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CHAPTER

2 Biological Molecules

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Animation 2.1 : Molecular Biology
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INTRODUCTION TO BIOCHEMISTRY

Biochemistry is a branch of Biology, which deals with the study of chemical components and the chemical processes in living organisms. 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, muscle contraction can all be described in biochemical terms.

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 consists of chemicals as shown in the following table.

Table 2.1 Chemical composition of a Bacterial and a Mammalian cell.

	Chemical components	% total cell weight	
		Bacterial cell	Mammalian cell
1	Water	70	17
2	Proteins	15	18
3	Carbohydrates	3	4
4	Lipids	2	3
5	DNA	1	0.25
6	RNA	6	1.1
7	Other organic molecules (Enzymes, hormones, metabolites)	2	2
8	Inorganic ions (Na^+, K^+, Ca^{++}, Mg^{++} Cl^-, SO_4^{--} etc)	1	1

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

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constantly taking in new substances and changing 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. This chemical activity is maintained with a high degree of organization. All the chemical reactions taking place within a cell are collectively called metabolism. Metabolic processes are characterized as anabolism and catabolism. Those reactions in which simpler substances are combined to form complex substances are called anabolic reactions. Anabolic reactions need energy. Energy is released by the break down of complex molecules into simpler ones, such reactions are called catabolic reactions. 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. Interconversions of carbohydrates, proteins, and lipids that occur continuously in living cells are examples of co-ordinated catabolic and anabolic activities.

Animation 2.2: Introduction to BioChemistry
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IMPORTANCE OF CARBON

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

Carbon is tetravalent. It can react with many other known elements forming covalent bonds.

Covalent bonds result when two or more atoms complete their electron shells by sharing electrons. When an electron pair is shared between two atoms, a single covalent bond results. An example is the bond between two hydrogen atoms to form a hydrogen molecule. Covalent bond stores large amount of energy.

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. The stability associated with the tetravalency of carbon atoms makes it a favourable element for the synthesis of complicated cellular structures. Carbon atoms can also combine mutually forming stable, branched or unbranched chains or rings. This ability of carbon is responsible for the vast variety of organic compounds. C - C bonds form a skeleton of organic molecules as shown in Fig. 2.1

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

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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 association in glycosidic linkages provides stability to the complex carbohydrate molecules. Carbon combines with nitrogen in amino acid linkages to form peptide bonds and forms proteins which are very important due to their diversity in structure and functions.

Large organic molecules (macromolecules) such as cellulose, fats, proteins, etc. are generally insoluble in water, 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, such as glucose, amino acids, fatty acids etc. serve either as a source of energy, or as subunits to build macromolecules. Some small molecules are so unstable that they are immediately broken down to release energy e.g. ATP. Such substances serve as immediate source of energy for cellular metabolism.

Animation 2.3: Carbon
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IMPORTANCE OF WATER

Water is the medium of life. It is the most abundant compound in all organisms. It varies from 65 to 89 percent in different organisms. Human tissues contain about 20 per cent water in bone cells and 85 percent in brain cells. Almost all reactions of a cell occur in the presence of water. It also takes part in many biochemical reactions such as hydrolysis of macromolecules. It is also used as a raw material in photosynthesis.

Solve. t 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. When in solution, ions and molecules move randomly and are in a more favourable state to react with other molecules and ions. It is because of this property of water that almost all reactions in cells occur in aqueous media. In cells all chemical reactions are catalyzed by enzymes which work in aqueous environment. Nonpolar organic molecules, such as fats, are insoluble in water and help to maintain membranes which make compartments in the cell.

Heat capacity

Water has great ability of absorbing heat with minimum of change in its own temperature. The specific heat capacity of water - the number of calories required to raise the temperature of 1g of water from 15 to 16°C is 1.0. 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.

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Animation 2.4: Heat Capacity
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Heat of vaporizatio.

Water absorbs much heat as it changes from liquid to gas. Heat of vaporization is expressed as calories absorbed per gram vaporized. The specific heat of vaporization of water is 574 Kcal/kg, which plays an important role in the regulation of heat produced by oxidation. It also provides cooling effect to plants when water is transpired, or to animals when water is perspired. Evaporation of only two ml out of one liter of water, lowers the temperature of the remaining 998 ml by 1°C.

Io. izatio. of water

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

$$H_20 \rightleftharpoons H^+ + OH^-$$

This reaction is reversible but an equilibrium is maintained. At 25°C the concentration of each of H^+ and OH^- ions in pure water is about 10^{-7} mole/litre. The H^+ and OH^- ions affect, and take part in many of the reactions that occur in cells.

Protectio.

Water is effective lubricant that provides protection against damage 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.

CARBOHYDRATES

Carbohydrates occur abundantly in living organisms. They are found in all organisms and in almost all parts of the cell. Cellulose of wood, cotton and paper, starches present in cereals, root tubers, cane sugar and milk sugar are all examples of carbohydrates. Carbohydrates play both structural and functional roles. Simple carbohydrates are the main source of energy in cells. Some carbohydrates are the main constituents of cell walls in plants and micro-organisms.

The word carbohydrate literally means hydrated carbons. They are composed of carbon, hydrogen and oxygen and the ratio of hydrogen and oxygen is the same as in water. Their general formula is $C_x (H_20)_y$ where(x) is the whole number from three to many thousands whereas y may be the same or different whole number. Chemically, carbohydrates are defined as polyhydroxy aldehydes or kentones, or complex substances which on hydrolysis yield polyhydroxy aldehyde or ketone subunits. (Hydrolysis involves the break down of large molecules into smaller ones utilizing water molecules).

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

Carbohydrates in cell combine with proteins and lipids and the resultant compounds are called glycoproteins and glycolipids, respectively. 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, and (iii) Polysaccharides.

Monosaccharides: These are simple sugars. They are sweet in taste, are easily soluble in water, and cannot be hydrolysed into simpler sugars. Chemically they are either polyhydroxy aldehydes or ketones. All carbon atoms in a monosaccharide 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; and with the keto group as keto-sugar. These are indicated in the case of two trioses sketched below (Fig. 2.2).

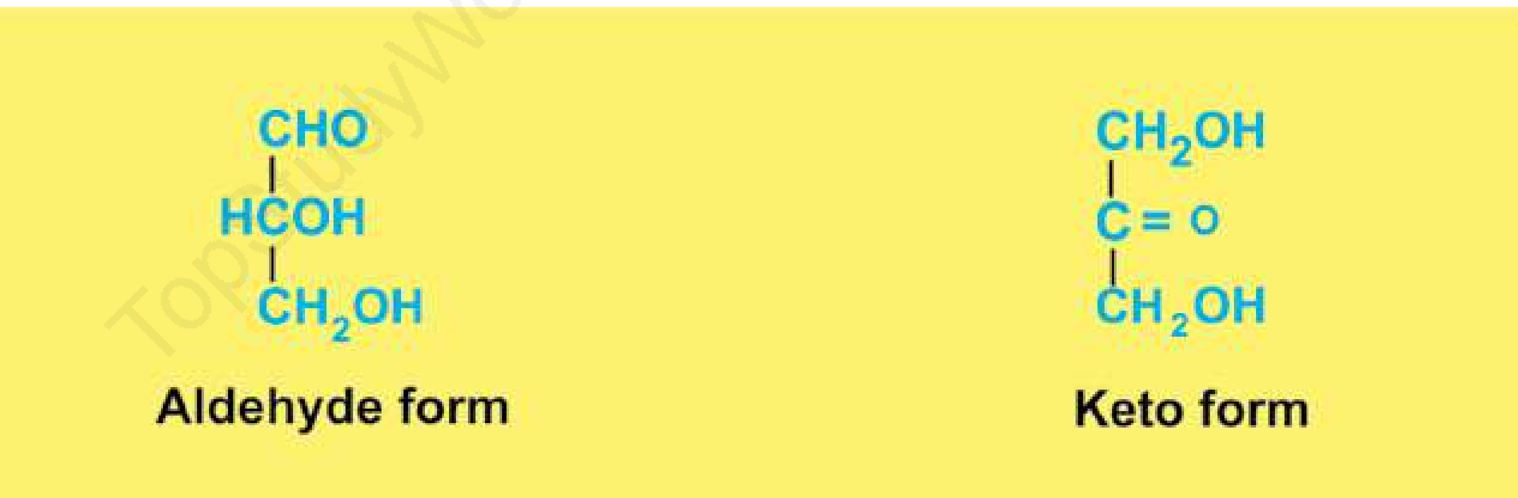

Fig. 2.2: Structure of glyceraldehyde, a 3C Sugar ($C_3H_6O_3$). The aldehyde form is glyceraldehyde, whereas ketonic form is dihydroxyacetone.

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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 thousands.

