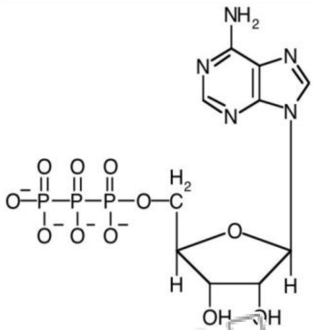


Chapter 2
Biological Molecules

2.1 BIOCHEMISTRY

Biochemistry is a branch of biology, which deals with the study of chemical components and the chemical processes in living organisms.

Role of Biochemistry

A basic knowledge of biochemistry is essential for understanding anatomy and physiology, because all of the structures of an organism have biochemical organization. For example, photosynthesis, respiration, digestion and muscle contraction can all be describe in biochemical terms.

Chemical Compounds of Living Organisms

All living things are made of certain chemical compounds, which are generally classified as organic and inorganic.

- Most important ***organic compounds*** in living organisms are carbohydrates, proteins, lipids and nucleic acids.
- Among ***Inorganic substances*** are water, carbon dioxide, acids, bases and salts.

Typically an animal and a bacterial cell consist of chemicals as shown in following table.

Sr. No.	Chemical Components	% total cell weight	
		Bacterial Cell	Mammalian Cell
1.	Water	70	70
2.	Proteins	15	18
3.	Carbohydrates	3	4
4.	Lipids	2	3
5.	DNA	1	0.25
6.	RNA	6	1.1
7.	Organic molecules (enzymes, hormones, métabolites)	2	2
8.	Inorganic ions (Na^+, K^+, Mg^{+2}, Cl^-, SO_4^{-2} etc)	1	1

Importance of Chemicals

The survival of an organism depends upon its ability to take some chemicals from its environment and use them to make chemicals of its living matter. For this reason, cells of every organism are constantly taking in new substances and change them chemically in various ways i.e. building new cellular materials and obtaining energy for their needs. Life of an organism depends upon the ceaseless chemical activities in its cells.

QUESTION RELATED TO ABOVE ARTICLE

Explain term Biochemistry and describe the significance of biochemistry in survival of an organism.

Write percentage of Chemical Compounds in bacterial & mammalian cell.

2.1.1 Metabolism

All the chemical reactions taking place within a cell are collectively called as metabolism.

Types

Metabolic processes are characterized as anabolic reactions (anabolism) and catabolic reactions (catabolism).

i) Anabolic Reactions

- Reactions in which simpler substances are combined to form complex substances are called anabolic reactions.
- Anabolic reactions need energy (Endothermic).
- Example is ***photosynthesis***.

ii) Catabolic Reactions

- Reactions in which larger substances are broken down into simpler one are called catabolic reactions.
- Energy is released during these reactions (Exothermic)
- Example is ***respiration***.

Coordinated Catabolic and Anabolic Activities

Anabolic and catabolic reactions go hand in hand in the living cells. Complex molecules are broken down and the resulting smaller molecules are reused to form new complex molecules.

Interconversion of carbohydrates, proteins and lipids that occur continuously in living cells are examples of coordinated catabolic and anabolic activities.

QUESTION RELATED TO ABOVE ARTICLE

What is metabolism? Explain its types.

2.2 IMPORTANCE OF CARBON

Introduction

Carbon is the basic element of organic compounds. Due to its unique properties, carbon occupies the central position in the skeleton of life.

Features of Carbon

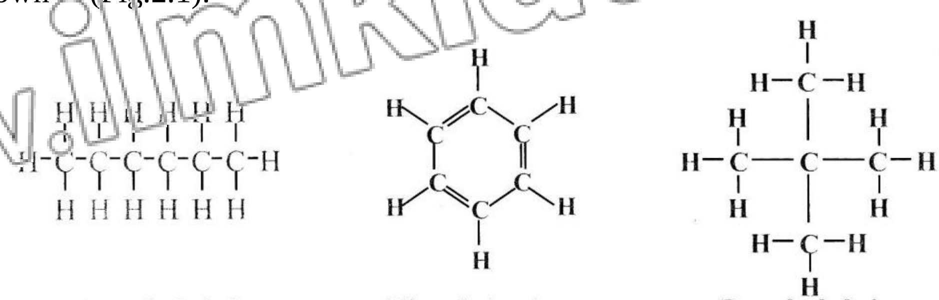
(i) Carbon is a ***tetravalent***.

(ii) It can react with many other known elements forming covalent bonds.

(iii) When a carbon atom combines with four atoms or radicals, the four bonds are arranged symmetrically in a ***tetrahedron*** and result to give a stable configuration.

(iv) ***Stability*** of carbon due to tetravalency makes it a favourable element for the synthesis of complicated cellular structures.

(v) Carbon atoms also can combine mutually forming stable branched or unbranched ***chains or rings***. C-C bonds form different types of skeleton in a variety of organic molecules as shown in (Fig.2.1).



Unbranched chain **Ringed structure** **Branched chain**

Fig. 2.1 Unbranched and branched chains, and ring structure formed by C-C bonds.

Combinations of Carbon with other Elements

Carbon combines commonly with H, O, N, P and S. Combinations with these and other elements contribute to the large variety of organic compounds.

- Carbon and hydrogen bond (***C-H bond***) is the potential source of chemical energy for cellular activities.
- Carbon-oxygen (***C-O-C bond***) association in glycosidic linkages provides stability to the complex carbohydrate molecules.
- Carbon combines with nitrogen (***C-N bond***) in amino acid linkages to form peptide bonds and form proteins, which are very important due to their diversity in structure and function.

Importance of (Carbon Containing) Organic Compounds

➢ ***Large organic molecules*** (macromolecules) such as cellulose, fats, proteins, etc. are generally insoluble in water and hence;

- They form structures of cells.
- They also serve as storage for smaller molecules like glucose, which in turn are responsible for providing energy to the body.

➢ ***Small molecules*** (micromolecules) such as glucose, amino acids, fatty acids etc. and are generally soluble in water and hence;

- Serve as a source of energy.
- Serve as subunits to build macromolecules.
- Some small molecules are so unstable are immediately broken down to release energy e.g. ATP. Such substance serves as immediate source of energy for cellular metabolism.

QUESTION RELATED TO ABOVE ARTICLE

Discuss the Importance of Carbon.
Describe importance of carbon in the skeleton of life. (SGD 2019, FSD 2021)
Why carbon occupies the central position in the skeleton of life. (RWP 2021)

2.3 IMPORTANCE OF WATER

Introduction

Water is the medium of life. It is most abundant compound in all organisms.

Amount

It varies from ***65 to 89 %*** in different organisms. Human tissues contain about ***20 %*** water in ***bone cells*** and ***85 %*** *in* ***brain cells***.

Importance

i) Almost all the reactions of a cell occur in presence of water. It also takes part in many ***biochemical reactions*** such as hydrolysis of macromolecules.

ii) It is used as ***raw material*** in photosynthesis.

Some other properties

1) Solvent properties

- Due to its polarity, water is an excellent solvent for ***polar substances***.
- ***Ionic substances*** when dissolved in water, dissociate into positive and negative ions.
- ***Non-ionic substances*** having charged groups in their molecules are dispersed in water.

