Chapter 21

Biochemistry

Major Concepts

21.1 Carbohydrates
21.2 Proteins
21.3 Enzyme
21.4 Lipids
21.5 Nucleic acids
21.6 Minerals of Biological Significance

Learning Outcomes:

Students will be able to:

- Explain the basis of classification and structure-function relationship of carbohydrates **(Understanding)**
- Explain the role of various carbohydrates in health and diseases. **(Understanding)**
- Identify the nutritional importance and their role as energy storage. **(Applying)**
- Explain the basis of classification and structure-function relationship of proteins. **(Understanding)**
- Describe the role of various proteins in maintaining body functions and their nutritional importance. **(Applying)**
- Describe the role of enzyme as biocatalyst and relate this role to various functions such as digestion of food. **(Applying)**
- Identify factors that affect enzyme activity such as effect of temperature and pH.
- Explain the role of inhibitors of enzyme catalyzed reactions. **(Understanding)**
- Describe the basis of classification and structure-function relationship of lipids. **(Applying)**
- Identify the nutritional and biological importance of lipids. **(Applying)**
- Identify the structural components of DNA and RNA. **(Applying)**
- Recognize the structural differences between DNA polymer (double strand) and RNA (single strand).
- Relate DNA sequences to its function as storage of genetic information. **(Applying)**
- Relate RNA sequence (transcript) to its role in transfer of information to protein (Translation). **(Applying)**
- Identify the sources of minerals such as iron, calcium, phosphorous and zinc in nutrition. **(Applying)**

Introduction

Biochemistry is the study of chemical processes associated with living organisms. Biochemistry is the study of the structures, functions and interactions of biological molecules (or biomolecules) such as carbohydrates, proteins, enzymes, lipids, and nucleic acids, the mechanisms of enzyme action, the chemistry of vitamins and the energy transformations in the cell.

21.1 Carbohydrates

Carbohydrates are the most abundant naturally occurring compounds. They are widely distributed in plants and animals. Plants are the major sources of carbohydrates. About three-fourths of the dry weight of plants and less than 1% of the body weight of animals is made up of carbohydrates. Carbohydrates such as glucose, glycogen and starch are the main sources of energy for our brains and bodies to function properly. Cellulose, the complex carbohydrate, is also used in plants for structural support.

The name carbohydrate means hydrate of carbon and comes from the general formula $C_x(H_2O)_y$. The modern definition of carbohydrates includes polyhydroxyaldehydes or polyhydroxyketones or **compounds which give such compounds on hydrolysis are called carbohydrates.** For example, glucose, lactose, sucrose, starch etc. They exist mainly in their hemiacetal or acetal forms. Carbohydrates are frequently referred to as saccharides (Sanskrit, *Sarkara*; Greek, *Sakcharon*; Latin, *Saccharum*, sugar) because of the sweet taste of low molecular mass carbohydrates. They are synthesized by photosynthesis in green plants and algae.

21.1.1 Classification of Carbohydrates

They are divided into three major classes:

(i) Monosaccharides (ii) Oligosaccharides

(iii) Polysaccharides

21.1.1.1 Monosaccharides

These are also known as simple sugars or single sugars. **The carbohydrates that cannot be hydrolyzed into simpler carbohydrates are called monosaccharides.**

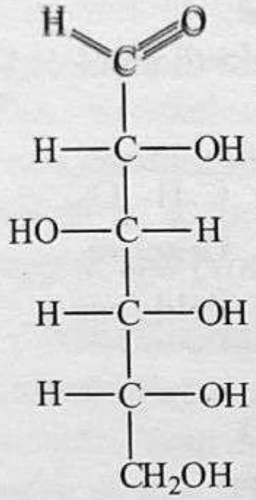
$$C_6H_{12}O_6 + H_2O \xrightarrow{H^+} \text{No Reaction}$$

Their general formula is $C_x(H_2O)_y$. For example, glucose, fructose etc. They have three to six carbon atoms. They have sweet taste and are easily soluble in water. Monosaccharides are of two types: aldoses and ketoses.

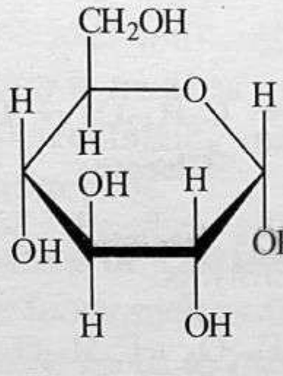
Aldoses

Monosaccharides which have aldehydic group **are called aldoses.** Examples are glyceraldehyde and glucose.

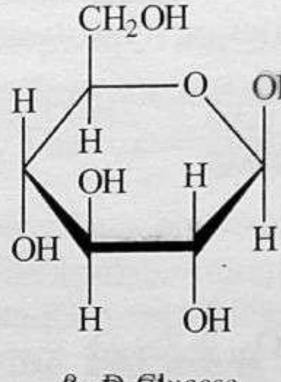
Glucose is also called dextrose, grape sugar or blood sugar. It is present both in free and combined states. In free state, it is present in sweet fruits and honey. It is present in human blood and urine in small amount. In combined state, it is present in disaccharides and polysaccharides. It is the source of energy in our body. The open chain and cyclic structures of glucose are:



Open chain structure



α- D-Glucose



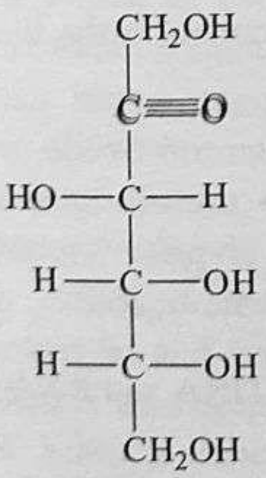
β - D-Glucose

Cyclic structures

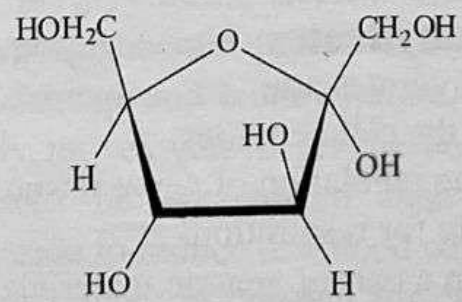
Ketoses

Monosaccharides which have ketonic group are called ketoses. Examples are dihydroxyacetone and fructose.

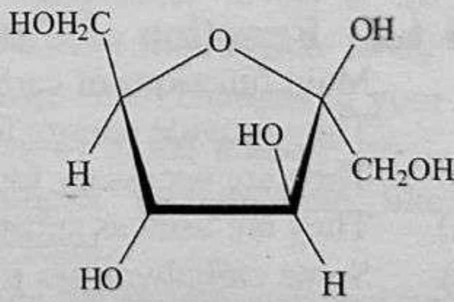
Fructose is found in free and combined states. It is used as sweetening agent in confectionary and as a substitute for cane sugar. The open chain and cyclic structures of fructose are:



Open chain structure



α-D-fructose



β-D-fructose

Cyclic structures

21.1.1.2 Oligosaccharides

The name is derived from Greek word "oligos" meaning "few." These are complex sugars. The carbohydrates which give 2 to 10 molecules of monosaccharides on hydrolysis are called oligosaccharides. Sucrose, raffinose and scorodose are the examples of oligosaccharides. On the basis of number of monosaccharide molecules, they are further divided into disaccharides, trisaccharides, tetrasaccharides and so forth. Sucrose, lactose and maltose are disaccharides because they yield two molecules of monosaccharides on hydrolysis.

$$\underset{\text{Sucrose}}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow{H^+} \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Fructose}}{C_6H_{12}O_6}$$

Raffinose and rabinose are trisaccharides because they yield three molecules of monosaccharides on hydrolysis.

$$\underset{\text{Raffinose}}{C_{18}H_{32}O_{16}} + 2H_2O \xrightarrow{H^+} \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Fructose}}{C_6H_{12}O_6} + \underset{\text{Galactose}}{C_6H_{12}O_6}$$

Scorodose and stachyose are tetrasaccharides because they yield four molecules of monosaccharides on hydrolysis.

$$\underset{\text{Stachyose}}{C_{24}H_{42}O_{21}} + 3H_2O \longrightarrow \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Fructose}}{C_6H_{12}O_6} + \underset{\text{Galactose}}{2C_6H_{12}O_6}$$

21.1.1.3 Polysaccharides

In Greek "poly" means "many." These are complex carbohydrates. The carbohydrates which give more than 10 molecules of monosaccharides on hydrolysis are called polysaccharides. The most important polysaccharides are starch, glycogen and cellulose. They are polymers of monosaccharides. They may have hundreds or thousands of monosaccharide units. They have relatively high molecular masses. They are tasteless amorphous solids and are called non-sugars. They are water insoluble. The formula of starch and cellulose is $(C_6H_{10}O_5)_n$. The plants store glucose in the form of starch whereas animals store in the form of glycogen in the liver and muscles.

