6. Biomolecules

Can you recall?

1. Which are different cell components?
2. What is the role of each component of cell?

Our planet is having a wide diversity of living organisms that are classified as unicellular (consisting of a single cell; including bacteria and yeast) or multicellular having many cells (e.g. plants and animals). You have also learnt that living organisms have cell as the basic structural and functional unit. The cells have protoplasm containing numerous chemical molecules, the biomolecules.

Biochemistry is biological chemistry that provides us the idea of the chemistry of living organisms and molecular basis for changes taking place in plants, animals and microbial cells. It develops the foundation for understanding all biological processes and communication within and between cells as well as chemical basis of inheritance and diseases in animals and plants.

Chemical analysis of all living organisms indicates presence of the most common elements like carbon, hydrogen, nitrogen, oxygen, sulphur, calcium, phosphorus, magnesium and others with their respective content per unit mass of a living tissue.

Chemically, all living organisms have basic three types of macromolecules, which are polymers of simple subunits called monomers. The polysaccharides (carbohydrates), polypeptides (proteins) and polynucleotides (nucleic acids) are the polymers of monosaccharides, amino acids and nucleotides respectively (Figure 6.1). Lipids are water insoluble and small molecular weight compounds as compared to macromolecules.

6.2 Biomolecules in the cell

A. Carbohydrates :

The word carbohydrates means 'hydrates of carbon'. They are also called saccharides. They are biomolecules made from just three elements: carbon, hydrogen and oxygen with the general formula $C_x(H_2O)_y$. They contain hydrogen and oxygen in the same ratio as in water (2:1). Carbohydrates can be broken down (oxidized) to release energy.

Based on number of sugar units, carbohydrates are classified into three types namely, monosaccharides, disaccharides and polysaccharides (Table 6.2).