Importance

i) When in solution, ions and molecules move randomly and are in a more favourable state to react with other molecules and ions.

ii) It is because of this property of water that almost all reactions in living organisms occur in aqueous media.

iii) In cells, all chemical reactions are catalyzed by enzymes, which work in aqueous environment.

iv) Non-polar organic molecules such as fats are insoluble in water and help to maintain membranes, which make compartment in the cell.

2) Heat capacity

The specific heat capacity of water is defined as the number of calories required to raise the temperature of 1g of water from 15 to 16ºC.

Specific heat capacity of water is *1 cal/ g ºC or 4.184 J/g ºC.*

Importance

This is because much of the energy is used to break hydrogen bonds water thus works as ***temperature stabilizer*** for organisms in the environment and hence protects living material against sudden thermal changes.

3) Heat of vaporization

Amount of heat required to convert a substance from its liquid to gaseous state without change in temperature is called heat of vaporization.

- It is expressed in calories per gram or kilocalories per kilogram.
- The specific heat of vaporization of water is ***574 Kcal/kg***.

Importance

i) It plays an important role in ***regulation of heat*** produced by oxidation.

ii) It provides ***cooling effect*** to plants when water is transpired or to animals when water is respired.

Evaporation of only 2 ml out of one liter of water lowers the temperature of the remaining 998 ml by 1ºC.

4) Ionization of water

Water molecules ionize to form H^+ and OH^- ions:

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

This reaction is reversible but equilibrium is maintained. At 25ºC the concentration of each of H^+ and OH^- ions in pure water is about 10^{-7} mole/litre.

Importance

The H^+ and OH^- ions affect and take part in many of the reactions that occur in cells.

5) Protection

- Water is effective ***lubricant*** that provides protection against damages resulting from friction. For example, tears protect the surface of eye from the rubbing of eyelids.
- Water also forms a ***fluid cushion*** around organs that helps to protect them from trauma.

QUESTION RELATED TO ABOVE ARTICLE

Water is medium of life. Discuss.

Describe importance of Water by discussing its various properties. (BWP 2019)

Explain various aspect of importance of water. (MTN 2021)

Describe importance of water for living organisms. (GRW 2022, RWP 2022)

Describe the importance of water for life. (Exercise Question i)

2.4 CARBOHYDRATES

Introduction

Carbohydrates occur abundantly in living organisms. They are found in all organisms and in almost all parts of the cell.

Meaning

- The word carbohydrate literally means ***hydrated carbon***. They are composed of carbon, hydrogen and oxygen, the ratio of hydrogen and oxygen is the same as in water.
- Their general formula is $C_x(H_2O)_y$, where x and y are the whole number from three to many thousands whereas y may be the same or different whole number.

Definition

- Chemically carbohydrates are defined as polyhydroxy aldehydes or ketones or complex substances, which on hydrolysis yield polyhydroxy aldehyde or ketone subunits. (Hydrolysis involves the breakdown of large molecules into smaller ones utilizing water molecules).

Source

The source of carbohydrates are green plants. These are the primary products of photosynthesis. Other compounds of plants are produced from carbohydrates by various chemical changes.

Examples

Cellulose of wood, cotton, and papers, starches present in cereals, root tubers, cane sugar and milk sugar are all examples of carbohydrates.

Conjugated Molecules of Carbohydrates

Carbohydrates in cell combine with:

- Protein forming ***glycoproteins***
- Lipids forming ***glycolipids***

Glycoproteins and glycolipids have structural role in the ***extracellular matrix*** of animals and bacterial cell wall. Both these conjugated molecules are components of biological membranes.

Classification of carbohydrates

Carbohydrates are also called ***'saccharides'*** (derived from Greek word 'sakcharon' meaning sugar) and are classified into three groups;

i) Monosaccharides
ii) Oligosaccharides
iii) Polysaccharides

1) Monosaccharides

These are simple sugars.

Features

i) They are sweet in taste
ii) They are easily soluble in water and they cannot be hydrolyzed into simple sugars.

Composition

- Chemically they are either polyhydroxy aldehydes or ketones.
- All carbon atoms in monosaccharides except one, have a hydroxyl group.
- The remaining carbon atom is either a part of an aldehyde group or a keto group.
- The sugar with aldehyde group is called ***aldo-sugar*** e.g. glyceraldehydes and with the keto group as ***keto-sugar*** e.g. dihydroxyacetone.

These are indicated in the case of two trioses sketched below.

Aldehyde form **Keto form**

Fig. 2.2 Structure of glyceraldehydes, a 3C Sugar ($C_3H_6O_3$). The aldehyde form is glyceraldehydes, whereas ketonic form is dihydroxyacetone.

Types

In nature monosaccharides with **3 to 7** carbon atoms are found. They are called ***trioses*** (3C), ***tetroses*** (4C), ***pentoses*** (5C), ***hexoses*** (6C) and ***heptoses*** (7C). They have general formula $(CH_2O)_n$. Where n is the whole number from three to seven.

Examples

- Two trioses mentioned above i.e. glyceraldehydes and dihydroxyacetone, are intermediates in respiration and photosynthesis.
- Tetroses are rare in nature and occur in some bacteria.
- Pentoses and hexoses are most common. Form the biological point of view most important hexose is glucose, which is an aldose sugar.

Structures of ribose and glucose is give below.

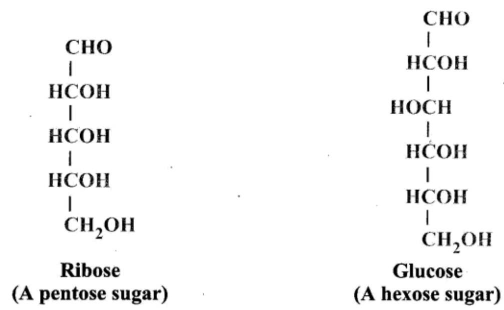


Fig. 2.3 Structure of Ribose and Glucose

Ring formation

Most of the monosaccharides form a ring structure when in solution. For example ribose will form a five-cornered ring known as ***ribofuranose***, whereas glucose will form six-cornered ring known as ***glucopyranose.***

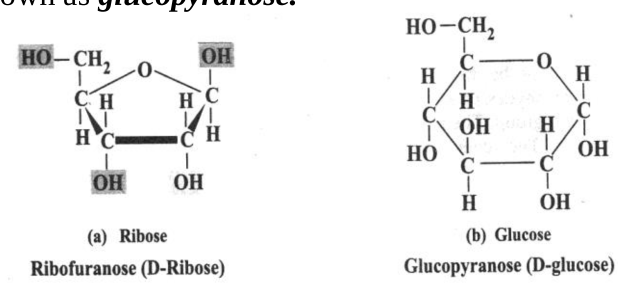


Fig.2.4 Ribose and glucose form ring shaped structures.

