conjugated protein enzymes are made up of two components, namely a protein part called apoenzyme and a non-protein part. The two components together form a holoenzyme.

$$\text{Holoenzyme} \longleftrightarrow \text{Apoenzyme + Non-Protein}$$

- The non-protein part of the enzyme may be firmly bond to the enzyme and cannot be separated by dialysis. This tightly bound non-protein part of the enzyme is called prosthetic group. The loosely bound prosthetic group is the coenzyme.

$$\text{Holoenzyme} \longleftrightarrow \text{Apoenzyme + Prosthetic group}$$

$$\text{Holoenzyme} \longleftrightarrow \text{Apoenzyme + Coenzyme}$$

- The coenzyme is also called co-substrate or co-factor. It is an organic substance. It is a small molecule with low molecular weight. Hence it can be separated by dialysis. Coenzymes are heat stable. Most of them are derivatives of vitamin B complex. They are necessary for enzyme action and they accelerate the reaction rate.

5.7.1 Salient Features of Coenzymes

1. Coenzymes are non-protein organic substances loosely attached to enzymes and are easily separated by dialysis and are inevitable for enzyme action.
2. Coenzymes are also called co-substrates.
3. They are small molecules with low molecular weight. They can be reversibly separated from enzymes by dialysis.
4. They are heat-stable.
5. They are closely related to vitamins and are derivatives of vitamin B complex.
6. They function as catalysts and are essential for enzyme action. They accelerate the rate of reaction.
7. An essential component of most of coenzymes is phosphate in the form of nucleotide.
8. Coenzymes are usually not firmly attached to the enzyme protein. But they exist in the three state in the solution. They contact the enzyme protein only at the time of enzyme action.
9. The coenzymes, is repeatedly used to split many molecules of substrates both apoenzyme and coenzyme are regenerated at their original forms at the end of the reaction.

10. The coenzyme act as intermediate carriers of hydrogen atoms in the biological oxidation reduction reactions.

5.7.2 Role of Coenzymes

- The function of coenzymes is to transport groups between enzymes.
- Chemical groups include hydride ions which are carried by coenzymes such as NAD.
- Phosphate groups are carried by coenzymes such as ATP.
- Acetyl groups are carried by coenzymes such as coenzyme A.
- Coenzymes which lose or gain these chemical groups in the course of the reaction are often reformed in the same metabolic pathway.

For example NAD^+ used in glycolysis and the citric acid is replaced in the electron transport chain.

5.7.3 Mechanism of Coenzyme Action

The coenzyme helps an enzyme to combine with the substrate and at the end it is cleaved from the substrate. One of the cleavage products is transferred to the coenzyme. Finally the coenzyme is released from the product and is ready for further enzyme action.

5.7.4 Classification of Coenzymes

Coenzymes are classified into three groups on the basis of their functions. They are:

1. Hydrogen transferring coenzymes
2. Group transferring coenzymes
3. Isomerase coenzymes

1. Hydrogen Transferring Coenzymes

Certain coenzymes transfer hydrogen atoms or electrons from one. These coenzymes are called hydrogen transferring enzymes. E.g. NAD, NADP, FMN, FAD, Ubiquinine (Q), etc.

2. Group Transferring Coenzymes

These coenzymes are involved in group transfer. Eg.ATP, CDP, UDP, CoA, TPP, etc.

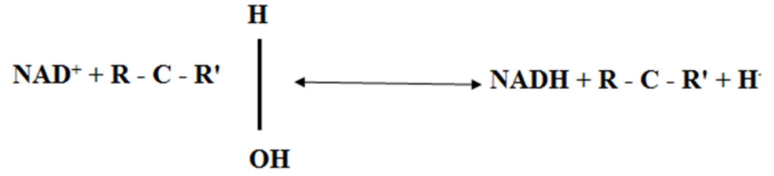
3. Isomerase Coenzymes

These coenzymes are responsible for the interconversion of isomers. E.g. UDP, TPP, etc.

5.7.5 Common Coenzymes

5.7.5.1 Nicotinamide Adenine Dinucleotide (NAD)

1. Nicotinamide Adenine Dinucleotide(NAD) is a coenzyme
2. It plays an important role in the oxidation of fuel molecules, such as glucose and fatty acids. The fuel molecules and their products during their oxidation do not transfer the electrons directly to O_2. Instead, these substrates transfer electrons to special carries which are either NAD or FAD.
3. Thus, NAD is an electro carriers of the electron transport chain located in the inner membrane of mitochondria.
4. NAD is a major electron acceptor in the electron transport system.
5. When NAD accepts electrons, NAD is reduced and the reduced form of NAD is called NADH.
6. It is a derivative of nicotinic acid, Vitamin B_5.
7. Chemically NAD is formed of four components, namely
   a. A nicotinamide
   b. An adenine
   c. Two pentose sugars, D-Ribose
   d. Two phosphate groups.
8. The coenzyme Nicotinamide Dinucleotide Phosphate (NADP) is another coenzyme related to NAD. It also functions as an electron acceptor. When it accepts electrons, it is reduced. The reduced NADP is called NADPH. The chemical structure of NAD is similar to that of NADP. But in NADP, a phosphate group (PO_3-*)* replaces the H of a ribose sugar.
9. In NAD and NADP, the Nicotinamide / nicotinamide ring is the most active part. In oxidation of a substrate, the Nicotinamide / nicotinamide ring accepts a hydrogen ion and two electrons which are equivalent to a hydride ion.
10. NAD^+ is the electron acceptor in many reactions of this type. In this dehydrogenation reaction one hydrogen atom of the substrate is directly transferred to NAD^+, where as the other appears in the solvent.
11. Both electrons lost by the substrate are transferred to the Nicotinamide ring.



$$NAD^+ + R - \overset{H}{\underset{OH}{C}} - R' \longleftrightarrow NADH + R - C - R' + H^-$$

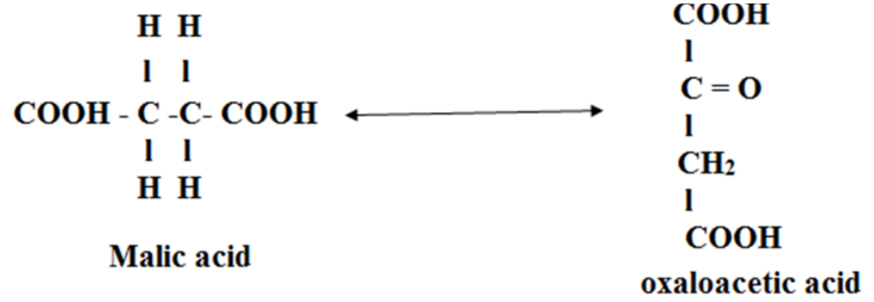
NAD accepts an electron

12. NAD and NADP are involved in most of the dehydrogenation reactions which occur in the oxidation of carbohydrates and fatty acids.
13. The dehydrogenation reactions are catalyzed by dehydrogenases. The coenzyme NAD or NADP is bound to the enzyme dehydrogenase transiently during the catalytic reaction and the hydride ion is removed from the substrate.

A very good example of such enzymatic reaction is that catalyzed by malic acid dehydrogenase which dehydrogenates malic acid to yield oxaloacetic acid, a step in Krebs' cycle.

$$\textbf{Malic acid + NAD} \xrightarrow[\textbf{dehydrogenase}]{\textbf{Malic acid}} \textbf{Oxaloacetic acid + NADH + H}^+$$

The dehydrogenase catalyzes the reversible transfer of a hydride ion from malic acid to NAD$^+$ to from NADH. The coenzyme NAD plays an important roles in glycolysis, Krebs' cycle, β oxidation, DNA splicing, etc.



5.7.5.2 *Flavin Adenine Dinucleotide(FAD)*

1. Flavin Adenine Dinucleotide (FAD) is a coenzyme.
2. It plays an important role in oxidation of carbohydrates and fatty acids. These fuel molecules and their products, during their oxidation, do not transfer the electrons directly to O$_2$. Instead, these substrates transfer electrons to special carriers which are either NAD or FAD.

3. Thus FAD is an electron acceptor of the electron transport chain located in the inner membrane of mitochondria.
4. When FAD accepts electrons, the FAD is reduced and the reduced form of FAD is called $FADH_2$.
5. FAD, like NAD^+ is a two-electron acceptor. However unlike NAD^+, FAD accepts both of the hydrogen atoms lost by the substrate.
6. FAD is a derivative of riboflavin, vitamin B_2.
7. Chemically, FAD consists of four components,

   They are,

   a. An isoalloxazine ring

   b. An adenine

   c. A ribose sugar

   d. Two phosphate groups
8. FMN, Flavin Adenine Mononucleotide is related coenzyme.

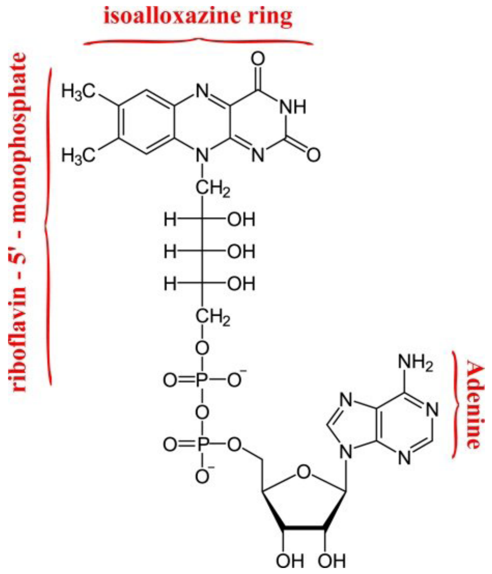
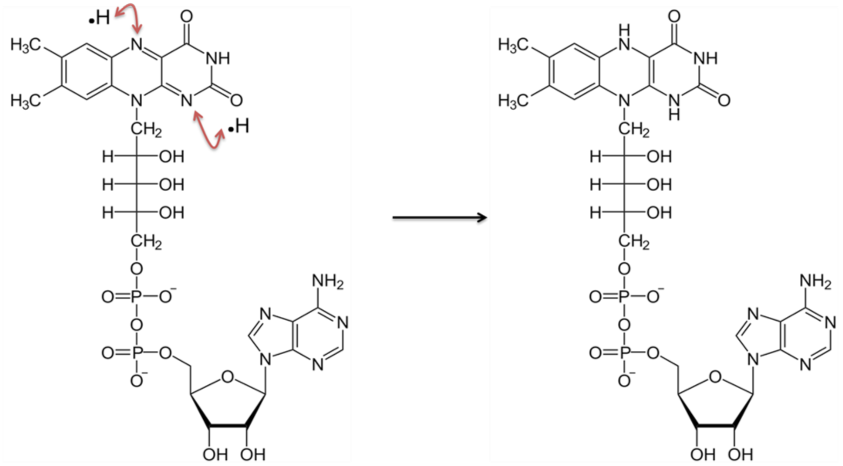


Fig 5.3 Flavin Adenine Dinucleotide (FAD)

9. In FAD and FMN, the isoalloxazine ring is the active site for accepting the hydrogen atoms.
10. They function as tightly bound prosthetic groups of a class of dehydrogenase called flavoproteins or flavin dehydrogenases. Succinic acid dehydrogenase is an example of a flavin dehydrogenase.



FAD FADH₂

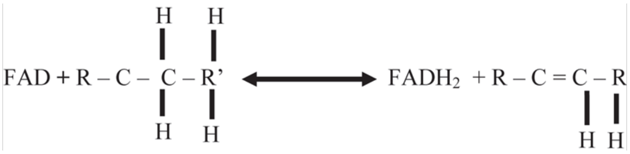
In FAD, isoalloxazine ring is the active part. It accepts two hydrogen atoms and becomes $FADH_{2.}$

It contains covalently bound protein prosthetic group of FAD and catalyzes the following reaction.

$$\text{Succinic acid} + \text{E-FAD} \longrightarrow \text{Fumaric acid} + \text{E} - FADH_2$$

In this reaction E-FAD refers to the succinic acid dehydrogenase molecule with its bound FAD.

11. FAD accepts electrons in the reactions of the following type.



$$FAD + R - \underset{H}{\overset{H}{C}} - \underset{H}{\overset{H}{C}} - R' \longleftrightarrow FADH_2 + R - \underset{H}{C} = \underset{H}{C} - R$$

12. A very good example, where FAD catalyzes the reaction is the conversion of succinic acid into fumaric acid in krebs' cycle.

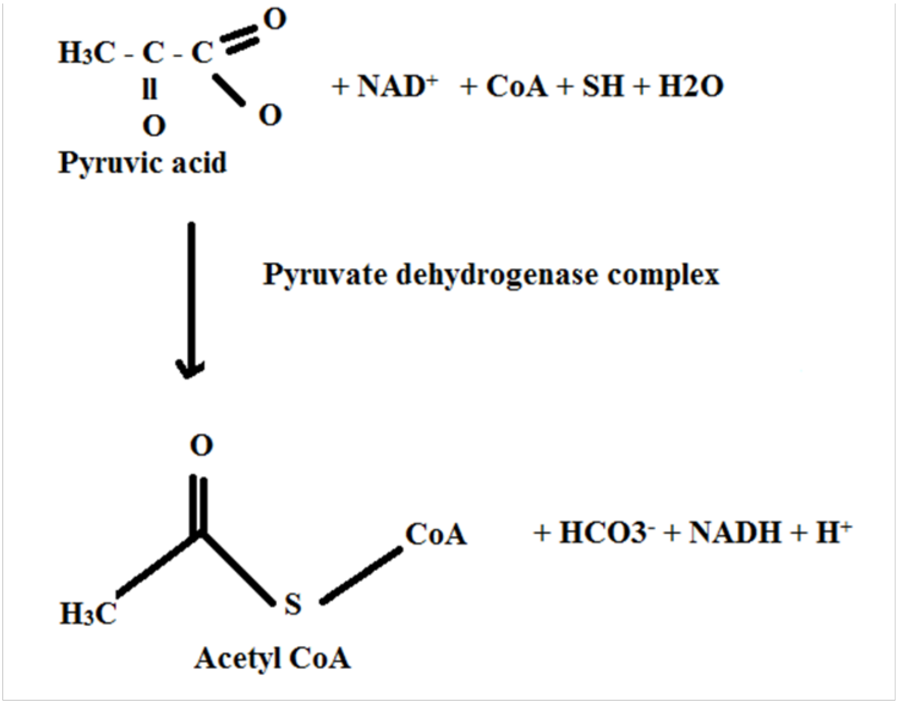
$$FAD^+ + \text{Succinic acid} \xleftrightarrow[\text{dehydrogenase}]{\text{Succinate}} \text{Fumaric acid} + FADH_2$$

FAD accepts two hydrogen atoms from succinic acid and becomes $FADH_2$.

5.7.5.3 Coenzyme A (CoA)

1. Coenzyme A is an universal coenzyme.
2. It was discovered by Lipmann in 1945.

3. CoA is involved in the transfer of acyl and acetyl groups and hence the name CoA. ‘A’ stands for acetylation. It is a transient carrier of acyl groups.
4. It is a derivative of pantothenic acid.
5. The CoA is composed of four units, namely
   a) β – mercaptoethylamine
   b) Pantothenic acid
   c) Adenine
   d) Ribose 3’ – phosphate
6. One end of CoA has a reactive group called thiol or sulfhydryl group (-SH). It is a very active group and hence CoA is abbreviated as CoA - SH.
7. During acyl group transfer the acyl group is covalently linked to the thiol group of CoA by a thioester bond. The resulting derivative is called an acyl CoA. An acyl group often linked to CoA is the acetyl unit. This derivative is called acetyl CoA. Acetyl CoA has a high acetyl group transfer potential.
8. CoA is a carrier of activated acetyl or other acyl group, just as ATP is a carrier of activated phosphoryl groups.
9. CoA plays important roles in carbohydrate and fat metabolism.



The CoA functions as a carrier of acetyl group. The acetyl group removed from pyruvic acid is accepted by CoA to become acetyl CoA. A very good example for the reaction where CoA involved is the conversion of pyruvic acid into acetyl CoA catalyzed by pyruvic acid dehydrogenase. In this reaction, the carboxyl group of pyruvic acid is removed as CO_2 and the acetyl group links with CoA to form acetyl CoA. This reaction is called oxidative decarboxylation. In this reaction, CoA functions as the carrier of acetyl group. In another reaction in Krebs' cycle, the acetyl CoA transfers its acetyl group to oxaloacetic acid which in turn is converted into citric acid and CoA is released for repeating the reactions.

$$\text{Acetyl CoA + Oxalo acetic acid + } H_2O \xrightarrow[\text{Synthetase}]{\text{Citric acid}} \text{Citric acid + Coenzyme A}$$

The acetyl CoA transfer its CoA to Oxaloacetic acid and the CoA is released for repeating the reaction.

5.7.5.4 Adenosine Triphosphate (ATP)

1. ATP is the universal currency of free energy.
2. ATP is a nucleotide consisting of three units, namely
   a) Adenine
   b) Ribose sugar
   c) Triphosphate unit

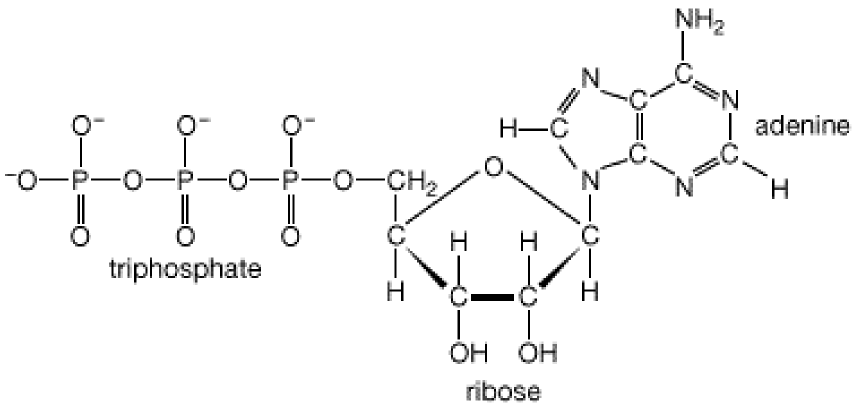


Fig 5.4 Adenosine Triphosphate (ATP)

3. ATP is an energy rich compound because its Triphosphate unit contains two phosphoanhydride bonds.
4. A large amount of free energy is released when ATP is hydrolyzed to adenosine diphosphate (ADP) and orthophosphate (Pi)

$$ATP + H_2O \longleftrightarrow ADP + Pi + H^+$$

or when ATP is hydrolyzed to adenosine monophosphate (AMP) and pyrophosphate (PPi).

$$ATP + H_2O \longleftrightarrow AMP + PPi + H^+$$

5. It functions as immediate donor of free energy.
6. ATP has a higher phosphate group transfer potential.
7. As a coenzyme, ATP is involved in transphosphorylation reactions.
8. It can transfer its orthophosphate group or diphosphate group or adenosyl monophosphate group.
9. When it transfer orthophosphate group, it release ADP.

$$ATP \longleftrightarrow ADP + Pi$$

When ATP transfers adenosyl monophosphate, it releases pyrophosphate.

$$ATP \longleftrightarrow AMP + PPi$$

5.7.5.5 *Thiamine pyrophosphate (TPP)*

1. Thiamine pyrophosphate is a coenzyme.
2. It is derivative of *vitamin* B_1.
3. It is a *prosthetic* group because it is tightly bound to the enzyme protein.
4. Chemically TPP is formed of four units, namely
    a) A *pyrimidine* ring
    b) A *thiazole* ring
    c) A *pyrophosphate* unit

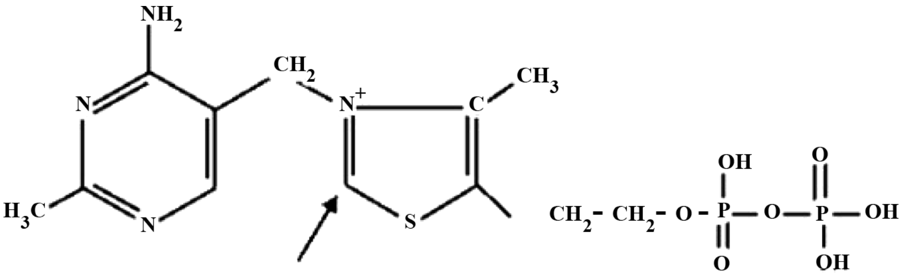
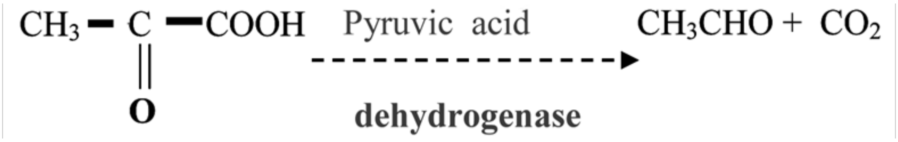


Fig 5.5 Thiamine pyrophosphate (TPP)

5. The thiazole ring is the active part of this coenzyme.
6. TPP functions as a coenzyme in several enzymatic reactions in which acetyl and aldehyde groups are transferred from a donor to an acceptor molecule. In such reactions, TPP serves as a transient intermediate carrier of the aldehyde group, which is covalently attached to the thiazole ring.
7. An example, in which TPP, involved is the reaction catalyzed by pyruvic acid decarboxylase, an important step in the fermentation of glucose.