Two trioses mentioned above are, intermediates in respiration and photosynthesis. Tetroses are rare in nature and occur in some bacteria. Pentoses and hexoses are most common. From the biological point of view the most important hexose is glucose. It is an aldose sugar. Structure of ribose and glucose is given below (Fig. 2.3).

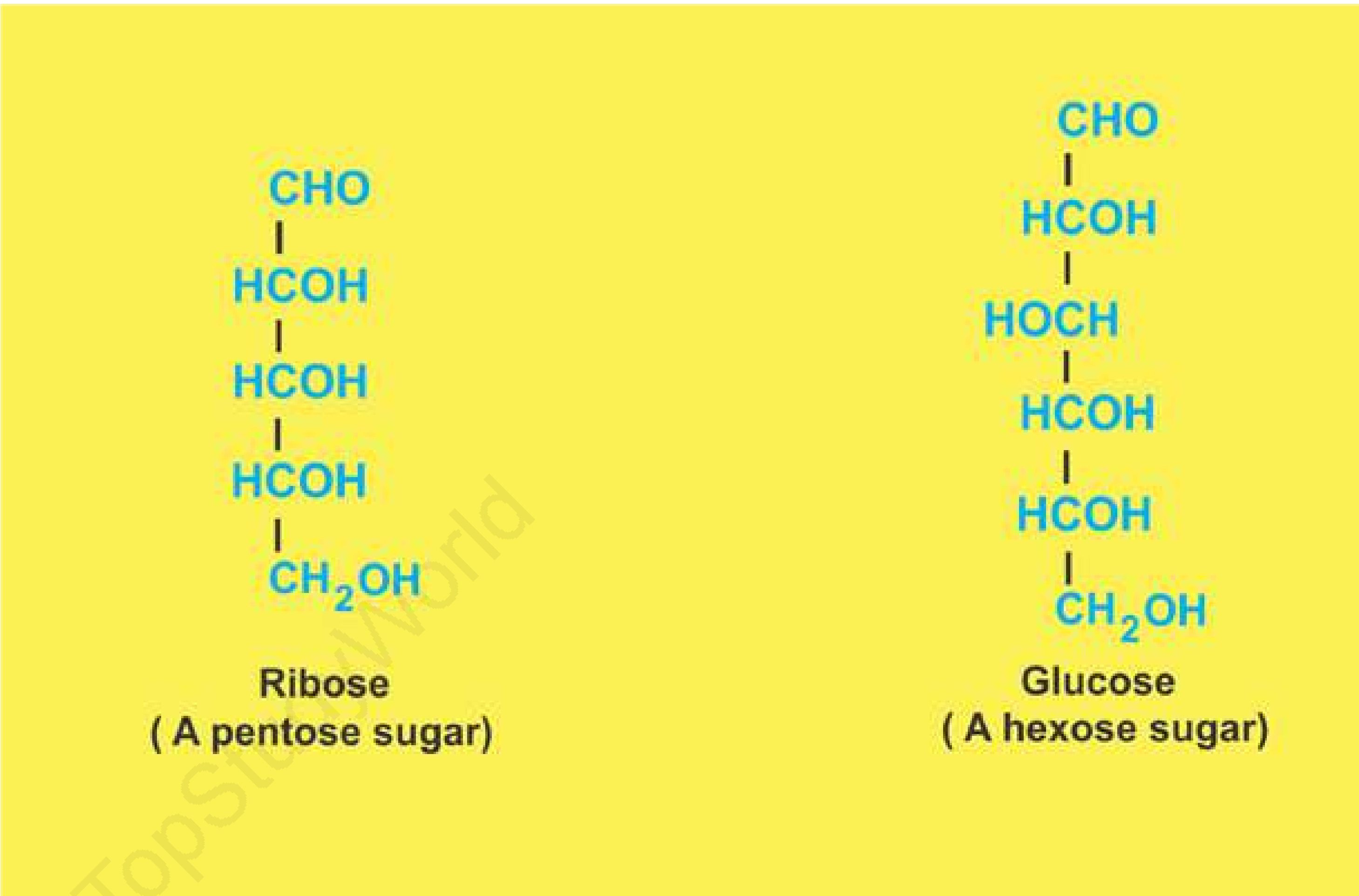

Fig. 2.3 Structure of Ribose and Glucose.

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).

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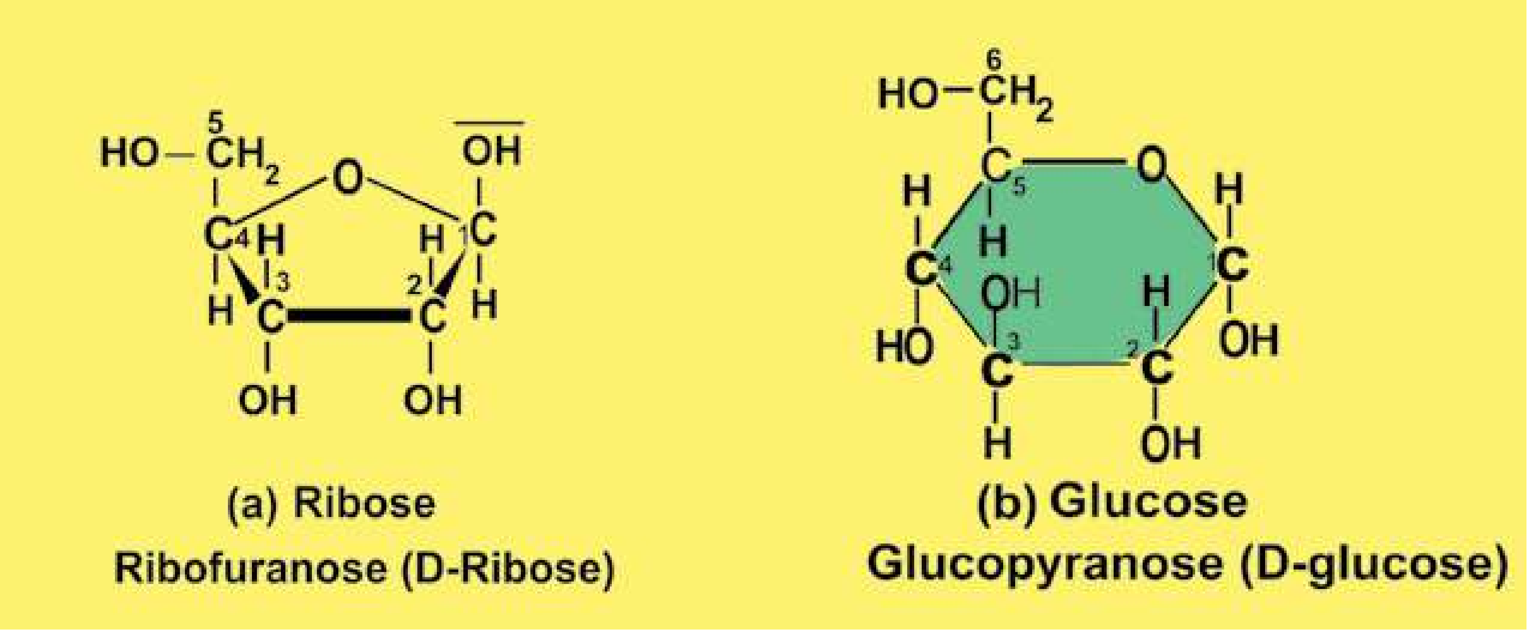

Fig. 2.4 Ribose and glucose form ring shaped structures.

In free state, glucose is present in all fruits, being abundant in grapes, figs, and dates. Our blood 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. Glucose is naturally produced in green plants which take carbon dioxide from the air and water from the soil to synthesize glucose.

$$6CO_2 + 12H_20 \xrightarrow[\text{chlorophyll}]{\text{light energy}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

As indicated in the equation, energy is consumed in this process which is provided by sunlight. This is why the process is called Photosynthesis. It is noteworthy that for the 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.

Oligosaccharides: These are comparatively less sweet in taste, and less soluble in water. On hydrolysis oligosaccharides yield from two to ten monosaccharides. The ones yielding two monosaccharides are known as disaccharides, those yielding three are known as trisaccharides and so on. The covalent bond between two monosaccharides is called **glycosidic bond.**

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Physiologically important disaccharides are maltose, sucrose, and lactose (see Fig. 2.5). 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 in Fig. 2.5.