Glucose a common example

- Glucose is naturally produced in green plants, which take carbon dioxide from the air and water from the soil to synthesize glucose.

$$6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{light energy}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

- As indicated in the equation, energy is consumed in this process which is provided by sunlight. That is why the process is called ***photosynthesis***.
- For synthesis of ***10g*** of glucose ***717.6 Kcal*** of solar energy is used. This energy is stored in the ***glucose molecules*** as chemical energy and becomes available in all organisms when it is oxidized in the body.
- In Free State, glucose is present in all fruits, being abundant in grapes, figs and dates.
- Our body normally contains ***0.08%*** glucose.
- In combined form, it is found in many disaccharides and polysaccharides. Starch, cellulose and glycogen yield glucose on complete hydrolysis.

2) Oligosaccharides

Features

i) These are less sweet in taste.
ii) These are less soluble in water.
iii) On hydrolysis, they yield from **two to ten** monosaccharides.
iv) The covalent bond between two monosaccharides is called ***Glycosidic linkage***.

Types

- Those yielding two monosaccharides on hydrolysis are called ***disaccharides***.
- Those yielding three are known as ***trisaccharides*** and so on.

Examples

- Physiologically important disaccharides are maltose, sucrose and lactose.

Glucose + Galactose ⟶ Lactose
Glucose + Glucose ⟶ Maltose
Glucose + Fructose ⟶ Sucrose

Most familiar disaccharide is sucrose (cane sugar), which on hydrolysis yields glucose and fructose, both of which are reducing sugars. Its molecular formula is $C_{12}H_{22}O_{11}$. Its structural formula is given below.

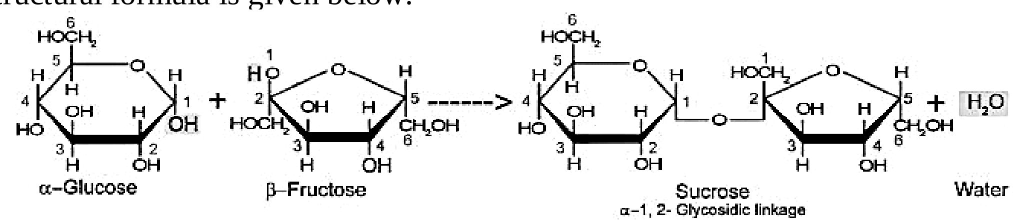


Fig. 2.5 A disaccharide. Note carefully the glycosidic linkage between the two monosaccharides.

3) Polysaccharides

Polysaccharides are the most complex and most abundant carbohydrates in nature.

Features

i) They are usually branched and tasteless.
ii) They are formed by several monosaccharide units linked by glycosidic bonds.
iii) They have high molecular weights.
iv) They are sparingly soluble in water

Examples

Some biologically important polysaccharides are starch, glycogen, cellulose, dextrins, agar, pectin and chitin etc.

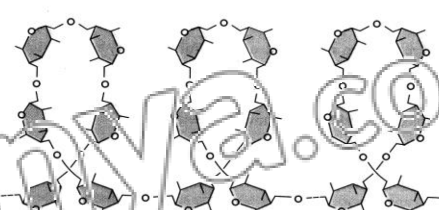


Fig. 2.6 Polysaccharides are polymers of monosaccharides

1) Starch

- ➢ It is found in fruits, grains, seeds and tubers.
- ➢ It is the main source of carbohydrates for animals.
- ➢ On hydrolysis, it yields glucose molecules.
- ➢ It gives blue colour with iodine
- ➢ It occurs in two types;
- ***Amylose*** starches have unbranched chains of glucose and are soluble in hot water.
- ***Amylopectin*** starches have branched chains and are insoluble in hot or cold water.

2) Glycogen

- It is also called ***animal starch.*** It is the chief form of carbohydrate stored in animal body.
- Found abundantly found in liver and muscles, though found in all animal cells.
- It is insoluble in water.
- It gives red colour with iodine solution.
- It also yields glucose on hydrolysis.

3) Cellulose

- It is the most abundant carbohydrate in nature.
- It is the main constituent of cell walls of plants and is highly insoluble in water. Cotton is the pure form of cellulose.
- On hydrolysis, it also yields glucose molecules.
- It gives no colour to iodine solution.
- It is not digested by human digestive tract. In the herbivores, it is digested because of microorganisms (bacteria, yeasts, protozoa) in their digestive tract. These microorganisms secrete an enzyme called ***cellulase*** for its digestion.

QUESTION RELATED TO ABOVE ARTICLE

Describe the monosaccharide in detail.
Write note on oligosaccharide.
Compare monosaccharide with oligosaccharide.
Explain polysaccharides with examples. (LHR 2017)
What are polysaccharides? Discuss starch and glycogen in detail. (LHR 2019)
What are monosaccharide? Give their characteristics. (DGK 2019)
Write a note on carbohydrates. (DGK 2021)
Describe polysaccharides in detail. (RWP 2019, SGD 2021)
What are polysaccharides? Give details of some biologically important polysaccharides. (LHR 2022)
What do known about polysaccharides? (Exercise Question ii)

2.5 LIPIDS

Introduction

The lipids are a heterogenous group of compounds related to fatty acids. They are insoluble in water but soluble in organic solvents such as ether, alcohol, chloroform and benzene.

Lipids include fats, oils, waxes, cholesterol and related compounds.

Functions

i) Lipids as hydrophobic compounds are ***components of cellular membranes***.
ii) They also ***store energy***, because of higher proportion of C-H bonds and very low proportion of oxygen, lipids store double the amount of energy as compared to the same amount of any carbohydrate.
iii) Some lipids provide ***insulation*** against atmospheric heat and cold and also act as water proof material.
iv) Waxes, in the ***exoskeleton*** of insects and cutin, are an additional protective layer on the cuticle of epidermis of some plant organs. Leaves, fruits and seeds etc. are some of the main examples.

Lipids have been classified as:

1) Acylglycerols
2) Waxes
3) Phospholipids
4) Sphingolipids
5) Glycolipids
6) Terpenoids-lipids including carotenoids and steroids.

The structure of some of them is given below.

1) Acylglycerols

It is one of the most important groups of lipids.

Chemical Composition

- Acylglycerols are composed of ***glycerol*** and ***fatty acids***. Chemically, acylglycerols can be defined as esters of fatty acids and alcohol.
- An ***ester*** is the compound produced as the result of a chemical reaction of an alcohol with an acid and a water molecule is released as shown below.

$$\underset{\text{Alcohol}}{C_2H_5OH} + \underset{\text{Acetic acid}}{HOOCCH_3} \longrightarrow \underset{\text{An ester}}{C_2H_5OCOCH_3} + \underset{\text{Water}}{H_2O}$$

Example

The most widely spread acylglycerol is ***triacylglycerol***, also called triglycerides or neutral lipids

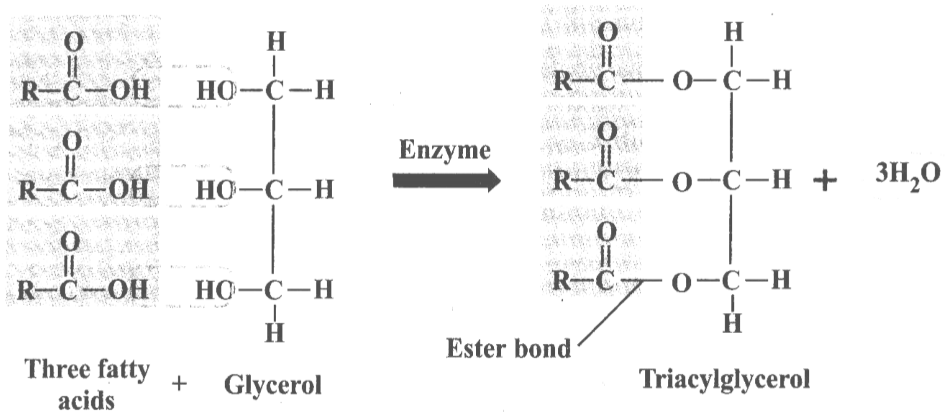


Fig. 2.7 Triacylglycerol is composed of one glycerol and three fatty acids molecules

Fatty Acids

- Fatty acids contain ***even numbers (2-30)*** of carbon atoms in straight chain attached with having an acidic groups COOH (carboxylic group).
- There may be two types of fatty acids i.e.,

i) ***Saturated fatty acids*** which contain no double bonds.

ii) ***Unsaturated fatty acids***, which contain upto **6** double bonds.