21.1.2 Function of Carbohydrates

Main functions of carbohydrates are:

i) They provide energy for the cell activities.
ii) They are necessary for the regulation of nerve tissue.
iii) They are used as substrate for respiration.
iv) Some carbohydrates form a part of genetic materials like DNA and RNA in the form of deoxyribose and ribose sugars.
v) The glucose (in excess) is converted into glycogen (stored in liver), fats (stored in body) and non-essential amino acids (protein synthesis diet). They are used in times of starvation.
vi) The heart, brain, kidneys and muscles all need carbohydrates to function.
vii) Carbohydrates are constituents of many hormones, vitamins, and enzymes.

viii) They form components of bio-molecules which have a key role in blood clotting, immunity, fertilization etc.

ix) Some carbohydrates help to clear the gut and prevent constipation.

x) Starch contains fibers which play an important role in the process of digestion.

xi) They are constituents of all the cellular organelles like cell membrane, mitochondria, nucleus, endoplasmic reticulum etc. in one or other way to give structural integrity.

xii) They (cellulose) provide structural support to the plant cells.

xiii) The exoskeleton (outer skeleton) of arthropods (insects, lobsters, crabs,crustaceans, and others) is made of the biological macromolecule chitin, which is a polysaccharide-containing nitrogen. The exoskeleton provides support and protection to arthropods.

21.1.3 Nutritional Importance of Carbohydrates

Carbohydrates are found in foods such as fruits, grains, vegetables, breads and dairy products. Your body uses these foods to make glucose. Glucose is your body's main energy source. They help to fuel your brain, kidneys, heart, muscles and central nervous system. Your body stores excess glucose as glycogen in your muscles and liver for later use, such as during exercise.

Carbohydrates provide nutrients for the good bacteria in our intestines that help us digest our food. They protect our muscles because carbohydrates are the first source of energy for our body, without it, protein and fats from our body will be used.

Low blood sugar (hypoglycaemia) occurs when the glucose levels in the blood drop below normal. While hypoglycaemia is often associated with diabetes, it can be caused by a lack of carbohydrates in healthy people. Symptoms of hypoglycaemia include tiredness, weakness, light-headedness, confusion and hunger.

High blood sugar (Hyperglycaemia) occurs when the glucose levels in the blood rise above normal. Hyperglycaemia makes more serious complication to the body like heart disease, eyes damage and kidney failure. Make small changes in your daily habit and lifestyle surely moves you to get the normal of blood glucose level. Complex carbohydrates should be encouraged than simpler carbohydrate like monosaccharides and disaccharide to reduce the blood sugar level.

Fibre is an essential component in our diet for cancer prevention and healthy digestion. Fibrous (whole grains etc.) foods also reduce the risk of constipation. Without some whole grains, one would need to consume a large amount of fruits, vegetables and legumes to meet daily fibre requirements.

Ketosis occurs in the absence of carbohydrates when glycogen is depleted. Regularly consuming fruits, which contain carbohydrates, and starchy vegetables will prevent ketosis from occurring. Ketosis is the normal metabolic process occurs when your body does not have enough carbohydrates from food for your cells to burn for energy, it burns fat in its place. As apart of this process, it makes ketones. If you are eating a balanced diet, your body controls how much fat it burns, and you don't normally make or use ketones.

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Muscular Activities and Glycogen Storage

Glucose is an important source for energy. Energy is required for all kinds of bodily processes. Glucose is stored in the human's body as glycogen. In humans the majority of glycogen is stored in the cells of skeletal muscles (~500 g) and liver (~100 g). However, small amounts of glycogen are also present in the cells of heart, kidneys and brain. The liver will store glycogen for a later time when the body requires it for physical activity. The more carbohydrate a person eats, the more glycogen muscles store (ultimate extent), and the longer the stores will last to support physical activity.

The liver release its glucose into the blood stream to share with other bodily tissues while muscles do not release their glucose into the blood stream directly. During intense activities such as running(marathon race), the muscles glycogen is broken down and released as lactate into the blood. Lactate travels to the liver. The liver convert the lactate back into glucose. Glucose is then return to the muscles to fuel additional activity. The muscles glycogen is important for muscular activities such as running, cycling, weights lifting, climbing hills or stairs, dancing, yoga, football, hockey and push-ups.

Peoples who run out of muscle glycogen during an intense activity such as running, they have to slow down to conserve energy. At this stage, their legs cannot go one in front of the other and they are unable to run anymore. If they continue, their glycogen stores will get so low that their brain will shut down their body down and even jogging will be almost impossible. This can be prevented by eating sufficient quantities of simple carbohydrates both before and during intense activities.

Complex Carbohydrates that Provide Lubrication to Elbow and Knee

Complex carbohydrates (starch and cellulose) are very common in animals, plants, and bacteria. They are constituents of cell membranes, as well as subcellular materials of cells. They are also found in physiological fluids such as blood, tears, milk, and urine.

Many other naturally occurring complex carbohydrates are covalently attached to other biological molecules, such as amino acids, proteins or lipids, by glycosidic linkages of the sugar residues at their reducing ends to form glycoconjugates. They provide lubrication to elbow and knee.

Glucosamine

Clucosamine is an aminosaccaride. It helps in repairing and lubricating joints (elbow, knee and shoulder) and thus can improve flexibility and mobility of joints.

Glucosaminoglycans (GAGs)

Glycosaminoglycans such as chondroitin sulphate (most abundant GAG) are jelly-like substances and are found in cartilage, tendons and connective tissues. It helps lubricate the surfaces of joints. Other glycosaminoglycans such as hyaluronic acid are found in synovial fluid (a viscous and slippery fluid found in cavities of synovial joints) that lubricate the joints. The chondroitin sulphate and hyaluronic acid both reduce the friction between the cartilage and other tissues of joints especially elbows and knees and help you to move about freely.

Proteoglycans (Mucoproteins)

Proteoglycans are proteins that are covalently bonded at multiple sites along the protein chain to glycosaminoglycans. They are found in connective tissues and serve as joint lubricants.

21.2 Proteins

The high molecular mass organic compounds which on complete hydrolysis give amino acids are called proteins (Greek, Proteios = first). Proteins are present in all the living organism. Life is impossible without protein. They are present in skin, hair, wool, feathers, nails, horns, hoofs, nerves etc.

The %age of elements in proteins is:

$C = 51\%$, $H = 7\%$, $O = 23\%$, $N = 16\%$, $S = 1\text{-}3\%$, $P = < 1\%$

They may have copper, iodine, manganese and zinc.

21.2.1 Classification of Proteins

Proteins are classified into three types on the basis of physical and chemical properties: Simple proteins, compound proteins and derived proteins.

Simple proteins

The proteins which give only amino acids or their derivatives on hydrolysis are called simple proteins. Examples of such proteins are albumins, globulins, legumin, glutelins, histones, collagen etc. They are the most abundant proteins in the animals and form about 25-35% of body protein.

Albumins are found in blood, egg white, wheat, etc.

Globulins are found in blood, muscle, potatoes, etc.

Legumin and collagen are found in connective tissues of body.

Glutelins are found in wheat and rice.

Histones are found in thymus gland, pancreas and nucleoproteins.

Compound or Conjugated Proteins

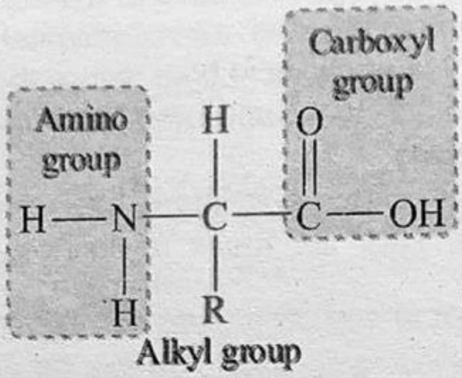
The proteins which give an amino acid and non-protein group on hydrolysis are called compound proteins. They are also known as conjugated proteins. The non-protein group is called prosthetic group. For example, phosphoproteins are conjugated (attached) with phosphoric acid and lipoproteins are conjugated with lipids such as cholesterol, fatty acids.