In this reaction, the carboxyl group of pyruvic acid is lost as CO_2 and the rest of the pyruvic acid is called active acetaldehyde.



$$CH_3-\underset{\underset{O}{\|}}{C}-COOH \xrightarrow[\textbf{dehydrogenase}]{\text{Pyruvic acid}} CH_3CHO + CO_2$$

The active acetaldehyde is simultaneously transferred to the 2nd position (the carbon atom between the nitrogen and sulfur atoms) of the thiazole ring of the tightly bound TPP to yield is α-hydroxyethyl derivative.

Pyruvic acid + TPP – E ⟷ α- hydroxyethyl – TPP – E

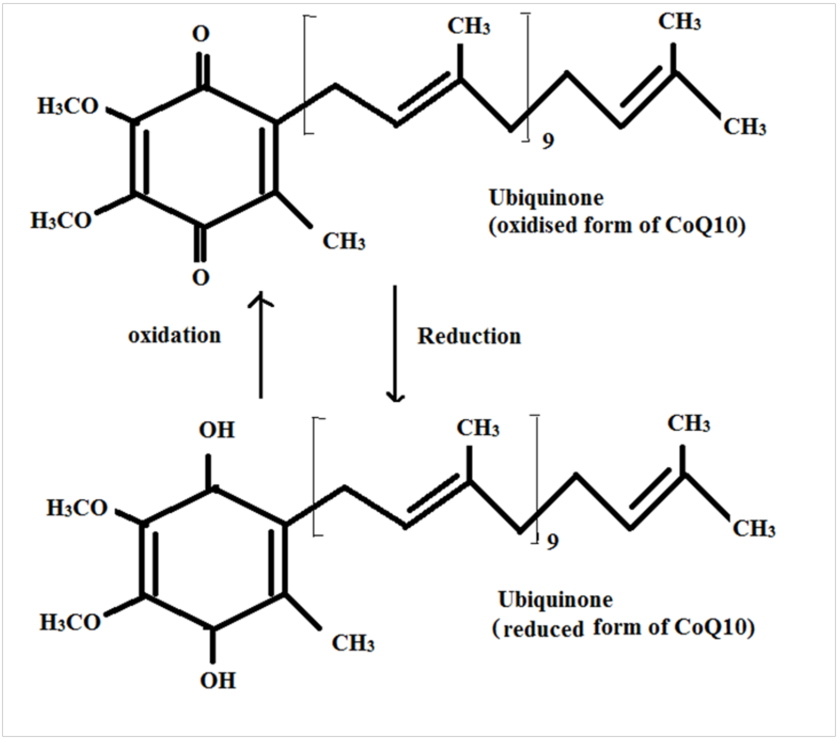
This intermediate exists only transiently, since the hydroxyethyl group is quickly cleaved from the coenzyme to yield free acetaldehyde.

α- hydroxyethyl – TPP – E ⟷ Acetaldehyde + TPP + E

8. TPP also serve as the coenzyme in pyruvic acid dehydrogenase and α-ketoglutaric acid dehydrogenase reactions taking place in citric acid cycle.

5.7.5.6 Ubiquinone or coenzyme Q

1. Ubiquinone is also called coenzyme Q. It is called Ubiquinone because it is ubiquitous in biological systems.
2. Co-Q is a quinone derivative with a long isoprenoid tail. The number of isoprene units in Q depends on the species.
3. The most forms in mammals contains10 isoprene units and so it is designated as Q_{10}.
4. Co-Q is the only electron carrier in the respiratory chain that is not tightly bound or covalently attached to a protein.
5. In fact, Q serves as a highly mobile carrier of electrons between the flavoproteins and the cytochromes of the electron- transport chain.



5.8 FUNCTION OF COENZYME

- The coenzyme is essential for the biological activity of the enzyme.
- A coenzyme is a low molecular weight organic substance, without which the enzyme cannot exhibit any reaction.
- One molecule of the coenzyme is able to convert a large number of substrate molecules with the help of enzyme.

5.9 FACTORS AFFECTING ENZYME ACTIVITY

The activity of enzyme is affected by a number of factors such as temperature, pH, enzyme and substrate concentration.

5.9.1 Effect of Temperature on Enzymes

- The rate of enzyme action increases with increase of temperature upto 40^0C.
- The temperature at which the enzyme action is maximum is called the optimum temperature.
- For most of the enzymes, the optimum temperature lies between 30^0C and 40^0C. At low temperature, the enzyme is ineffective.
- At high temperature, for example at 60^0C the enzyme becomes inactive. This is because the enzyme is denatured or destroyed by high temperature. Thus enzymes are said to be thermolabile.

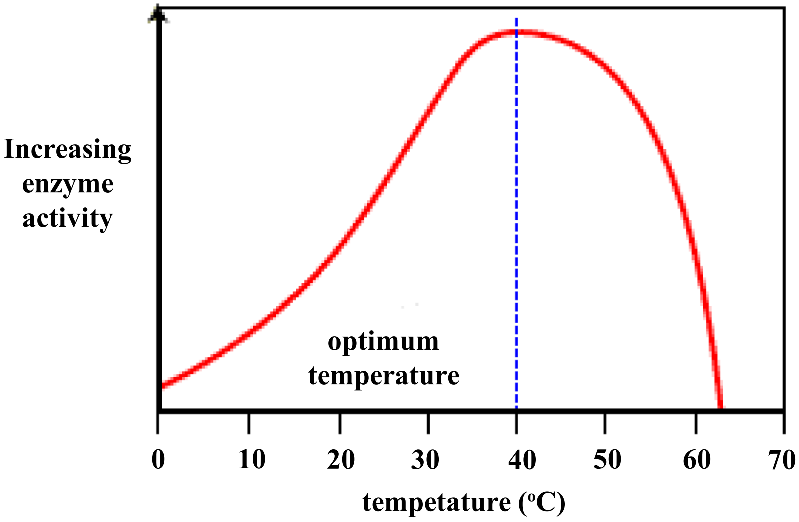


Fig 5.6 Effect of temperature on enzymes

5.9.2 Effect of pH on Enzymes

- The rate of enzyme action increases with increase in the H^+ ion concentration up to a certain pH when the enzyme action is maximum. This pH is called the optimum pH.
- Increased H^+ ion concentration beyond this peak point will destroy the enzymes, because of their protein nature and bring down the enzyme action.
- Most of the enzymes act effectively in a pH range 5.0 to 9.0. But some enzymes like pepsin are active even at pH value between 1.2 and 1.8.

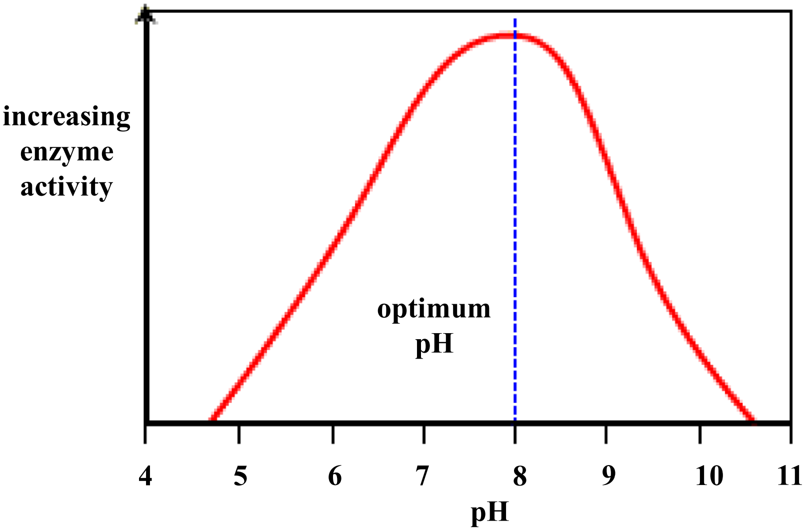


Fig 5.7 Effect of pH on enzymes

5.9.3 Effect of Enzyme Concentration

- An enzyme works even when it is present in low quantity. The velocity of the reaction increases with the increase in the concentration of enzymes.
- The velocity (V) of a reaction is proportional to the concentration of enzyme (E). When the enzyme concentration is doubled, the velocity is also doubled. This is because when concentration is doubled as much as twice, the active sites become available to combine with the substrate.

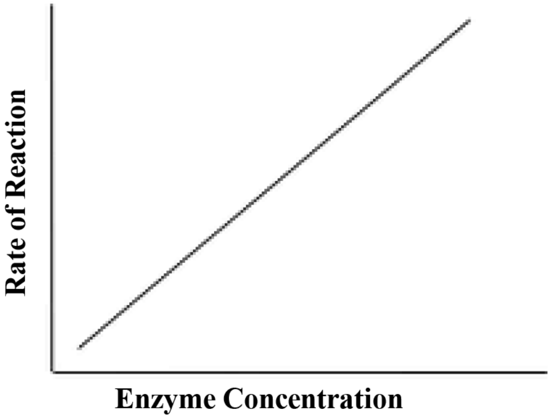


Fig 5.8 Effect of enzyme concentration

5.9.4 Effect of Substrate Concentration

- An increase of substrate concentration results in a very rapid increase in the velocity of reaction.
- As the substrate concentration continues to increase, the increase in the rate of reaction begins to slow down with a large substrate concentration. Thus up to a certain point the reaction rate is proportional to the substrate concentration.

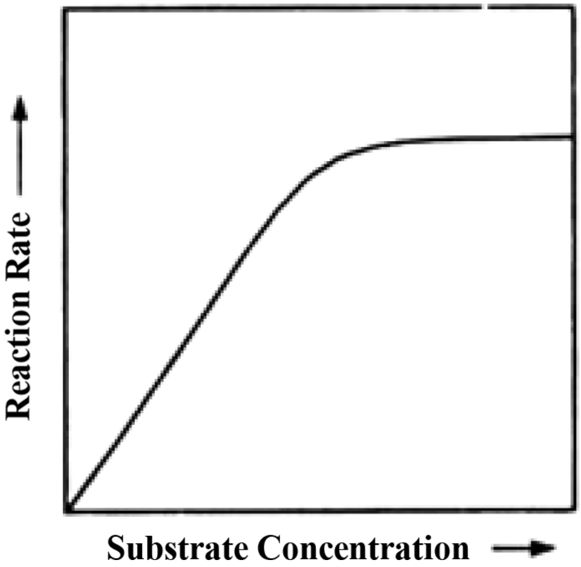


Fig 5.9 Effect of substrate concentration

UNIT VI

NUCLEIC ACIDS

Nucleic acids - Classification – DNA, Chemical composition, Nucleoside, Nucleotide, Polynucleotide, Watson and Crick Model Of DNA- RNA, Types - mRNA, tRNA, rRNA - Biological Function of Nucleic acids.

6

NUCLEIC ACIDS

- The nuclei acid was first isolated in 1868 by *Miescher* from the nuclei of pus cells on hospital bandages. Hence it was called Nuclein. Altmann (1889) gave the name nucleic acid.
- Nucleic acid is a macromolecule with acid property and it was isolated from the nucleus of cells and hence it is named as nucleic acid. It is made up of C, H, O, N and P.
- Nucleic acids are found in all organisms such as plants, animals, bacteria and viruses. They are found in the nucleus as well as in the cytoplasm.
- Nucleic acid molecule is a long chain polymer. It is composed of monomeric units, called nucleotides. Each nucleotide consists of a nucleoside and a phosphate group. Each nucleoside consists of pentose sugar and a nitrogenous base. The sugar is ribose in the case of RNA and deoxyribose in the case of DNA.
- The nitrogenous bases are of two types, namely purines and pyrimidines. There are two main purine bases, adenine and guanine. Similarly there are three main pyrimidine bases. They are cytosine, thymine and uracil. DNA contains all these bases except uracil. RNA contains these entire bases except thymine.

6.1 POLYNUCLEOTIDE OR NUCLEIC ACIDS

- A number of nucleotide units link with one another to form a polynucleotide chain or nucleic acid. Nucleotide is derived from a nucleoside by the addition of a molecule of phosphoric acid. A base combined with a sugar molecule is called a nucleoside.

6.1.1 Classification of Nucleic acids

Nucleic acids are broadly classified into two types based on the type of sugar present in them. They are:

- Deoxyribonucleic acid (DNA)
- Ribonucleic acid (RNA)

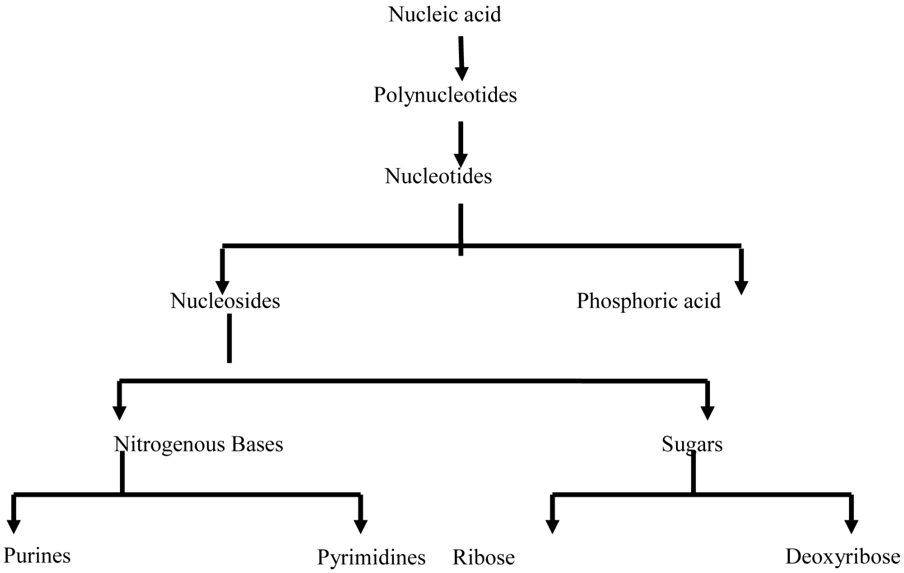


Fig 6.1 Composition of Nucleic acids

The ribonucleic acid is further divided into three types, namely

- Messenger RNA (mRNA)
- Transfer RNA (tRNA)
- Ribosomal RNA (rRNA)

6.2 DEOXYRIBONUCLEIC ACID (DNA)

- Deoxyribonucleic acid is the molecule of heredity. It is a nucleic acid containing deoxyribose sugar. It is made up of two polynucleotide chains. Each chain has a large number of deoxyribonucleotides.
- Deoxyribonucleotides are formed of deoxyribose sugar, nitrogenous bases and phosphoric acid. The sugar and phosphoric acid perform a structural role. The nitrogenous bases of DNA carry genetic information.
- DNA is present in all cells majority of plant viruses contain RNA except pure plant virus for example, cauliflower mosaic virus has double stranded DNA. In eukaryotic cells, DNA is present in the chromosomes of nucleus. In addition, the mitochondria and plastids also contain DNA.

- In eukaryotic nucleus, the DNA is in the form of double helix. In bacteria, mitochondria and plastids the DNA molecules are circular. In viruses and bacteriophages, they are coiled.
- The number of DNA molecules in eukaryotic cells corresponds to the number of chromosomes per cell.

6.2.1 Chemical Composition

- DNA is made up of three chemical components namely,
  1. Sugar
  2. Phosphoric acid and
  3. Nitrogenous bases.

Sugar

- The sugar present in the DNA is called deoxyribose. It is pentose sugar which contains five carbon atoms. It contains one O atom less than the ribose sugar. At carbon No. 2 of deoxyribose, H-C-H group is present. But in ribose sugar, the second carbon atom contains H-C-OH group.

Phosphoric acid

- Phosphoric acid links the consecutive nucleotides by joining their pentose sugars with a phosphate diester bond. This bond links carbon 5’ in one nucleoside with carbon 3’ in the next nucleoside.

Nitrogenous bases

- These are N_2 containing organic compounds. They are of two types namely purines and pyrimidines.
- Purines are two ringed nitrogen compounds. They are of two types namely adenine and guanine.
- Pyrimidines are single ringed nitrogen compounds. They are of two types namely thymine and cytosine.

6.2.2 Nucleosides

- A base combined with a sugar molecule is called a nucleoside. In DNA, four different nucleosides are present. They are

  Adenosine – Deoxyribose sugar + Adenine

  Guanosine – Deoxyribose sugar + Guanine

Cytidine – Deoxyribose sugar + Cytosine

Thymidine – Deoxyribose sugar + Thymine

- In a nucleoside, the first carbon of sugar is linked with 3rd position of pyrimidines or 9th position of purines.
- In RNA, deoxyribose sugar is replaced by ribose and the base thymine is replaced by uracil.

6.2.3 Nucleotides

- Nucleotides is derived from a nucleoside by the addition of a molecule of phosphoric acid. The phosphate molecule is linked with sugar molecules at 3rd carbon or 5th carbon.
- The nucleotides will be called 5'p*3 OH nucleotide and 3'p5' OH nucleotide.
- The *5'p3' OH nucleotide mean it has a phosphate group at the 5' end and a hydroxyl group at the 3' end. The 3'p5' OH nucleotide means it has a phosphate group at the 3' end and a hydroxyl group at the 5' end.
- The DNA contains four different types of nucleotides. They are adenylic acid, guanylic acid, cytidylic acid and thymidylic acid.
- The RNA contains uridylic acid instead of thymidylic acid.

6.2.4 Polynucleotide

- A number of nucleotide units are linked with one another and form a polynucleotide chain. Nucleotides are linked with another by phosphodiester bond. A phosphodiester bond will be formed between any two adjacent nucleotides.

6.3 WATSON AND CRICK MODEL OF DNA

- Watson and Crick in 1953 proposed a model to explain the arrangement of molecules in DNA. The model is characterized by the following features.
- DNA is a nucleic acid. It is deoxyribonucleic acid.
- It is a macromolecule.
- Each DNA is formed of two polypeptide chains.
- The two chains are spirally coiled to form a double helix.
- Each chain is formed of many units called nucleotides. Nucleotides are the building blocks of DNA.

- A nucleotide is formed of three components namely a phosphoric acid, a deoxyribose sugar and a nitrogenous base. As there are four kinds of nitrogenous bases, there are four kinds of nucleotides, namely

  Adenylic acid = Phosphate group + Adenine

  Guanylic acid = Phosphate group + Guanine

  Cytidylic acid = Phosphate group + Cytosine

  Thymidylic acid = Phosphate group + Thymine
- A nucleotide is formed of a nucleoside and a phosphoric acid. Thus a nucleoside is formed of a base and a deoxyribose sugar. As there are four types of nitrogenous bases, four types of nucleosides are present. They are

  Adenosine = Deoxyribose + Adenine

  Guanosine = Deoxyribose + Guanine

  Cytidine = Deoxyribose + Cytosine

  Thymidine = Deoxyribose + Thymine
- Adenine and guanine belongs to a group of compound called purines. Similarly, thymine and cytosine belong to another group called pyrimidines.
- In DNA molecules, purines are linked with pyrimidines.
- Adenine is linked with thymine and guanine is linked with cytosine.
- The adjacent chains are linked by hydrogen bonds. Adenine of one chain is linked with the thymine of another chain by two hydrogen bonds. Similarly guanine of one chain is linked with the cytosine of the second chain by three hydrogen bonds.
- The amount of adenine is equal to the amount of thymine and the amount of guanine is equal to the amount of cytosine.
- The two chains of a DNA are complementary to each other.
- One end of the polynucleotide chain is 3’ and the other end is called 5’. In the 3’ end, the third carbon of the sugar is free and it is not linked to any nucleotide. In the 5’ end, the fifth carbon of the sugar is free and it is not linked to any nucleotide.
- A DNA molecule looks like a ladder. The sugar and phosphate form the back bones and base pairs from the horizontal rounds.
- A single DNA molecule may contain about 2000 base pairs or nucleotides.
- The two complementary chains are twisted around each other to form a double helix. One turn of helix measures about 34A°. It contains 10 paired nucleotides. Distance between two base pairs is 3.4A°.

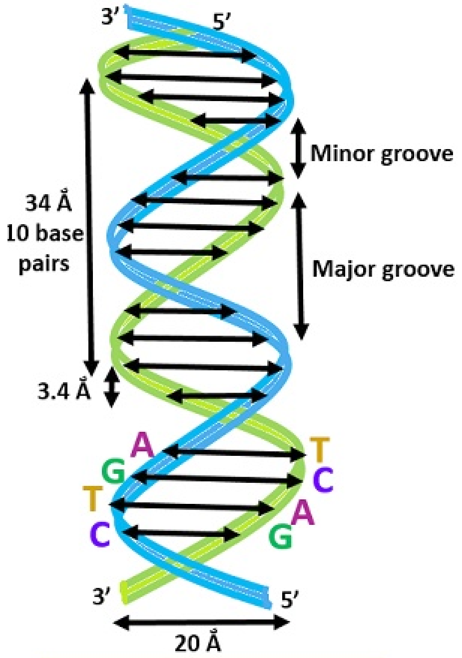


Fig 6.2 Structure of DNA by Watson and Crick Model

Structural variation in DNA

- In addition to the double helicular DNA, there are single stranded DNA and circular shaped DNA having the same chemical composition.
- **Single stranded DNA** - DNA exists normally as single stranded molecules. Such a type of DNA was isolated by Sinshemer in 1959.
- **Circular DNA** - The circular DNA is characteristic of the cell organelle, mitochondria. Mitochondrial DNA differs from nuclear DNA in several aspects. The GC content is higher in mitochondrial DNA. The amount of genetic information carried by mitochondrial DNA is not sufficient to provide specifications for all the proteins and enzymes present in the organelles.