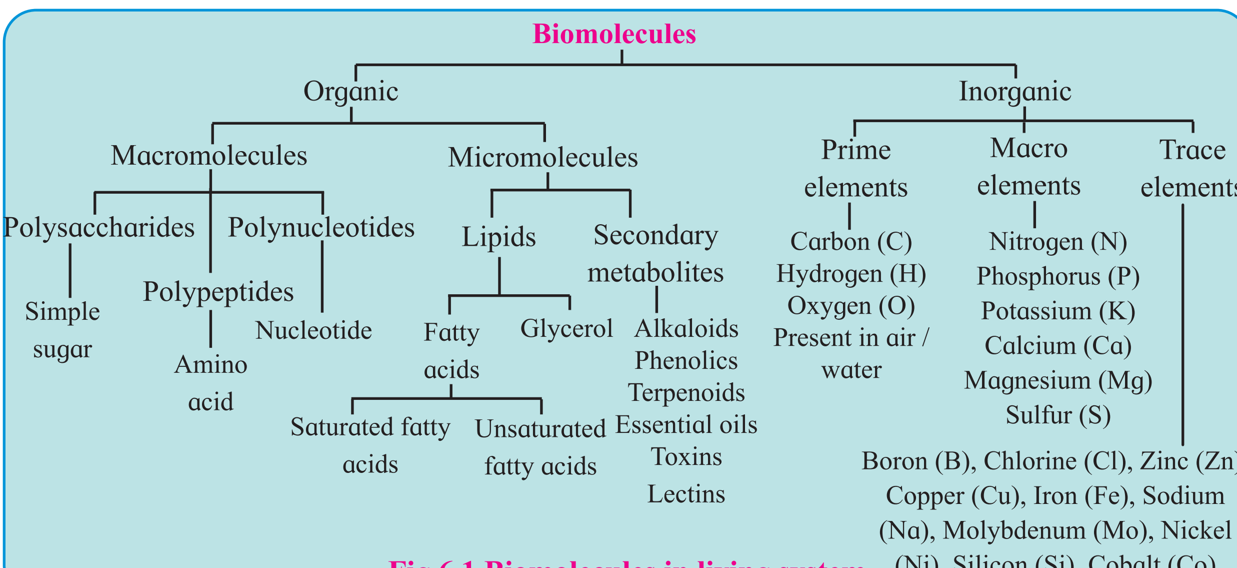


Fig.6.1 Biomolecules in living system

Carbohydrates

Monosaccharides (Simple sugars)	Disaccharides (Two monosaccharides)	Polysaccharides (Polymer of monosaccharides)
1. **Triose**-3carbons (e.g. Glyceraldehyde) 2. **Tetrose**-4 carbons (e.g. Erythrose) 3. **Pentose**-5 carbons (e.g. Ribose in RNA and deoxyribose in DNA) 4. **Hexose-** 6 carbons (e.g. Glucose- blood sugar, Fructose-fruit sugar and Galactose-product of lactose) 5. **Heptose**-7 carbons (e.g. Sedoheptulose)	1. **Sucrose** (cane sugar) on hydrolysis, it produces Glucose and Fructose 2. **Lactose** (milk sugar) on hydrolysis, it produces Glucose and Galactose 3. **Maltose** (malt sugar) on hydrolysis, it produces two units of Glucose	a. **Homopolysaccharides**: polymer of one type of monosaccharides e.g. **Starch -** plant storage molecule e.g. **Cellulose** - cell wall component e.g. **Glycogen** - animal storage molecule b. **Heteropolysaccharides**: polymer of different types of monosaccharides e.g. Hyaluronic acid, heparin, blood group substances, chondroitin sulphate

Table 6.2 Classification of Carbohydrates

1. Monosaccharides : These are the simplest sugars having crystalline structure, sweet taste and are soluble in water. They cannot be further hydrolysed into smaller molecules. They are the building blocks or monomers of complex carbohydrates. They have the general molecular formula $(CH_2O)_n$, where n can be 3, 4, 5, 6 and 7. They can be classified as triose, tetrose, pentose, etc. according to the number of carbon atoms in a molecule as mentioned in the table 6.2.

Monosaccharides containing the aldehyde (-CHO) group are classified as **aldoses** e.g. glucose, xylose, and those with a ketone(-C=O) group are classified as **ketoses**. eg. ribulose, fructose.

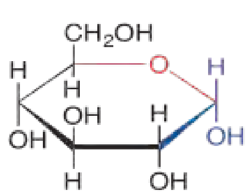


Fig. 6.3 Structure of Glucose

All monosaccharides are reducing sugars due to presence of free aldehyde or ketone group. These sugars reduce the Benedict's reagent (Cu^{2+} to Cu^{+}) since they are capable of transferring hydrogens (electrons) to other compounds, a process called reduction.

a. Glucose : It is the most important fuel in living cells. Its concentration in the human blood is about 90mg per 100ml of blood. The small size and solubility in water of glucose molecules allows them to pass through the cell membrane into the cell. Energy is released when the molecules are metabolised by cellular respiration.

b. Galactose : It looks very similar to glucose molecules. They can also exist in α and β forms. Galactose react with glucose to form the dissacharide **lactose**. However, glucose and galactose cannot be easily converted into one another. Galactose cannot play the same role in respiration as glucose.

c. Fructose : It is the fruit sugar and chemically it is ketohexose but it has a five-atom ring rather than a six-atom ring. Fructose reacts with glucose to form the sucrose, a disaccharide.

2. Disaccharides : Monosaccharides are rare in nature. Most sugars found in nature are disaccharides. Disaccharide is formed when two monosaccharide react by condensation reaction releasing a water molecule. This process requires energy. A glycosidic bond forms and holds the two monosaccharide units together.

Sucrose, lactose and maltose are examples of disaccharides. Sucrose is a non-reducing sugar since it lacks free aldehyde or ketone group. Lactose and maltose are reducing sugars. Lactose also exists in beta form, which is made from β-galactose and β-glucose.