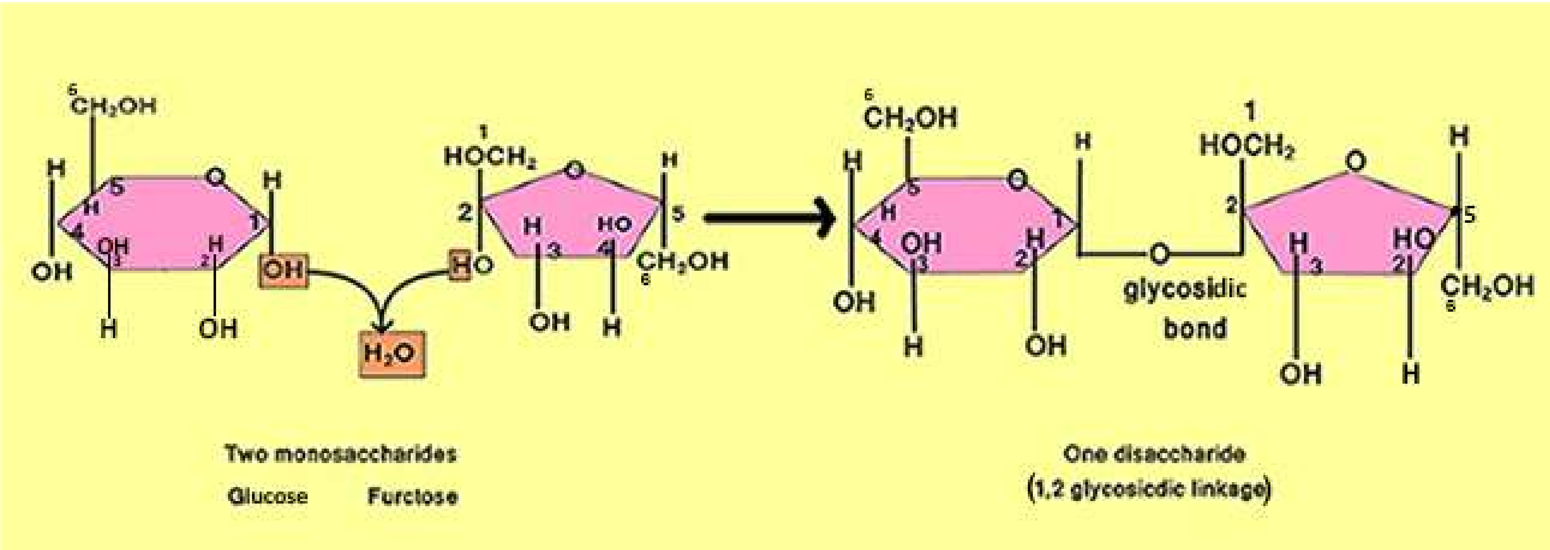

Fig. 2.5 A disaccharide. Note carefully the glycosidic linkage between the two monosaccharides.

Animation 2.5: Carbohydrates
Source and Credit: answers

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Polysaccharides: Polysaccharides are the most complex and the most abundant carbohydrates in nature. They are usually branched and tasteless. They are formed by several monosaccharide units linked by glycosidic bonds (Fig. 216). Polysaccharides have high molecular weights and are only sparingly soluble in water. Some biologically important polysaccharides are starch, glycogen, cellulose, dextrins, agar, pectin, and chitin.

Animation 2.6: Structural Features of Polysaccharides
Source and Credit: biologie.uni-hamburg

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. Starches are of two types, amylose and amylopectin. 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. Starches give blue colour with iodine.

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Animation 2.7: Starch
Source and Credit: dynamicscience

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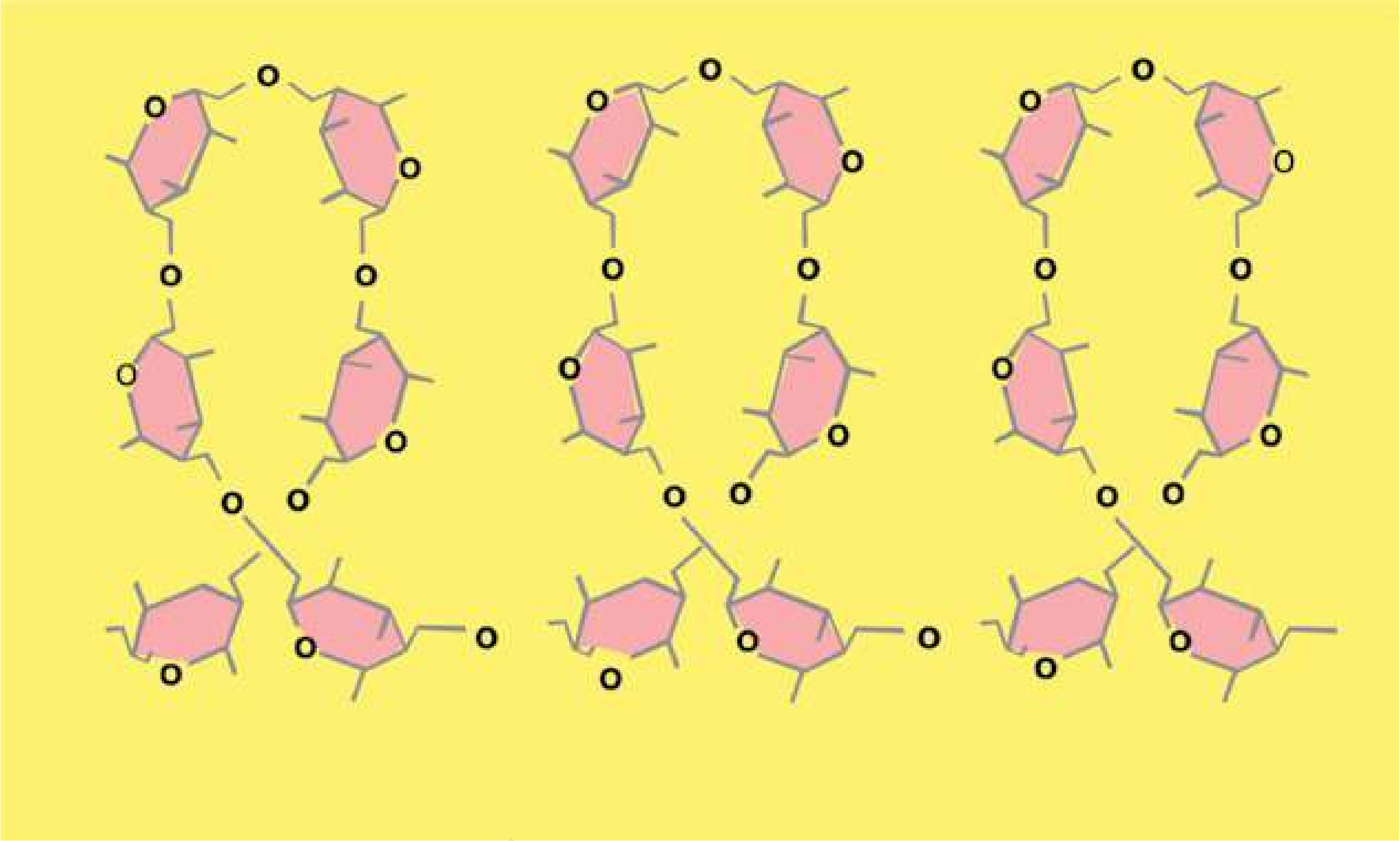

Fig 2.6.: Polysaccharides are polymers of monosaccharides.

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

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

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LIPIDS

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.

Lipids as hydrophobic compounds, are components of cellular membranes. Lipids are also used to 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. Some lipids provide insulation against atmospheric heat and cold and also act as water proof material. Waxes, in the exoskeleton of insects, and cutin, an additional protective layer on the cuticle of epidermis of some plant organs e.g. leaves, fruits, seeds etc., are some of the main examples.

Lipids have been classified as acylglycerols, waxes, phospholipids, sphingolipids, glycolipids and terpenoid lipids including carotenoids and steroids. The structure of some of these lipids is given below.

Acylglycerols

Acylglycerols are composed of glycerol and fatty acids (Fig. 2.7). The most widely spread acyl glycerol is triacyl glycerol, also called triglycerides or neutral lipids. 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:

$$\underset{\text{alcohol}}{C_2H_5OH} + \underset{\text{acetic acid}}{HOOCCH_3} \longrightarrow \underset{\text{an ester}}{C_2H_5OCOCH_3} + H_20$$

As indicated by dotted squares, OH is released from alcohol and H from an acid.

H and OH combine and form a water molecule. Fatty acids are one of the most important components of triglycerides.