Derived Proteins

The proteins which are derived from simple and conjugated proteins are called derived proteins. For example, poly-peptides and proteases enzymes.

21.2.2 Structure of Proteins

Let us start by looking at the structure of amino acid:



The amino acids are generally represented using three letters. They can also be represented using one letter for easier convention as given in the image below.

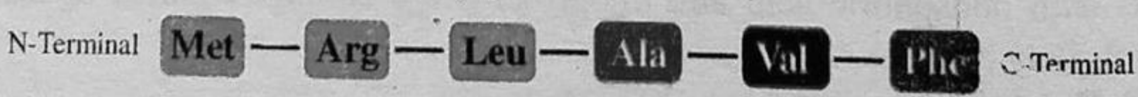
G	Glycine	Gly
A	Alanine	Ala
L	Leucine	Leu
M	Methionine	Met
F	Phenylalanine	Phe
W	Tryptophan	Trp
K	Lysine	Lys
Q	Glutamine	Gln
E	Glutamic acid	Glu
S	Serine	Ser

P	Proline	Pro
V	Valine	Val
I	Isoleucine	Ile
C	Cysteine	Cys
Y	Tyrosine	Tyr
H	Histidine	His
R	Arginine	Arg
N	Asparagines	Asn
D	Aspartic acid	Asp
T	Threonine	Thr

There are four types of proteins on the basis of structure: primary, secondary, tertiary, and quaternary structures.

Primary Structure

The sequence of the amino acids in the polypeptide chain is called primary structure. The primary structure is held together by peptide bonds that are made during the process of protein biosynthesis. The sequence is described by starting with the first amino acid found at the amino terminal (N) and ending with the last amino acid found on the carbonyl terminal (C).



Understanding the primary structure of proteins is important because many genetic diseases result in proteins with abnormal amino acid sequences, which cause improper folding and loss or impairment of normal function. The best example of primary structure is hemoglobin.

Secondary Structure

The regular coiled or zigzag structures of polypeptide chains which are held by hydrogen bonding between —NH group and —CO group are called secondary structures. Myoglobin is the good example of secondary structure.

Tertiary Structure

The three-dimensional twisting and folding of the polypeptide chains results in the tertiary structure. The best example of the tertiary structure of protein is myoglobin. Insulin, like all other proteins, has primary, secondary and tertiary structures.

Quaternary Structure

The structure which is formed by the polymerization of two or more tertiary structures is called quaternary structure. The polypeptides may be similar or different in them. Most proteins are made from only one peptide chain so they have primary, secondary and tertiary structures, but not quaternary structure. All those proteins have quaternary structure, which are made from more than one peptide chain. Haemoglobin and collagen are among those proteins which have quaternary structures. Collagen consists of three polypeptide chains while haemoglobin consists of four polypeptide chains.

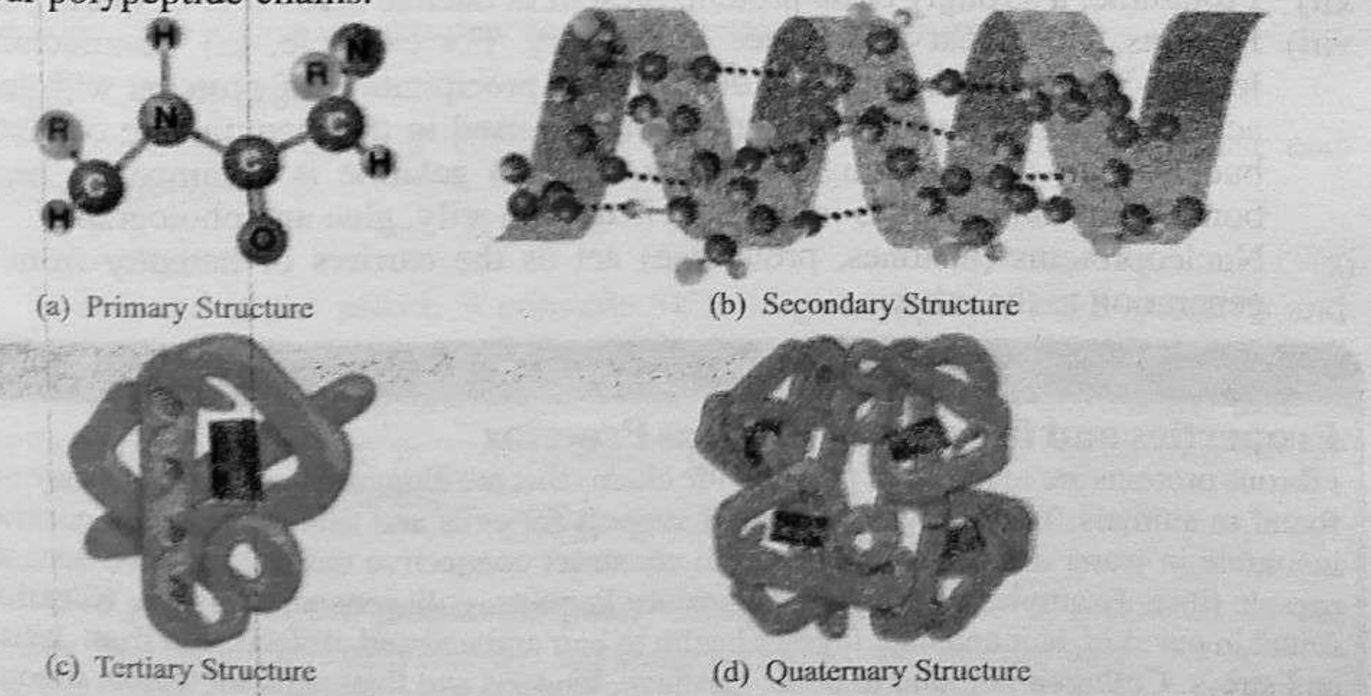


Figure 21.1: Structures of Proteins

Every protein in your body has a primary, secondary and tertiary structure, but only some proteins have a quaternary structure.

21.2.3 Properties of Protein

i) They contain carbon, hydrogen, oxygen and small amount of sulphur.
ii) They are complex biological molecules and are composed of amino acids. Amino acids are linked together by polypeptide bonds.
iii) They are biological catalysts and catalyse chemical reactions in living cells.
iv) They provide structural support to the cells.
v) They secrete hormones.
vi) They are amphoteric in nature and react with both acids and bases.
vii) Proteins can be denatured. Denaturing of protein is the disruption of the structure (secondary, tertiary and quaternary structures) of protein by heat, change in pH or by using strong oxidizing and reducing agents. The coagulation of the protein is the most common observation in the denaturing process. For example, the coagulation of albumin (the major component of egg white) occurs when egg is heated.

21.2.4 Importance of Protein

i) Protein is essential for the formation of protoplasm.
ii) Proteins play an important role in the contraction of muscles, digestion of food and clotting of blood.
iii) Almost all enzymes are proteins and they acts as organic catalysts.
iv) Haemoglobin, a protein, transports O_2 from lungs to the cellular tissues.
v) Insulin, a protein, regulates glucose metabolism.
vi) Myosin, a protein, present in muscles.
vii) Protamine, a strongly basic protein, present in nucleic acids (i.e. in sperm cells)
viii) Proteins have great importance in industry. For example, (a) manufacture of leather by tanning of hides is done by the precipitation of proteins with tannic acid, (b) casein, a protein found in milk, is used in the manufacture of buttons, buckles and in the sizing of papers, and (c) gelatine is obtained by heating bones, skins and tendons in water. It is used in jelly, glue and photography.
ix) Nucleoproteins (histones, protamine) act as the carriers of heredity from one generation to the other.

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Properties and function of Fibrous Proteins

Fibrous proteins are made up of polypeptide chains that are elongated in shape. They are only found in animals. They provide structural support for cells and tissues. They are generally insoluble in water and are usually used to construct connective tissues, tendons, bone and muscle fibre. Examples of fibrous proteins are keratins, collagens and elastins. **Keratin** is found in our skin, hair and nail. It gives health to hair and nail and protects skin from damage and stress. **Collagen** is found in bone, cartilage, tendons and ligaments for tensile strength. **Elastin** is found in connective tissues and is responsible for elastic properties. It allows many tissues in the body to resume their shape after stretching or contracting. It helps skin to return to its original position when it is poked or pinched.