- In animals, fatty acids are straight chains.
- In plants, they may be branched or ringed.
- Solubility of fatty acids in organic solvents and their melting points increase with increasing number of carbon atoms in chain.

For example **palmitic acid (C_{16})** with melting point **63.1 °C** is much more soluble in organic solvents than **butyric acid (C_4)** with melting point **- 8 °C.**

$CH_3.COOH$	Acetic Acid (C_2)
$CH_3.CH_2.CH_2.COOH$	Butyric Acid (C_4)
$CH_3.CH_2.CH_2.CH_2.CH_2.CH_2.CH_2.CH_2.CH_2.CH_2.CH_2.CH_2.CH_2.CH_2.CH_2.COOH$	Palmitic Acid (C_{16})
$CH_3.CH_2.CH_2.CH_2.CH_2.CH_2.CH_2.CH_2.CH{=}CH.CH_2.CH_2.CH_2.CH_2.CH_2.CH_2.CH_2.COOH$	Oleic Acid (C_{18})

Fig. 2.8 some fatty acids with carbon numbers 2-18 are shown. Oleic acid is an unsaturated fatty acid (note a double bond between C_9 and C_{10}). Other fatty acids are saturated

Types of Fats

- Fats containing unsaturated fatty acids are usually liquid at room temperature and are said to be ***oils***. Animal fats are solid at room temperature, whereas most of the plants fats are liquids.
- Fats containing saturated fatty acids are solid at room temperature and are simply said as ***fats***.

Fats and oils are lighter than water and have a specific gravity of about ***0.8***. They are not crystalline but some can be crystallized under specific conditions.

2) Waxes

Chemical Composition

Chemically, waxes are mixtures of long chain alkanes (with odd number of carbons ranging from **C_{25} to C_{35})**, and alcohols, ketones and esters of long chain fatty acids.

Characteristics

i) Waxes are widespread as protective coatings on fruits and leaves.
ii) Some insects also secrete wax.
iii) Waxes protect plants from water loss and abrasive damage.
iv) They also provide water barrier for insects, birds and animals such as sheep.

3) Phospholipids

They are widespread in bacteria, animal and plant cells and are frequently associated with membranes.

Chemical Composition

Phospholipids are derivatives of ***phosphatidic acid.*** Which are composed of glycerol, fatty acids and phosphoric acid.

Nitrogenous bases such as choline, ethanolamine and serine are important components of phospholipids.

Example

Phosphatidylcholine is one of the common phospholipids.

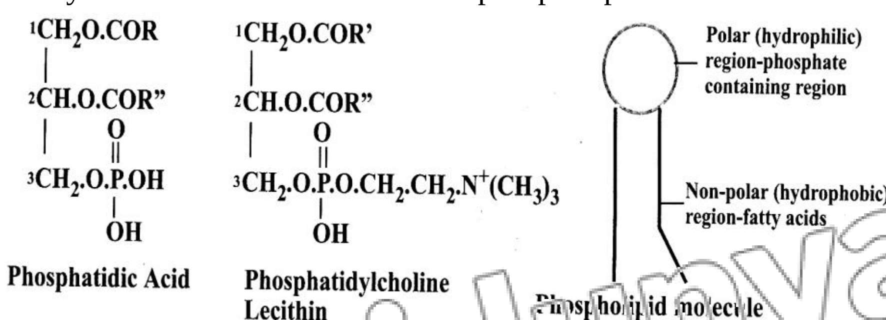


Fig. 2.9 Phosphatidic acid is composed of glycerol, 2 fatty acids (on C_1 and C_2), and a phosphoric acid on C_3 of glycerol. In phospholipids a nitrogenous base (e.g. choline) is attached to phosphoric acid as in phosphatidic acid.

4) Terpenoids

Terpenoids are a very large and important group of compounds, which are made up of a simple repeating units, ***isoprenoid units.***

This unit, by condensation, in different ways give rise to compounds such as rubber, carotenoids, steroids, terpenes etc.

$$\overset{1}{H_2C} = \overset{2}{\underset{}{C}}(CH_3) - \overset{3}{CH} = \overset{4}{CH_2}$$

Isoprenoid unit
(2 methyl- 1, 3 – butadiene)

QUESTION RELATED TO ABOVE ARTICLE

What is lipids? Give its importance.
Write note on acylglycerol and waxes.
Write note on phospholipids and terpenoids.
What is fatty acid? Explain its types.
What a note on acylglycerols including fatty acids? **(GRW 2018)**
Write a note on Acylglycerol. **(LHA 2018, GRW 2017, MTN 2019)**
Write short note on lipids **(LHR 2021)**
How phospholipids are formed; also draw the structure of lecithin. **(MTN 2022)**

2.6 PROTEINS

Introduction

Proteins are the most abundant organic compounds to be found in cells and comprise over ***50%*** of their total dry weight. They are present in all types of cells and in all parts of the cell.

Function

Proteins perform many functions. Some of their important functions are;

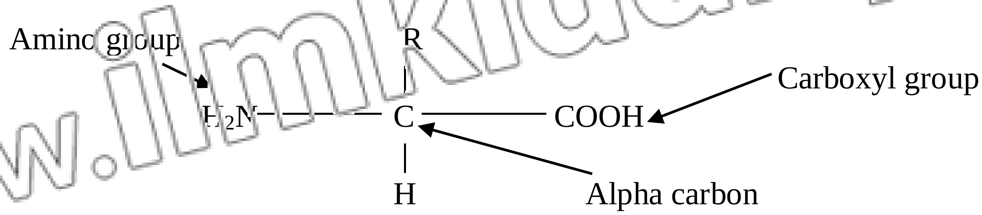
i) They ***build many structures*** of the cell.
ii) All ***enzymes*** are proteins and in this way they control the whole metabolism of the cell.
iii) Some ***hormones*** are also proteins and regulate metabolic processes.
iv) Some proteins (e.g. ***haemoglobin***) work as carriers and transport specific substances such as oxygen, lipid, metal ions etc.
v) Some proteins called ***antibodies***, defend the body against pathogens.
vi) ***Blood clotting*** proteins prevent the loss of blood from the body after an injury.
vii) ***Movement*** of organs and organisms and movement of chromosomes during anaphase of cell division, are caused by proteins.