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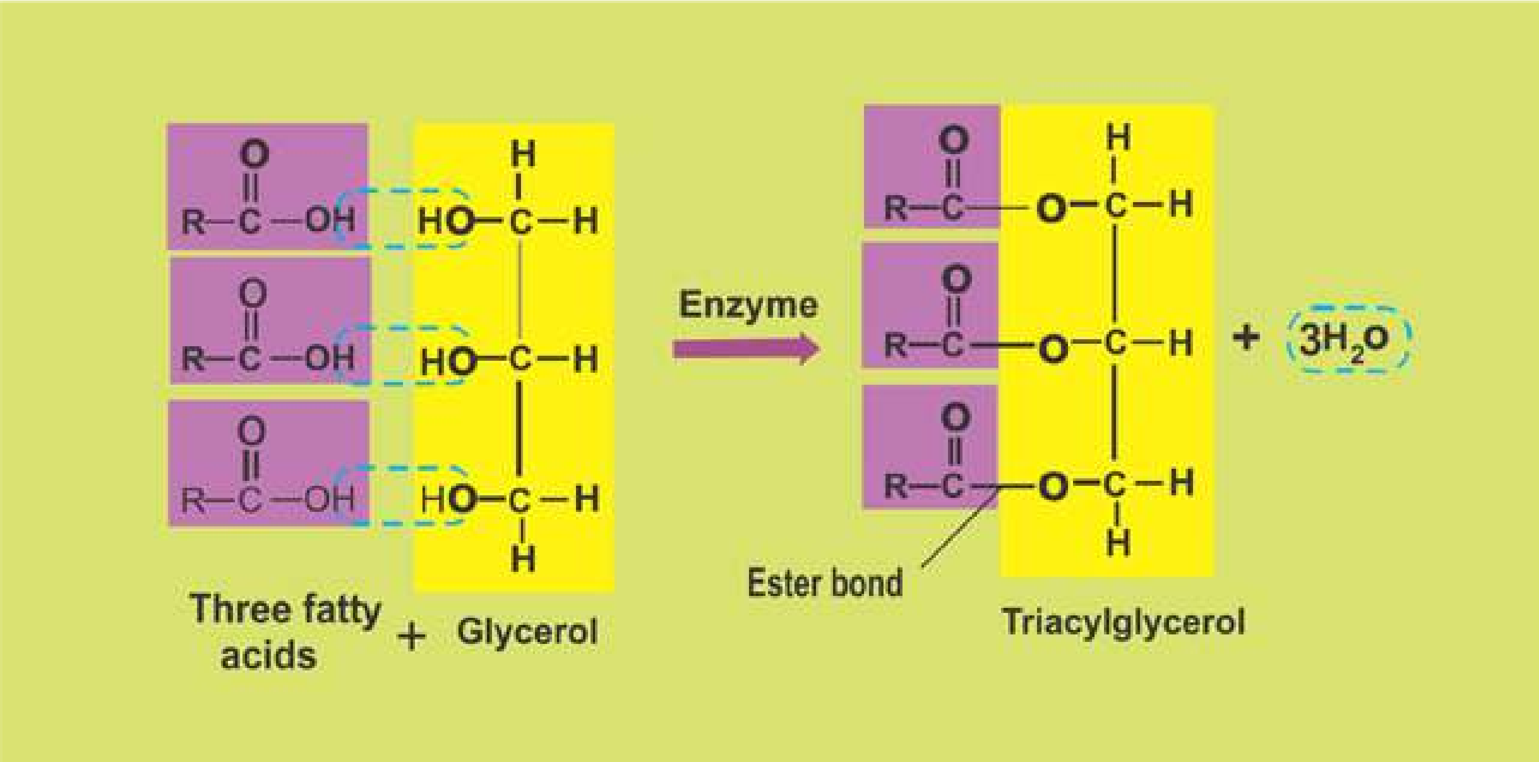

Fig. 2.7: Triacylglycerol is composed of one glycerol and three fatty acid molecules.

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Animation 2.8: Triglyceride
Source and Credit: i-biology

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Fatty acids contain even numbers (2-30) of carbon atoms in straight chain attached with hydrogen and having an acidic group COOH (carboxylic group). They may contain no double bond (saturated fatty acids) or up to 6 double bonds (unsaturated fatty acids). In animals the fatty acids are straight chains (Fig. 2.8.), while in plants these 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. Palmitic acid (C_{16}) is much more soluble in organic solvent than butyric acid (C_4). The melting point of palmitic acid is 63.1°C as against -8°C for butyric acid.

$\overset{2}{C}H_3.\overset{1}{C}OOH$ — Acetic Acid (C_2)

$\overset{4}{C}H_3.\overset{3}{C}H_2.\overset{2}{C}H_2.\overset{1}{C}OOH$ — Butyric Acid (C_4)

$\overset{16}{C}H_3.\overset{15}{C}H_2.\overset{14}{C}H_2.\overset{13}{C}H_2.\overset{12}{C}H_2.\overset{11}{C}H_2.\overset{10}{C}H_2.\overset{9}{C}H_2.\overset{8}{C}H_2.\overset{7}{C}H_2.$
$\overset{6}{C}H_2.\overset{5}{C}H_2.\overset{4}{C}H_2.\overset{3}{C}H_2.\overset{2}{C}H_2.\overset{1}{C}OOH$ — Palmitic Acid (C_{16})

$\overset{18}{C}H_3.\overset{17}{C}H_2.\overset{16}{C}H_2.\overset{15}{C}H_2.\overset{14}{C}H_2.\overset{13}{C}H_2.\overset{12}{C}H_2.\overset{11}{C}H_2.\overset{10}{C}H{=}\overset{9}{C}H.$
$\overset{8}{C}H_2.\overset{7}{C}H_2.\overset{6}{C}H_2.\overset{5}{C}H_2.\overset{4}{C}H_2.\overset{3}{C}H_2.\overset{2}{C}H_2.\overset{1}{C}OOH$ — 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.

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Fats containing unsaturated fatty acids are usually liquid at room temperature and are said to be oils. Fats containing saturated fatty acids are solids. Animal fats are solid at room temperature, whereas most of the plant fats are liquids. 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.

Waxes

Waxes are widespread as protective coatings on fruits and leaves. Some insects also secrete wax. Chemically, waxes are mixtures of long chain alkanes (with odd number of carbons atoms ranging from C_{25} to C_{35}) and alcohols, ketones and esters of long chain fatty acids. Waxes protect plants from water loss and abrasive damage. They also provide water barrier for insects, birds and animals such as sheep.

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Phospholipids

Phospholipids are derivatives of phosphatidic acid (Fig.2.9.), which are composed of glycerol, fatty acids and phosphoric acid. Nitrogenous bases such as choline, ethanolamine and serine are important components of phospholipids. They are widespread in bacteria, animal and plant cells and are frequently associated with membranes. Phosphatidylcholine is one of the common phospholipids.

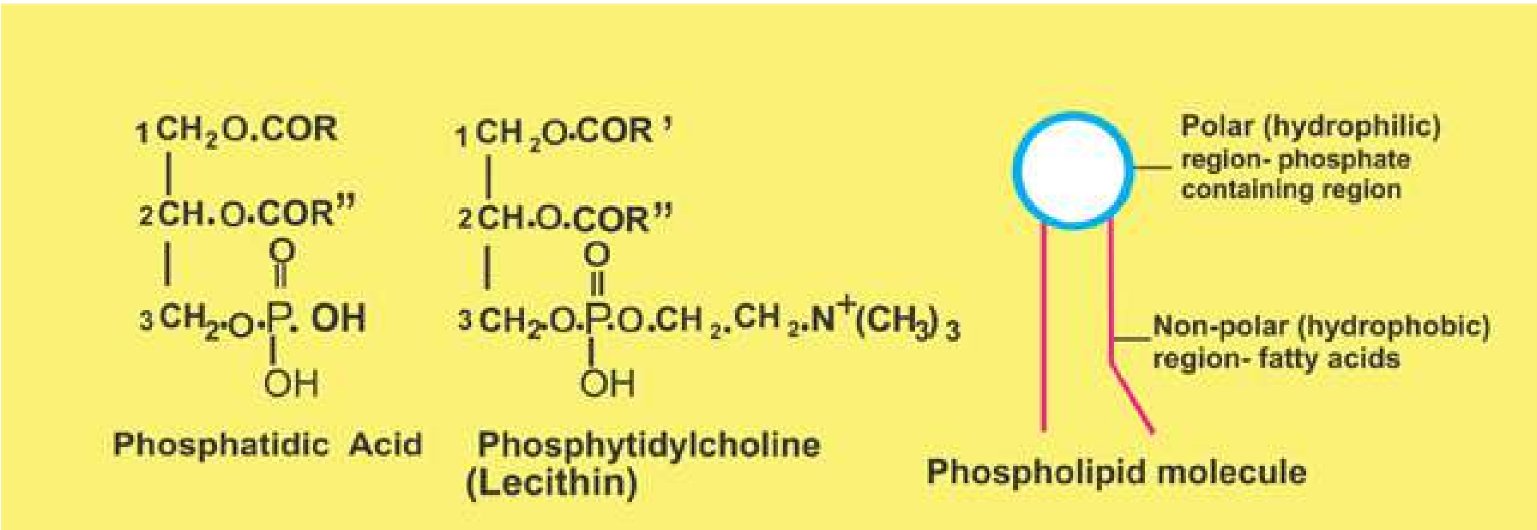

Fig. 2.9.: Phosphatidic acid is composed of glycerol, 2 fatty acids (on Cl and C2), and a phosphoric acid on C3 of glycerol. In phospholipid a nitrogenous base (e.g. choline) is attached to phosphoric acid in phosphatidic acid.