Fig 6.3 Single Stranded DNA

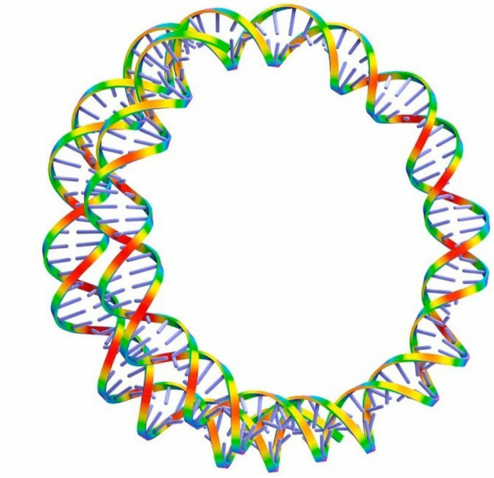


Fig 6.4 Circular DNA

6.4 RIBONUCLEIC ACID

- Ribonucleic acid is a nucleic acid containing ribose sugar. It is found in large amount in the cytoplasm and at a lesser amount in the nucleus. In the cytoplasm, it is mainly found in the ribosome and in the nucleus.
- RNA is formed of a single strand. It consists of several units called ribonucleotides. Hence each RNA molecule is formed of several nucleotides.
- Each nucleotide is formed of three different molecules, namely phosphate, ribose sugar and nitrogen base. The nitrogen bases are of two types, namely purines and pyrimidines. The purines present in the RNA is adenine and guanine. The pyrimidines present in RNA are cytosine and uracil.
- The RNA molecule is single stranded. Sometimes, the strand may be folded back upon it and this double strand may be coiled to form a helical structure like that of DNA.
- In RNA, the purines and pyrimidines are not present in equal amount.

6.4.1 Types of RNA

There are three types of RNA. They are the following

1. Messenger RNA (mRNA)
2. Transfer RNA (tRNA)
3. Ribosomal RNA (rRNA)

6.4.1.1 Messenger RNA (mRNA)

- Messenger RNA (mRNA) is a ribonucleic acid which carries genetic information for protein synthesis from the DNA to the cytoplasm. The term mRNA was coined by Jacob and Monad in 1961.
- The mRNA forms about 3 to 5% of the total cellular RNA. The mRNA is synthesized as a complementary strand upon the chromosomal DNA. The genetic message from DNA is transcribed to this mRNA. The mRNA carries the message in the form of triplet codes.
- The hybrid mRNA inside the nucleus is called heterogenous nuclear RNA (hnRNA). It is processed in the nucleus and enters the cytoplasm through nuclear membrane. In the cytoplasm mRNAs are deposited on some ribosomes. In the ribosomes, mRNA acts as a template for protein synthesis.
- The life span of mRNA in bacteria is about 2 minutes. In eukrayotes, it lives for few hours to a few days. In the animal eggs and plant seeds, the mRNA is stabilized for months or years. Protein synthesis must be carried out within this lifespan.

Structure of mRNA

- mRNA is the messenger RNA. It is a ribonucleic acid carrying information from the DNA to the cytoplasm.
- The mRNA is a single stranded polynucleotide chain.
- The mRNA contain phosphoric acid, ribose sugar, purines namely adenine and guanine and pyrimidines namely cytosine and uracil.
- The mRNA carriers genetic information from DNA. The genetic information carried by the mRNA is called genetic code. The genetic code is the sequence of nitrogen bases in mRNA. The genetic code is formed of several codons. Each codon is a sequence of three nitrogen basses which codes for one amino acid. As each codon is formed of three nitrogen bases, it is called triplet code.
- Among RNAs, mRNA is the longest one. Most of the mRNAs contain 900 to 15, 000 nucleotides.
- Each mRNA contains the codons from one polypeptide chain. If the mRNA contain 900 nucleotides the polypeptide chain synthesized by this mRNA will contain 300 amino acids.
- One end of mRNA is called 5’ end and the other end is called 3’ end.

- At the 5' end a cap is found in most eukrayotes and animal viruses. The cap formed by the condensation of a guanylate residue. The cap helps the mRNA to bind with ribosomes.
- The cap is followed by a non-coding region. It does not contain code for protein and hence it cannot translate protein. It is formed of 10 to 100 nucleotides and is rich in A and U residues.
- The non coding region is followed by the initiation codon. It is made up of AUG.
- The initiation codon is followed by the coding region which contains the code for protein. It has an average of 1.500 nucleotides.
- The coding region is followed by a termination codon. It completes the translation. It is made up of UAA or UAG or UGA in eukaryotes.
- The termination codon is followed by a non- coding region. It has a nucleotide sequence of AAUAAA.
- At the 3' end of mRNA there is a polyadenylate sequence.

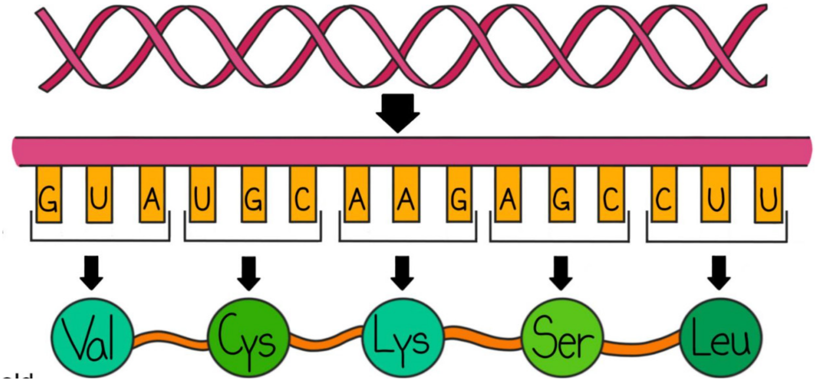


Fig 6.5 mRNA

6.4.1.2 *Transfer RNA (tRNA)*

- It is a single stranded RNA.
- It is smaller than mRNA.
- It transports amino acids to the site of protein synthesis.
- Each tRNA transport only one variety of amino acid.
- There are about 60 types of tRNA. As there are only 20 types of amino acids, certain amino acids are carried by more than one tRNA.
- The tRNA is formed of small units called nucleotides. There are about 75 to 80 nucleotides in a tRNA.

- The tRNA contains phosphoric acid, ribose sugar, purines and pyrimidines.
- The tRNA is folded on itself to form a clover leaf like structure. It has two terminal ends, three main loops and one mini loops.
- tRNA has four regions, namely
- Acceptor arm or amino acid binding site
- D arm or enzyme site
- TψC arm or ribosomal site
- Anticodon arm or recognition site
- Each amino acid is activated by a specific enzyme. The activating enzyme is attached to a main loop of tRNA. Hence the site is called enzyme site. It recognizes, catalyzes and picks up the appropriate amino acid from the cytoplasm.
- The tRNA is attached to the ribosome through one main loop. Hence this region of tRNA is called ribosome site.
- The tRNA contains certain rare and unusual nitrogen bases, namely pseudouridine, methylguanine, methylamino-purine, inosinic acid.
- Transfer RNA are more stable.
- They are synthesised from the DNA of chromosome.

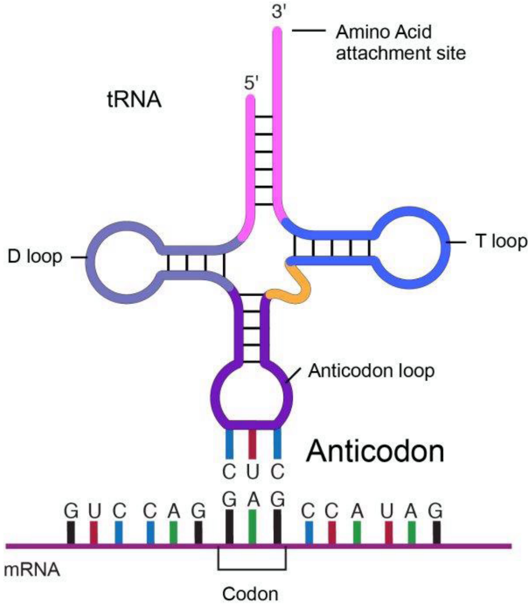


Fig 6.6 tRNA

6.4.1.3 Ribosomal RNA (rRNA)

- Ribosomal RNA is a ribonucleic acid present in the ribosome and hence it is called ribosomal RNA. It is also called insoluble RNA. It constitutes about 80% of the cellular RNA. It is the most stable form of RNA.
- The ribosomal RNA is formed of a single strand. It is polynucleotide chain. Each strand is formed of many nucleotide units. Each nucleotide is formed of three different molecules namely phosphate, a ribose sugar and a nitrogen base.
- The nitrogen bases are of two types namely purines and pyrimidines. The purines present in the rRNA are adenine and guanine. The pyrimidines present in rRNA are cytosine and uracil.
- In some regions, the single strand itself align upon itself to form a double helix. The helical regions are connected by intervening single stranded regions. In the helical regions most of the base pairs are complementary. They are joined by hydrogen bonds. In the unfolded single strand regions, the base pairs are not complementary. Because of this nature, in the rRNA the purines and pyrimidines bases have no equality.
- The rRNA are classified into 7 types according to their sedimentation coefficient. They are the following.

  28S rRNA

  18 S rRNA

  5.8S rRNA

  5S rRNA

  23 S rRNA

  16 S rRNA
- Though the rRNA constitutes the main bulk of the cytoplasmic RNA its function is not clearly known. However it is believed that rRNA plays the major role in protein synthesis.
- In all organisms except virus, the RNA is doing non- genetic functions. Such RNAs are called non genetic RNAs.

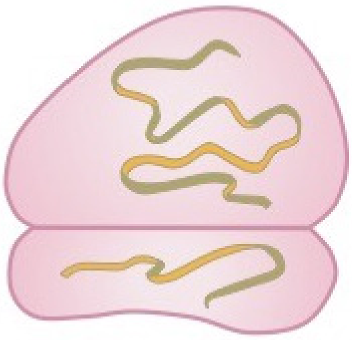


Fig 6.7 rRNA

6.5 BIOLOGICAL FUNCTION OF NUCLEIC ACIDS

Nucleic acids play vital roles in the life of organisms

1. Protein synthesis

Nucleic acid synthesize the various proteins of the protoplasm.

2. Memory

RNA is associated with memory storage functions in the brain.

3. Replication

During cell division, DNA divides and offers exact copies to the daughter cells.

4. Genetic information

DNA contains genetic information. DNA transfers characters from parents to offspring.

5. Mutation

DNA produces mutation resulting in new characters.

UNIT VII

VITAMINS

Introduction, Vitamins and it's classification – provitamins – biological functions – Properties of Vitamins – Classification of Vitamins – fat soluble vitamins (Vitamin – A, D, E and K) and water soluble vitamins (Vitamin - B_1, B_2, B_3, B_5, B_6, B_7, B_9 and B_{12}) Vitamin C and their composition, structure, sources, properties, functions, deficiency symptoms and dietary requirements.

7

VITAMINS

Vitamins are required by the body to grow and develop. Different organisms have different vitamin needs. Some organisms do not require vitamins. Example: Bacteria A. Hope you have verified this information. I couldn't find any information regarding this fact since I'm not aware of 'bacteria A'.

Vitamin is an organic compound and an essential nutrient that an organism needs in small amounts. Vitamins are classified by both biological and chemical activity and not their structure.

Different kind of vitamins are required by different organisms. Vitamins must be included in the diet in optimum amount. Excess of vitamin or low level of vitamin causes disorders.

7.1 VITAMINS AND IT'S CLASSIFICATION

Vitamins are the group of organic compounds which are essential for normal growth and nutrition and are required in small quantities in the diet because they cannot be synthesized by the body.

Vitamins are classified into fat soluble vitamins and water soluble vitamins.

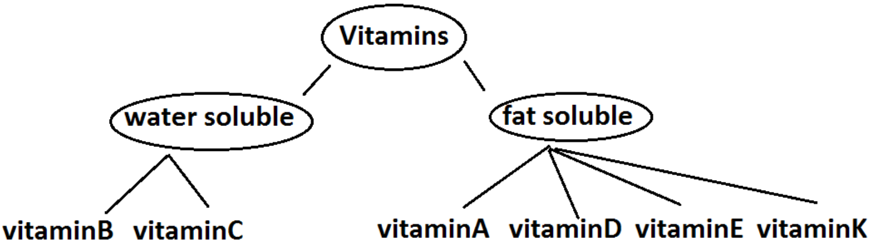


Fig 7.1 Classification of Vitamins

Totally there are 13 vitamins in which 4 is a fat soluble vitamin (A, D, E, K) and the remaining 9 is a water soluble vitamin (B and C).

7.2 PROVITAMINS

Provitamin is an inactive vitamin which can be converted into a vitamin. It is a precursor of vitamin. A precursor is converted by the body to the vitamin.

Examples: Carotene – provitamin for Vitamin A

Ergosterol – provitamin for Vitamin D

7.3 BIOLOGICAL FUNCTIONS

7.3.1 Water-soluble vitamins

The important roles of water soluble vitamins are

Table 7.1 Water-soluble vitamins- Functions and Sources

Nutrient	Function	Sources
Vitamin B_1 Thiamine	Nerve function, Required for energy metabolism.	whole-grain or enriched breads and cereals, legumes, Rice polishing's, liver, kidney, yeast, milk, groundnuts, eggs, green vegetables and dairy products (except butter)
Vitamin B_2 Riboflavin	Normal vision and skin health	Milk and milk products; leafy green vegetables. Yeast, egg white, liver, kidney, meat
Vitamin B_3 Niacin	Essential for nervous system, digestive system, and skin health	Meat, poultry, fish, whole-grain or enriched breads and cereals, leafy green vegetables, peanut butter
Vitamin B_5 Pantothenic acid	Required for energy metabolism	Plant and animal tissues, meat products like liver, meat and kidney, yeast, grain, cereals, pulses, groundnut and coffee
Vitamin B_6 Pyridoxine	Required for protein metabolism.	Meat, fish, poultry, vegetables, fruits, cereal grains, molasses and yeast
Vitamin B_7 Biotin	Part of an enzyme needed for energy metabolism	Widespread in foods; also produced in intestinal tract by bacteria
Vitamin B_9 Folic acid	Essential for blood cells.	Green leafy vegetables and fruits

Vitamin B_{12} Cobalamin	Part of an enzyme needed for making new cells; important to nerve function	Meat, poultry, fish, seafood, eggs, milk and milk products; not found in plant foods
Vitamin C Ascorbic acid	Essential for immune system	Found only in fruits and vegetables, especially citrus fruits, vegetables in the cabbage family, cantaloupe, strawberries, peppers, tomatoes, potatoes, lettuce, papayas, mangoes, kiwifruit

7.3.2 Fat-soluble vitamins

Table 7.2 Fat-soluble Vitamins – Functions and Sources

Nutrient	Function	Sources
Vitamin A	Needed for vision, healthy skin and mucous membranes, bone and tooth growth, immune system health	Leafy, dark green vegetables, dark orange fruits, fish oil, particularly in shark liver oil
Vitamin D	Bones development	Sunlight, egg yolks, liver, fatty fish, fortified milk
Vitamin E	Antioxidant; protects cell walls	Oils of soyabean, corn, cottonseed, safflower, leafy green vegetables, whole-grain products, liver egg yolks; nuts and seeds
Vitamin K	Needed for proper blood clotting	Leafy green vegetables

7.4 PROPERTIES OF VITAMINS

- Vitamins are organic compounds.
- Plants synthesize vitamins.
- Animals obtain the vitamins from the food stuffs.
- Man requires lesser vitamins. They are required in very small quantities.
- They do not provide any energy for the animals; but they regulate the physiological activities functioning as coenzymes.
- Vitamins are destroyed by high temperature and cooking for longer duration of time.

- When vitamins are deficient in the food, they produce a set of diseases called deficiency diseases. These diseases can be cured only by treatment with the particular vitamin deficient.

7.5 CLASSIFICATION OF VITAMINS

Vitamins are classified based on their solubility. They are classified as fat -soluble vitamins and water-soluble vitamins.Vitamins A, D, E and K are called fat soluble vitamins. B-complex vitamins and Vitamin C are called water soluble vitamins.

7.6 FAT SOLUBLE VITAMINS

7.6.1 Vitamin A: Retinol or Anti Xerophthalmic Vitamin

It is a fat soluble vitamin. Vitamin A is needed by the retina of the eye in the form of retinal rhodopsin, the light-absorbing molecule which was necessary for both low-light and color vision. It exists in two forms, Vitamin A_1 (Retinol$_1$) and Vitamin A_2 (Retinol$_2$). The empirical formula of A_1 is $C_{20}H_{29}OH$ and A_2 is $C_{20}H_{27}OH$.

Animals synthesize vitamin A from carotene. So carotene is called provitamin A. A single carotene is split into two molecules of Vitamin A.

Composition

- Vitamin A is an alcohol.
- The empirical formula is $C_{20}H_{29}OH$
- Vitamin A consists of an ionone ring and a hydrocarbon chain. It has 5 conjugated double bonds. The hydrocarbon chain ends in a terminal alcohol group.

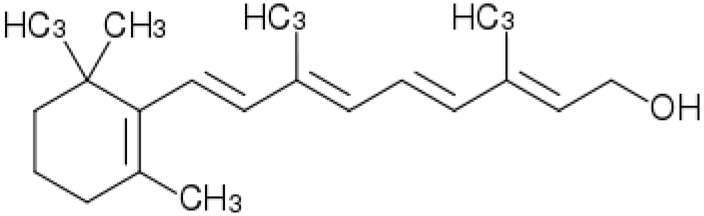


Fig 7.2 Structure of Vitamin A

Sources

Leafy, dark green vegetables; dark orange fruits Fish oil, particularly in shark liver oil

Properties of Vitamin A

- Vitamin A is soluble in fat and soluble in water.
- It is destroyed by light and oxidation.
- It is thermo labile.
- It forms esters.
- It can be oxidized to form aldehyde.

Functions

- Vitamin A is an important component of rhodopsin of retina. Hence it is essential for vision.
- Vitamin A is essential for cell growth, immune function, fetal development and vision.
- It promotes growth.
- It is essential for protein synthesis.
- It maintains the normal growth and shape of bones.
- It is essential for the synthesis of mucopolysaccharides.
- It promotes fertility.
- It has some specific functions on carbohydrate metabolism.
- It is essential to the normal structure and functions of epithelial tissues.
- It is essential for the metabolism of DNA.

Deficiency

- Deficiency of vitamin A retards growth in children.
- Vitamin A is essential for the synthesis of rhodopsin which was essential for vision in dim light. When vitamin A is deficient rhodopsin cannot be synthesized. This leads to a failure of vision in dim light. This type of eye defect is called night blindness or nyctalopia.
- Vitamin A deficiency leads to reddening, dryness and lusterless condition of the eye. This defect is called xerophthalmia. When the level of deficiency is more, the cornea becomes soft, disorganized and destroyed. This defect is called keratomalacia.
- Deficiency causes phrynoderma or toad skin. The skin becomes hard and horny. The skin appears scaly and rough.
- Degeneration of lachrymal gland.
- Sweat and sebaceous glands of skin degenerate.

- The glands present in the alimentary canal and the epithelial lining degenerate.
- The epithelium of the respiratory tract becomes stratified and degenerate.

7.6.2 Vitamin D or Calciferol or Antirachitic vitamin

- Vitamin D is also called Sunshine Vitamin. It exists in five forms D_1, D_2, D_3, D_4 and D_5.
- The skin of man contains large amount of cholesterol. This cholesterol is converted into vitamin D on exposure of skin to sunlight.

Composition

- Vitamin D is a sterol.
- The empirical formula of vitamin D_2 is $C_{28}H_{43}OH$ and it is called Ergocalciferol.

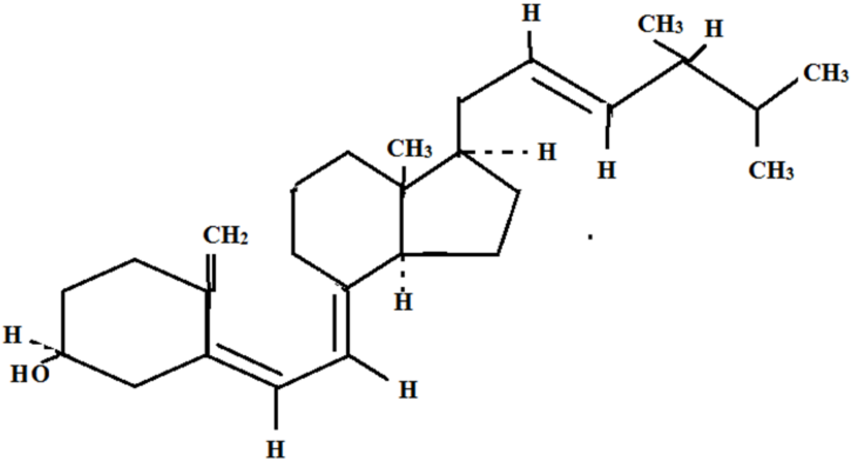


Fig 7.3 Structure of Vitamin D

Sources

Sunlight, Egg yolks, liver, fatty fish, fortified milk.

Properties

- Vitamin D acts both as hormone and a vitamin.
- It helps for the absorption of calcium.
- Vitamin D is involved in many biological processes.