Disaccharides are soluble in water, but they are too big to pass through the cell membrane by diffusion. They are broken down in the small intestine during digestion. Thus formed monosaccharides then pass into the blood and through cell membranes into the cells.

$$C_{12}H_{22}O_{11} + H_2O \xrightarrow{\text{hydrolysis}} C_6H_{12}O_6 + C_6H_{12}O_6$$

Disaccharide + Water   monosaccharide + monosaccharide

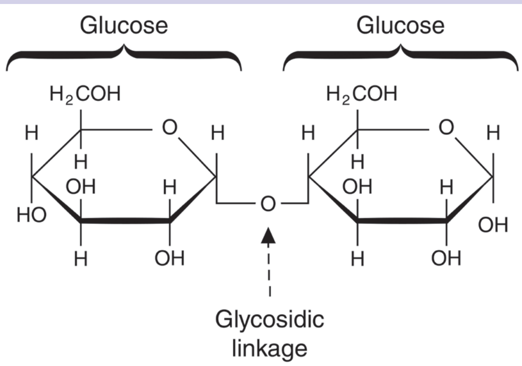


Fig. 6.4 Maltose

Monosaccharides are used very quickly by cells but if a cell is not in need of all the energy released immediately, then it may get stored. Monosaccharides are converted into disaccharides in the cell by condensation reactions, which result in the formation of polysaccharides as macromolecules. These are too big to escape from the cell.

3. Polysaccharides :

Monosaccharides can undergo a series of condensation reactions, adding one unit after the other to the chain till a very large molecule (polysaccharide) is formed. This is called **polymerization**. Polysaccharides are broken down by hydrolysis into monosaccharides. The properties of a polysaccharide molecule depend on its length, branching, folding and coiling.

a. Starch : Starch is a stored (Reserve) food in the plants. It exists in two forms: amylose and amylopectin. Both are made from α-glucose. Amylose is an unbranched polymer of α-glucose. The molecules coil into a helical structure. It forms a colloidal suspension in hot water. Amylopectin is a branched polymer of α-glucose. It is completely insoluble in water.

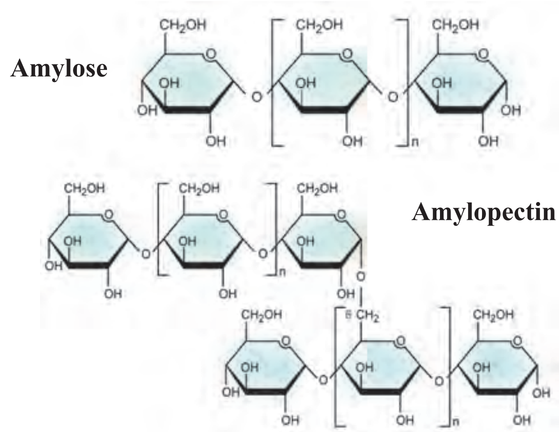


Fig. 6.5 Starch

b. Glycogen : It is amylopectin with very short distances between the branching side-chains. Glycogen is stored in animal body particularly in liver and muscles from where it is hydrolysed as per need to produce glucose.

c. Cellulose : It is a polymer made from β-glucose molecules and the polymer molecules are 'straight'. Cellulose serves to form the cell walls in plant cells. These are much tougher than cell membranes. This toughness is due to the arrangement of glucose units in the polymer chain and the hydrogen-bonding between neighbouring chains.

Biological significance of Carbohydrates:

It supplies energy for metabolism. Glucose is the main substrate for ATP synthesis. Lactose, a disaccharide is present in milk provides energy to lactating babies. Polysaccharide serves as structural component of cell membrane, cell wall and reserve food as starch and glycogen.

Can you tell?

1. Enlist the natural sources, structural units and functions of the following polysaccharides.
   a. starch b. cellulose c. glycogen
2. The exoskeleton of insects is made up of chitin. This is a ....
   a. mucoprotein b. lipid
   c. lipoprotein d. polysaccharide
3. List names of structural polysaccharides
4. What are carbohydrates?
5. Write a note on disaccharide and glycosidic bond.

B. Lipids :

These are group of substances with greasy consistency with long hydrocarbon chain containing carbon, hydrogen and oxygen. In lipids, hydrogen to oxygen ratio is greater than 2:1 (in carbohydrates it is always 2:1). Lipid is a broader term used for fatty acids and their derivatives. They are soluble in organic solvents (non-polar solvents). Let's understand what fatty acids are?