Amino acids as units of protein

- Proteins are polymers of amino acids, the compounds containing carbon, nitrogen, oxygen and hydrogen.
- The number of amino acids varies from a **few to 3000 or even more** in different proteins.
- About **170** types of amino acids have been found to occur in cells and **tissues**.
- Out of these about **25** are constituents of **proteins**.
- Most of the proteins are however made of **20** types of amino acids.

Chemical composition of amino acids

All the amino acids have ***an amino group (-NH₂)*** and ***carboxyl group (-COOH)*** attached to the same carbon atom, also known as ***alpha carbon***. They have the general formula as:



R may be Hydrogen atom as in glycine and CH_3 group as in alanine. So amino acids mainly differ due to the type or nature of R group.

Linkage between amino acids

- Amino acids are linked together to form polypeptide proteins. The amino group of one amino acid may react with the carboxyl group of another, releasing a molecule of water. For example, glycine and alanine may combine and form a dipeptide.
- The linkage between the hydroxyl group of carboxyl group of one amino acid and the hydrogen of amino group of another amino acid release H_2O and C-N link to form a bond called ***peptide bond***.
- The resultant compound glycylalanine, has two amino acid subunit and is dipeptide.
- A dipeptide has an amino group at one end and a carboxyl group at the other end of the molecule. So both reactive parts are again available for further peptide bonds to produce tripeptides, tetrapeptides and pentapeptide etc, leading to polypeptide chains.

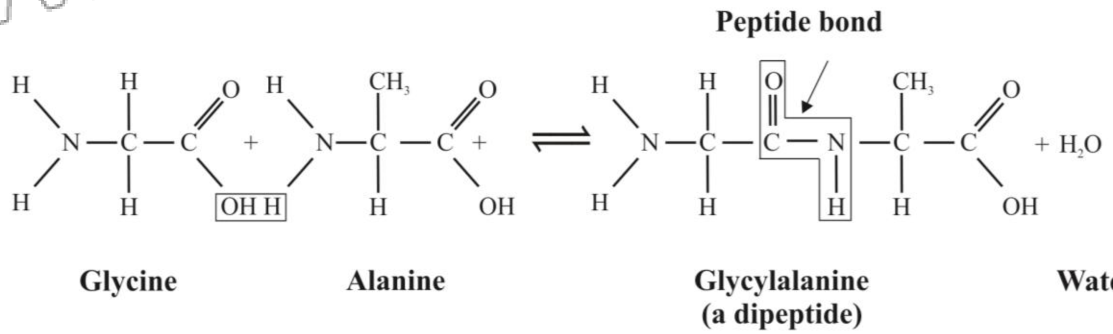


Fig. 2.10 Peptide linkage-formation of peptide bond

Arrangement of amino acids in proteins

- There are over 10,000 proteins in the human body, which are composed of unique and specific arrangement of 20 types of amino acids.
- The sequence of amino acid in protein is determined by the order of nucleotides in the DNA.
- The arrangement of amino acids in a protein molecule is highly specific for its proper functioning.
- If any amino acid is not at its normal place, the protein fails to carry on its normal function.

Example

The best example is the ***sickle cell haemoglobin***. In this case only one amino acid in each beta chain out of the 574 amino acids do not occupy the normal place in the proteins and the heamoglobin fails to carry any or sufficient oxygen, hence leading to death of the patient.

Size of proteins

The size of protein molecules is determined by the ***type of amino acids*** and the ***number of amino acids*** comprising the particular protein molecule.

Structure of Proteins

Each protein has specific properties, which are determined by the number and the specific sequence of amino acids in a molecule and upon the shape, which the molecule assumes as the chain folds into its final, compact form.

There are four levels of organization, which are described below.

1) Primary structure

Primary structure comprises the ***number and sequence of amino acids*** in a protein molecule.

F. Sanger was the first scientist who determined the sequence of amino acids in a protein molecule.

Example

- F. Sanger concluded that ***insulin*** is composed of **51** amino acids in two chains. One of the chains has **21** amino acids and the other has **30** amino acids and they are held together by disulphide bridges.
- ***Haemoglobin*** is composed of four chains, two alpha and two beta chains. Each alpha chain contains **141** amino acids, while each beta chain contains **146** amino acids.

2) Secondary structure

Secondary structure tells us about the ***helix structure or other regular configuration*** of polypeptide chains.

Polypeptide chains do not lie flat. They usually coil in a helix or into some other regular configuration.

Example

- One of the common secondary structure is α ***-helix***. It involves a spiral formation of the basic polypeptide chain. The α-helix is a very uniform geometric structure with **3.6 amino acids** in each turn of the helix.
- The helical structure is kept by the formation of hydrogen bonds among amino acid molecules in successive turns of the spiral
- ***β-pleated sheet*** is formed by fold backs of the polypeptide.

3) Tertiary structure

Usually a polypeptide chain bends and folds upon itself forming a globular shape. Tertiary structure tells us about ***shape of protein after bending and folding***.

Tertiary structure is maintained by three types of bonds, namely ionic, hydrogen and disulphide (-S-S-).

Example

In aqueous environment, the most stable tertiary structure (conformation) is that in which hydrophobic amino acids are buried inside while hydrophilic amino acids are on the surface of the molecule.

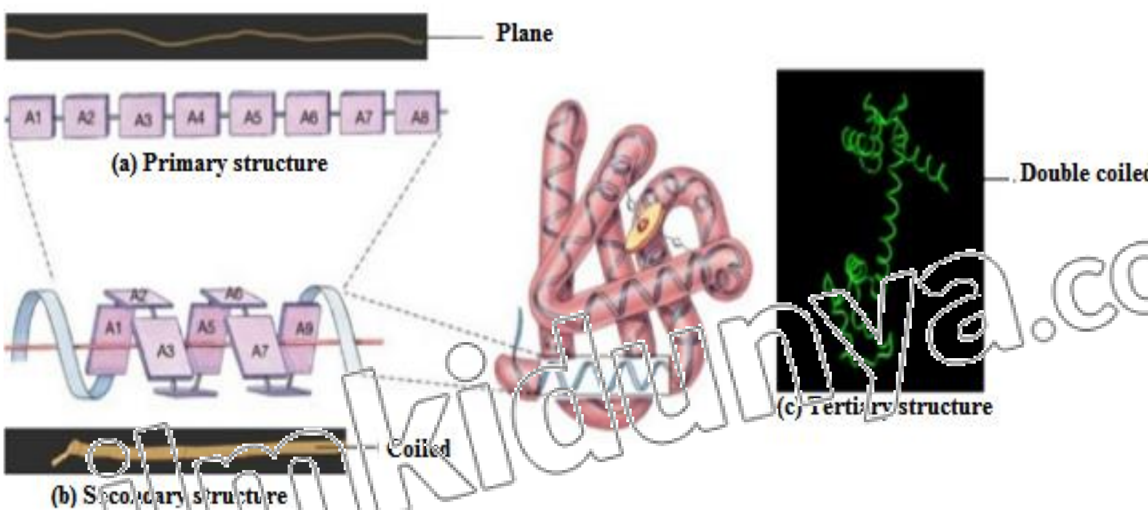


Fig. 2.12 Three levels of protein structures compared with a telephone wire

4) Quaternary structure

In many highly complex proteins, polypeptide tertiary chains are ***aggregated*** and held together by hydrophobic interactions, hydrogen and ionic bonds. This specific arrangement is the quaternary structure.