Functions

1. It helps calcium absorption in the intestine.
2. It improves absorption of phosphate.
3. It is essential for calcium metabolism.
4. It helps in the normal development of bone and teeth.
5. It helps in the deposition of calcium and phosphates in the bones.
6. It maintains normal cellular growth and function.
7. It helps for immune function.

Deficiency

- Deficiency of this vitamin causes **rickets** in children and **osteomalacia** in adults. It is a disease of bones. It occurs in children.The long bones especially the leg bones tend to bend leading to the development of **bow legs.**
- The chest becomes protruded leading to pigeon chest**.**

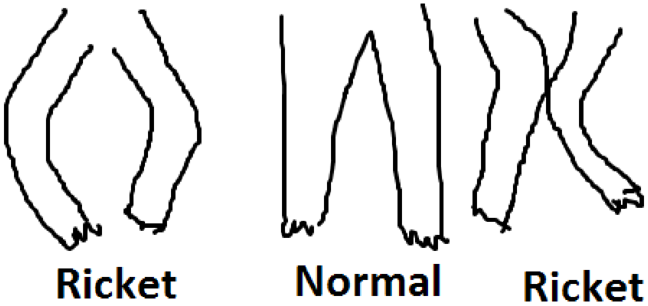


Fig 7.4 Rickets

7.6.3 Vitamin E or Tocopherol or Antisterlity vitamin

- It is a fat soluble vitamin.
- Tocopherol is a Greek word. Tokos means children and phero means to bear.
- It exists in 3 forms α, ß, γ – tocopherol.

Composition

- Vitamin E is a tocopherol which contains an unsaturated alcohol.
- The empirical formula of α – tocopherol is $C_{29}H_{50}O_2$

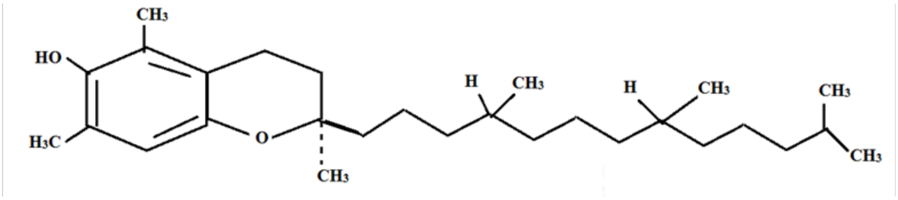


Fig 7.5 Structure of Vitamin E

Sources

- Oils of soyabean, corn, cotton seed, safflower, leafy green vegetables, whole-grain products, liver, egg yolks, nuts and seeds.

Properties

- Vitamin E has anti – oxidant properties.
- Vitamin E is essential for health and it has anti inflammatory properties.

Functions

- It functions as an antioxidant. It prevents oxidation of certain substances like vitamin A, fatty acids and sulphur containing amino acids.
- Vitamin E is very effective to reduce UV damage in skin.
- Essential for the normal reproduction of rats.
- Essential for the normal functioning of muscles.
- Essential for the biosynthesis of Co-enzyme Q.

Deficiency

- Vitamin E is essential for central nervous system. So the deficiency of vitamin E leads to muscle weakness.
- Deficiency causes Neurological and Neuromuscular problems.
- In rats, guinea pigs and rabbits, deficiency leads to degenerative changes in the muscles and paralysis. The defect is called nutritional muscular dystrophy.
- In chicks, the deficiency leads to the disintegration of blood vessels.
- Exudative diathesis occurs which shows the appearance of large patches of subcutaneous oedema on the breast, abdomen, neck and legs.
- Combined deficiency of Vitamin E and selenium causes hepatic necrosis.

7.6.4 Vitamin K or Anti haemorrhagic vitamin:

- It is a fat soluble vitamin.
- It is named K because it is essential for coagulation or blood clotting.

Composition

- Vitamin K is a naphthoquinone derivative and it exists in two forms naturally as K_1 $K_2$and K_3 is a manmade.

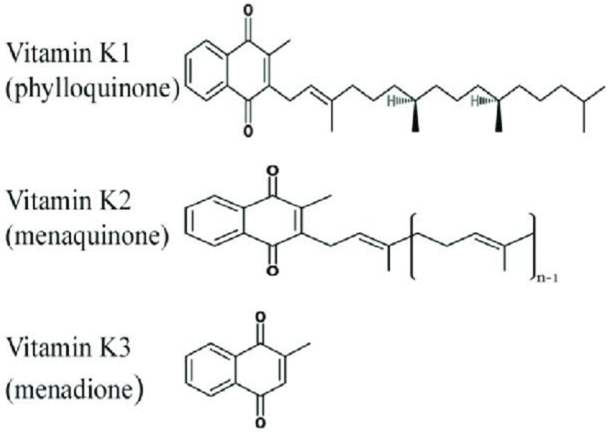


Fig 7.6 Structure of Vitamin K

Sources

Leafy green vegetables.

Properties

- Vitamin D helps in preventing mineralization which helps for maintaining blood pressure.

Functions

- It is essential for the synthesis of prothrombin in the liver. Prothrombin is essential for the coagulation of blood. Hence vitamin K is essential for the coagulation of blood. Hence it is called an antihaemorrhagic vitamin.
- Vitamin K is very essential for bone density.
- It also helps for the heart to pump the blood freely.
- It plays a key role in the respiratory chain mechanism and oxidative phosphorylation.

Deficiency symptoms

When vitamin K is deficient, coagulation is prevented; when there occurs an injury, generally bleeding is stopped within 5 to 8 minutes. This is due to coagulation of blood on the wound surface. When vitamin K is deficient coagulation cannot occur. This leads to continuous bleeding from the wound and the victim dies because of loss of blood.

7.7 WATER SOLUBLE VITAMINS

Vitamin B complex

It includes a set of water soluble vitamins. It is divided into four groups namely B_1, B_2, B_6 and B_{12}. The important B complex vitamins are

B_1 - Thiamine
B_2 - Riboflavin
B_3 - Niacin
B_5 - Pantothenic acid
B_6 - Pyridoxine
B_7 - Biotin
B_9 - Folic acid
B_{12} - Cobalamine

7.7.1 Vitamin B_1 or Thiamine:

It is soluble in water. Unpolished rice is the richest source.

Composition

Thiamine contains pyrimidine and thiazole molecule. The empirical formula of thiamine is $C_{12}H_{17}N_4OS$. Thiamine is 2,5-di methyl -6-amino pyrimidine bonded through a methylene linkage to 4-methyl-5-hydroxy ethyl thiazole.

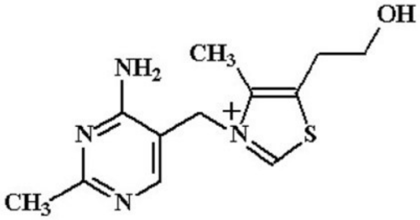


Fig 7.7 Structure of vitamin B_1

Structure of Vitamin B_1

Sources

Whole-grain or enriched breads and cereals, legumes, rice polishing's, liver, kidney, yeast, milk, groundnuts, eggs, green vegetables.

Properties

- It is an yellow coloured water soluble vitamin.
- It is stable in acid medium.
- It was unstable in alkaline medium.
- On improper cooking, vitamin B_1 gets destroyed.
- It is hygroscopic.

Functions

- It helps in maintaining the healthy nervous system.
- It helps for the digestion of food.
- It provides muscle strength.
- It is essential for heart functioning.

  $$\text{Thiamine} + \text{ATP} \longrightarrow \text{AMP} + \text{Thiamine pyrophosphate.}$$

- The thiamine pyrophosphate acts as a coenzyme. It also acts as co-enzyme in many biological reactions.
- It activates carboxylase. Carboxylase is essential for the oxidative decarboxylation of pyruvic acid, keto-glutaric acid and other keto acids. It is an important step in the final oxidation of sugar in the tissues and brain.
- It also helps the enzyme system which is important in synthesis of fats.

Deficiency

Deficiency causes beriberi. Beriberi is characterized by oedema in legs.

7.7.2 Vitamin B_2 or Riboflavin

It is an orange-yellow compound containing D-ribose alcohol and flavin. Riboflavin is a flavin derivative. Riboflavin consists of a dimethyl isoalloxazine ring and a sugar alcohol D-ribitol attached at position number 9.

Composition

Vitamin B_2 is 7,8-dimethyl-10-(1Y-D-ribityl)isoalloxazine

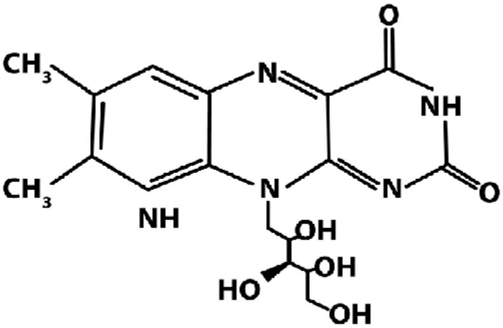


Fig 7.8 Structure of Vitamin B_2

Sources

Milk and milk products; leafy green vegetables. Yeast, egg white, liver, kidney, meat.

Properties

- The word flavin means yellow and it is a yellow orange coloured compound.
- It is unstable at high temperature.
- It is nontoxic.
- It is stable to heat in neutral and acid medium.
- It is sensitive to light.

Functions

- Riboflavin is very essential for maintaining good health of our body.
- Riboflavin is a component of two important co-enzymes, namely flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD). They play major roles in various enzyme systems.
- It helps for breaking down the food components.
- It is essential for the metabolism of growth.
- It is an important component of acyl-CoA dehydrogenase.

Deficiency Symptoms

- Cheilosis: It is characterized by the development of fissures developing in the lips and at the corners of the mouth.

- Sore tongue.
- Deficiency leads to Night blindness.
- Seborrheic dermatitis affecting the face (ears, nose and forehead).
- Deficiency of riboflavin leads to avascularization of the cornea i.e eye becomes itchy, vision becomes poor in dim light
- The skin loses hair and it becomes dry and scaly.
- Growth is arrested.
- Deficiency of the vitamin also leads to anaemia.

7.7.3 Vitamin B_3 or Niacin

It is a pyridine derivative. It occurs in tissue as nicotinamide. Niacin is pyridine-3-carboxylic acid.

Composition

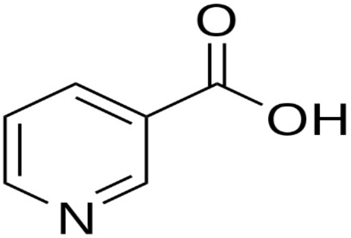


Fig 7.9 Structure of Vitamin B_3

Sources

Meat, poultry, fish, whole-grain or enriched breads and cereals, leafy green vegetables, peanut butter

Properties

- Niacin is an odourless, crystalline substance
- It is resistant to heat, oxidation and alkalis.
- It is important for the synthesis of protein and fats.

Functions

- Niacin is important for the release of energy.
- This vitamin is a component of coenzyme A.
- It is essential for several basic reactions in metabolism.

Deficiency symptoms

- Pellagra – Rough skin was formed. It is characterized by 3 symptoms namely dermatitis, diarrhea and dementia (organic loss of intenstinal function).

7.7.4 Vitamin B_5 or Pantothenic acid

Composition: It empirical formula is $C_9H_{17}O_5N$. Pantothenic acid is an amide of pantoic acid. It is compound of ß–alanine and α-γ-dihydroxy beta, beta dimethyl butyric acid. The empirical formula of Vitamin B_3 is $C_9H_{17}O_5N$.

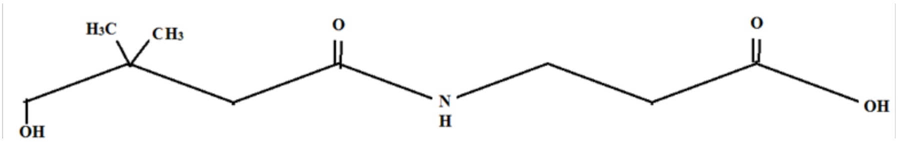


Fig 7.10 Structure of Vitamin B_5

Structure of Vitamin B_5

Sources

Plant and animal tissues, meat products like liver, meat and kidney, yeast, grain, cereals, pulses, groundnut and coffee.

Properties

- It is stable to heat.
- It is stable to oxidising and reducing agents.
- It is soluble in water.
- It is insoluble in chloroform.

Functions

- It is essential for growth.
- It plays an important role in oxidation and metabolism.
- It promotes the formation of fats from carbohydrates.
- It is an important component of two co-enzymes NADP and DPN.
- They control large number of reactions.

Deficiency

- Burning feet syndrome in man.
- It also causes respiratory infections.

7.7.5 Vitamin B_6 or Pyridoxine

Composition

- It is a pyridine derivative. Its empirical formula is $C_8H_{11}O_3N$.
- It occurs in 3 forms namely pyridoxine, pyridoxol and pyridoxamine.

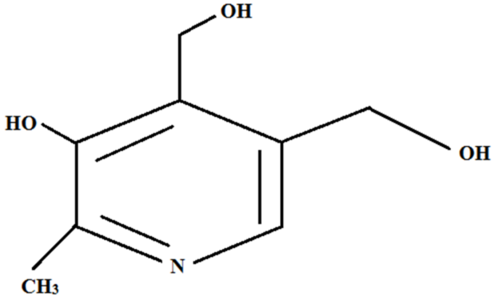


Fig 7.11 Structure of Vitamin B_6

Sources

Meat, fish, poultry, vegetables, fruits, Cereal grains, molasses and yeast

Properties

- It is sensitive to light and alkali.
- It exist as colourless crystals at room temperature.
- It has bitter taste.

Functions

- Vitamin helps for protein metabolism.
- Pyridoxol phosphate acts as a coenzyme.
- It helps in the synthesis of fats from carbohydrates and proteins.
- Premenstrual syndrome can be cured using vitamin B_6.
- It is involved in the active transport of aminoacids and certain metallic ions across cell membranes.
- It is linked with the metabolism of central nervous system.
- It helps to prevent the eye diseases.

Deficiency symptoms

- Deficiency leads to premenstrual tension.
- It is characterized by the scaliness, loss of hair, swelling, inhibition of growth.

- Deficiency leads to skin inflammation.
- Deficiency of the vitamin causes cardiovascular problems and anaemia.

7.7.6 Vitamin B_7: Anti-Egg-White injury factor

Composition

- The empirical formula is $C_{10}H_{16}O_3N_2$.
- It is a heterocyclic S-containing monocarboxylic acid containing two five – sided rings.

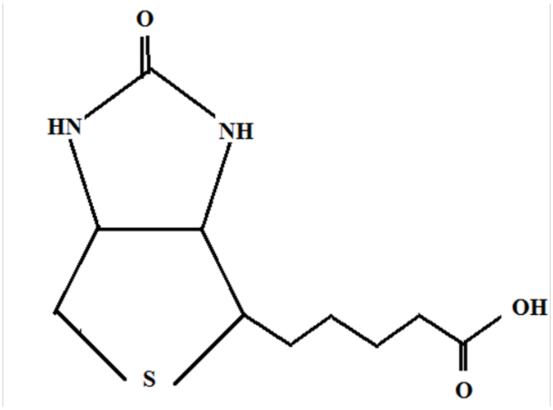


Fig 7.12 Structure of Vitamin B_7

Sources

Widespread in foods; also produced in intestinal tract by bacteria

Functions

- It is called co-enzyme R because it is a growth factor for the nitrogen fixing bacterium Rhizobium.
- It involves in the fixation of CO_2 and carboxylation.
- It involved in deamination of certain amino acids.
- It is essential for synthesis of lipids.
- It prevents dermatitis in dogs and rats.

Deficiency symptoms

- Deficiency causes muscle pains.
- Symptoms of thiamin deficiency.
- Blood cholesterol increases.

7.7.7 Vitamin B_9 or Folic acid

Vitamin B_9 is extracted from spinach leaf.

Composition

- A molecule of folic acid consists of 3 units, namely

1. Glutamic acid 2. Para amino benzoic acid 3. Pterin

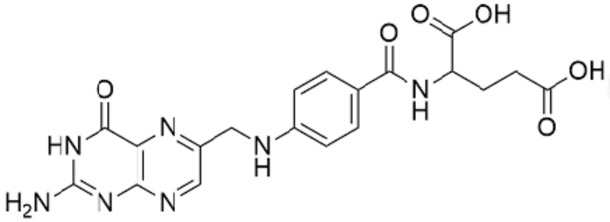


Fig 7.13 Structure of Vitamin B_9

Sources

Green leafy vegetables and fruits.

Properties

- It functions as a co-enzyme.

Functions

- It is essential for the synthesis of RNA.
- Its main role is in the formation and maturation of red cells.

Deficiency symptoms

- Deficiency causes anaemia.
- Deficiency leads to poor growth.
- Deficiency in man causes **megaloblasticanaemia** during pregnancy. It also causes **glossitis** (inflammation of the tongue) and gastrointestinal disorders.

7.7.8 Vitamin B_{12} or Cyanocobalamine:

Vitamin B_{12} is called Anti pernicious anaemia factor.

Composition

The empirical formula is $C_{63}H_{88}o_{14}N_{14}PCo$. The cobalt atom is centrally situated and it is surrounded by 4 reduced pyrrole rings collectively called corrin.

Sources

Meat, poultry, fish, seafood, eggs, milk and milk products. But it was not found in plant foods

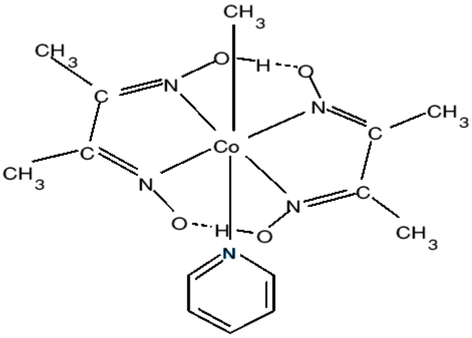


Fig 7.14 Structure of Vitamin B_{12}

Properties

- It is very stable at high temperature.
- Vitamin gets degraded in light.
- It is soluble in water, ethanol and methanol.
- Vitamin are deeply red coloured crystals.
- In the living cells B_{12} is converted into a co-enzyme called co-enzyme B_{12}. It is involved in a number of metabolic reactions.

Functions

- It is essential for the formation and maturation of RBC.
- It is involved in the synthesis of nucleic acids.
- It stimulates bone marrow to produce WBC and platelets.
- It helps the growth of micro-organisms.
- It synthesizes lipids from carbohydrates.
- It prevents hyperglycaemia.
- It prevents pernicious anaemia.

Deficiency symptoms

- Deficiency of B_{12} causes pernicious anaemia. It is characterized by a drastic decrease in blood cell count. RBC becomes abnormally larger.
- Another deficiency sign is hyperglycaemia.

7.7.9 Vitamin C

Composition

- Vitamin C has the chemical formula $C_6H_8O_6$
- Vitamin C is L-enantiomer of ascorbate

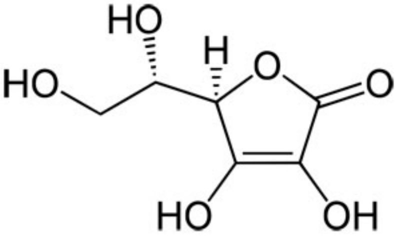


Fig 7.15 Structure of Vitamin C

Sources

- Oranges, Broccoli, Brussels sprouts and cauliflower, Spinach, cabbage and other leafy greens, Sweet and white potatoes, Tomatoes.

Properties

- It is a water soluble vitamin
- It increases the absorption of non haem iron
- It is an anti oxidant.

Function

- Vitamin C is a vital nutrient for health.
- Vitamin C may include protection against immune system, cardiovascular disease, eye disease and even skin wrinkling.
- Vitamin C may also help prevent acute respiratory infections.
- It helps to maintain bones, skin and blood vessels.

Deficiency

- Deficiency of vitamin C causes Scurvy.
- Poor wound healing occurs and immune functioning becomes weak due to vitamin C deficiency.

Vitamins	**Daily Dietary Requirements**
Vitamin A	Daily requirement of Vitamin A for adults is 750 µg. The requirement for infants and young children is 300 µg. Women during pregnancy and lactation require 1200 µg per day.
Vitamin D	Infants : 400 to 800 I.U. daily Children and adolescents : 400 I.U. daily During pregnancy and lactation : 400 to 800 I.U. daily Exposure to sunlight produces adequate amount of vitamin D in the skin.
Vitamin E	A daily allowance of 20 - 25 mg of vitamin E has been recommended for man.
Vitamin K	Sufficient quantity of the vitamin is synthesized by intestinal bacteria under normal conditions. However, exogenous supply is necessary only in conditions of potential vitamin K deficiency.
Vitamin B_1 (Thiamine)	For each 1000 calories, 0.5 mg is recommended for an average man.
Vitamin B_2 (Riboflavin)	Adults : 1.5 to 1.8 mg Pregnant, lactating women and children : 2 to 2.5 mg daily
Vitamin B_3 (Pantothenic acid)	Recommended daily requirement is 5 to 12 mg for adults.
Vitamin B_5 (Niacin)	Adults : 17 to 21 mg
Vitamin B_6 (Pyridoxine)	A daily intake of 2 mg for adults is recommended.
Vitamin B_7 (Biotin)	It is abundantly produced by intestinal bacteria
Vitamin B_9 (Folic acid)	No definite requirement for normal human.
Vitamin B_{12} (Cyanocobalamine)	Daily requirement of vitamin B_{12} is 2 to 4 µg.
Vitamin C	Recommended daily requirement is 75 to 100 mg.