Fatty acids are organic acids which are composed of hydrocarbon chain ending in carboxyl group (-COOH). They can be **saturated fatty acids** with no double bonds between the carbon atoms of the hydrocarbon chain. Palmitic and stearic acids found in all animal and plant fats are examples of saturated fatty acids.

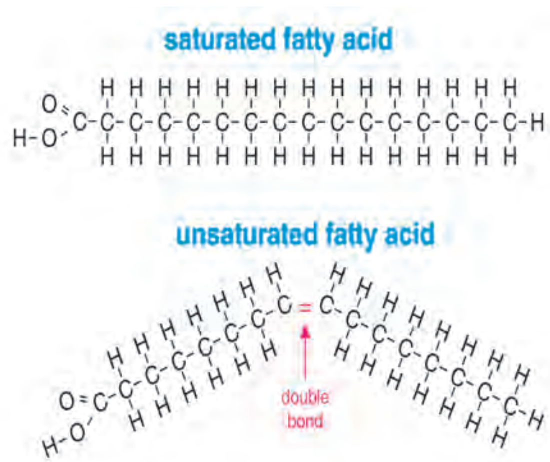


Fig. 6.6 Saturated and unsaturated fatty acid

Unsaturated Fatty Acids are with one or more double bonds between the carbon atoms of the hydrocarbon chain. Oleic acid found in nearly all fats and linoleic acid found in many seed oils are examples of unsaturated fatty acids.

These fatty acids are basic molecules which form different kinds of lipids. Lipids may be classified as simple, compound and derived lipids.

Simple Lipids : These are esters of fatty acids with various alcohols. Fats and waxes are simple lipids. Fats are esters of fatty acids with glycerol (CH_2OH-$CHOH$-CH_2OH). Triglycerides are three molecules of fatty acids and one molecule of glycerol. Generally, unsaturated fats are liquid at room temperature and are called oils. Unsaturated fatty acids are hydrogenated to produce fats e.g.Vanaspati ghee.

Fats are a nutritional source with high calorific value. Fats act as reserve food materials. In plants, it is stored in seeds to nourish embryo during germination. In animals, fat is stored in the adipocytes of the adipose tissue. Fats deposited in subcutaneous tissue act as an insulator and minimise loss of body heat. Fats deposited around the internal organs act as cushions to absorb mechanical shocks.

Wax is another example of simple lipid. They are esters of long chain fatty acids with long chain alcohols. They are found in blood, gonads and sebaceous glands of the skin. Waxes are not as readily hydrolysed as fats and are solid at ordinary temperature e.g. wax in beehive.

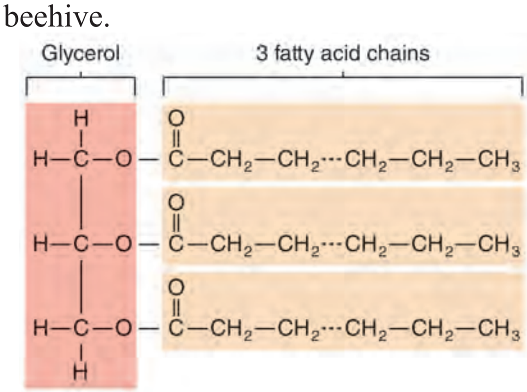


Fig. 6.7 Triglyceride

Waxes form water insoluble coating on hair and skin in animals, waxes form an outer coating on stems, leaves and fruits.

Fig. 6.8 Wax in bee hive

Compound lipids : These are ester of fatty acids containing other groups like phosphate (Phospholipids), sugar (glycolipids), etc. They contain a molecule of glycerol, two molecules of fatty acids and a phosphate group or simple sugar. Some phospholipids such as lecithin also have a nitrogenous compound attached to the phosphate group. Phospholipids have both hydrophilic polar groups (phosphate and nitrogenous group) and hydrophobic non-polar groups (hydrocarbon chains of fatty acids). Phospholipids contribute in the formation of cell membrane. Glycolipids contain glycerol, fatty acids, simple sugars such as galactose. They are also called cerebrosides. Large amounts of them have been found in the brain white matter and myelin sheath.