Terpenoids

Terpenoids are a very large and important group of compounds which are made up of simple repeating units, isoprenoid units. This unit by condensation in different ways gives rise to compounds such as rubber, carotenoids, steroids, terpenes etc. Lipids constitute major source of energy, and play an important role in the structure of membranes of the cell and of organelles found in the cell. They also provide insulation, mechanical protection and protection from water loss and abrasive damage.

PROTEINS

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.

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Proteins perform many functions. They build many structures of the cell. All enzymes are proteins and in this way they control the whole metabolism of the cell. As hormones, proteins regulate metabolic processes. Some proteins (e.g. hemoglobin) work as carriers and transport specific substances such as oxygen, lipids, metal ions, etc. Some proteins called antibodies, defend the body against pathogens. Blood clotting proteins prevent the loss of blood from the body after an injury. Movement of organs and organisms, and movement of chromosomes during anaphase of cell division, are caused by proteins.

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.

Amino acids: About 170 types of amino acids have been found to occur in cells and tissues. Of these, about 25 are constituents of proteins. Most of the proteins are however, made of 20 types of amino acids.

All the amino acids have an amino group ($-NH_2$) and a carboxyl group (-COOH) attached to the same carbon atom, also known as alpha carbon. They have the general formula as:

Animation 2.9: Amino Acid
Source and Credit: wikipedia

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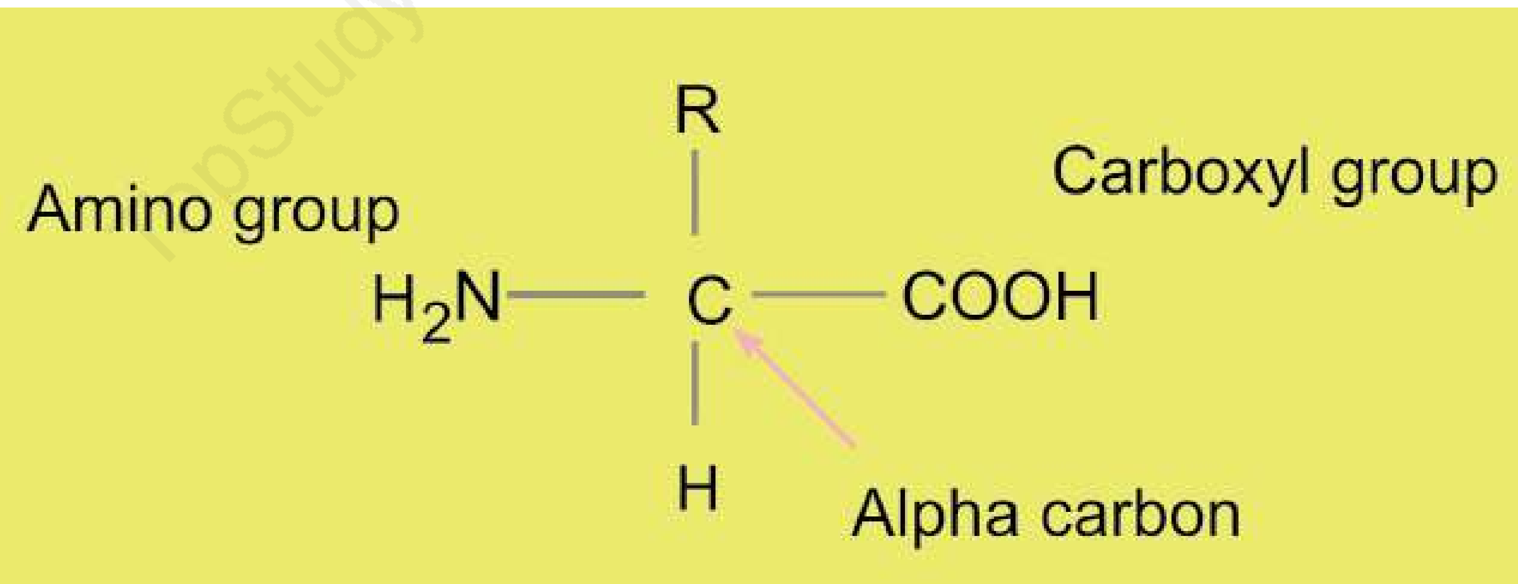

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R may be a hydrogen atom as in glycine, or CH_3 as in alanine, or any other group. So amino acids mainly differ due to the type or nature of R group.

Amino acids are linked together to form polypeptides **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 as shown in Fig.2.10.

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_20 and C - N link, to form a bond called **peptide bond**. The resultant compound glycylalanine, has two amino acid subunits and is a 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 pentapeptides etc, leading to polypeptide chains.

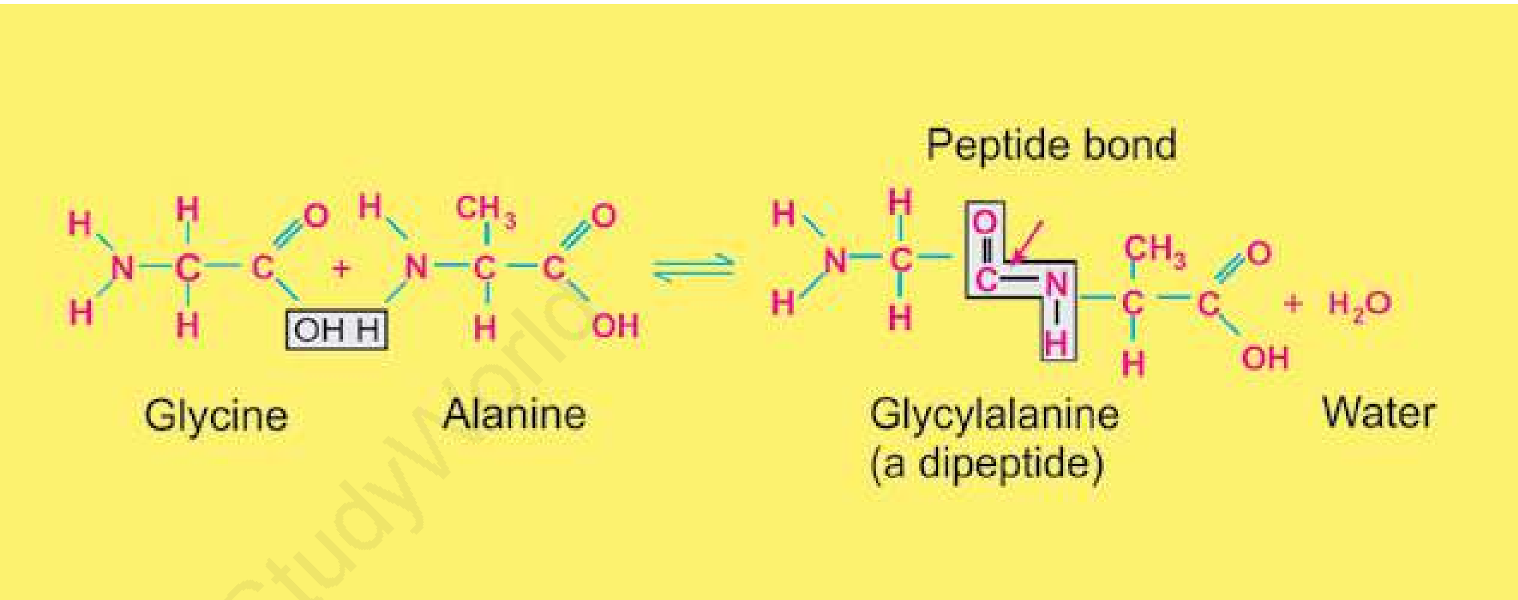

Fig. 2.10 Peptide linkage - formation of peptide bond

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.

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Primary structure: The 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. After ten years of careful work, he concluded, that insulin is composed of 51 amino acids in two chains.

One of the chains had 21 amino acids and the other had 30 amino acids and they were 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 (Fig. 2.11). The size of a protein molecule is determined by the type of amino acids and the number of amino acids comprising that particular protein molecule.