UNIT VIII

NUTRITIONAL BIOCHEMISTRY

Nutritive value of Milk – Egg – Meat – Fish – Vegetable food (Cereals, Pulses, Nuts, Roots and Tubers, Green leafy vegetables) – Fruits – Tea – Coffee – Cocoa – Alcohol – Principles in balancing a diet – Energy yielding, Body building and Protective food – Bioavailability – absorption – interactions between diet and drug ingredients – gastric emptying and drug absorption – drug excretion – low protein diets – dehydration and starvation – effect of drugs on growth, vitamins and minerals

8

NUTRITIONAL BIOCHEMISTRY

8.1 NUTRITIVE VALUE OF FOOD

Nutrition is the study of nutrients in food. The study of nutrients is very important to know about the requirements of micronutrients and macronutrients in our body. The study of nutrition tells the relation between diet, health and disease. Eating wrong type of food leads to the deficiency of nutrition. Malnutrition occurs when the intake of nutrients is too high or low.

8.2 MILK

Milk is the first food for humans and it is the richest nutritional food. Milk is obtained from cow, goat, buffalo, cattle and camels. Cow's milk is the most widely used.

The different types of milk used are fresh milk, dried milk, long –term milk, domestic condensed milk. The milk products derived from milk used are butter, ice cream, yoghurt, hard White and creamy cheese.

- Milk is a perfect and complete food. It is rich in calcium, potassium, sodium, chlorine and phosphorus.
- It contains not only protein, fat and carbohydrate but also minerals and vitamins.
- The carbohydrate of milk is lactose which is less sweet than sucrose.
- The chief proteins are caseinogen and lactalbumin. Caseinogen is a phosphoprotein. Caseinogen is associated with calcium as calcium caseinogenate. Small amounts of other proteins are also present.
- Milk fat is in the form of a very fine emulsion. It contains all saturated fatty acids as well as unsaturated fatty acids.
- It is rich in vitamin A and vitamin B_2 and good in vitamin B_1 and nicotinic acid but poor in C and D.
- Milk kept on unsterilized becomes sour due to formation of lactic acid from lactose by bacteria present in milk.

- When milk comes in contact with rennin or proteolytic enzymes, it becomes clotted.
- The protein of milk neutralizes gastric HCl to allow clotting.
- Condensed milk is prepared by the removal of water by evaporation vacuum. Vitamins A and B are preserved.
- Dried milk is prepared by passing a film of milk over hot rollers or spraying milk into hot to evaporate water.

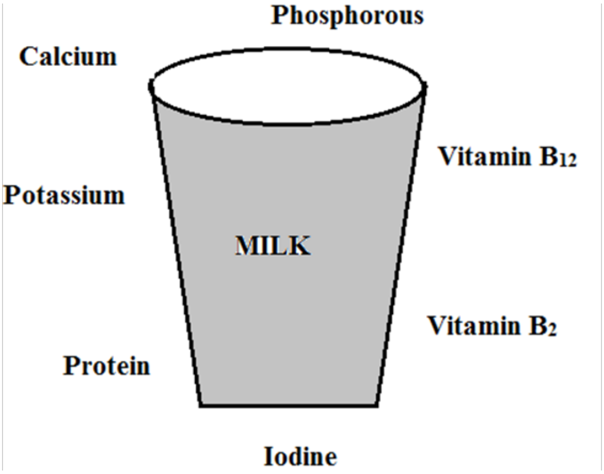


Fig 8.1 Composition of Milk

Health Benefits of Milk

- Milk helps to provide the body with energy and it helps for the growth.
- Milk helps to maintain the bone and teeth.
- Prevents cardiac diseases.
- Keeps the blood pressure at a normal rate.
- It improve the performance of the nervous system.
- It improves the digestion process.
- It protects the eyesight and maintain the skin, hair and delicate membranes.
- It helps to treat the dehydration.

Milk is very essential for our health maintenance. Taking beverages and food containing caffeine such as fizzy beverages, tea, coffee and chocolate reduces the absorption of calcium. Also, vitamin C rich fruits such as citrus must be taken in plenty, as it is instrumental in absorbing the calcium from the milk.

8.3 EGG

Eggs are very essential for a healthy diet and it is an inexpensive healthy food. It contains several vitamins and minerals. Eggs are also a source of vitamins A,B,E and K.

- Eggs store significant amounts of protein and choline.
- The hen's egg contains about 30% yolk, 59% white and 11% shell. The chemical composition of duck's egg is similar to that of hen's egg.
- The white part of egg contain proteins and salts. The greater part of the protein is ovalbumin. The other proteins are conalbumin, ovoglobulin and ovomucoid (a glycoprotein).
- The pale yellow colour is due to riboflavin. The white contains 10.7% protein, 0.1% fat and 1.4% carbohydrate.
- The yolk contains 51% water, 15% protein, 33% fat of which 4% cholesterol and 1% mineral. The proteins are vitellin (a phosphoprotein) and livetin (a globulin). The minerals are calcium, iron and phosphate.
- The yolk is rich in vitamins A_1, B_1, B_2 and D but not C. The other B group vitamins and E are also present.
- The egg is a powerhouse of disease-fighting nutrients.
- Eggs are rich sources of selenium, vitamin D, B_6, B_{12} and minerals such as zinc, iron and copper. Egg yolks contain more calories and fat than the whites.

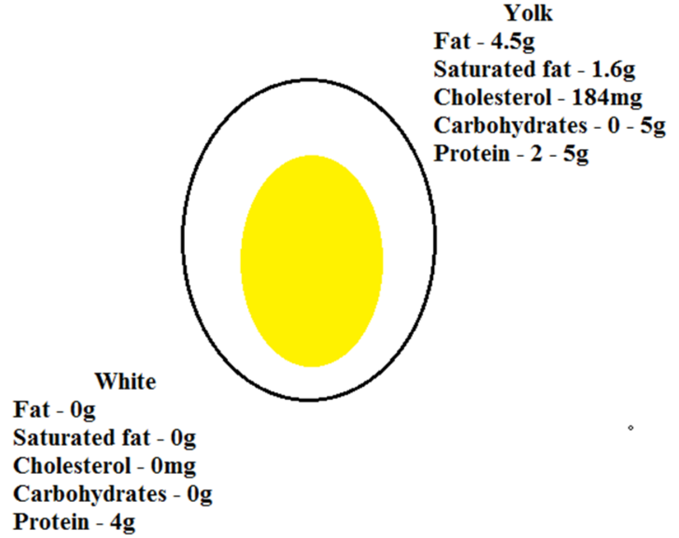


Fig 8.2 Composition of Egg

Health Benefits of Egg

- Egg contains the essential body nutrients.
- The protein present in egg helps to maintain the muscle.
- Egg helps to maintain the nervous system.

8.4 MEAT

- Meat is the flesh of animals.
- Meat contains about 22% protein and B group vitamins but does not contain vitamins A, C or D.
- In boiling, there is a loss of salts, gelatin and extractives. During roasting, this loss is reduced.
- Protein obtained from meat is needed by the body for a variety of functions, such as wound healing, muscle building and immune function.
- Red meat is a good source of iron, which is needed for red blood cell production.
- Some meats are high in saturated fat and cholesterol. Eating too much fat and cholesterol can lead to higher risk for heart disease.
- The flavor of meat is due to the organic substances extracted from meat by boiling water.
- Meat has benefits for muscle and bone health, metabolism and iron absorption.

8.5 FISH

- Fish is a nutritious food containing protein, vitamins and minerals which are essential for the health.
- The three types of fish available are oily fish, white fish and shellfish.
- Oily fish contain vitamins A, D and E. They are also rich in essential omega-3 fatty acids which are essential for healthy brain, eye and nerve development in babies and children.
- Fish oils in fatty fish are the richest source of a type of fat that is vital to normal brain development in unborn babies and infants.

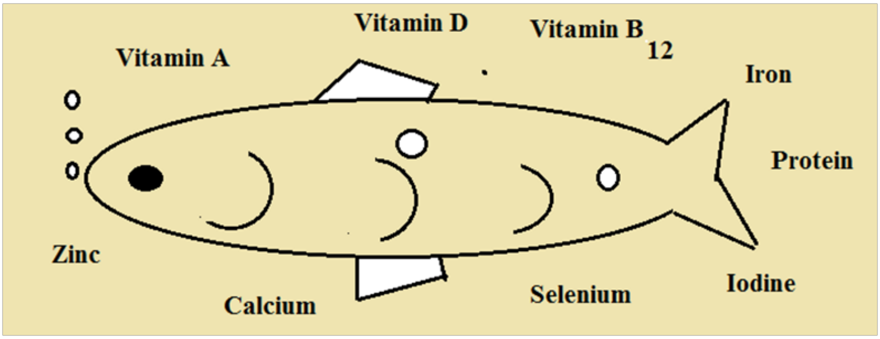


Fig 8.3 Composition of Fish

- Fish is free from carbohydrate just like meat. The fat content ranges from a trace to 5%. It is fair source of B group vitamins. Fatty fish contains some vitamins A and D.
- Large fish is rich in phosphorous but deficient in calcium. Small fish eaten with bones are good sources of calcium.
- It contains 22% protein, 1.4% fat, 75% water. The dried fish may contain about 5% carbohydrate because of the use of flour.

8.6 VEGETABLE FOOD

8.6.1 Cereals

Cereals can be defined as a grain or edible seed of the grass family. Cereals are very essential for a healthy diet. They are good sources of fibre, carbohydrates, protein and a wide range of vitamins and minerals. For a child's normal growth and development, grains are very essential. The crude cereals (wheat, rice, barley, maize, oats) contain 11% protein, 70% carbohydrate, 0.5 to 8% fat, 11% water and 2% minerals. Oatmeal is the richest in protein and fat, rice is the poorest.

- The main proteins of cereals are glutelins and gliadins. Small amounts of albumins and globulins are generally present.
- The carbohydrate is almost completely starch in the form of grains covered by a thin membrane of cellulose. Small amounts of sugar are also often present in cereals.

- The abundant mineral elements are calcium and phosphate. The phosphate is partly in the form of phytic acid (inositol hexaphosphate) which interferes the absorption of calcium.
- There is a great loss of vitamins B and E and mineral elements, especially Ca, P and Fe in the roller milled white flour. Carotene and riboflavin are lost by chemical blenching.
- Brown rice contains bleaching a fair amount of fiber (1.8%), while white rice is very low in fiber (0.3%).

8.6.2 Pulses

Pulses are globally important due to the higher content of protein. The term "pulses" includes a range of grams and peas. They are important food as they are easily available and inexpensive.

- Pulses include grams and peas. Pulses are good sources of important vitamins and minerals like iron, potassium and folate, calcium and phosphorous.
- Pulses are 20 to 25 per cent protein by weight which is double the protein content of wheat and three times that of rice.
- The dried pulses (peas, beans, lentils etc), contain large amounts of protein. The main protein is a globulin called legumin. The dried pulses contain 20-25% protein, 11% water, less than 2% fat.

Fig 8.4 Pulses

- Due to their high soluble-fibre content, legumes are believed to reduce blood cholesterol.
- The soya bean contains high protein, high fat and low carbohydrate. Soya bean oil used for frying "fish and chips".

- The dried pulses are the good sources of many B group vitamins and minerals but deficient in vitamins A, D, B_{12} and C.

8.6.3 Nuts

Nuts are the storehouse of health.

- Nuts contain vitamins and are rich in minerals like manganese, potassium, calcium, iron, magnesium, zinc, fluoride and selenium.
- Nuts contain high protein and fat but low carbohydrate. The protein content is slightly lower than that of dried pulses.
- Nuts are the good sources of Vitamin-E (a powerful lipid soluble antioxidant). Vitamin-E is required for maintaining the integrity of cell membrane of mucosa and skin which is helpful for protecting from harmful oxygen-free radicals.
- Nuts also contain important B-complex groups of vitamins such as riboflavin, niacin, thiamin, pantothenic acid, Vitamin B_{-6} and folates which are very important for health.

Fig 8.5 Nuts

- They can be used for the preparation of milk substances which can be fed to infants over 6 months of age and to young children of some areas where milk is not available in sufficient amounts.
- Nuts reduced the risk of cardio vascular diseases and diabetes.

8.6.4 Roots and Tubers

Root and tuber crops consist of root crops, such as beets and carrots and tuber crops, such as potatoes and sweet potatoes, and the leaves of root crops.

- Roots and tubers primarily contains fibre content. These are the chief sources of starch. These can substitute sugar and cereals and are the valuable sources of iron and vitamin C.
- The common roots (carrots, beetroots, turnips) are almost free from starch. Their caloric value is completely due to sugars (sucrose, fructose and glucose). Carrots, the richest in sugars, are the sources of carotene.
- Roots contain valuable salts but negligible protein and fat.
- The main nutrient supplied by roots and tubers is carbohydrates. The protein content is low.
- Cassava, sweet potato, potato and yam contain some vitamin C and yellow varieties of sweet potato, yam and cassava contain beta-carotene or provitamin A.
- Roots and tubers are deficient in most other vitamins and minerals but contain significant amounts of dietary fibre.
- Taro is a good source of potassium. Leaves of taro are cooked and eaten as a vegetable. They contain betacarotene, iron and folic acid, which protects against anaemia.

Fig 8.6 Roots and Tubers

8.6.5 Green Leafy Vegetable

Dark green leafy vegetables contain vitamins and minerals which are essential for our health and it may prevent certain types of cancers and promote heart health.

- Green leafy vegetables are rich in carotenes. They are good sources of calcium, riboflavin, folic acid and vitamin C. Yellow pumpkin is a fair source of carotene.
- Green leafy vegetables are the cheapest among the protective food.
- Green leafy vegetables gives beautiful skin and hair. Antioxidants such as vitamin C, lutein and zeaxanthin in greens reduce the risk of cataracts and muscular degeneration.
- Eating a diet rich in leafy greens can offer numerous health benefits including reduced risk of obesity, heart disease, high blood pressure.

Fig 8.7 Green Leafy Vegetables

8.7 FRUITS

Fresh fruits are the protective food. Their energy value is due to sugars and starch. Many fruits contain pentoses and pectins.

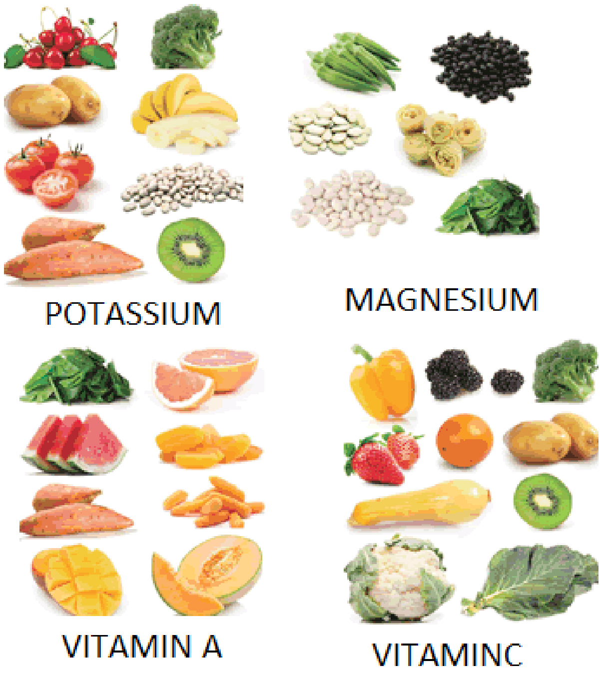


Fig 8.8 Fruits

- Fruits are naturally low in fat and have no cholesterol.
- Fruits are sources of many essential nutrients such as potassium, dietary fiber, vitamin C and folate (folic acid).
- Fruit sources of potassium help to maintain healthy blood pressure. Potassium containing fruits are bananas, prunes and prune juice, dried peaches and apricots.
- Vitamin C present in fruits is important for growth and repair of all body tissues, helps heal cuts and wounds and keeps teeth and gums healthy.
- Dietary fibre from fruits reduce blood cholesterol levels and may lower risk of heart disease.
- Cooking destroys vitamin C and makes fruits more digestible by softening the cellulose.
- Some fruits, notably the banana, contain starch as well as sugar. It has high protein content.

8.8 TEA, COFFEE, COCOA

- Tea contains no calories and it is a rich source of phytochemicals as well as a specific group of chemicals called methylxanthines.
- The black tea sold consists of the leaves of young shoots of the tea plant which are fermented and dried by heat. It has negligible caloric value. It has a stimulant and a diuretic effect. Strong tea disturbs gastric digestion due to tannic acid.
- Tea increases lipid oxidation and improves blood vessel function. Tea boost up the immune system.
- Coffee is the roasted seed of *Coffea arabica*. The odour is due to an oil, caffeol, formed when the beans are roasted. It has little caloric value. It contains caffeine and tannic acid.
- Caffeine in coffee make you more alert and actually improve your concentration.
- The seeds are obtained from the pods of the cocoa tree after fermentation and roasting. They contain 50% fat.
- Cocoa as beverage is of little importance. It becomes nourishing when taken with milk and sugar. Chocolate consists of ground cocoa-nibs mixed with sugar. Starch and flavouring are frequently added.

8.9 ALCOHOL

Alcohols have no nutritional values.

- Alcohol has an energy value of 7 calories per gram. It is consumed in the form of wines, spirits or liquors.
- Beers are the fermented product of malt and contain 4-8% alcohol. It has small amount of protein and some sugar. The process of making beer is known as brewing.
- Wines are the products of fermentation of fruit juices (usually grapes). The alcohol content is 10-20% and sugar 0.1-4%. They contain large amount of organic acids (tartaric, malic, succinic etc). Yeast consumes the sugar in the grapes and converts it to ethanol, carbon dioxide and heat. Different wines are produced from different varieties of grapes.

- Spirits are the distillation product of many fermented products. Whisky is a distilled beer and brandy is a distilled wine. They are practically free from sugar. The alcoholic content is 30-50%.
- Liquors are alcohol sweetened with cane sugar and flavoured with essences. The sugar content is 30% and alcohol is 35-55%.

8.10 PRINCIPLES IN PLANNING A BALANCED DIET

A balanced diet is a healthy diet.

In planning a balanced diet it is to be aimed that the diet must contain various groups of foodstuffs such as energy yielding food, body building food and protective food in the correct proportions. The constituents of balanced diet differ according to age, sex, physical activity, economic status and the physiological condition.

A Nutritious food include

- Eating a variety of food, including vegetables, fruits and whole-grain products.
- Eating lean meats, poultry, fish, beans and low-fat dairy products.
- Limiting consumption of salt, sugar, alcohol, saturated fats and trans fats.
- Reading food labels to ensure a healthy diet.

The food that we eat must contain all the nutrients such as proteins, carbohydrates, fats, vitamins and minerals. The WHO (World Health Organization) has given the basis of nutrition as

- Eat roughly the same amount of calories that your body uses.
- Healthy body weight = “calories in”- “calories out”.
- Eat a lot of plant food such as vegetables, legumes, whole grains, fruits and nuts.
- Limit your intake of fats, preferring the healthier unsaturated fats to saturated fats and trans fats.
- Limit your intake of granulated sugar, ideally less than 10g/day.
- Limit salt / sodium consumption from all sources

For a balanced diet, children, elderly people need a little bit more protein and calcium for growth, maintenance or repairing. Also, eggs, fish, white meat, legumes and dairy products are essential for a healthy diet. Eating fresh fruits and vegetables not only acts as healthy diet, but it also gives the diet as pleasure .

8.10.1 Energy Yielding Food

1. The group contains high carbohydrates and also pure fats and carbohydrates. They are divided into two groups. (a) cereals, roots and tubers and (b) pure carbohydrates, fats. Because energy yielding food provide body with energy that is measured in calories.
2. Cereals provide proteins, certain minerals and vitamins in addition to energy in the diets of the low-income groups.
3. Roots and tubers provide some amount of proteins, minerals and vitamins.
4. Pure carbohydrates and fats provide only energy.

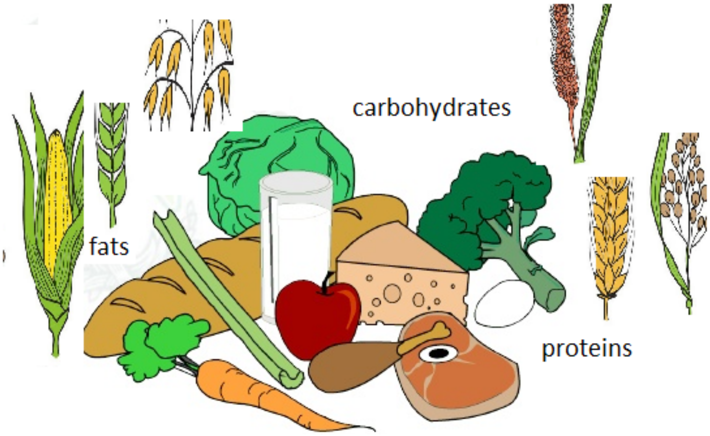


Fig 8.9 Energy yielding food

8.10.2 Body Building Food

Body building is defined as the developing of the body through exercise and diet. Our body needs protein to develop muscles.

Body building food contain high protein and are divided into two groups:

(a) Milk, egg, meat and fish.

(b) Pulses oilseeds and nuts.