21.3 Enzymes

Enzymes are proteins that act as catalysts to increase the rate of chemical reactions. These reactions include respiration, photosynthesis and forming new proteins. Examples of enzymes are lipase, zymase, glycosidase and isomerase. They are produced by living cells only but they catalyse (speed up) chemical reactions occurring inside and outside of living cells. Without enzymes, many chemical processes happen at a very slow rate; at such a slow rate that existence of life is practically not possible. An enzyme increase the rate of chemical reaction between 10^4 to 10^{20} times. Enzymes are specific in their action. An enzyme catalyses only one type of reaction not others. For example, sucrase will hydrolyse only sucrose and glucokinase can catalyse only glucose. Enzymes have two parts, namely the protein component (part) and the non-protein component. The protein part of the enzyme is known as apo-enzyme while the non-protein part of the enzyme is known as co-enzyme or co-factor.

21.3.1 Role of Enzyme as a Biocatalyst

A natural substance especially an enzyme that initiates or increases the rate of chemical reaction in a living body is called biocatalyst. Enzymes play an important role in the metabolism, respiration, digestion of food and other important life processes. Our body produces two types of enzymes: the digestive enzymes and the metabolic enzymes. The digestive enzymes are responsible for digestion of food and metabolic enzymes are responsible for all biochemical reactions that occur in the cell of our body. The digestive enzymes and their functions are given below:

21.3.1.1 Amylase

This enzyme is made in two places and are divided into salivary amylase and pancreatic amylase.

Salivary Amylase

It is found in the saliva. It converts 30% of carbohydrates such as starch and sugar present in our food into simple sugars in the mouth. That is why you are advised to chew food for a long time. If you chew food (bread) for a long time, it starts to taste sweet because the amylase present in the saliva breaks down the starch into simple sugars like glucose and fructose.

Pancreatic Amylase

It is present in the pancreatic juice. The pancreatic juice is produced by the pancreas. The pancreatic amylase has the same action as salivary amylase.

21.3.1.2 Lipase

It is present in the pancreatic juice. It is used to break down dietary fats into smaller molecules called fatty acids and glycerol.

Digestion of fat in the small intestine is helped by bile (bile acid), made in the liver. Bile is secreted into the intestine, where it breaks down the fat into small droplets that are easier for the lipase enzymes to work on. Bile is not an enzyme.

21.3.1.3 Protease

Protease is a general term used for three main enzymes, namely pepsin, trypsin and chymo-trypsin. Pepsin is present in the gastric juice of stomach. It breaks proteins into peptides. The trypsin and chymotrypsin are produced in the pancreas. They are released into small intestine through the pancreatic duct. When partially digested food moves from your stomach into your intestine, trypsin and chymotrypsin complete protein digestion, producing simple amino acids.

Keep in Mind

- The substances like vitamins, minerals and water are not digested because they are already small enough to be absorbed by the body without being broken down.
- The digestive enzymes cannot break down dietary fibre that is why the body cannot absorb it.

21.3.2 Factors Affecting Enzyme Activity

The factors that affect the activity of enzyme are:

21.3.2.1 Concentration

It can be explained in two ways:

Enzyme Concentration

The rate of reaction increases with an increase in the concentration of enzyme. For example, the rate of digestion increases by increasing the concentration of pepsin (an enzyme).

Substrate Concentration

The rate of enzymatic reaction is also directly proportional to the concentration of substrate.

21.3.2.2 Temperature

The enzyme activity increases with rise in temperature up to 45°C. The enzymes being protein in nature are denatured and become inactive at the temperature above 45°C. They are completely destroyed at 100°C. The activity of enzyme is reduced at low temperature (0°C) but they are not destroyed. The optimum temperature (The temperature at which enzyme activity is maximum) of enzymes in the body of mammals is about 37°C to 40°C. The optimum temperature is different for different enzymes.

21.3.2.3 Effect of pH

Changes in pH will greatly affect the activity of enzymes. The pH at which enzyme activity is maximum is called optimum pH. The optimum pH of salivary amylase is 6.4 to 6.9. The optimum pH of pepsin of stomach is 1.4. It is inactive in neutral and alkaline solutions. The optimum pH value of enzymes has never been found above 10.

21.3.2.4 Effect of Other Substances

The enzyme action is increased or decreased by the presence of other substances. These substances are: (i) Co-enzymes, (ii) Activators, (iii) Inhibitors

Co-enzymes

The non- proteinaceous part of the enzyme is called co-enzyme and the proteinaceous part of enzyme is called apo-enzyme.

Enzyme = Coenzyme + Apoenzyme

Vitamins are the examples of co-enzymes. The certain enzymes are unable to function without co-enzymes.

Activators

Inorganic substances which increase the activity of an enzyme are called activators. For example, Mg^{2+} and Zn^{2+} ions act as activators for the enzyme phosphatase and carbonic anhydrase respectively.

Inhibitors

The substances which either reduce (inhibit) or destroy the enzyme activity are called inhibitors. For example, sulpha drugs, penicillin and streptomycin act as inhibitors and cure many infections.

21.3.2.5 Radiation

Enzymes are generally inactivated by UV light, $\beta-$, $\gamma-$and X- rays.

21.3.3 Industrial Application of Enzymes

Enzymes are the most proficient catalysts. Enzymes have a wide variety of applications in industries. They are used in food, beverages, cosmetics, detergents, leather, agriculture and medicines. They are also used in biofuels and biopolymers. Some of the important industrial applications of enzymes are as follows:

21.3.3.1 Food Industry

They are used to process carbohydrates, proteins and fats. The enzymes that are used in food processing include amylase, lactases, cellulases and lipase. Amylase, lactases, and cellulases are used to break complex sugars into simple sugars. Lipase is used to break lipids into fatty acids and glycerol.

21.3.3.2 Beverage Industry

They are used to increase juice yield and decrease energy consumption. The pectinase, an enzyme, is used in fruit juice manufacture to break pectins and makes juice less viscous. The cellulases and hemicellulases are used to break the plant cell wall for efficient liquefaction. The number of enzymes such as neutral proteases, alpha amylase, beta-glucanase, cellulases etc. are used in the industrial production of alcoholic beverages like beer, wine, brandy, whiskey and rum.

21.3.3.3 Detergent Industry

Enzymes such as proteases, lipases, amylases and cellulases are added to some detergents to break or remove the dirt and stains from the cloth fibres.

21.3.3.4 Leather Industry

Enzymes can be applied during different steps of the leather production process: soaking, dehairing, dying etc. Proteases are used to remove hair from hides. These hides are then treated with pancreatic enzymes to increase the softness of leather.

21.3.3.5 Paper Industry

The amylases, xylanases, cellulases, laccase, lipase and ligninases are the most important enzymes that are used in the pulp and paper processes. They are used to lower viscosity, coating paper, remove colour, smooth fibres, enhance water drainage, and for softness of paper.

21.4 Lipids

The naturally occurring heterogeneous group of organic compounds of animals and plants which are soluble in organic solvents (acetone, benzene, CCl_4 etc.) but insoluble in water are called lipids. Examples are fats, oils, waxes etc. The word 'lipid' is derived from Greek word 'Lipas' which means fats. The fats and oils are the most important lipids found in nature. Lipids which are solid at ambient temperatures tend to be referred as "fats" while those which are liquid are called "oils".

21.4.1 Classification of Lipids

They are classified into the following types:

Simple Lipids

The esters of fatty acids with glycerol are called simple lipids. Examples are common fats and oils.

Compound Lipids

The lipids which have radicals in addition to fatty acids and alcohols are called compound lipids. Examples are glycerol, phospholipids, lipoproteins etc.

Derived Lipids

The lipids which are obtained by the hydrolysis of simple or compound lipids are called derived lipids (or **associated lipid**). For example, sterols, vitamin D, terpenes etc.

Edible Lipids

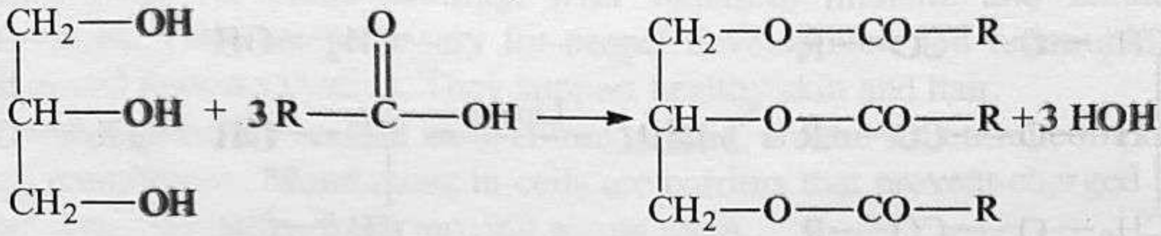
The lipids which have fats, oils and waxes are called edible lipids.