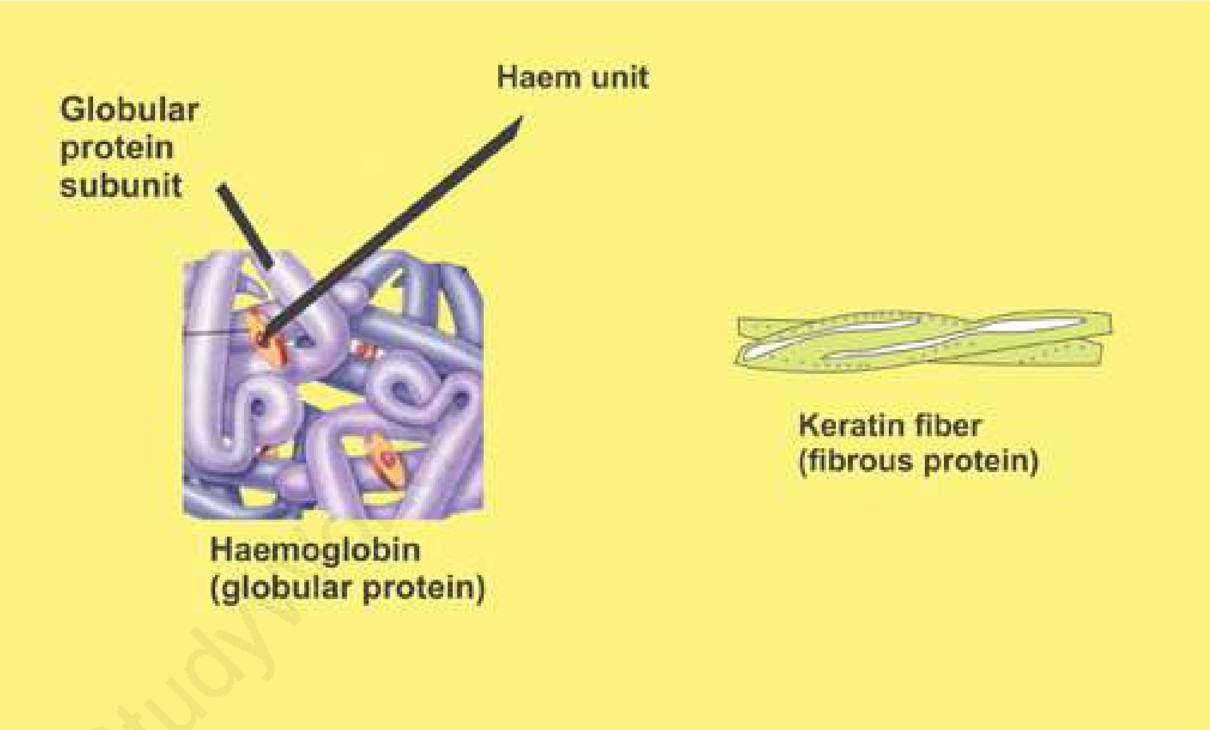

Fig. 2.11. Polypeptide chains in keratin (fibrous protein) and in haemoglobin (globular protein) are held together to form respective functional proteins.

Now we know that there are over 10,000 proteins in the human body which are composed of unique and specific arrangements of 20 types of amino acids. The sequence 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 in its normal place, the protein fails to carry on its normal function. The best example is the sickle cell hemoglobin of human beings. 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 (in fact this particular amino acid is replaced by some other amino acid), and the hemoglobin fails to carry any or sufficient oxygen, hence leading to death of the patient.

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Secondary structure: The polypeptide chains in a protein molecule usually do not lie flat. They usually coil into a helix, or into some other regular configuration. One of the common secondary structures is the 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 folding back of the polypeptide.

Tertiary structure: Usually a polypeptide chain bends and folds upon itself forming a globular shape. This is the proteins' tertiary conformation. It is maintained by three types of bonds, namely ionic, hydrogen, and disulfide (-S-S-). For example, in aqueous environment the most stable tertiary conformation is that in which hydrophobic amino acids are buried inside while the hydrophilic amino acids are on the surface of the molecule.

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

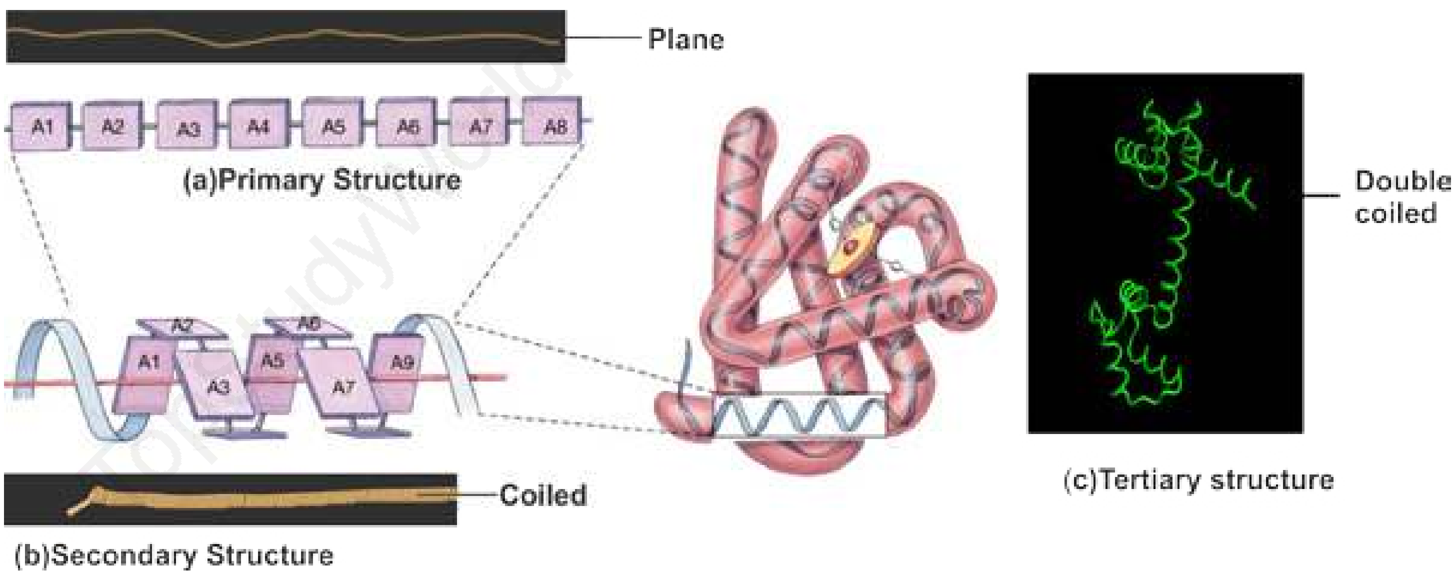

Fig 2.12 Three levels of protein structures compared with a telephone wire

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Classification of proteins

Because of the 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:

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 are elastic in nature. They perform structural roles in cells and organisms. Examples are silk fiber (from silk worm, and spiders' web) myosin (in muscle cells), fibrin (of blood clot), and keratin (of nails and hair).

Globular proteins: These 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 or bases, or aqueous alcohol. They can be crystallized. They disorganize with changes in the physical and physiological environment. Examples are enzymes, antibodies, hormones and hemoglobin.

NUCLEIC ACIDS (DNA AND RNA)

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 nucleic acids. Nucleic acids are of two types, deoxyribonucleic acid or DNA and ribonucleic acid or RNA. DNA occurs in chromosomes, in the nuclei of the cells and in much lesser amounts in mitochondria and chloroplasts. RNA is present in the nucleolus, in the ribosomes, in the cytosol and in smaller amounts in other parts of the cell.