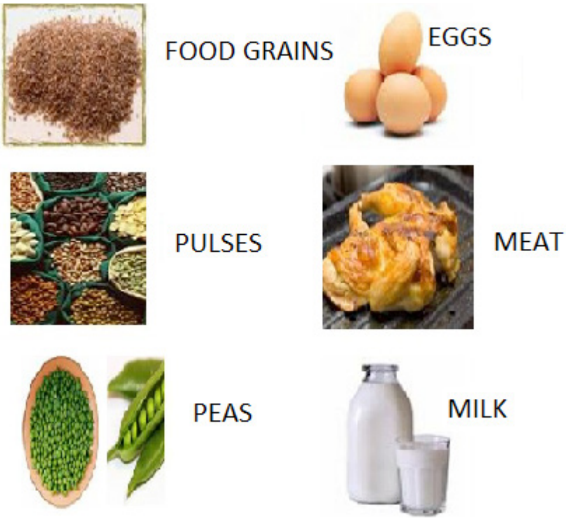


Fig 8.10 Body Building Food

8.10.3 Protective Food

The protective food are rich in proteins, vitamins and minerals.These are classified into two groups:

a. Food rich in vitamins, minerals and proteins of high biologic value Example: milk, eggs, fish and liver.

b. Food rich in certain vitamins and minerals only E.g. green leafy vegetables and some fruits.

Fig 8.11 Protective Food

Vitamins and minerals are important because they help to keep the body healthy by regulating body processes. Vitamins and minerals help the body to produce substances that fight disease causing agents. Hence they are called protective food.

8.11 BIOAVAILABILITY

The term bioavailability refers to the extent to which a drug reaches its site of pharmacologic action. It is the degree and rate at which an administered drug is absorbed by the body's circulatory system, the systemic circulation.

The bioavailability of a drug depends directly on the extent to which the drug is absorbed and distributed to the site of action and depends inversely on the extent to which it is metabolized and excreted prior to arriving at the site of action. The factors affecting bioavailability of the drug are

- Physical properties of the drug such as hydrophobicity, pKa, solubility
- The drug formulation
- Gastric emptying rate
- Interactions with other drugs/food such as antacids, alcohol and fruit juices
- Health of the gastrointestinal tract
- Age
- Enzyme induction/inhibition by other drugs/food:

  Enzyme induction which increases the rate of metabolism E.g. Phenytoin

  Enzyme inhibition which decreases the rate of metabolism E.g. grapefruit juice

8.12 ABSORPTION

- The term absorption refers to the rate at which and the extent to which, a drug leaves its site of administration. It is the movement of a drug from the site of administration to bloodstream.

  The factors that affect absorption include

- the route and site of drug administration
- the site and area of absorption
- the concentration of the drug at that site
- drug's solubility and therefore its ability to reach a site of entry into the bloodstream or cerebrospinal fluid and finally, the circulation at the site of absorption

- Molecular size of the drug.
- Degree of ionisation of drugs.
- Dosage forms affect the rate and extent of absorption.
- Absorption involves several phases. First, the drug needs to be introduced via some route of administration and in a specific dosage form such as a tablet, capsule, solution and so on. Absorption depends upon the route of administration.
- Absorption is influenced by physico-chemical processes.
- Food components affect drug absorption and bioavailability through three general mechanisms: Physico-chemical interactions between drug and food components in the gut lumen.

8.13 INTERACTIONS BETWEEN DIET AND DRUG INGREDIENTS

The action or side effects of a drug caused by taking with a food, beverage, supplement or another drug is called drug interaction.

- After taking a drug, the process involved are absorption, complex formation, precipitation and the effects of one interactant on another.
- Presence of food and nutrients in intestinal tract may affect absorption of drug.
- Absorption of iron from supplements reduces to 50% when taken with food.
- Antacid medications can result in reduced acidity in the stomach.
- Certain drugs chelate minerals and render both the drug and the mineral unavailable for absorption, Ex. Doxycycline chelates with calcium, magnesium, iron or zinc.
- Other drugs like ciprofloxacin, penicillamine and thyroxine form stable complexes with iron.

8.14 GASTRIC EMPTYING AND DRUG ABSORPTION

- A drug leaves the stomach at a rate that depends on gastric emptying. Gastric emptying, in turn, depends on the general functioning of the stomach and gastrointestinal tract.

- The rate of gastric emptying affects all drugs. This is because of the fact that the small intestine has a significantly larger surface area and contributes the most to drug absorption.
- In the fasting state or when little food is in the stomach, drugs usually leave the stomach rapidly and thus reach the small intestine.
- There must be a enough time between the meals and snacks so that the clearance of drug may takes place easily.
- If the drugs are given in multiple doses throughout the day, these drugs may accumulate in the stomach and be dumped into the duodenum at night when the stomach finally empties. This can be prevented by taking the drug on an empty stomach.
- Drugs must be taken one hour before or one hour after eating. Consequently, the presence of food in the digestive tract may reduce absorption of a drug.

The most common method for drugs to cross the cell membrane is by passive diffusion. To be absorbed, drugs must be transported across the lipid membrane of the mucosal barrier, either by diffusion or by a specific carrier. Most drugs are absorbed in the small intestine and by simple diffusion that depends on the concentration gradient of the drug across the intestinal mucosa.

Good food gives us good health. Poor eating habits such as insufficient intake or high intake both will leads us to obesity, high blood pressure, high cholesterol, heart disease and stroke, type-2 diabetes, osteoporosis etc. When a drug acts on processes that involve dietary components, that dietary component may affect that drug's functions.

- Consumption of vitamin K enriched food or supplements may counteract the effects of the anticoagulants such as Warfarin, Coumadin, Dicumerol. It is more important to maintain a steady, consistent intake of vitamin K containing food while receiving anticoagulants.
- Certain herbal leaves contain natural coumarins that can augment the effects of coumarins and should be avoided.
- Caffeine and other methyl xanthines have numerous effects on the function of other drugs.

8.15 DRUG EXCRETION

Drug excretion is a process of elimination of drugs from the body. Drugs are primarily excreted via the kidneys and the gastro intestinal tract.

- Many drugs are excreted by the kidneys in urine. Hence the drug dosing depends on the kidney function.
- Many drugs are excreted into breast milk and non-electrolytes (Ex. Ethanol) reach the same concentration in breast milk as they do in plasma.
- The half-life of a drug in circulation is a direct function of the volume of distribution of the drug and an inverse function of its clearance.
- The clearance of a drug depends on the amount of drug delivered to the organ of excretion and the extent to which the drug is extracted from the blood for excretion (the extraction ratio).
- In the case of renal excretion, clearance of the drug depends on the concentration of free drug in the plasma and on the amount of drug secreted and/or reabsorbed in the tubules per unit rate.

8.16 LOW PROTEIN DIETS AND HYPOALBUMINEMIA

- Hypoalbuminemia occurs when albumin levels in the blood are very low. Since albumin is a blood protein it is the liquid portion of the blood that maintains the proteins and blood cells.
- Albumin is very important for maintaining pressure in the blood vessels, hormones and medications.When the level of albumin is low, blood may not be able to transport essential materials effectively.
- The concentration of free drug in the plasma depends on the chemical characteristics of the drug.First, hypoalbuminaemia leads to an increase in total body water.
- Chronic low protein consumption with hypoalbuminaemia leads to an increase in free drug available for excretion.
- Another effect of a low protein diet, is to increase net renal excretion of base. The increased excretion of base is due to decreased production of acid residues (phosphate, sulphate and chloride) from protein metabolism.

- For the patients receiving basic drugs such as antacids, urinary pH should be monitored and if the pH is increasing, the drug dose should be reduced or an alternative drug considered.
- The common symptoms of hypoalbuminemia are jaundice, weakness, rapid heart beat, vomiting, diarrhea, nausea, dry and itchy skin.

8.17 DEHYDRATION AND STARVATION

- The loss of body fluids, mostly water is called dehydration. Dehydration occurs when the intake of water is low. The symptoms include thirst and urine becomes darker.
- Starvation leads to deficiency of calorific values. It leads to several organ failures.
- People who are lean but not starved have a higher proportion of body water per kilogram than nonlean people, so the half-life of drugs that are primarily distributed in the aqueous compartment is prolonged in lean persons.

8.18 ACTION OF DRUGS ON GROWTH

- Drug is defined as a substance used in the diagnosis, treatment, or prevention of a disease, or component of a medication. Drug-nutrient interactions involve changes to a drug caused by a nutrient, or changes to a nutrient as a result of the drug. Drugs can alter food intake by causing either a loss of appetite or an increase in appetite.
- Drugs may also cause a dry or sore mouth and make eating difficult or painful which leads to avoidance of food intake. Dry mouth may be caused by drugs that decrease salivary flow.
- Drugs can alter the taste of saliva or food by excretion in the saliva, often leading to a metallic waste.
- Many drugs cause gastric irritation that leads to a loss of appetite, e.g. aspirin
- Some of the drugs E.g. erythromycin , increase the rate of gastric emptying and the overall motility of the GI tract.
- Food aversions develop in more than half of all patients who undergo cancer chemotherapy and usually affect consumption of two to four food.

- Beozars may cause feelings of gastric fullness, pain, nausea, vomiting and gastric outlet obstruction.

8.19 EFFECT OF DRUGS ON VITAMINS AND MINERALS

Drugs can affect vitamin and mineral status by interfering with absorption, metabolism and function.

Antacids

By increasing stomach pH, antacids decrease the bioavailability of vitamin A, folate, thiamine and phosphate.

- Thiamine is unstable at high pH and hence is inactivated when taken with antacids.
- When the pH of the upper part of the jejunum is increased after ingestion of sodium bicarbonate, folate absorption is reduced.
- Sodium overload with development of congestive heart failure can occur from intake of excessive sodium.
- Dietary phosphate combines with aluminium and magnesium hydroxide to form insoluble aluminium and magnesium phosphates, which are excreted through gastrointestinal tract. Hence a phosphate depletion syndrome may develop due to the low phosphate diet. Effect of phosphate depletion include muscle weakness, paresthesia in the limbs, anorexia, haemolytic anaemia convulsions and myocardial depression.
- Milk alkali syndrome occurs due to an excessive intake of milk and alkali. Use of calcium salt supplements cause this syndrome.
- Magnesium containing antacids can develop magnesium intoxication, symptoms of magnesium overload are nausea, vomiting, flushing, impaired respiratory function and partial or complete heart block.
- Absorption of iron occurs when it is in ferrous state, at low pH. The elevated pH induced by antacids may lead to iron aggregate formation and conversion of iron to its ferric form. In addition, aluminium hydroxide gels bind iron and thereby decrease its absorption.

Antituberculous agents

- The drugs used in the treatment of tuberculosis, rifampin and isoniazid, affect vitamin D metabolism because of their effect on vitamin D hydroxylase.
- Isoniazid can also cause a secondary niacin deficiency. This results due to an inhibition of the enzyme kynureninase.

Anticonvulsants

- The anticonvulsant drugs phenytoin and phenobarbital can cause hypocalcaemia, rickets in children and high turnover osteoporosis in adults.
- High doses of folic acid may counteract the anticonvulsant effects of phenobarbital, phenytoin and primidone.
- Phenytoin and phenobarbital decrease production of vitamin K dependent proteins.
- Drugs that bind bile acids (Ex. Cholestyramine and aluminium containing antacids) may lead to malabsorption of fats and hence to malabsorption of fat soluble vitamins, particularly vitamin A and E.
- Diuretics act by altering renal excretion of sodium and potassium, they may lead to the development of electrolyte imbalance. Common drugs that cause potassium deficiency include thiazide, laxatives, etc.

Nonnutritive food increase the flavor and texture of food. Nutritive sweeteners provide the body with calories, while nonnutritive sweeteners are very low in calories or contain no calories at all. They can both be added to food and beverages.

Monosodium glutamate (MSG): This is used as a flavor enhancer in many food, especially chinese food. MSG can cause mental retardation in infants and intestinal discomfort in adults.

Tartrazine: It is a colour additive used in both food and drugs which causes allergy.

Sulphites: These are added to food, beverages and drugs as preservatives because of their antioxidant properties. They can cause severe allergic reactions.

UNIT IX

ANTIBIOTICS

Introduction – Role of Antibiotics – administration – Side effects – Types – Antibiotics affecting cell wall synthesis Penicillin, Cephalosporin, Cycloserine, Vancomycin, Bacitracin – Antibiotics affecting cytoplasmic membrane – Antibiotics interfering with Nucleic acid function – Antibiotics inhibiting protein synthesis Rifamycin, Streptomycin, Tetracylines, Chloroamphenicol, Erythromycin, Neomycin) – Antibiotics affecting enzyme systems – Drug resistance.

9

ANTIBIOTICS

Antibiotic substances are produced by certain members of the plant kingdom chiefly by micro organisms and green plants. Antibiotics are also produced by the kingdom fungi and animalia. Antibiotics are the substances that destroy or slow down the growth of bacteria. They can stop bacteria from reproducing or destroy them. Tomato plants, raddish seeds and other plants are the sources of antibacterial substances.

9.1 ROLE OF ANTIBIOTICS

An antibiotic is a chemical substance produced by a living organism. It is powerful medicines that fight bacterial functions. They either kill bacteria or keep them from reproducing.

- Antibiotics treat infections caused by bacteria and certain parasites but not viruses.
- Antibiotics are not effective against viruses such as the common cold or influenza.
- Antibiotics also lead to the side effects such as diarrhea, stomach problems, nausea, vomiting and rashes.
- The different types of antibiotics used are bactericidal antibiotic and bacteriostatic antibiotic. Bactericidal antibiotic kills the bacteria by interfering with the cell wall or cell components. Ex: penicillin. Bacteriostatic stops bacteria from multiplying.

9.2 ADMINISTRATION OF ANTIBIOTICS

For treating infections using antibiotics, different routes are used.

- Antibiotics are also available as creams, ointments or lotion to apply to the skin to treat certain skin infection.

- Antibiotics are also used in soaps and disinfectants.
- Antibiotics are usually taken as tablets and syrup.
- For severe infections, antibiotics can be given as injection.

9.3 SIDE EFFECTS

Antibiotics will cause side effects such as

- Vomiting
- Diarrhoea
- Stomach upset
- Allergies
- White patches on tongue

9.4 TYPES OF ANTIBIOTICS

The most commonly used antibiotics are

- Penicillins - phenoxymethylpenicillin, flucloxacillin and amoxicillin.
- Cephalosporins - cefaclor, cefadroxil and cefalexin.
- Tetracyclines - tetracycline, doxycycline and lymecycline.
- Aminoglycosides - gentamicin and tobramycin.

9.5 ANTIBIOTICS AFFECTING CELL WALL SYNTHESIS

- Antibiotics commonly target bacterial cell wall formation.
- Any substance that destroys the cell wall or prevents the synthesis of cell wall leads to the formation of sensitive cells.
- The peptidoglycan layer is important for cell wall structural integrity. Peptidoglycan consists of polysaccharide chains composed of alternating units of N-acetyl-glucosamine and N-acetylmuramic acid.
- Antibiotics prevent the bacteria from synthesizing peptidoglycan.
- Antibiotics that affect the bacterial cell wall are

  a. Penicillin
  b. Cephalosporin
  c. Cycloserine

d. Vancomycin

e. Bacitracin

β-lactam antibiotics are a broad class of antibiotics that includes penicillin derivatives and cephalosporin.

9.5.1 Penicillin

- Penicillin in the most widely used antibiotic.
- Penicillin is produced by Penicillium notatum, Penicillium chrysogenum and other species of molds.
- Penicillin's are a class of β-lactam antibiotics of related structure with slightly different properties and activities.
- All penicillin's have a common basic nucleus, a β-lactam thiazolidine ring with different side chains.

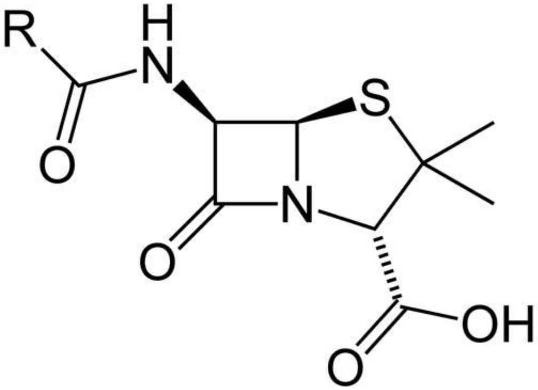


Fig 9.1 Structure of Penicillin

- It is rarely toxic to humans and may cause some skin reactions.
- Penicillin is used to treat many kinds of infections.
- Benzyl penicillin known as penicillin G is the most useful natural penicillin.
- Phenethicillin, semi synthetic penicillin is effective as penicillin G.
- Ampicillin, a semisynthetic penicillin acts against bacteria.
- Ampicillin is strongly bactericidal and it has no toxicity.
- Penicillin is used to prevent and control infections caused by gram-positive organisms.

- Penicillin is ineffective against gram-negative infections such as typhoid, fever and dysentry.
- The side effects of using penicillin are skin rashes, diarrhoea, irregular breathing, joint pain.

9.5.2 Cephalosporins

- Cephalosporin is a group of β-lactam antibiotics derived from fungi.
- They are used for the treatment of infections caused by bacteria.
- Cephalosporin nucleus has been modified to gain different properties.
- Cephalosporin's are effective against gram-positive and gram-negative bacteria.
- Cephalosporin's have anti-bacterial properties similar to semi-synthetic penicillin's.

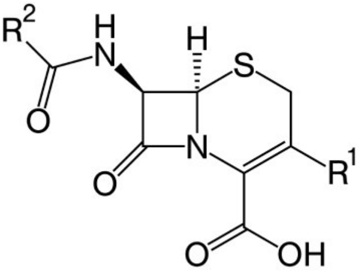


Fig 9.2 Structure of Cephalosporin

- They have a low toxicity.
- Some adverse effect of the drug reactions are diarrhoea, rash, vomiting, headache, dizziness and fever.
- They inhibit enzymes in the cell wall of susceptible bacteria, disrupting cell synthesis.
- The adverse effects of the drug leads to diarrhea, rashes, electrolytic disturbances.

9.5.3 Cycloserine

- Cycloserine is used to treat tuberculosis bacteria and also for urinary problems
- Cycloserine is stable under basic conditions.
- The side effects include allergies and sleepiness.

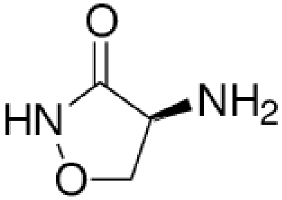


Fig 9.3 Structure of Cycloserine

9.5.4 Vancomycin

- Vancomycin is used to treat the bacterial infections caused in skin, blood stream, bone and joints.
- The side effects of this drug mainly causes allergic reactions.

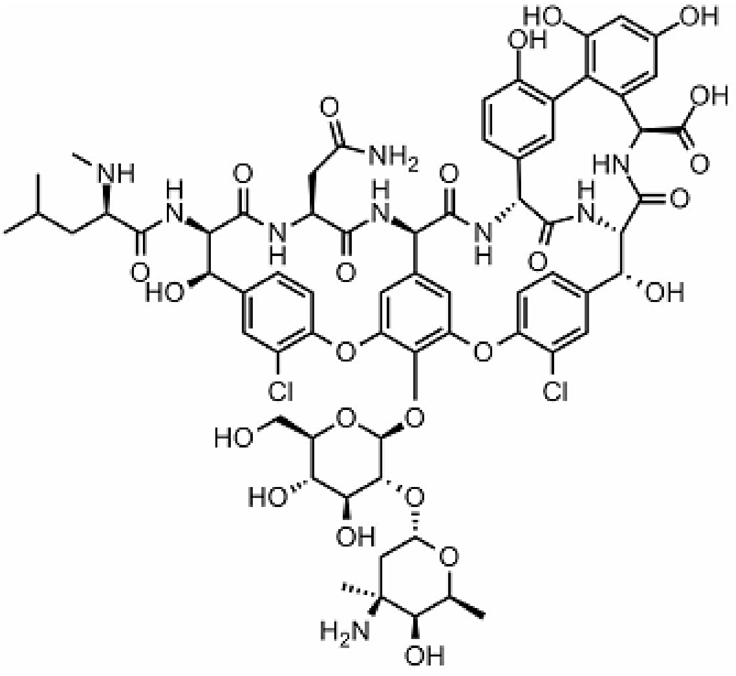


Fig 9.4 Structure of Vancomycin

9.5.5 Bacitracin

- Bacitracin is a mixture of cyclic peptides. It works by stopping the growth of bacteria. It is used to treat the infections caused by burns and cuts.
- It is also used in plant tissue culture to reduce the bacterial infections.

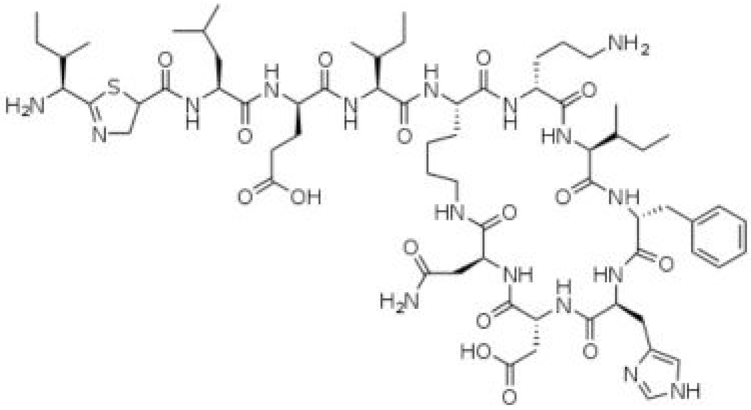


Fig 9.5 Structure of Bacitracin

9.6 ANTIBIOTICS AFFECTING CYTOPLASMIC MEMBRANE

- The cell membrane plays a vital role in the cell.
- Several polypeptide antibiotics produced by *Bacillus sp*. have the ability to damage cell membrane structure.
- Polymyxins, gramicidin's and polyene tyrocidines are antibiotics which damage the cytoplasmic membrane.