Example

Hemoglobin, the oxygen carrying protein of red blood cells, which exhibits such a structure.

Classification of proteins

Because of complexity of structure and diversity in their function, it is very difficult to classify proteins in a single well-defined fashion. However, according to their structure, proteins are classified as follows:

1) Fibrous proteins

- They consist of molecules having one or more polypeptide chains in the form of ***fibrils***.
- ***Secondary structure*** is most important in them.
- They are ***insoluble in aqueous media***.
- They are ***non-crystalline and elastic*** in nature.
- They perform ***structural role*** in cells and organisms.

Examples

Examples are silk fiber (from silkworm and spiders' web), myosin (in muscle cells), fibrin (of blood clot) and keratin (of nails and hair).

2) Globular proteins

- They are ***spherical or ellipsoidal*** due to multiple folding of polypeptide chains.
- ***Tertiary structure*** is most important in them.
- They are ***soluble in aqueous media*** such as salt solution, solution of acids and bases or aqueous alcohol.
- They can be ***crystallized***.
- They disorganize with changes in the physical and physiological environment.

Example

Examples are enzymes, antibodies, hormones and hemoglobin.

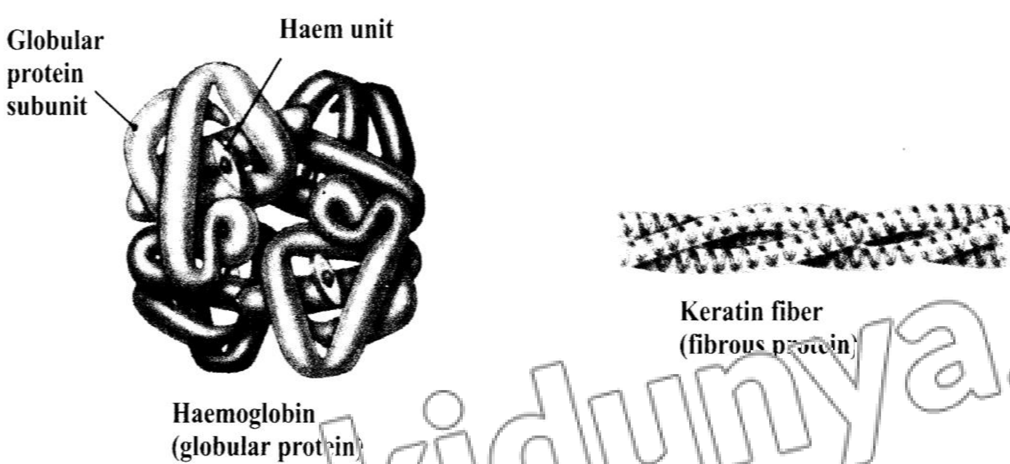


Fig. 2.11 Polypeptide chains in keratin (fibrous protein) and in hemoglobin (globular protein) are held together to form respective functional proteins.

QUESTION RELATED TO ABOVE ARTICLE

What are proteins? Give its importance.
Discuss the different structural level of proteins.
Describe the different classes of proteins.
Explain primary, secondary and tertiary structure of proteins.
Describe the classification of protein.
Describe the structure of protein.
Describe secondary and tertiary structure of protein. **(GRW 2021)**
Write a note on amino acids. **(SWL 2021)**
Write different structures of proteins (primary and secondary) **(MTN 2021)**
Describe the primary and secondary structure of protein
(LHR 2019, MTN 2019, GRW 2019, LHR 2021, DGK 2021)
Write down any six functions of proteins. How fibrous proteins are different from globular proteins. **(BWP 2022)**
Explain the primary structure of protein with example of insulin and hemoglobin.
(SGD 2022)
Describe the structure of amino acids and importance of proteins.
(SWL 2022, FSD 2022)
Write a short note on amino acids. **(Exercise Question iii)**

2.7 NUCLEIC ACIDS (DNA and RNA)

Introduction

Nucleic acids are important component of cells, which control all the activities of cell.

Discovery

Nucleic acids were first isolated in 1869 by **F. Miescher** from the nuclei of pus cells. Due to their isolation from nuclei and their acidic nature, they were named as nucleic acids.

Types of nucleic acids

There are two main types of nucleic acids i.e,
Ribonucleic acid (RNA)
Deoxyribonucleic acid (DNA)
Their chemical composition is described as follows;

Nucleotide

Nucleotides are units of nucleic acids, which are linked to each other by ester linkage to form polynucleotide chains.

- DNA is made of deoxyribonucleotides.
- RNA is made of ribonucleotides.

Chemical composition of nucleotide

Typically a nucleotide is composed of three components i.e.

- Pentose sugar
- Nitrogenous base
- Phosphoric acid

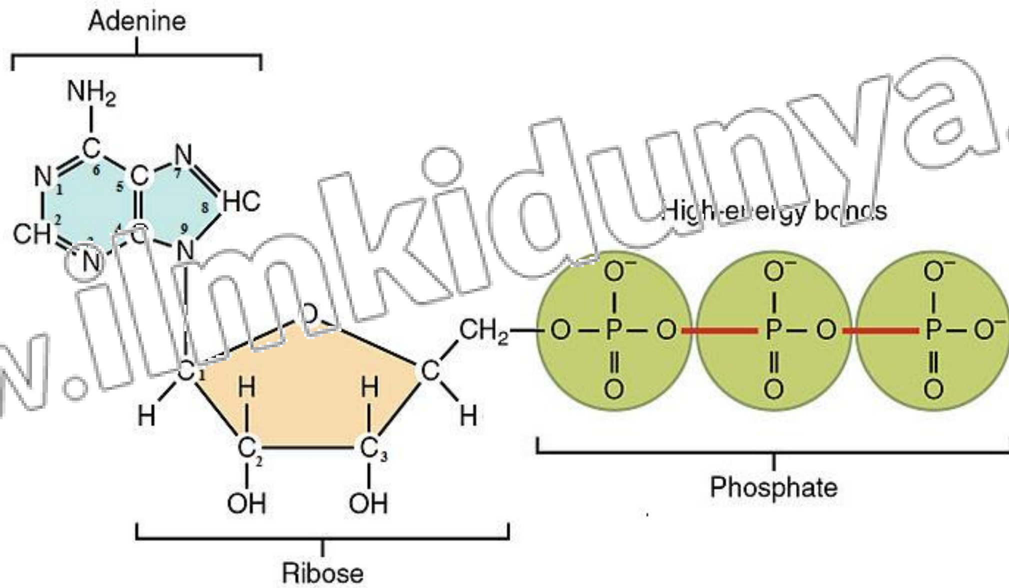


Fig. 2.13 Structural formula of ATP (a nucleotide)

Pentose Sugar

- Pentose sugar in RNA is ***ribose*** **($C_5H_{10}O_5$)**
- Pentose sugar in DNA is ***deoxyribose*** **($C_5H_{10}O_4$)**

2) Nitrogenous Bases

Nitrogenous bases are of two types:

i) Single-ringed ***pyrimidines***, which include cytosine **(C)**, thymine **(T)** and uracil **(U).**

ii) Double-ringed ***purines***, which include adenine **(A)** and guanine **(G).**

3) Phosphoric Acid

- Phosphoric acid (H_3PO_4) has the ability to develop ester linkage with OH group of pentose sugar.
- In a typical nucleotide, the nitrogenous base is attached to **position 1** of pentose sugar while phosphoric acid is attached to **position 3** of pentose sugar in front and **position 5** of pentose sugar behind it.
- Since phosphate forms a double ester linkage with pentose sugar, the linkage is known as phosphodiester ***linkage***.