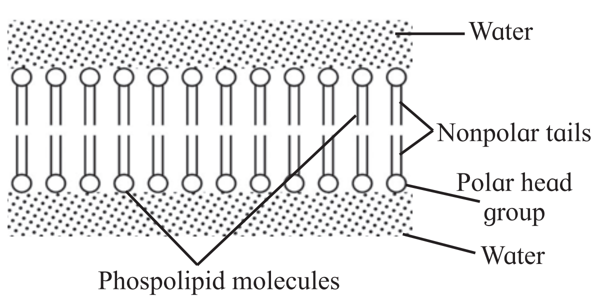


Fig. 6.9 Lipid bilayer in aqueous medium

Sterols : They are derived lipids. They are composed of fused hydrocarbon rings (steroid nucleus) and a long hydrocarbon side chain. One of the most common sterol is cholesterol. It is widely distributed in all cells of the animal body, but particularly in nervous tissue. Cholesterol exists either free or as cholesterol ester.

Adrenocorticoids, sex hormones (progesterone, testosterone) and vitamin D are synthesised from cholesterol. Cholesterol is not found in plants. In plants, sterols exist chiefly as Phytosterols. Yam Plant (*Dioscorea*) produces a steroid compound called diosgenin. It is used in the manufacture of antifertility pills. i.e. birth control pills.

Find out

1. Why do high cholesterol level in the blood cause heart diseases?
2. Polyunsaturated fatty acids are believed to decrease blood cholesterol level. How?

Can you tell?

1. Differentiate between the saturated and unsaturated fats.
2. What are lipids? Classify them and give at least one example of each.

C. Proteins :

The term 'protein' (Gk. proteious meaning first or of primary importance) was suggested by Berzelius (1830). Mulder adopted the term protein to refer to the complex organic nitrogenous substances found in the cell of all animals and plants.

Characteristics : Proteins are large molecules containing amino acid units (building blocks) ranging from 100 to 3000. Proteins have high molecular weights. In proteins, amino acids are linked together by peptide bonds which join the carboxyl group of one amino acid residue to the amino group of another residue. A protein molecule consists of one or more polypeptide chains. Proteins can contain any or all of the 20 naturally occurring amino acid types.

The linear sequence of amino acids in polypeptide chain of a protein forms its primary structure. Functional proteins have 3-dimensional conformation. Some proteins such as keratin of hair consists of polypeptide chain arranged like a spiral helix.

Such spirals are in some cases right-handed called α-helix, in others left-handed called β-helix. The spiral configuration is held together by hydrogen bonds. The sequence of amino acids in the polypeptide chain also determines the location of its bend or fold and the position of formation of hydrogen bonds between different portions of the chain or between different chains. Due to formation of hydrogen bonds peptide chains assume a secondary structure.

In some proteins, two or more peptide chains are linked together by intermolecular hydrogen bonds. Such structures are called pleated sheet. Pleated sheet structure is found in protein of silk fibres. In large proteins such as myoglobin and enzymes, peptide chains are much looped, twisted and folded back on themselves due to formation of disulphide bonds. Such loops and bends give the protein a tertiary structure. Whereas in haemoglobin, protein subunits are held together to form quaternary structure.

Proteins are extremely reactive and highly specific in behaviour. Proteins are amphoteric in nature i.e. they act as both acids and bases. The behaviour of proteins is strongly influenced by pH. Like amino acids, proteins are dipolar ions at the isoelectric point i.e. the sum of the positive charges is equal to the sum of the negative charges and the net charge is zero. The ionic groups of a protein are contributed by the side chains of the polyfunctional amino acids. A protein consists of more basic amino acids such as lysine and arginine exists as a cation at the physiological pH of 7.4. Such proteins are called basic proteins. Histones of nucleoproteins are basic proteins. A protein rich in acidic amino acids exists as an anion at the physiological pH. Such proteins are called acidic proteins. Most of the blood proteins are acidic proteins.