Steroids

The lipids which have high molecular mass tetracyclic compounds are called steroids. Cholesterol is the example of steroids.

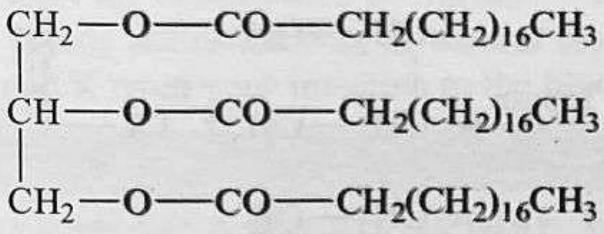
21.4.2 Structure of Lipids (Fats and Oils)

Fats and oils are the triesters of glycerols with fatty acids. They are known as triglycerides or glycerides. Lipids have no single common structure. We will discuss the structure of the most common lipid namely triglycerides. Triglycerides contain a glycerol molecule attached to three fatty acid "tails".



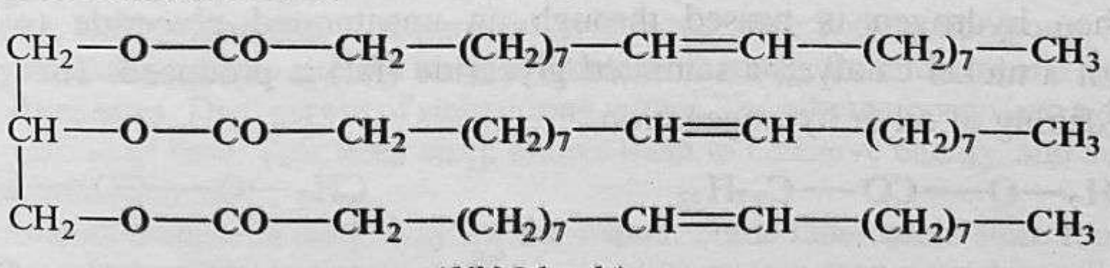
Glycerol   Fatty acid   Triglyceride

The common oils and fats are the mixture of saturated and unsaturated triglycerides. The solids or semi-solids triesters of long chain saturated fatty acids with glycerol at room temperature are known as fats.



(Fat Molecule)

The liquid triesters of long chain unsaturated fatty acids with glycerol at room temperature are known as oils.



(Oil Molecule)

21.4.3 Properties of Lipids

Physical Properties

i) Pure fats and oils are colourless, odourless and tasteless.

ii) They may either be liquid or non-crystalline solids.

iii) They are insoluble in water but are readily soluble in organic solvents.

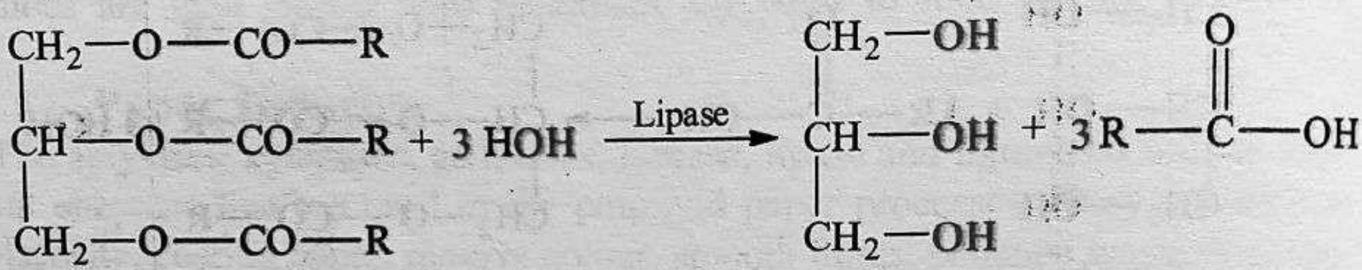
iv) They form emulsions when shake with water in the presence of a base like NaOH.

v) They are poor conductors of heat and electricity and act as excellent insulators for the animal body.

Chemical Properties

Hydrolysis

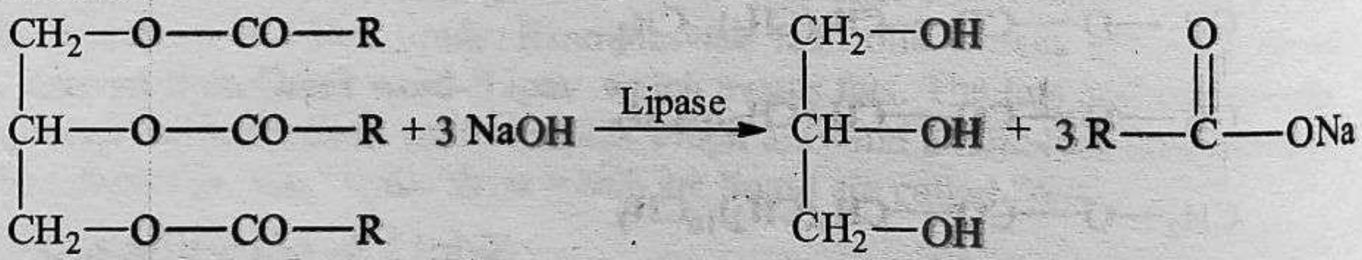
The oils and fats give glycerol and fatty acid on hydrolysis in the presence of enzyme lipase.



Triglyceride Glycerol Fatty acid

Saponification

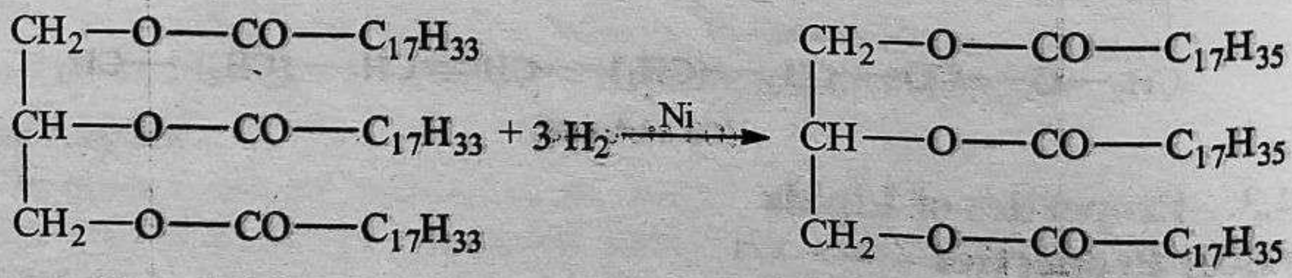
The reaction of fats or oils with NaOH to give soap and glycerol is called saponification.



Triglyceride Glycerol Soap

Hardening of Oils

When hydrogen is passed through an unsaturated glyceride (oil) in the presence of a nickel catalyst, a saturated glyceride (fat) is produced. This process is called hardening of oil or hydrogenation.



Glycerol trioleate (an oil) Glycerol trioleate (a fat)

This reaction is used for the production of vegetable ghee or margarine. Hardened oils are also used for making soap and candles.

21.4.4 Nutritional and Biological Importance of Lipids

Lipid play an important role in living organisms.

i) The main role of lipids in your body is to provide energy for muscles and body processes. Fat contains 9 calories per gram, whereas protein and carbohydrate contain only 4 calories per gram.

ii) Lipids provide energy to digest and absorb food properly.

iii) The essential lipids (linoleic and alpha-linolenic) cannot be synthesized in your body and must be obtained from diet. They are necessary for regulation of blood pressure, blood clotting, liver function, immune and inflammatory responses. They are necessary for proper development and functioning of the brain and nervous system. They support healthy skin and hair.

iv) Phospholipids, the second most common lipid, are the structural components of cell membranes. Membranes in cells are barriers that prevent charged particles and large molecules from moving across them.

v) Cholesterol, a steroid lipid, serves as the starting material for other important molecules in the body, including vitamin D and bile acids, which aid in the digestion and absorption of fats from dietary sources.

vi) Cholesterol is also used in the synthesis of sex hormones

vii) They are components of the nervous system.

viii) Lipids act as carriers of natural fat-soluble vitamins such as vitamin A, D, E and K from your intestine to the blood stream.