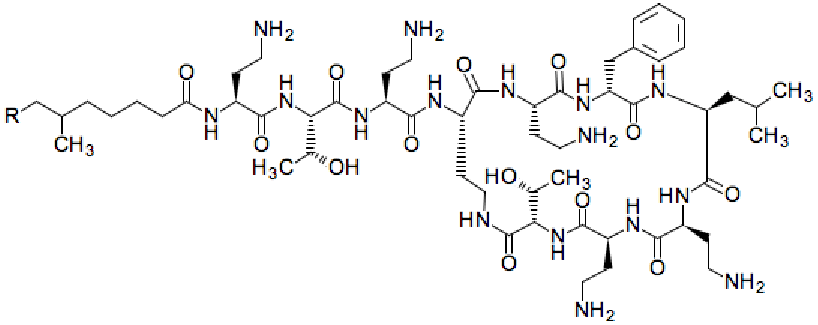


Fig 9.6 Structure of Polymyxin

- Polymyxins are particularly effective against gram-negative organisms. They work mostly by breaking up the bacterial cell membrane. Polymyxins bind specifically to cell membrane.
- Gramicidin are linear peptides with fifteen aminoacids.
- Tyrocidines and gramicidin's are more effective against gram-positive organisms.
- Nystatin, amphotericin act upon fungi and animal cells but do not affect bacteria. They increase the cell permeability.

9.7 ANTIBIOTICS INTERFERING WITH NUCLEIC ACID FUNCTION

- Certain group of antibiotics interfere with the DNA synthesis.
- Example - quinolones

9.8 ANTIBIOTICS INHIBITING PROTEIN SYNTHESIS

- A protein synthesis inhibitor is a substance that stops the growth of cells.
- A number of antibiotics interfere with the metabolism of proteins. Some important antibiotics are
  1. Rifamycin
  2. Streptomycin
  3. Tetracyclines
  4. Chloramphenicol
  5. Erythromycin
  6. Neomycin

9.8.1 Rifamycin

- Rifamycins are synthesized by the bacterium *Amycolatopsis rifamycinica*.
- Rifamycin is used to treat diarrhoea.
- This antibiotics can treat the bacterial infections by stopping the growth of bacteria.

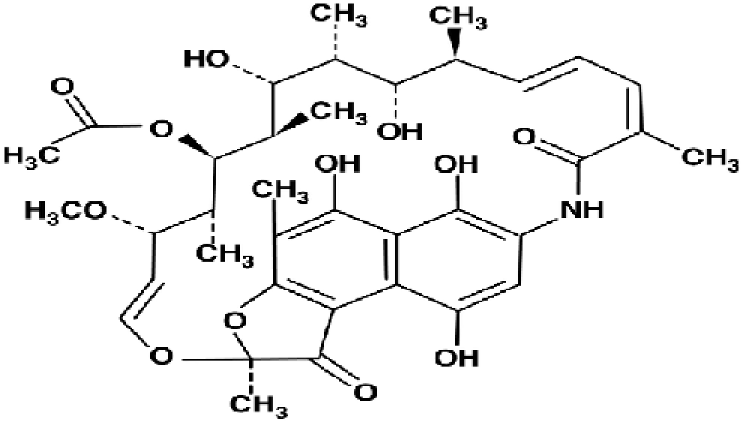


Fig 9.7 Structure of Rifamycin

9.8.2 Streptomycin

- Streptomycin is an antibiotic used to treat a number of bacterial infections.
- Streptomycin is produced by *Streptomyces griseus*.
- Streptomycin is an amino glycoside antibiotic.
- Highly purified streptomycin is non-toxic to humans and other animals when given in small doses.
- Streptomycin inhibits protein synthesis by combining irreversibly with 30S subunit mRNA. So it disturbs the normal sequence.
- Streptomycin is inhibitory particularly for tuberculosis. It is also used for the treatment of plague.
- In veterinary medicine, it is used against gram negative bacteria in large animals such as horses, sheep and cattle.

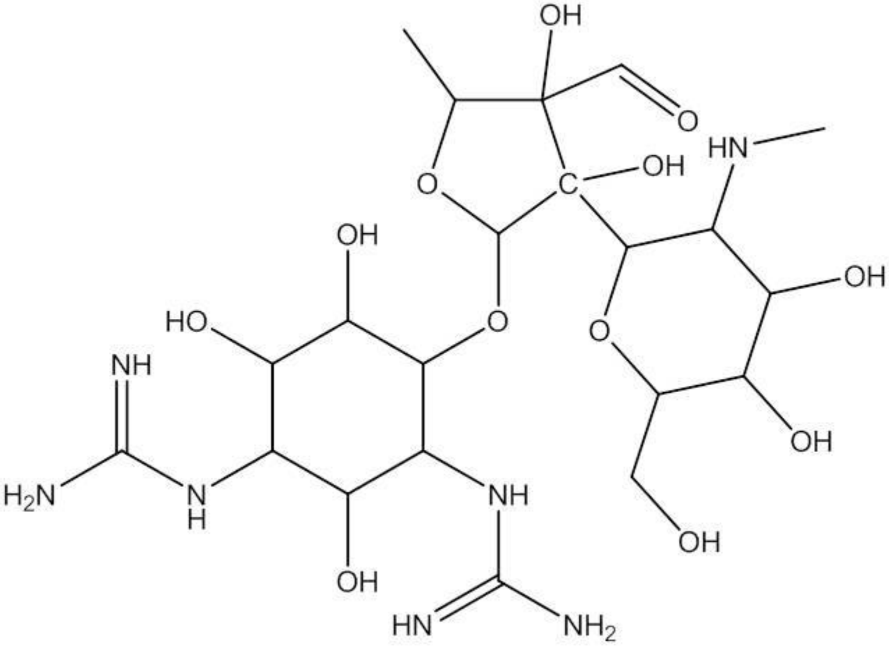


Fig 9.8 Structure of Streptomycin

- Streptomycin is used as pesticide and it used to control bacterial diseases of certain fruit, vegetables.
- It also causes side effects such as vomiting, fever and rash.

9.8.3 Tetracylines

- Many type of bacterial infections can be cured by tetracycline.
- Tetracylines are mainly used to treat urinary infections.
- The common side effects of tetracylines are nausea, vomiting, diarrhoea, vagina itching.
- For childrens, tooth damage may happens.
- Tetracyclines are used as biomarker.

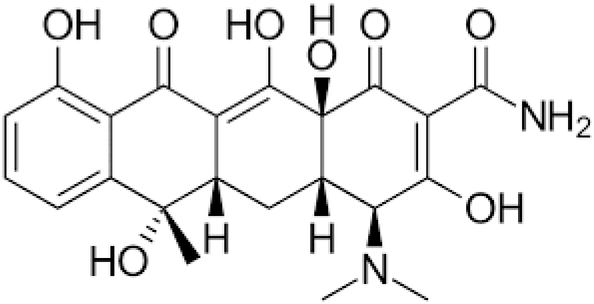


Fig 9.9 Structure of Tetracylines

9.8.4 Chloramphenicol

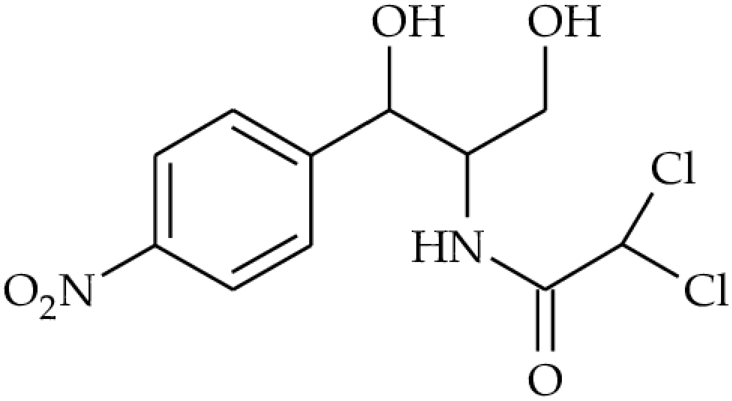


Fig 9.10 Structure of Chloramphenicol

Chloramphenicol was discovered after being isolated from Streptomyces venezuelae and it is used to treat many infections.

Chloramphenicol can be taken as ointments, injections.

9.8.5 Erythromycin

- Erythromycin is an antibiotic useful for the treatment of a number of bacterial infections.
- Erythromycin is produced by a strain of Streptomyces erythraeus.
- Erythromycin is active against the gram-positive bacteria and with some gram-negative bacteria.
- It resembles penicillin but it is active against organisms which are resistant to penicillin and streptomycin.
- It contains large lactone ring linked with amino sugars through glycosidic bonds.
- It belongs to the chemical class of antibiotics known as macrolides.

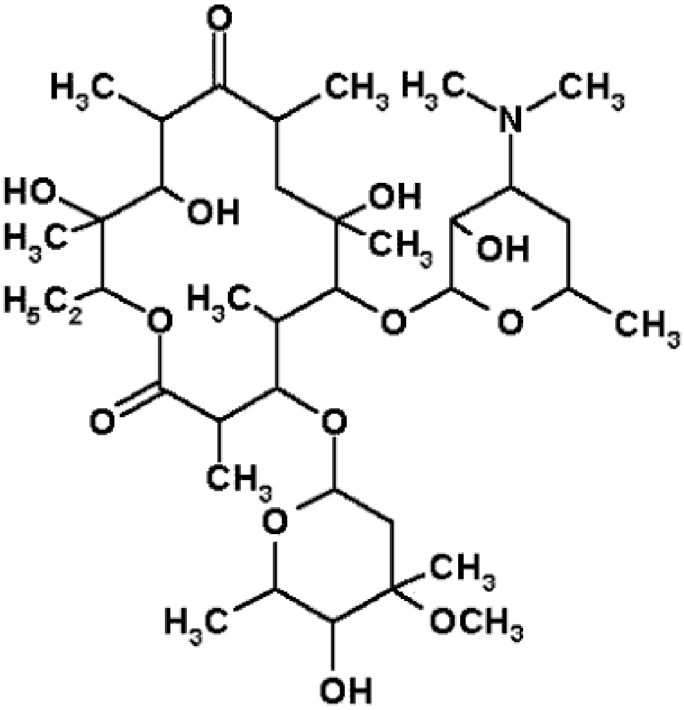


Fig 9.11 Structure of Erythromycin

- Erythromycin inhibits protein synthesis because of binding on 50s subunit ribosome. So, it leads to the blocking of transpeptidation and translocation in protein synthesis.

- Some side effects are skin infections and respiratory tract infections, vomiting, diarrhoea and abdominal pain.

9.8.6 Neomycin

- Neomycin is bactericidal.
- It is an aminoglycoside antibiotic.
- They can be used as creams, ointments and eye drops.

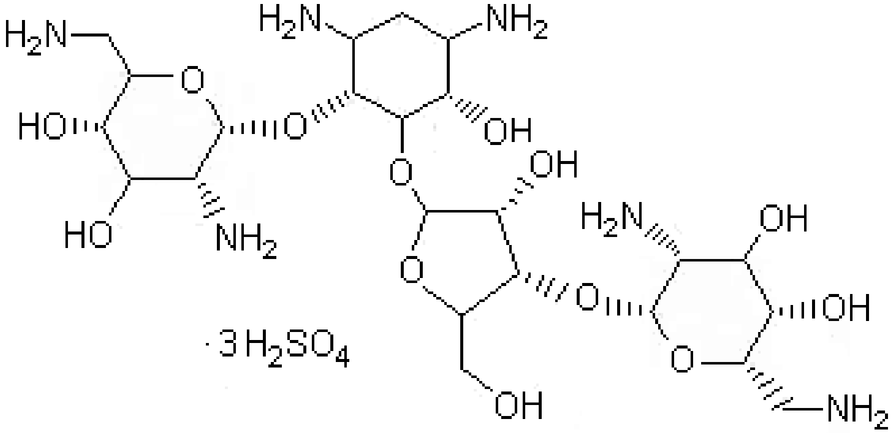


Fig 9.12 Structure of Neomycin

- It is not given as injection since it causes kidney damage.

9.9 ANTIBIOTICS AFFECTING ENZYME SYSTEM

- Antibiotics bind to the target and destroy the enzyme.

9.10 DRUG RESISTANCE

- Drug resistance is the resistance which causes the reduction in effectiveness of medication in curing a disease.
- Drug resistance is the major problem in controlling the micro-organism.
- Drug resistance may be due to competitive inhibition between an essential metabolite and a metabolic drug , development of an alternative metabolic pathway, inability of the drug to penetrate the cell, alteration of ribosomal protein structure.

- Development of resistance can be minimized by correct dosage, using combinations of antibiotics, using different antibiotic and avoiding antibiotics for unnecessary needs.
- The main causes of antibiotic resistance are
    - Over-prescription of antibiotics.
    - Patients not finishing the entire antibiotics.
    - Over use of antibiotics in livestock and fish farming.
    - Poor infection control in health care.
    - Poor hygiene and sanitation.

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GLOSSARY

Absorption	The process by which one thing absorbs or is absorbed by another.
Acetyl-CoA	Acetyl-CoA (acetyl coenzyme A) is a molecule that participates in many biochemical reactions in protein, carbohydrate and lipid metabolism
Acidic amino acids	They have a carboxyl group in the side chain.
Aromatic amino acids	They have a benzene ring in the side chain
Agar - Agar	Agar or agar-agar also known as "China grass" is a jelly-like substance, obtained from red algae. Agar is a mixture of two components: the linear polysaccharide agarose and a heterogeneous mixture of smaller molecules called agaropectin.
Agriculture	It is the science and art of cultivating plants and livestock.
Allergies	A condition in which the immune system reacts abnormally to a foreign substance.
Amino acids	They are organic compounds that combine to form proteins. Amino acids and proteins are the building blocks of life
Aminoglycosides	Aminoglycosides are a class of antibiotics used mainly in the treatment of aerobic gram-negative bacilli infections, although they are also effective against other bacteria including Staphylococci and Mycobacterium tuberculosis.
Amphipathic lipids	The lipid molecules in cell membranes are amphipathic (or amphiphilic) - that is, they have a hydrophilic ("water-loving") or polar end and a hydrophobic ("water-fearing") or nonpolar end.

Antacids	Antacids are a class of medicines that neutralize acid in the stomach. They contain ingredients such as aluminum, calcium, magnesium, or sodium bicarbonate which act as bases (alkalis) to counteract stomach acid and make its pH more neutral.
Antibiotics	An antibiotic is a type of antimicrobial substance active against bacteria and is the most important type of antibacterial agent for fighting bacterial infections.
Anticonvulsant	Anticonvulsants (also commonly known as antiepileptic drugs or as antiseizure drugs) are a diverse group of pharmacological agents used in the treatment of epileptic seizures.
Atom	An atom is the smallest constituent unit of ordinary matter that constitutes a chemical element.
Atomic number	The atomic number or proton number of a chemical element is the number of protons found in the nucleus of every atom of that element.
Atomic theory	Atomic theory is a scientific theory of the nature of matter, which states that matter is composed of discrete units called atoms.
Atomic weight	The total weight of an atom is called the atomic weight. It is approximately equal to the number of protons and neutrons.
ATP	ATP (adenosine 5′-triphosphate) is the main energy currency in living cells. It undergoes a type of reaction called hydrolysis where one or two of the terminal phosphate groups are released.
Amylose	Amylose is a polysaccharide made of α-D-glucose units, bonded to each other through α glycosidic bonds. It is one of the two components of starch, making up approximately 20-30%.
Amylopectin	Amylopectin is a water-insoluble polysaccharide and highly branched polymer of α-glucose units found in plants.

Apoenzyme	An apoenzyme is an inactive enzyme, activation of the enzyme occurs upon binding of an organic or inorganic cofactor.
Bacitracin	Bacitracin is a mixture of related cyclic peptides produced by organisms of the licheniformis group of Bacillus subtilis var Tracy, first isolated in 1945. These peptides disrupt Gram-positive bacteria by interfering with cell wall and peptidoglycan synthesis. Bacitracin is primarily used as a topical preparation.
Basic amino acids	They contains an amino group in the side chain
β pleated sheet	The β-sheet is a common motif of regular secondary structure in proteins. Beta sheets consist of beta strands connected laterally by at least two or three backbone hydrogen bonds, forming a generally twisted, pleated sheet.
Bioavailability	The proportion of a drug or other substance which enters the circulation when introduced into the body and so is able to have an active effect.
Biochemistry	It is the branch of science that explores the chemical processes within and related to living organisms.
Biomolecule	A molecule that is produced by a living organism.
Biological buffers	A biological buffer is an organic substance that has a neutralizing effect on hydrogen ions.
Bicarbonate buffer system	The bicarbonate buffer system is an acid-base homeostatic mechanism involving the balance of carbonic acid, bicarbonate ion and carbon dioxide in order to maintain pH
Buffer	A buffer solution is an aqueous solution consisting of a mixture of a weak acid and its conjugate base, or vice versa.
Carbohydrates	A carbohydrate is a biomolecule consisting of carbon, hydrogen and oxygen atoms, usually with a hydrogen–oxygen atom ratio of 2:1.
Carboxypeptidases	A carboxypeptidase is a protease enzyme that hydrolyzes a peptide bond at the carboxy-terminal end of a protein or peptide.

Caramelization	It is the browning of sugar, a process used extensively in cooking for the resulting sweet nutty flavour and brown colour.
Catalyst	A catalyst is a substance that can be added to a reaction to increase the reaction rate without getting consumed in the process.
Carotenoids	Carotenoids, also called tetraterpenoids, are yellow, orange, and red organic pigments that are produced by plants and algae, as well as several bacteria, and fungi.
Cell	It is the fundamental unit of life
Cellulose	Cellulose is a polysaccharide consisting of a linear chain of several hundred to many thousands of β linked D-glucose units. Cellulose is an important structural component of the primary cell wall of green plants.
Cephalosporins	The cephalosporins are a class of β-lactam antibiotics originally derived from the fungus Acremonium, which was previously known as "Cephalosporium".
Chemical bonds	A chemical bond is a lasting attraction between atoms, ions or molecules that enables the formation of chemical compounds.
Chitin	A fibrous substance consisting of polysaccharides, which is the major constituent in the exoskeleton of arthropods and the cell walls of fungi.
Chloramphenicol	Chloramphenicol is an antibiotic useful for the treatment of a number of bacterial infections.
Cholesterol	Cholesterol is an organic molecule. It is a sterol, a type of lipid. Cholesterol is biosynthesized by all animal cells and is an essential structural component of animal cell membranes.
Chondroitin	Chondroitin is a substance that occurs naturally in the connective tissues of people and animals.
Compound lipids	Compound lipids are also called heterolipids and they are esters of fatty acids with alcohol.

Co-enzyme	A substance that enhances the action of an enzyme. Coenzymes are small molecules. They cannot by themselves catalyze a reaction but they can help enzymes to do so.
Conjugated protein	A conjugated protein is a protein that functions in interaction with other chemical groups attached by covalent bonding or weak interactions.
Cyclic fatty acids	Cyclic fatty acids are an unusual class of minor fatty acids generally produced by bacteria and less frequently by plants.
Cycloserine	Cycloserine, sold under the brand name Seromycin, is an antibiotic used to treat tuberculosis.
Diglycerides	A diglyceride, or diacylglycerol (DAG), is a glyceride consisting of two fatty acid chains covalently bonded to a glycerol molecule through ester linkages.
Decarboxylation	Decarboxylation is a chemical reaction that removes a carboxyl group and releases carbon dioxide.
Dehydrogenases	Enzymes that catalyze the removal of hydrogen from one substrate and pass it on to second substrate.
Deoxyribose	A sugar derived from ribose by replacement of a hydroxyl group by hydrogen.
Derived lipids	Derived lipids are the substances derived from simple and compound lipids by hydrolysis.
Derived proteins	These are proteins derived by partial to complete hydrolysis from the simple or conjugated proteins by the action of acids, alkalies or enzymes.
Dextrorotation	It refers to clockwise or right-handed rotation
Diarrhea	Loose, watery bowel movements that may occur frequently and with a sense of urgency.
Disaccharide	A disaccharide is the sugar formed when two monosaccharides are joined by glycosidic linkage.

Disulfide bond	A disulfide bond, also called an S-S bond, or disulfide bridge, is a covalent bond derived from two thiol groups.
DNA	Deoxyribonucleic acid is a molecule composed of two chains that coil around each other to form a double helix carrying genetic instructions for the development, functioning, growth and reproduction of all known organisms and many viruses.
Drugs	A drug is any substance that causes a change in an organism's physiology or psychology when consumed.
Enzyme	An enzyme is a substance that acts as a catalyst in living organisms, regulating the rate at which chemical reactions proceed without itself being altered in the process.
Essential amino acids	An essential amino acid, or indispensable amino acid, is an amino acid that cannot be synthesized by the organism at a rate commensurate with its demand and thus must be supplied in its diet.
Essential fatty acids	Essential fatty acids, or EFAs, are fatty acids that humans and other animals must ingest because the body requires them for good health but cannot synthesize them.
Esterases	An esterase is a hydrolase enzyme that splits esters into an acid and an alcohol in a chemical reaction with water called hydrolysis.
Ergosterol	Ergosterol is a sterol that resides on the cell membranes of fungi and acts to maintain cell membrane integrity, similar to mammalian cholesterol.
Erythrocyte	A red blood cell, which (in humans) is typically a biconcave disc without a nucleus.
Erythromycin	Erythromycin is an antibiotic used for the treatment of a number of bacterial infections.
Epimers	An epimer is each of two isomers with different configurations of atoms about one of several asymmetric carbon atoms present.