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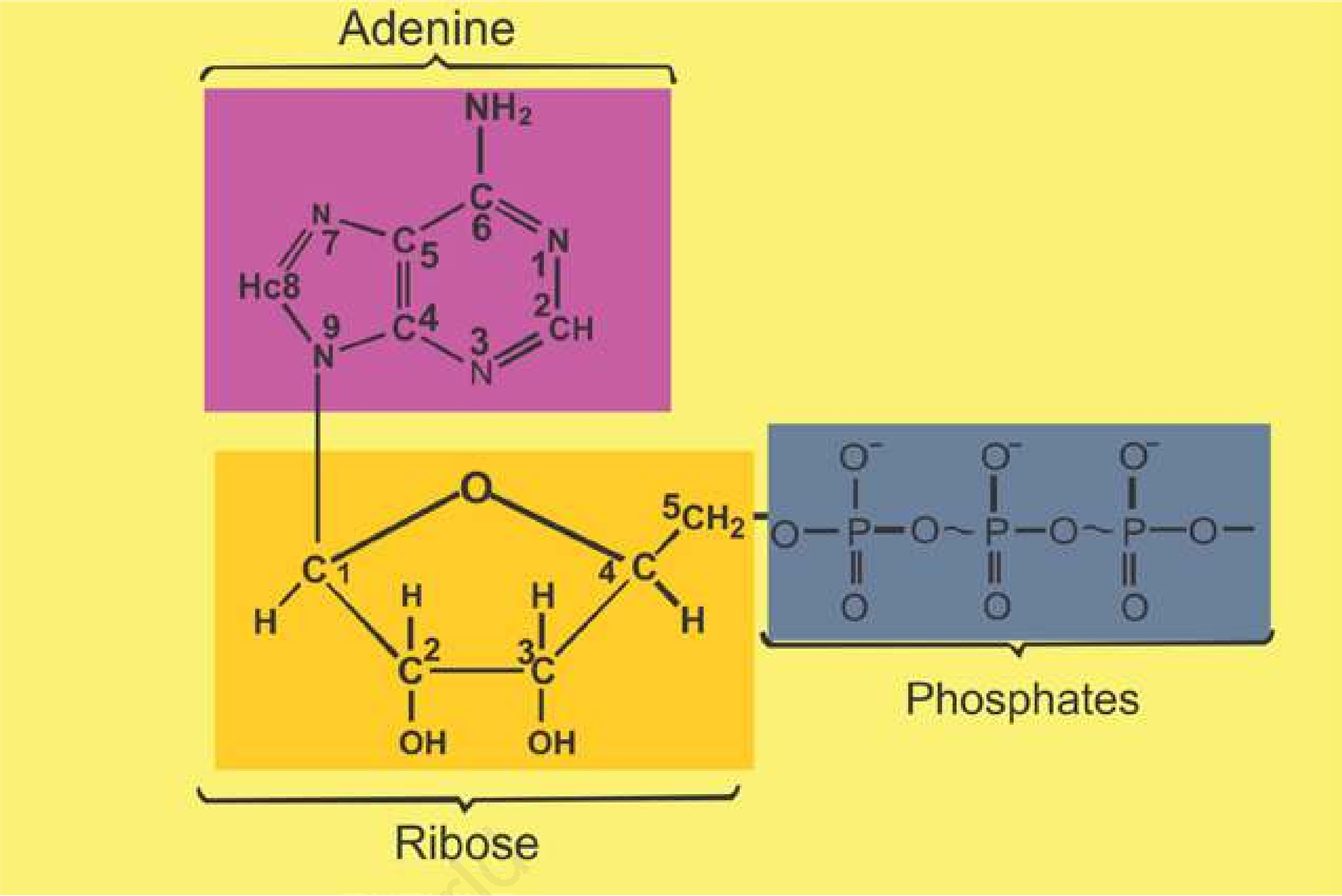

Fig. 2.13. Structural formula of ATP (a nucleotide)

Nucleic acids are complex substances. They are polymers of units called nucleotides. DNA is made up of deoxyribonucleotides, while RNA is composed of ribonucleotides. Each nucleotide is made of three subunits, a 5-carbon monosaccharide (a pentose sugar), a nitrogen containing base, and a phosphoric acid. Pentose sugar in ribonucleotide is ribose, while in deoxyribonucleotide it is deoxyribose. Nitrogenous bases are of two types, single-ringed pyrimidines, and double-ringed Purines. Pyrimidines are cytosine (abbreviated as C), thymine (abbreviated as T), and uracil (abbreviated as U). Purines are adenine (abbreviated as A) and guanine (abbreviated as G). 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 carbon at position 5 of pentose sugar (Fig 2.13).

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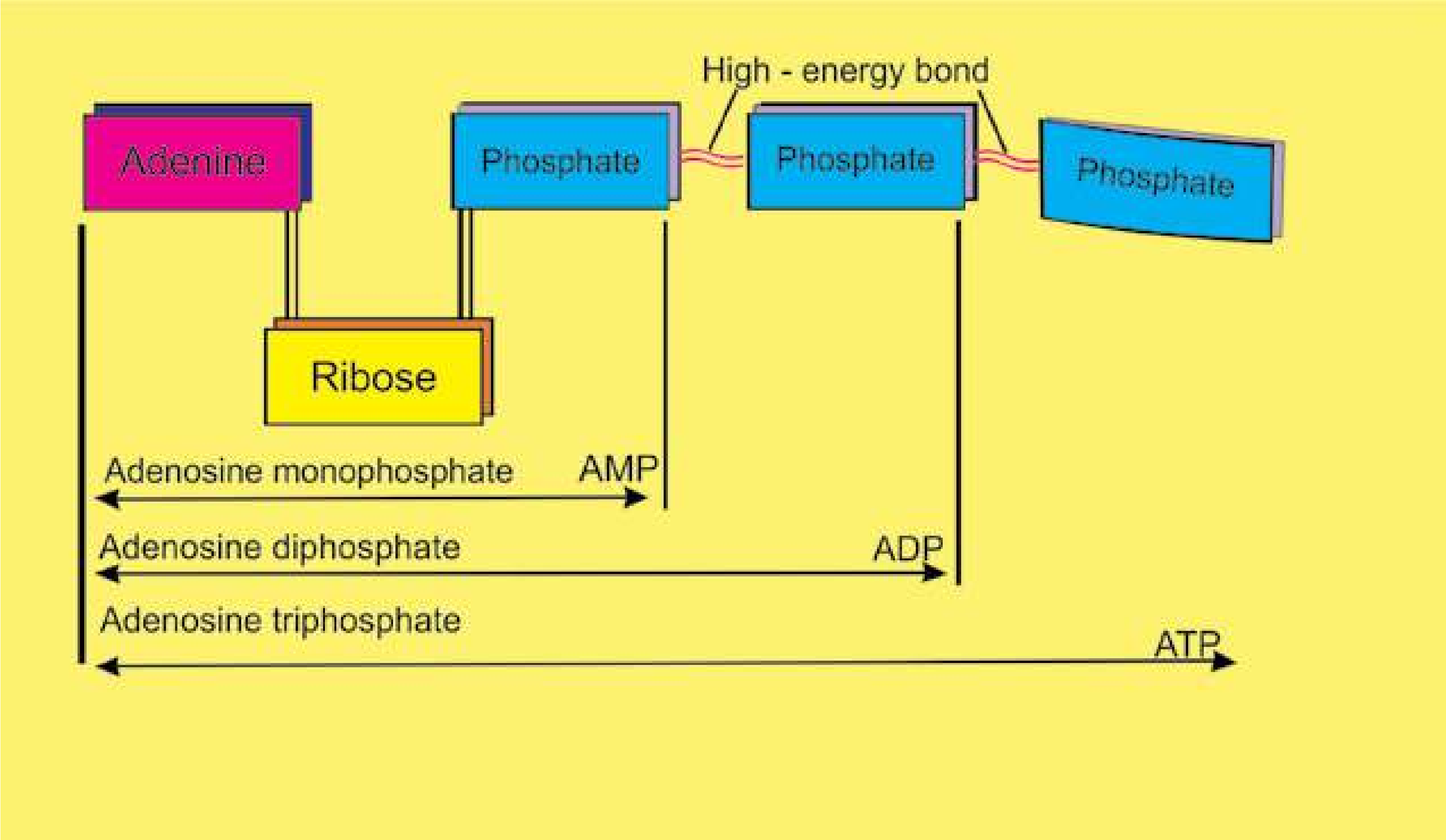

Fig. 2.14 : Components of ATP, a nucleotide.

The compound formed by combination of a base and a pentose sugar is called nucleoside. A nucleoside and a phosphoric acid combine to form a nucleotide. Each nucleotide of RNA contains ribose sugar, whereas sugar in each nucleotide of DNA is deoxyribose (one oxygen removed from OH group at carbon number 2). ATP is also an important nucleotide used as an energy currency by the cell (Fig.2.14.)

DNA (Deoxyribonucleic acid)

DNA is the heredity material. It controls the properties and potential activities of a cell. It is made of four kinds of nucleotides namely d-adenosine monophosphate (d-AMP), d-guanosine monophosphate (d-GMP), d-cytidine monophosphate (d-CMP), and d-thymidine monophosphate (d-TMP). These nucleotides are united with one another through phosphodiester linkages in a specific sequence to form long chains known as polynucleotide chains (Fig.2.15). Two nucleotides join together to form dinucleotide whereas three join together to form trinucleotide. Nicotinamide adenine dinucleotide, abbreviated as NAD, is an example of dinucleotide. It is an important coenzyme in several oxidation-reduction reactions in the cell.