Society, Technology and Science

Hibernating Animals (Polar bear, reptiles and amphibians) Accumulate Fat to Meet Energy Resources during Hibernation

The food (insects and green plants) is unavailable during the winter months, the animals either need to migrate to warmer regions or hibernate. Hibernation is the state of inactivity of animals during winter. During hibernation, the animals will reduce their body temperature, heart rate, breathing rate and metabolic rate. All kinds of animals hibernate, from insects and amphibians to birds and primates. They get out of sight during winter. The hibernators go into a deep sleep for a long period of time. This deep sleep allows them to conserve energy, and survive the winter with little or no food.

Most hibernators prepare in some way for the winter. Some hibernators store food in their burrows (tunnels used by small animals such as rabbit) or dens (caves used by wild animals such as lion), to eat when they awake for short periods. Many eat extra food in the autumn while it is abundant. The food in hibernating animals is stored as body fat to be consumed in the winter for energy. The fat is rich and efficient source of energy and can store a lot of energy in a small space. For example, one gram of fat contains 9 kcal while one gram carbohydrate and protein contain 4 kcal. The hibernating period of animals depends on different factors: species, time of the year and individual's body condition. Animals can put themselves into a deep sleep for few days, weeks or months.

21.5 Nucleic Acids

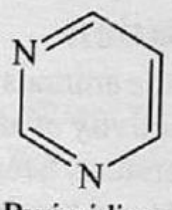
The high molecular mass biopolymers of nucleotides are called nucleic acids. They are present in the nucleus of all eukaryotic living cells as well as in viruses. They are the carriers of necessary hereditary information. They were first isolated from the nuclei of puss cells (white blood corpuscles) in 1869 by Friedrich Miescher. They were named nucleic acids because: (i) they are present in the nucleus (ii) they are acidic in the nature.

21.5.1 Structural Components of DNA and RNA

The two main classes of nucleic acids are DNA and RNA. DNA is the master blueprint for life and constitutes the genetic material in all free-living organisms and most viruses. RNA is the genetic material of certain viruses, but it is also found in all living cells, where it plays an important role in certain processes such as the making of proteins. The DNA and RNA are formed by large number of nucleotides. Nucleotides contain nitrogenous bases, pentose sugars and phosphoric acids in ester linkage.

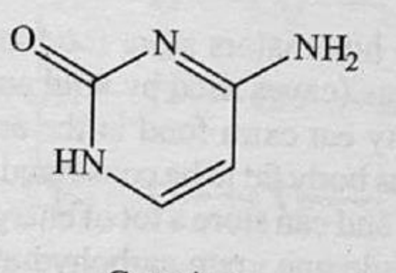
21.5.1.1 Nitrogenous bases

Nitrogenous bases are purine and pyrimidine derivatives. Pyrimidine derivatives (bases) have single rings. Pyrimidine has two nitrogen atoms at C1 and C3 of a six membered ring.

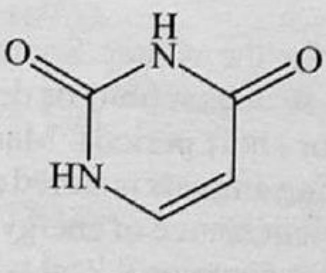


Pyrimidine

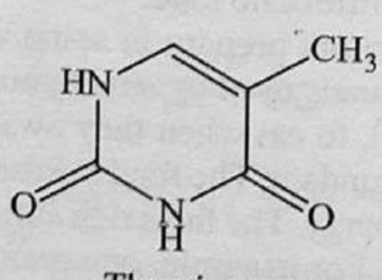
The pyrimidine derivatives consist of cytosine, thymine and uracil.



Cytosine

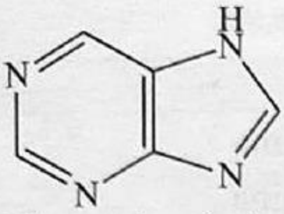


Uracil

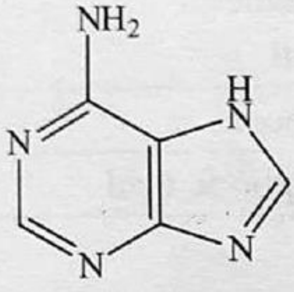


Thymine

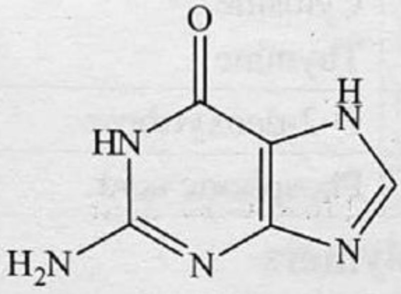
Purine derivatives (bases) have double rings. It has one pyrimidine ring and an imidazole ring ($C_3H_4N_2$).



The purine derivatives consist of adenine and guanine.



Adenine



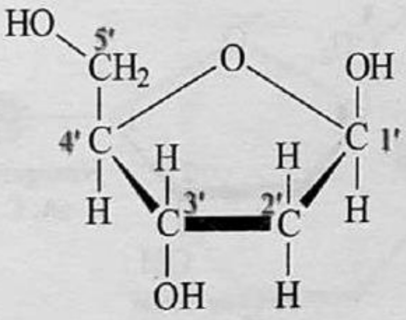
Guanine

Keep in Mind

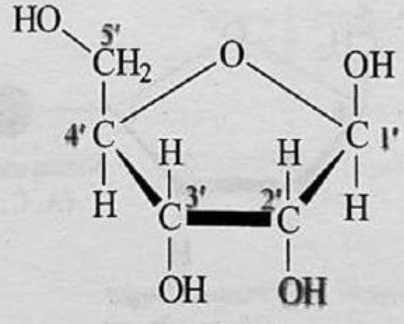
The four different bases in DNA are cytosine (C), Thymine (T), Adenine (A) and Guanine (G), while in RNA, thymine is not present and its place is taken by Uracil (U).

21.5.1.2 Pentose Sugar

Each nucleic acid has a different carbohydrate (sugar). The sugar in DNA is D-2-deoxyribose while the sugar in RNA is D-ribose.



Deoxyribose

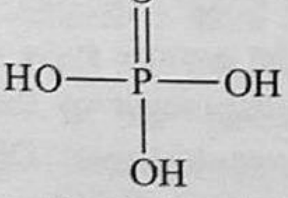


Ribose

By convention, the carbon atoms in the sugar are numbered from the original carbonyl position on the chain using a number plus the prime symbol (′). For example, in the deoxyribose sugar, the hydroxyl groups are boded to the 1′ (pronounced as "one prime), 3′ (three prime) and 5′ (five prime) carbon positions.

21.5.1.3 Phosphoric Acid

It forms phosphodiester bonds between nucleotides.



Phosphoric acid

Table 21.1 : Components of DNA and RNA

	DNA	RNA
Purines	Adenine Guanine	Adenine Guanine
Pyrimidines	Cytosine Thymine	Cytosine Uracil
Pentose	D-2-deoxyribose	D-ribose
Acid	**Phosphoric acid**	**Phosphoric acid**

21.5.2 Nucleic Acid Polymers

The nucleic acids (DNA and RNA) are polymers of nucleotides. As you know, components of each nucleotide are pentose sugar, phosphate group and nitrogenous base. The pentose sugar is the central component of the nucleotide. The nitrogenous base is attached to the number 1 carbon (right point) of the sugar. The phosphate is attached to the number 5 carbon (left point) of the sugar.