Formation of a nucleotide

A compound, nucleoside is formed by combination of a base and a pentose sugar. A nucleoside and a phosphoric acid combine to form a nucleotide.

As we know pentose sugar in RNA is ribose while in DNA is deoxyribose. Deoxyribose is formed from ribose by removing one oxygen from OH group at carbon number 2.

ATP is also an important nucleotide used as an energy currency by the cell.

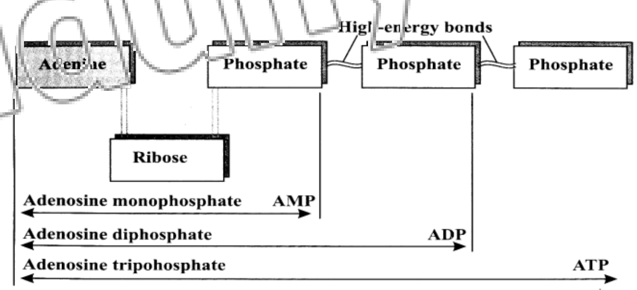


Fig.2.14 Components of ATP, a nucleotide

2.7.1 Deoxyribonucleic acid (DNA)

DNA is heredity material. It controls the properties and potential activities of a cell.

Location in cell

DNA occurs in chromosomes, in the nuclei of the cells and in much lesser amounts in mitochondria and chloroplast.

Chemical composition of DNA

- DNA is made of four kinds of ***nucleotides;***
- d-adenosine monophosphate (d-AMP)
- d-guanosine monophosphate (d-GMP)
- d-cytidine monophosphate (d-CMP)
- d-thymidine monophosphate (d-TMP)
- These nucleotides are united with one another through phosphodiester linkages in a specific sequence to form long chains.
- Two nucleotides join to form ***dinucleotide*** e.g nicotinamide adenine dinucleotide **(NAD)** which is important coenzyme in several oxidation-reduction reactions in the cell.
- Three nucleotides join to form ***trinucleotide***.

Ratio of bases in DNA

In 1951, ***Erwin Chargaff*** provided data about the ratios of different bases present in DNA. This data suggested that adenine and thymine are equal in ratio and so guanine and cytosine.

Source of DNA	Adenine	Guanine	Thymine	Cytosine
Man	30.9	19.9	29.4	19.8
Sheep	29.3	21.4	28.3	21.0
Wheat	27.3	22.7	27.1	22.8
Yeast	31.3	18.7	32.9	17.1

Physical structure of DNA

- ***Maurice Wilkins*** and ***Rosalind Franklin*** used the technique of X-ray diffraction to determine the structure of DNA.

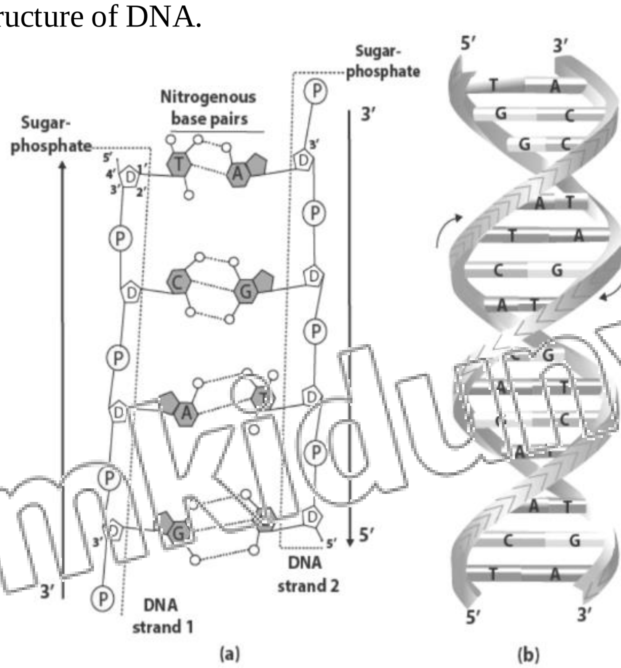


Fig. 2.15 Model of DNA. Double helical structure of DNA proposed by Watson & Crick (b). A hypothetical sequence of nucleotides (on the left side) shows hydrogen bonding between the complementary bases. Note a double bond between A and T, and triple bond between C and G (a).

- At the same time ***James D. Watson and Francis Crick*** built the scale to determine the structure of DNA.

- ➢ All the data thus obtained strongly suggested that DNA is made of two polynucleotide chains or strands. The two strands are coiled round each other in the form of double helix.
- ➢ Coiling of two strands is opposite i.e. they are coiled antiparallel to each other.
- ➢ The two chains are held together by weak hydrogen bonds.
- Adenine is opposite to thymine and there are **two hydrogen bonds** between them.
- Guanine is opposite to cytosine and there are **three hydrogen bonds** between them.
- ➢ The two strands are wound around each other so that there are 10 base pairs in each turn of about 34 **Angstrom** units (one Angstrom = 10^{-10} = 1/1,000,000,000 of a centimeter).

Amount of DNA

Amount of DNA is fixed for a particular species as it depends upon number of chromosomes. The amount of DNA in germ line cells (sperms and ova) is almost half to that of somatic cells.

Type of cell	Amount of DNA/nucleus in picogram in Chicken	Amount of DNA/nucleus in picogram in Carp
Red Blood Cells	2.3	3.3
Liver Cells	2.4	3.3
Kidney Cells	2.4	3.3
Sperm Cells	1.3	1.6

2.7.2 Ribonucleic acid (RNA)

RNA is also a polymer of ribonucleotides.

Location in cell

RNA is present in the nucleolus, in the ribosomes, in the cytosol and in smaller amounts in other parts of the cell.

Structure

- The RNA molecules occur as single strand, which may be folded back on it, to give double helical characteristics.
- Nitrogenous bases, which are involved, are adenine (A), guanine (G), cytosine (C) and uracil (U).
- RNA is synthesized by DNA in a process known as **transcription.**

Types of RNA

There are three main types of RNA i.e.

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

All these types of RNAs are synthesized from DNA in the nucleus and then are moved out in cytoplasm to perform their specific functions.

Messenger RNA (mRNA)

- It takes genetic message from the nucleus to the ribosomes in the cytoplasm to form particular proteins. They carry the genetic information from DNA to ribosomes, where amino acids are arranged according to the information in mRNA to form specific protein molecules.
- This type of RNA consists of a single strand of variable length. Its length depends upon the size of the gene as well as the protein for which it is taking the message. For example, for a protein molecule of **1,000 amino acids,** mRNA will have the length of **3,000 nucleotides.**
- mRNA is about **3-4%** of the total RNA in the cell.