Extracellular water	Extracellular water is the water located outside your cells. The water in your blood falls into this category.
FAD	Flavin adenine dinucleotide is a redox-active coenzyme associated with various proteins, which is involved with several important enzymatic reactions in metabolism
$FADH_2$	Flavin adenine dinucleotide or FADH2, is a redox cofactor that is created during the Krebs cycle and utilized during the last part of respiration, the electron transport chain.
Fats	Fat molecules consist of primarily carbon and hydrogen atoms and are therefore hydrophobic and are soluble in organic solvents and insoluble in water.
Fat soluble vitamins	Fat-soluble vitamins are absorbed along with fats in the diet and can be stored in the body's fatty tissue. They come from plant and animal foods or dietary supplements. Vitamins A, D, E, and K are fat-soluble.
Fatty acid	A fatty acid is a carboxylic acid with a long aliphatic chain which is either saturated or unsaturated.
Fermentation	It is a metabolic process that produces chemical changes in organic substrates through the action of enzymes.
Fibrous protein	A fibrous protein is a protein with an elongated shape. Fibrous proteins provide structural support for cells and tissues.
FMN	Flavin mononucleotide, is a biomolecule produced from riboflavin by the enzyme riboflavin kinase and functions as the prosthetic group of various oxidoreductases,
Fructose	Fructose, or fruit sugar, is a simple ketonic monosaccharide found in many plants, where it is often bonded to glucose to form the disaccharide sucrose.

Genetic Engineering	Genetic engineering is the manipulation of genes or the direct manipulation of an organism's genes using biotechnology.
Galactose	Galactose, is a monosaccharide sugar that is about as sweet as glucose, and about 65% as sweet as sucrose.
Globular proteins	Globular proteins or spheroproteins are spherical ("globe-like") proteins
Glucose	Glucose is a simple sugar with the molecular formula $C_6H_{12}O_6$.Glucose is mainly made by plants and most algae during photosynthesis from water and carbon dioxide, using energy from sunlight, where it is used to make cellulose in cell walls, which is the most abundant carbohydrate.
Glycogen	Glycogen is a multibranched polysaccharide of glucose that serves as a form of energy storage in animals, fungi and bacteria. The polysaccharide structure represents the main storage form of glucose in the body.
Glycolipids	Glycolipids are lipids with a carbohydrate attached by a glycosidic bond. Their role is to maintain the stability of the cell membrane.
Glycosidic linkage	A glycosidic bond or glycosidic linkage is a type of covalent bond that joins a carbohydrate (sugar) molecule to another group, which may or may not be another carbohydrate.
Haemoglobin	Haemoglobin (Hb) is a protein found in the red blood cells that carries oxygen in your body and gives blood its red colour.
Haworth projection	A Haworth projection is a common way of writing a structural formula to represent the cyclic structure of monosaccharides with a simple three-dimensional perspective.
Henderson–Hasselbalch equation	The Henderson–Hasselbalch equation relates the pH of a solution containing a mixture of the two components to the acid dissociation constant, K_a, and the concentrations of the species in solution.

Heterocyclic amino acids	The amino acids have a ring in their side chain
Heteropolysaccharides	Heteropolysaccharides (heteroglycans) contain two or more different monosaccharide units.
Holoenzyme	Holoenzymes are the active forms of enzymes.
Homopolysaccharides	Homopolysaccharides are polysaccharides composed of a single type of sugar monomer.
Hormone	A hormone is any member of a class of signaling molecules, produced by glands in multicellular organisms that are transported by the circulatory system to target distant organs to regulate physiology and behavior.
Hyaluronic acid	Hyaluronic acid, also called hyaluronan, is an anionic, nonsulfated glycosaminoglycan distributed widely throughout connective, epithelial, and neural tissues.
Hydrogen bonds	The hydrogen bond is an attractive interaction between a hydrogen atom from a molecule or a molecular fragment X–H in which X is more electronegative than H, and an atom or a group of atoms in the same or a different molecule.
Hydrolases	Hydrolases are enzymes that catalyze the cleavage of a covalent bond using water.
Hydrolytic rancidity	Hydrolytic rancidity refers to the odor that develops when triglycerides are hydrolyzed and free fatty acids are released.
Hydrophobic bonds	Hydrophobic bonds in proteins arise as a consequence of the interaction of their hydrophobic (i.e.,"water-disliking") amino acids with the polar solvent, water.
Hydroxy amino acids	They contain a hydroxyl group in their side chain
Hydroxy fatty acids	Any fatty acid carrying one or more hydroxy substituents.
Hypoalbuminemia	Hypoalbuminemia (or hypoalbuminaemia) is a medical sign in which the level of albumin in the blood is low.
Intracellular water	Intracellular water is the water inside cells that bathes all the necessary biological molecules including the proteins and nucleic acids.

Ionic bonds	Ionic bonding is a type of chemical bonding that involves the electrostatic attraction between oppositely charged ions.
Isoelectric point	The isoelectric point, is the pH at which a molecule carries no net electrical charge or is electrically neutral in the statistical mean.
Isomerases	Isomerases are a general class of enzymes that convert a molecule from one isomer to another.
Isomers	Isomers are each of two or more compounds with the same formula but a different arrangement of atoms in the molecule and different properties.
Isomerism	Isomerism is the phenomenon in which more than one compounds have the same chemical formula but different chemical structures.
Isoniazid	Isoniazid, also known as isonicotinic acid hydrazide (INH), is an antibiotic used for the treatment of tuberculosis.
Lactose	Lactose is a disaccharide. It is a sugar composed of galactose and glucose subunits. Lactose makes up around 2–8% of milk.
Lanosterol	Lanosterol is a tetracyclic triterpenoid and is the compound from which all animal and fungal steroids are derived.
Levorotation	It refers to counterclockwise or left-handed rotation.
Ligases	A ligase is an enzyme that can catalyze the joining of two large molecules by forming a new chemical bond, usually with accompanying hydrolysis of a small pendant chemical group on one.
Lipids	A lipid is a biomolecule that is insoluble in water and soluble in nonpolar solvents. It is also known as fats.
Lyases	A lyase is an enzyme that catalyzes the breaking of various chemical bonds by means other than hydrolysis and oxidation, often forming a new double bond or a new ring structure.

Maltose	Maltose, also known as maltobiose or malt sugar, is a disaccharide formed from two units of glucose joined with an α bond.
Medicine	It is the science and practice of establishing the diagnosis, prognosis, treatment, and prevention of disease.
Messenger RNA	Messenger RNA (mRNA) is a single-stranded RNA molecule that is complementary to one of the DNA strands of a gene.
Monoglycerides	Monoglycerides are a class of glycerides which are composed of a molecule of glycerol linked to a fatty acid via an ester bond.
Monosaccharide	Monosaccharides, also called simple sugar are the simplest form of sugar and the most basic units of carbohydrates.
Monosodium glutamate	Monosodium glutamate, also known as sodium glutamate, is the sodium salt of glutamic acid, one of the most abundant naturally occurring non-essential amino acids.
Molecule	A molecule is a particle made up of two or more atoms that are chemically bonded together.
Mucopolysaccharides	Mucopolysaccharides are long chains of sugar molecules that are found throughout the body, often in mucus and in fluid around the joints. They are more commonly called glycosaminoglycans.
Mutarotation	Mutarotation is the change in the optical rotation because of the change in the equilibrium between two anomers, when the corresponding stereocenters interconvert.
Mutation	A mutation is a change that occurs in our DNA sequence, either due to mistakes when the DNA is copied or as the result of environmental factors such as UV light and cigarette smoke.
Nicotinamide Adenine Dinucleotide (NAD)	Nicotinamide adenine dinucleotide (NAD) is a cofactor that is central to metabolism. NAD is called a dinucleotide because it consists of two nucleotides joined through their phosphate groups.

NicotinamideAdenine DinucleotidePhosphate (NADP)	Nicotinamide adenine dinucleotide phosphate, is a cofactor used in anabolic reactions, such as the Calvin cycle and lipid and nucleic acid synthesis, which require NADPH as a reducing agent.
NADPH	NADPH is the reduced form of NADP+; used in anabolic reactions, such as lipid and nucleic acid synthesis.
Neomycin	Neomycin is an antibiotic that fights bacteria in the body.
Neutral sugars	The neutral sugars are mainly D-galactose, L-arabinose and D-xylose, with the types and proportions of neutral sugars varying with the origin of pectin.
Nitrogenous bases	A molecule that contains nitrogen and has the chemical properties of a base. The nitrogenous bases in DNA are adenine (A), guanine (G), thymine (T), and cytosine (C). The nitrogenous bases in RNA are the same, with one exception: adenine (A), guanine (G), uracil (U), and cytosine (C).
Non- essential amino acids	An amino acid that can be made by humans and so is not essential to the human diet.
Non-essential fatty acids	Non essential fatty acids are which is not required by the body instead may cause harm.
Non-polar molecules	Nonpolar molecules occur when electrons are shared equal between atoms of a diatomic molecule or when polar bonds in a larger molecule cancel each other out.
Non – Reducing sugar	Non-reducing sugars do not have an OH group attached to the anomeric carbon so they cannot reduce other compounds.
Nucleic acids	Nucleic acids are the biopolymers or small biomolecules, essential to all known forms of life. The term nucleic acid is the overall name for DNA and RNA.

Nucleosides	Nucleosides are glycosylamines that can be thought of as nucleotides without a phosphate group. A nucleoside consists simply of a nucleobase and a five-carbon sugar ribose whereas a nucleotide is composed of a nucleobase, a five-carbon sugar, and one or more phosphate groups.
Nucleotides	Nucleotides are molecules consisting of a nucleoside and a phosphate group. They are the basic building blocks of DNA and RNA.
Nutrition	It is the science that interprets the nutrients and other substances in food in relation to maintenance, growth, reproduction, health and disease of an organism.
Oligosaccharides	An oligosaccharide is a saccharide polymer containing a small number of monosaccharides.
Osazone	Osazones are a class of carbohydrate derivatives found in organic chemistry formed when sugars are reacted with excess of phenylhydrazine.
Oxidation	Oxidation is the loss of electrons during a reaction by a molecule, atom or ion.
Oxidative rancidity	Oxidative rancidity is associated with the degradation by oxygen in the air.
Oxidoreductases	An oxidoreductase is an enzyme that catalyzes the transfer of electrons from one molecule, the reductant, also called the electron donor, to another, the oxidant, also called the electron acceptor.
Oximes	Oxime, any of a class of nitrogen-containing organic compounds usually prepared from hydroxylamine and an aldehyde, a ketone, or a quinone.
Penicillins	Penicillins are a type of antibiotic derived from Penicillium fungi. An antibiotic is a type of medicine that inhibits the growth of or kills bacteria.

Peptidases	Peptidases are enzymes that hydrolyse peptide bonds and constitute a structurally and functionally diverse set of proteins.
Peptide bond	A peptide bond is a chemical bond formed between two molecules when the carboxyl group of one molecule reacts with the amino group of the other molecule, releasing a molecule of water (H2O).
pH	pH is a scale used to specify how acidic or basic a water-based solution is.
Phenobarbital	Phenobarbital is a barbiturate. Phenobarbital slows the activity of your brain and nervous system. Phenobarbital is used to treat or prevent seizures. Phenobarbital is also used short-term as a sedative to help you relax.
Phenytoin	Phenytoin is an anti-epileptic drug, also called an anticonvulsant. Phenytoin works by slowing down impulses in the brain that cause seizures.
Phosphate buffer system	Phosphate buffer system operates in the internal fluids of all cells. It consists of dihydrogen phosphate ions as the hydrogen ion donor (acid) and hydrogen phosphate ion as the ion acceptor (base).
Phospholipids	Phospholipids are a class of lipids that are a major component of all cell membranes. They can form lipid bilayers because of their amphiphilic characteristic.
Phosphoric acid	Phosphoric acid is a colorless, odorless phosphorus-containing inorganic acid. Phosphoric acid is a sequestering agent which binds many divalent cations, including Fe++, Cu++, Ca++, and Mg++.
Physiology	It is the scientific study of functions and mechanisms in a living system.
Polar molecules	Polar molecules occur when there is an electronegativity difference between the bonded atoms.

Polymer	A polymer is a large molecule, or macromolecule, composed of many repeated subunits.
Polynucleotide	A polynucleotide molecule is a biopolymer composed of 13 or more nucleotide monomers covalently bonded in a chain. DNA and RNA are examples of polynucleotides with distinct biological function.
Polysaccharides	Polysaccharides are long chains of carbohydrate molecules, specifically polymeric carbohydrates composed of monosaccharide units bound together by glycosidic linkages.
Prosthetic group	A non-protein group forming part of or combined with a protein.
Proteases	A protease is an enzyme that catalyzes proteolysis, the breakdown of proteins into smaller polypeptides or single amino acids.
Proteins	Proteins are large biomolecules or macromolecules, consisting of one or more long chains of amino acid residues.
Protein synthesis	Protein synthesis is the process in which cells make proteins.
Provitamin	A substance which is converted into a vitamin within an organism.
Purines	A purine is an aromatic heterocycle composed of carbon and nitrogen. Purines include adenine and guanine, which participate in DNA and RNA formation.
Pyrimidines	Pyrimidine is one of two classes of heterocyclic nitrogenous bases found in the nucleic acids DNA and RNA. In DNA the pyrimidines are cytosine and thymine, in RNA uracil replaces thymine.
Ramachandran plot	The Ramachandran plot is a plot of the torsional angles - phi (φ)and psi (ψ) - of the residues (amino acids) contained in a peptide.
Rancidity	Rancidification is the process of complete or incomplete oxidation or hydrolysis of fats and oils when exposed to air, light, or moisture or by bacterial action, resulting in unpleasant taste and odor.

Reducing sugar	A reducing sugar is any sugar that is capable of acting as a reducing agent because it has a free aldehyde group or a free ketone group.
Reduction	Reduction is a chemical reaction that involves the gaining of electrons by one of the atoms involved in the reaction between two chemicals.
Replication	Replication is the process by which a double-stranded DNA molecule is copied to produce two identical DNA molecules.
Ribose	Ribose is a simple sugar and carbohydrate. The naturally-occurring form, d-ribose, is a component of the ribonucleotides from which RNA is built.
Ribosomal RNA	Ribosomal RNA (rRNA), molecule in cells that forms part of the protein-synthesizing organelle known as a ribosome and that is exported to the cytoplasm to help translate the information in messenger RNA (mRNA) into protein.
Rifamycin	Rifamycin is a nonabsorbable rifampin-like antibacterial agent that is used as treatment of travelers' diarrhea. Rifamycin has minimal oral absorption and has not been implicated in causing liver test abnormalities or clinically apparent liver injury.
Rifampin	Rifampin is an antibiotic that is used to treat or prevent tuberculosis (TB). Rifampin may also be used to reduce certain bacteria in your nose and throat that could cause meningitis or other infections.
RNA	Ribonucleic acid (RNA) is a polymeric molecule essential in various biological roles in coding, decoding, regulation and expression of genes.
Saturated fatty acids	Saturated fatty acids are compounds that consist of a hydrocarbon chain and a carboxylic acid group (-COOH) at the end of the chain.
Simple amino acids	They have no functional groups in the side chain

Simple lipids	A simple lipid is a fatty acid ester of different alcohols and carries no other substance.
Simple proteins	On hydrolysis they yield only the amino acids and occasional small carbohydrate compounds.
Starch	Starch or amylum is a polymeric carbohydrate consisting of numerous glucose units joined by glycosidic bonds. This polysaccharide is produced by most green plants as energy storage.
Starvation	Suffering or death caused by lack of food.
Steroids	A steroid is a biologically active organic compound with four rings arranged in a specific molecular configuration.
Stereo isomerism	Stereoisomerism, or spatial isomerism, is a form of isomerism in which molecules have the same molecular formula and sequence of bonded atoms (constitution), but differ in the three-dimensional orientations of their atoms in space.
Streptomycin	Streptomycin is an aminoglycoside antibiotic produced by the soil actinomycete Streptomyces griseus. It acts by binding to the 30S ribosomal subunit of susceptible organisms and disrupting the initiation and elongation steps in protein synthesis.
Substrate	A substrate is typically the chemical species being observed in a chemical reaction which reacts with a reagent to generate a product.
Sucrose	Sucrose is common sugar. It is a disaccharide, a molecule composed of two monosaccharides: glucose and fructose.
Sulfur-containing amino acids	They contain a sulfur atom in the side chain
Sulphites	Sulphites are substances that are naturally found in some foods. They are used as an additive to maintain food colour, shelf-life and prevent the growth of fungi or bacteria.

Tartrazine	Tartrazine is a synthetic lemon yellow azo dye primarily used as a food coloring.
Terpenes	Terpenes are a large and diverse class of organic compounds, produced by a variety of plants, particularly conifers, and by some insects.
Tetracyclines	Tetracycline is an antibiotic that fights infection caused by bacteria.
Thermoregulation	Thermoregulation is the ability of an organism to keep its body temperature within certain boundaries, even when the surrounding temperature is very different.
Thiamine pyrophosphate (TPP)	Thiamine pyrophosphate or thiamine diphosphate or cocarboxylase is a thiamine derivative which is produced by the enzyme thiamine diphosphokinase.
Transaminase	Transaminases or aminotransferases are enzymes that catalyze a transamination reaction between an amino acid and an α-keto acid.
Transferases	A transferase is any one of a class of enzymes that enact the transfer of specific functional groups from one molecule to another.
Transfer RNA	Transfer ribonucleic acid (tRNA) is a type of RNA molecule that helps decode a messenger RNA (mRNA) sequence into a protein.
Triglyceride	A triglyceride is an ester derived from glycerol and three fatty acids.
Ubiquinone	Ubiquinone (coenzyme Q) is a lipophilic metabolite that functions in the electron transport chain in the plasma membranes of prokaryotes and the inner mitochondrial membranes of eukaryotes, apart from its roles as an antioxidant and in the regeneration of tocopherols.
Unsaturated fatty acids	An unsaturated fat is a fat or fatty acid in which there is one or more double bond in the fatty acid chain.
Vancomycin	Vancomycin is an antibiotic used to treat a number of bacterial infections..

Vitamin	A vitamin is an organic molecule that is an essential micronutrient that an organism needs in small quantities for the proper functioning of its metabolism.
Vitamin A	Vitamin A is a group of unsaturated nutritional organic compounds that includes retinol, retinal, retinoic acid, and several provitamin A carotenoids (most notably beta-carotene).
Vitamin B_1	Thiamine, also known as thiamin or vitamin B_1, is a vitamin found in food, and manufactured as a dietary supplement and medication.
Vitamin B_2	Riboflavin, also known as vitamin B_2, is a vitamin found in food and used as a dietary supplement.
Vitamin B_3	Niacin, also known as nicotinic acid, is an organic compound and a form of vitamin B3, an essential human nutrient.
Vitamin B_5	Pantothenic acid, also called vitamin B_5, is a water-soluble vitamin. Pantothenic acid is an essential nutrient. Animals require pantothenic acid in order to synthesize coenzyme-A.
Vitamin B_6	Vitamin B_6 refers to a group of chemically similar compounds which can be interconverted in biological systems.
Vitamin B_7	Biotin also called vitamin H, vitamin B_7 is a water-soluble B vitamin. It is involved in a wide range of metabolic processes, both in humans and in other organisms.
Vitamin B_9	Folate, also known as vitamin B_9 and folacin, is one of the B vitamins used as a dietary supplement and in food fortification as it is more stable during processing and storage.
Vitamin B_{12}	Vitamin B_{12}, also known as cobalamin, is an important water-soluble vitamin. It plays an essential role in the production of your red blood cells and DNA.

Vitamin C	Vitamin C, also known as ascorbic acid and ascorbate, is a vitamin found in various foods and sold as a dietary supplement. It is used to prevent and treat scurvy.
Vitamin D	Vitamin D is a nutrient found in some foods that is needed for health and to maintain strong bones.
Vitamin E	Vitamin E is a group of fat soluble compounds that include four tocopherols and four tocotrienols. Vitamin E can cause nerve problems.
Vitamin K	Vitamin K is a group of structurally similar, fat-soluble vitamins found in foods and in dietary supplements. The human body requires vitamin K for complete synthesis of certain proteins that are needed for blood coagulation
Water	Water is an inorganic, transparent, tasteless, odorless, and nearly colorless chemical substance
Water soluble vitamins	Water-soluble vitamins are carried to the body’s tissues but are not stored in the body. Vitamin C and members of the vitamin B complex are water-soluble.
Wax	A wax is a simple lipid which is an ester of a long-chain alcohol and a fatty acid.
Xanthophylls	Xanthophylls are yellow pigments that occur widely in nature and form one of two major divisions of the carotenoid group; the other division is formed by the carotenes.
Van der Waals bond	Van der Waals forces include attraction and repulsions between atoms, molecules and surfaces as well as other intermolecular forces.
Zwitter ion	A molecule or ion having separate positively and negatively charged groups.