Nucleotide = Nitrogenous base **+** Pentose sugar **+** Phosphate group

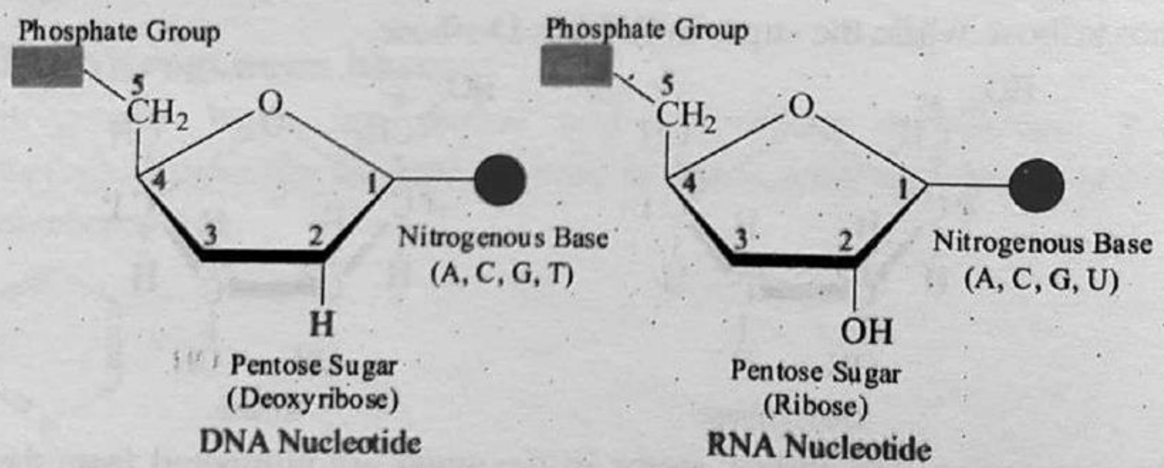


Figure 21.2: Three Parts of a Nudeotide

Nucleotides can link together by the formation of phosphate ester bonds. The hydroxyl group of a phosphate on one nucleotide undergoes a condensation reaction with the hydroxyl group on the carbohydrate ring of another nucleotide. The process may continue, building up nucleic acid molecules. These are polymers called polynucleotides. A covalent bond in RNA or DNA that holds a polynucleotide chain together by joining a phosphate group at position 5 in the pentose sugar of one nucleotide to the hydroxyl group at position 3 in the pentose sugar of the next nucleotide is called phosphodiester bond (or phosphodiester linkage). DNA is polydeoxyribonucleotide while RNA is polyribonucleotide.

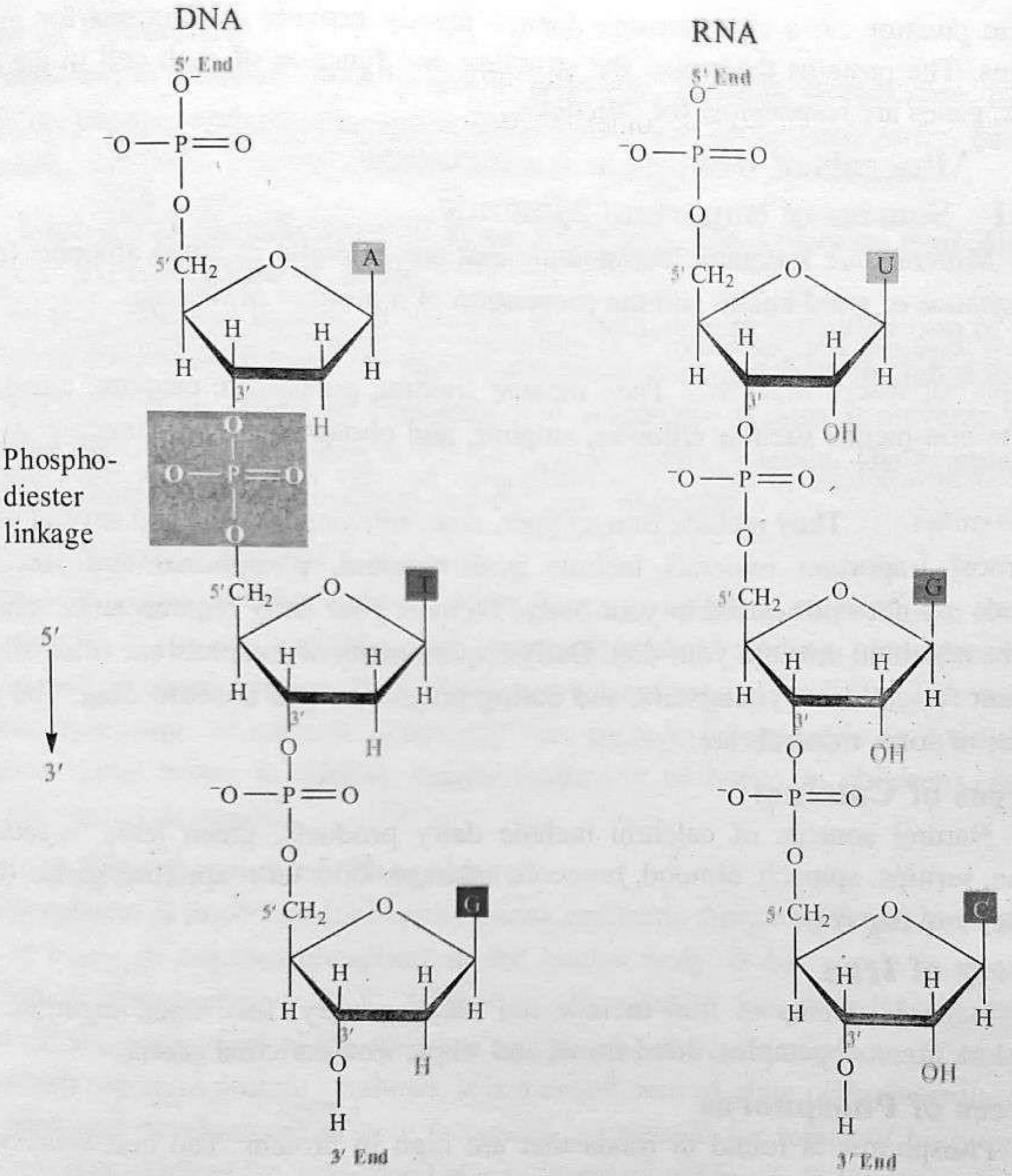


Figure 21.3: Phosphodiester linkages in the DNA and RNA

21.5.3 Storage of Genetic Information

Nucleic acids are macromolecules that carry out two main functions in the cell: storage of genetic information and synthesis of proteins. Two types of nucleic acids specialize in these functions: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). DNA is the genetic material that stores the biological information in sequences of four bases of nucleic acid that are, adenine, thymine, cytosine and guanine. The sequence of bases forms genes. Genes are located on chromosomal thread which runs along the entire length of chromosome. Each gene occupies a specific position on a chromosome. Genes mainly provide instructions for making proteins. The proteins determine the structure and function of each cell in the body. Hence, genes are responsible for inheritance.

21.6 Minerals of Biological Importance

21.6.1 Sources of Important Minerals

Minerals are inorganic compounds that are essential in small amounts for the maintenance of good health and the prevention of a number of diseases. The minerals that are required in amounts of 100 milligrams or more per day are called the major minerals (or macro minerals). They include sodium, potassium, calcium, manganese and the non-metals such as chlorine, sulphur, and phosphorus. The minerals that are required in amounts of only a few milligrams per day are called the trace minerals (micro minerals). They include iron, copper, zinc, selenium, iodine and several others. The most important minerals include iron, calcium, phosphorus and zinc. The minerals are not synthesized in your body. To meet your daily requirements, minerals must be obtained through your diet. Daily requirements of minerals are often slightly different for children, youngsters, and during pregnancy and breastfeeding. The main sources of some minerals are:

Sources of Calcium

Natural sources of calcium include dairy products, green leafy vegetables, salmon, turnips, spinach, almond, broccoli, cabbage, kale, tofu, apricots, garlic, dates, sardines and papaya.

Sources of Iron

Natural sources of iron include red meat, poultry, fish, liver, legumes, egg yolk, dark green vegetables, dried fruits, and whole iron-enriched grains.

Sources of Phosphorus

Phosphorus is found in foods that are high in protein. The best sources are dairy product, nuts, seeds, legumes, meat, and fish.

Sources of Zinc

Zinc is found in meats, mushrooms, liver, poultry, seafood, nuts, whole grains, soybeans, milk and other dairy products.

Sources of Magnesium

The natural sources of magnesium are nuts, seeds, whole grains, apricots, beans, green leafy vegetables, potatoes, banana, milk, and spinach. Magnesium is found especially in plant foods.

Sources of Potassium

Potassium is found in spinach, apples, tomatoes, bananas, strawberries, fresh orange juice, papaya, apricots, pineapple, dried fruits, rice, cucumbers, garlic, ginger and legumes.

21.6.2 Biological Significance of Iron, Calcium, Phosphorus and Zinc

Biological Significance of Iron

Iron is an essential mineral. It plays an important role in the production of red blood cells of your body. It helps red blood cells to carry oxygen from the lungs to all parts of the body. It also plays an important role in immune system. It prevents you from feeling tired. The lack of iron in red blood cells causes anaemia. The symptoms of anaemia include weakness, tiredness and shortness of breath.