2) **Transfer RNA (tRNA)**

- It transfers amino acid molecules to the site where peptide chains are being synthesized. There is one specific tRNA for each amino acid. So the cell will have at least **20** kinds of tRNA molecules. It picks up amino acids and transfers them to ribosomes, where they are linked to each other to form proteins.
- Their molecules are small, each with a chain length of **75 to 90** amino acids.
- It comprises about **10-20%** of the cellular RNA.

3) **Ribosomal RNA (rRNA)**

- It acts as machinery for the synthesis of proteins. On the surface of the ribosomes the mRNA and rRNA molecules interact to translate the information from genes into a specific protein.
- It is strongly associated with the ribosomal protein where **40-50%** of it is present.
- It is the major portion of RNA in the cell, and may be up to **80%** of the total RNA.

QUESTION RELATED TO ABOVE ARTICLE

Draw the structure of ATP.
What is nucleic acid? Explain the nucleotides in detail.
Write note on DNA in detail.
Give a comparison between DNA and RNA.
What is RNA? Explain its types.
Discuss Watson and Crick model of DNA **(LHR 2017)**
Explain the structure of DNA. **(LHR 2018)**
Write note on various types of RNAs. **(SWL 2019)**
Give composition and types of RNA in detail. **(FSD 2019)**

Write a note on Nucleic Acid. **(GRW2021, BWP 2021)**
Explain primary and secondary structure of DNA. **(DGK 2022)**

2.8 CONJUGATED MOLECULES

Definition

Two different molecules belonging to different categories, usually combine together to form conjugated molecules.

Examples with Their Role

- Carbohydrates may combine with proteins to form **glycoproteins** or with lipids to form **glycolipids**. Most of the cellular secretions are glycoprotein in nature. Both glycoproteins and glycolipids are integral structural components of plasma membrane.
- Lipids and proteins combine to form **lipoproteins** which are basic structural framework of all types of membranes in the cells.
- Nucleic acids have special affinity for basic proteins. They are combined together to form **nucleoproteins**. The nucleohistones are present in chromosomes. These conjugated proteins are not only of structural but also are of functional significance. They play an important role in regulation of gene expression.

QUESTION RELATED TO ABOVE ARTICLE

Describe the conjugated molecules.

KEY POINTS

Introduction to Organic chemistry:

The compounds of carbon are called organic compounds. Carbon has four valence electrons, so it can form four covalent bonds. It can form double or triple bonds.

Hydrogen forms single covalent bond, Oxygen two, nitrogen three, and phosphorus five.

Functional groups in organic chemistry:

(1) Alcohol group (–OH)

It is present in alcohol of glycerol, carbohydrates, fatty acid, and wax.

(2) Organic acid group or carboxylic acid group: (-COOH)

It is present in fatty acids, amino acids.

(3) Amine group (NH_3)

It is present in amino acids.

(4) Aldehyde group (-CHO)

It is present in glucose. Glucose is an aldo-sugar.

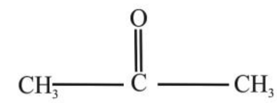
(5) Ketone group (RCOR)

It is present in carbohydrates. Fructose is a keto-sugar.

R may be any alkyl group. Like CH_3.

Difference between Aldehyde and Ketone:

IN Aldehyde, the carbonyl carbon (C = O) is present on one side of the chain. While in ketone carbonyl carbon is present in the middle of ring.



(6) Phosphate group (H_3PO_4)

It is present in nucleic acids.

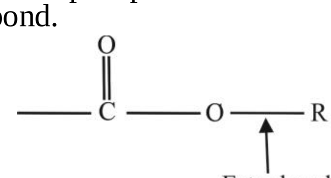
(7) Ester linkage

Ester bond is formed between carbonyl carbon (C--) and alkyl group. Bond is formed between these two by oxygen.

In case of nucleic acid P is present in place of carbon. So it is called phosphodiester bond. As this P forms two ester bonds so it is called Phosphodiester bond.

(8) Glycosidic linkage

In starch of sucrose, glucose molecules are linked by ester bonds. It is called glycosidic linkage.



Some terms:

Isoprenoid unit

It is an alkene, propene with two double bonds

ISOPRENOID

"d" FORM means dextrose. It is an isomer of a compound which can rotate in clockwise. Its opposite is L-FORM.

X-ray diffraction

It is a technique in which crystals of a compound like DNA are formed. X-rays are passed from these crystals. These are scattered in different directions. The pattern of scattering is measured. A model of a compound can be formed from this pattern.

Hydrophobic forces

It means water resisting or water fearing.

Hydrophilic forces

It means water loving.

Certain large compounds like haemoglobin have many small units. Some parts of these compounds i.e. some units are non-polar (without ions), they cannot interact with water, so they move away from water. They are called hydrophobic parts. But some units are polar. They can interact with water. They are called hydrophilic part.

When such compounds like haemoglobin are placed in water some parts of it try to move away from water. In this way a force of repulsion is produced. This force is called hydrophobic force. This make the molecule bend in such a way that its hydrophobic part moves inward and hydrophilic part comes out side. It causes coiling of the molecules.

Specific Gravity

The ratio of density of a compound to the density of water is called specific gravity. The specific gravity of water is taken as 1.0. Any compound which have specific gravity less than water float in on it.

EXERCISE

Q.1.

Fill In the Blanks

i) The sum of all the chemical reactions taking place within a cell is called __________.

ii) __________ is the basic element of organic compounds.

iii) All the amino acids have an amino group and a carboxyl group attached to the same __________ atom.

iv) ____________ is the most abundant carbohydrate in nature.

v) Adenine and guanine are double ringed bases and are called _________.

Ans: i) Metabolism ii) Carbon
iii) Carbon iv) Cellulose
v) Purines

Q.5. Extensive Questions.

vi) Describe the importance of water for life.

Ans: (See article 2.3)

i) What do you know about polysaccharides?

Ans: (See article 2.4)

ii) Write a short note amino acids.

Ans: (See article 2.6)

Q.2.

Write whether the statement is 'true' or 'false' and write the correct statement, if it is false.

i) A small proportion of water molecules are in ionized form. **(True)**

ii) Many diseases such as polio, whooping cough, measles, mumps etc. can be controlled by antibiotics. **(False)**

i) The covalent bond between two amino acids is called peptide bond.
Glycogen is also called *plant* starch.
(False)

ii) AIDS is caused by HIV and it spreads through sexual contacts, blood transfusion, by contaminated syringes or surgical instruments. **(True)**

iii) DNA molecule is made of two polynucleotide strands. **(True)**

Q.3.

Each Question Has Four Options. Encircle Correct Answer.

Ans: (For answers to this question, consult KIPS Objective Series)

Q.4. Short Questions

Ans: (For answers to short questions consult KIPS Objective Series)

Q.5. Extensive Questions.

i) Describe the importance of water for life.

Ans: (See article 2.3)

ii) What do you know about polysaccharides?

Ans: (See article 2.4)

iii) Write a short note amino acids.

Ans: (See article 2.6)