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Animation 2.10: DNA
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List of ribonucleotides and deoxyribonucleotides				
	RNA		DNA	
Nitrogenous base	Nucleosides (ribose + nitrogenous base)	Nucleotides (ribose + nitrogenous base+phosphoric acid)	Nucleosides (deoxyribose + nitrogenous base)	Nucleotides (deoxyribose + nitrogenous base + phosphoric acid)
Adenine	Adenosine	AMP, ADP, ATP	d-Adenosine	dAMP, dADP, dATP
Uracil	Uridine	UMP, UDP, UTP		
Guanine	Guanosine	GMP, GDP, GTP	d-Guanosine	dGMP, dGDP. dGTP
Cytosine	Cytidine	CMP, CDP, CTP	d-Cytidine	dCMP, dCDP, dCTP
Thymine			d-Thymidine	dTMP, dTDP. dTTP

In 1951 Erwin Chargaff provided data about the ratios of different bases present in this molecule. This data suggested that adenine and thymine are equal in ratio and so are guanine and cytosine as shown below in Table 2.2.

Table 2.2: Relative amounts of bases in DNA from various organisms (on percentage basis).

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

Maurice Wilkins and Rosalind Franklin used the technique of X-ray diffraction to determine the structure of DNA. At the same time James D. Watson and Francis Crick built the scale model 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 a 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 bonds (hydrogen bonds). Adenine (A) is always opposite to thymine (T), and guanine (G) and cytosine (C) are opposite to each other. There are two hydrogen bonds between A and T pair, and three hydrogen bonds between G and C pair. 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 = one 100-millionth of a centimeter) (Fig.2.15).

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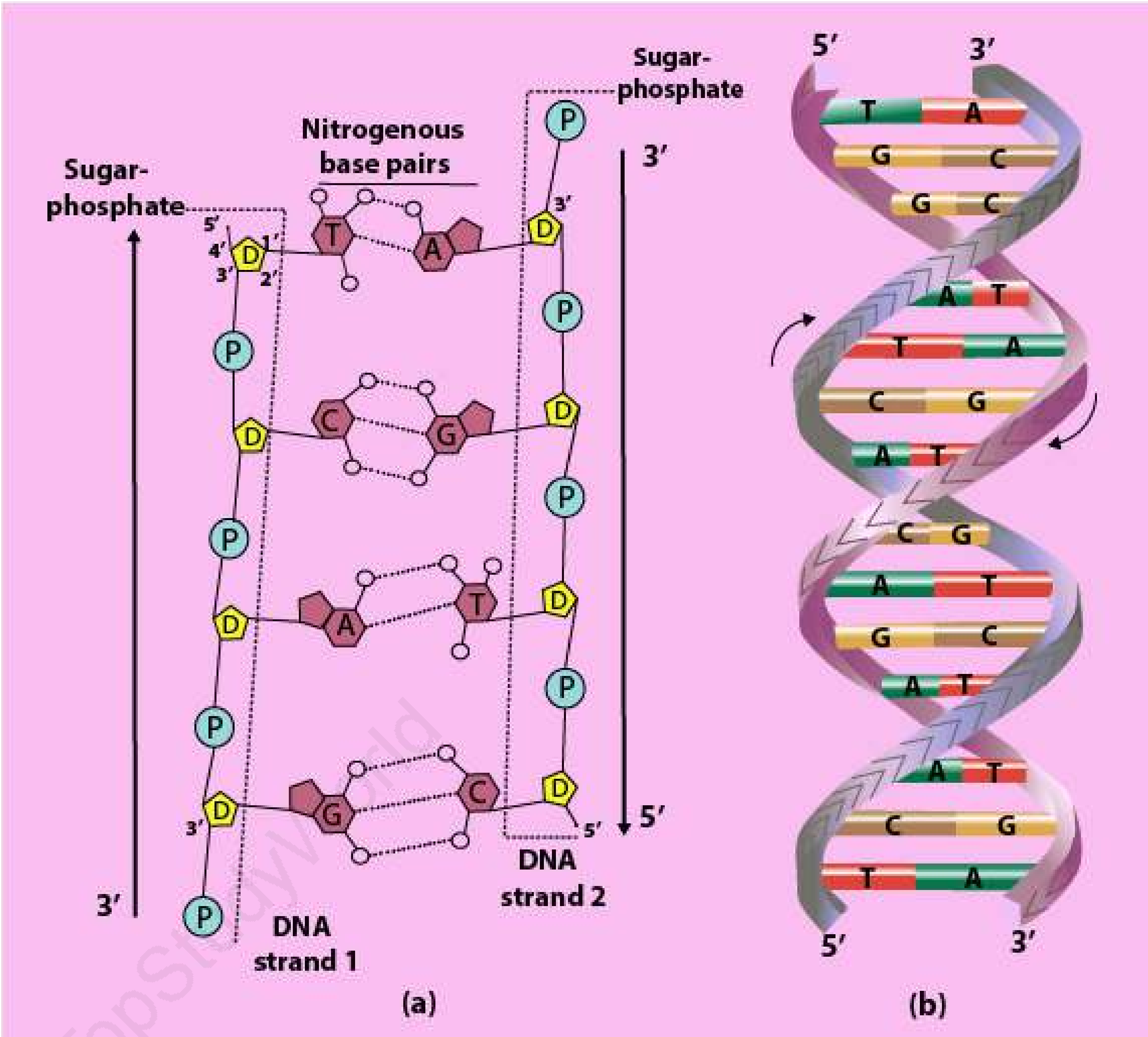

Fig. 2.15 Model of DNA. Double helical structure of DNA proposed by Watson & Crick (b). A hypothetical sequence of nucleotides (on the left side) shows hydrogen bonding between the complementary bases. Note a double boud between A and T, and triple bond between C and G (a).

The amount of DNA is fixed for a particular species, as it depends upon the number of chromosomes. The amount of DNA in germ cells (sperms and ova) is one half to that of somatic cells (Table 2.3).

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Table 2.3 Amount of DNA/nucleus in different types of cells of a chicken (bird) and a carp (fish).

Type of cell	Amount of DNA/nucleus(in picogram)	
	Chicken	Crap
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

All the information for the structure and functioning of a cell is stored in DNA. For example in the chromosome of the bacterium E.coli, each of the paired strand of DNA contains about 5 million bases arranged in a particular linear order, the information in those bases is divided into units of several hundred bases each. Each unit is a gene, a unit of biological inheritance. The E.coli genome consists of 4,639,221 base pairs, which code for at least 4288 proteins.

Haemophilus influenzae is the first microbe to have the genome completely sequenced and this was published on July 28, 1995.

RNA (Ribonucleic Acid)

Like DNA, RNA is a polymer of ribonucleotides. The RNA molecules occur as single strand, which may be folded back on itself, to give double helical characteristics. The nitrogenous bases form the usual complementary pairing viz. cytosine (C) with guanine (G) and uracil (U) with adenine (A). RNA is synthesized by DNA in a process known as **transcription.**

Types of RNA

Three main types of RNAs — messenger RNA (abbreviated as mRNA), transfer RNA (abbreviated as tRNA), and ribosomal RNA (abbreviated as rRNA) are recognized. All these three types of RNAs are synthesized from DNA in the nucleus and then are moved out in the cytoplasm to perform their specific functions.

Messenger RNA (mRNA): As the name indicates it takes the genetic message from the nucleus to the ribosomes in the cytoplasm to form particular proteins. Messenger RNA carries the genetic information from DNA to ribosomes, where amino acids are arranged according to the information in mRNA to form specific protein molecule. 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 to 4% of the total RNA in the cell.

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Transfer RNA (tRNA): It comprises about 10 to 20% of the cellular RNA. Transfer RNA molecules are small, each with a chain length of 75 to 90 nucleotides. 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. Transfer RNA picks up amino acids and transfers them to ribosomes, where they are linked to each other to form proteins.

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

Animation 2.11: RNA
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Animation 2.12: RNA
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CONJUGATED MOLECULES

Two different molecules, belonging to different categories, usually combine together to form conjugated molecules. Carbohydrates may combine with proteins to form glycoprotein or with lipids to form glycolipids. Most of the cellullar secretions are glycoprotein in nature. Both glycoproteins and glycolipids are integral structural components of plasma membranes. Lipoprotein formed by combination of lipids and proteins 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.

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Animation 2.13: Conjugated Molecules
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Exercise

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 ______________________.

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

ii. The covalent bond among two monosaccharides is called a peptide bond.

iii. Glycogen is also called plant starch.

iv. Adenine is always opposite to guanine, cytosine and thymine are opposite to each other in DNA molecule.

V. DNA molecule is made of two polynucleotide strands

3. Short questions.

i. Name the carbohydrates suitable as food for man.

ii. Why are fats considered as high energy compounds?

iii. What is the function of mRNA?

iv. What is the general formula for amino acids?

v. What is the percentage of water in brain cells of man?

4. Extensive questions.

i. Describe the importance of water for life.

ii. Describe what do you know about polysaccharides.

iii. Write a short note on amino acids.

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