Biological Significance of Calcium

Calcium is essential for building strong bones and teeth in children and teens. It helps muscles to contract and relax. It is important in blood clotting, blood pressure regulation and immune system. It supports nerve transmission and blood pressure regulation. Symptoms of calcium deficiency may include osteoporosis (a condition that causes brittle bones in adults), rickets (softening of bones in children), poor growth and mental depression.

Biological Significance of Phosphorus

Phosphorus is important for healthy bones and teeth. Above 80% phosphorus is located in bones as calcium phosphate in the human body. It has a role in energy production as components of ATP. ATP is readily used to fuel your body's many functions. It is a component of the complex nucleic acid structure of plants (DNA and RNA), which regulates protein synthesis. It is a constituent of plant cells, essential for cell division and development of new tissues. It is essential for repair of body cells and tissues. It is required for acid-base balance (regulate pH level) in the body. It has a role in the working of the body's muscular system and is therefore important to the beating of the heart.

The deficiency of phosphorus is relatively uncommon. Phosphorus deficiency may cause bone diseases such as rickets in children and osteomalacia (softening of bones) in adults especially in pregnant women. An improper balance of phosphorus and calcium may cause osteoporosis (a disease that causes the bones to become weaker and easily broken). The symptoms of phosphorus deficiency may include poor formation of teeth, irregular breathing pattern, joint stiffness and pain.

Biological Significance of Zinc

Zinc is an essential element. It is important for normal growth, wound healing, the nervous system, and especially for defensive (immune) system. It is needed for cell division, tissue growth and repair. It plays a role in the breakdown of carbohydrates. It enhances the action of insulin. It is important for proper sense of taste and smell. A lack of zinc may be associated with skin problems, slow healing of wounds, loss of appetite, weight loss and decreased ability to taste food.

Society, Technology and Science

Hormones and Their Functions

Hormones are chemical substances that act as a chemical messengers in the body. They are secreted by specific organs and glands and are travel to their target organs in the bloodstream or other body fluids. Hormones control and regulate various biological activities such as growth, development, reproduction, energy use and storage, and water and electrolyte balance. For example, insulin is a hormone that is secreted from pancreas and helps to lower glucose levels in the bloodstream and promote the storage of glucose in liver, muscle and other body tissues. Hormones can be classified into three groups based on their chemical structure: cholesterol-derived hormones, amino acid-derived hormones and peptide (or protein) hormones.

The cholesterol derived hormones are steroid hormones. They are secreted by adrenal cortex, male and female gonads and the placenta during pregnancy.

The amino acids derived hormones are derived from the amino acids tyrosine and tryptophan. Examples of amino acid-derived hormones include epinephrine, norepinephrine and thyroxine. Epinephrine and norepinephrine are synthesized in the medulla of the adrenal glands and thyroxine is produced by the thyroid gland.

Peptide or protein hormones are made from amino acids by specialized endocrine glands. Examples of Peptide hormones are insulin, glucagon, leptin, ADH and oxytocin.

Insulin as Protein Hormone whose deficiency leads to Diabetes Mellitus

Diabetes mellitus is disease in which insulin is either not produced by the pancreas (type 1 diabetes) or is produced in insufficient amounts (type 2 diabetes). Insulin is an important protein hormone that facilitates glucose transport, promotes glucose storage, stimulates protein synthesis and enhances free fatty acid uptake and storage. Insulin is often described as a "key," which unlocks the cell to allow sugar to enter the cell and be used for energy. The insulin deficiency leaves too much sugar in the blood and causes diabetes mellitus (DM). Symptoms of diabetes mellitus include frequent urination, fatigue, weight loss, excessive thirst and hunger. Diabetes mellitus causes serious health complications including kidney failure, heart disease, stroke and loss of sight. The treatment includes changes in diet, oral medications, and in some cases, daily injections of insulin.

Summary of Facts and Concepts

- Macromolecules are made up from small subunits, called monomers.
- Macromolecules are of two types (i) organic macromolecules (ii) inorganic macromolecules.
- Organic macromolecules are also of two types: (i) biological macromolecules (ii) non-biological macromolecules.
- Biological macromolecules are called life molecules. They are also known as biopolymers or natural macromolecules. Examples of biopolymers are: carbohydrates, proteins, lipids, DNA, RNA, etc.
- Carbohydrates are the most abundant biopolymers found on earth.
- Carbohydrates are further classified into three major classes: (i) monosaccharides, (ii) oligosaccharides (iii) polysaccharides.
- Glucose is an aldose and is known as dextrose. It is also known as grape sugar or blood sugar. It is present in honey and sweet fruits.
- Sucrose is oligosaccharides and is found in sugarcane, sugar beet and pineapple.
- Starch is polysaccharides and is present in wheat, rice, maize, potatoes and barley.
- Proteins are the building blocks of amino acids and are essential components of all living organisms.
- Lipids are high molecular mass organic compounds of animals and plants origin that are soluble in organic solvents.
- Steroids are lipids that have high molecular mass tetracyclic compounds. The most important steroid in the body is cholesterol.
- Oils and fats are the most important lipids found in nature.
- Enzymes are proteins that catalyse chemical reactions in living organisms. They are also known as biological catalysts.
- Nucleic acids are the high molecular mass biopolymers of nucleotides. They are present in the nucleus of all living cells as well as in viruses. They are the carriers of necessary hereditary information.
- Minerals are inorganic compounds that are essential in small amounts for the maintenance of good health and the prevention of a number of diseases.

Multiple Choice Questions

Q. Select one answer from the given choices for each question:

i) A large molecule that is made up of small repeating units is called:

(a) Isomer (b) Monomer

(c) Micromolecule (d) Macromolecule

ii) Which one of the following is a macromolecule?
(a) Amino acids (b) Sugars
(c) Lipids (d) Proteins

iii) $C_{12}H_{22}O_{11}$ is the chemical formula of:
(a) Blood sugar (b) Glucose
(c) Fructose (d) Cane sugar

iv) The most abundant biopolymer on the earth is:
(a) Proteins (b) Lipids
(c) Carbohydrates (d) Nucleic acids

v) The reaction between fat and NaOH is known as:
(a) Hydration (b) Saponification
(c) Esterification (d) Fermentation

vi) Which one of the following is the example of conjugated proteins?
(a) Albumins (b) Histones
(c) Phosphoproteins (d) Poly-peptides

vii) Proteins are essential for:
(a) Formation of protoplasm (b) Digestion of food
(c) Manufacture of buttons (d) All of the these

viii) Which one of the following transports oxygen from lungs to the cellular tissues:
(a) Haemoglobin (b) Nucleoprotein
(c) Albumins (d) Globulins

ix) Which one of the following enzymes is present in the pancreas?
(a) Pepsin (b) Trypsin
(c) Zymase (d) Isomerase

x) The mineral, which is essential for immune system:
(a) Iron (b) Zinc
(c) Magnesium (d) Calcium

Short Answer Questions

Q.1. Why boiling points of saturated fatty acid is higher than unsaturated fatty acid?
Q.2. What do you mean by carbohydrate?
Q.3. What happens when you eat too much protein?
Q.4. Why do weightlifters take amino acids?
Q.5. Where enzymes are found?
Q.6. Where are enzymes produced in the body?

Q.7. What are the three main functions of lipids?
Q.8. Why are lipids a better source of energy?
Q.9. Can lipids dissolve in polar solvents like water or not?
Q.10. What is the best solvent for lipids?
Q.11. What are the two main types of nucleic acids?

Long Answer Questions

Q.1. What is biochemistry? Discuss in four to five lines.
Q.2. What are carbohydrates? Explain briefly.
Q.3. Explain various classes of carbohydrates.
Q.4. Write down main functions of carbohydrates.
Q.5. What is the Nutritional Importance of Carbohydrates?
Q.6. What are proteins? Describe different classes of proteins.
Q.7. Write a short note on the properties of proteins. Discuss the importance of protein.
Q.8. What are enzymes? Explain the role of enzymes as a biocatalyst.
Q.9. What are the factors that affect enzyme activity? Discuss.
Q.10. What are the commercial uses of enzymes.
Q.11. What are lipids? Describe the classification of lipids.
Q.12. Explain the structure of lipids.
Q.13. Explain briefly the physical and chemical properties of lipids.
Q.14. What is the nutritional and biological importance of lipids?
Q.15. What are nucleic acids? What are the structural components of DNA and RNA?
Q.16. What are sources and biological significance of minerals? Describe briefly.