Classification of proteins :

On the basis of structure, proteins are classified into three categories:

Simple proteins : Simple proteins on hydrolysis yield only amino acids. These are soluble in one or more solvents. Simple proteins may be soluble in water. Histones of nucleoproteins are soluble in water. Globular molecules of histones are not coagulated by heat. Albumins are also soluble in water but they get coagulated on heating. Albumins are widely distributed e.g. egg albumin, serum albumin and legumelin of pulses are albumins.

Conjugated proteins : Conjugated proteins consist of a simple protein united with some non-protein substance. The non-protein group is called prosthetic group e.g. haemoglobin. Globin is the protein and the iron containing pigment haem is the prosthetic group. Similarly, nucleoproteins have nucleic acids coupled with histone proteins. On this basis, proteins are classified as glycoproteins and mucoproteins. Mucoproteins are carbohydrate-protein complexes e.g. mucin of saliva and heparin of blood. Lipopoteins are lipid-protein complexes e.g. conjugate protein found in brain, plasma membrane, milk etc.

Derived proteins : These proteins are not found in nature as such. These proteins are derived from native protein molecules on hydrolysis. Metaproteins, peptones are derived proteins.

Can you tell?

1. All proteins are made up of the same amino acids; then how proteins found in human beings and animals may be different from those of other ?
2. What are conjugated proteins? How do they differ from simple ones? Give one example of each.
3. Which of the following is a simple protein
   a. nucleoprotein
   b. mucoprotein
   c. chromoprotein
   d. globulin

D. Nucleic Acids :

Know the scientists

Swiss biochemist, Friederich Miescher (1869) discovered and isolated nucleic acids from the pus cells. By 1938, it became evident that nucleic acids are of two types- deoxyribose nucleic acid (DNA) and ribose nucleic acid (RNA). DNA is found in chloroplasts and mitochondria. DNA is the hereditary material in most of the organisms. The nucleic acids are among the largest of all molecules found in living beings. They contain three types of molecules a) 5 carbon sugar, b) Phosphoric acid and c) Nitrogen containing bases. Three join together to form a nucleotide of nucleic acid.

Fuelgen (1924) showed that chromosomes contain DNA. He established that nucleic acids contain two pyrimidine (cytosine and thymine) and two purine (adenine and guanine) bases. Wilkins and co-workers showed that the purine and pyrimidine bases are placed regularly along the DNA molecules at a distance of 3.4 Å , DNA is composed of **: Sugar molecule** (It is a pentose sugar of deoxyribose type) **Phosphoric acid (**also called phosphates when in chemical combination) **Nitrogen containing bases** (these are nitrogen containing organic ring compounds). Principally bases are of two types: (a) pyrimidine bases (b) purine bases

Pyrimidine bases are single ring (monocyclic) nitrogenous bases. **Cytosine**, **Thymine** and **Uracil** are pyrimidines. Purine are double ring (dicyclic) nitrogenous bases A**denine** and **guanine** are purines.

Erwin Chargaff (1950) estimated the relative amounts of the four nitrogenous bases viz. adenine, thymine, cytosine and guanine in DNA. He observed that the pyrimidine and purine always occur in equal amount in DNA. He also found that the base ratio i.e. A+T / G+ C may vary in the DNA of different groups of animals and plants but A+T/ G+C ratio remains constant for a particular species.

1. Structure of DNA :

DNA is a very long chain made up of alternate sugar and phosphate groups. The sugar is always deoxyribose and it always joined to the phosphate in the same way, so that the long chain is perfectly regular, repeating the same phosphate-sugar sequence over and over again. Each sugar of the sugar-phosphate chain has a 'base' attached to it and the base is not always the same. This unit which consists of a sugar, phosphate and a base is called **nucleotide**. The nitrogenous base and a sugar of a nucleotide together form- a molecule, nucleoside. Thus, nucleoside does not contain phosphate group. Four types of nucleosides are found in DNA molecule. In a nucleoside, nitrogenous base is attached to the first carbon atom (C-1) of the sugar and when a phosphate group gets attached with that of the carbon (C-5) atom of the sugar molecule a nucleotide molecule is formed.

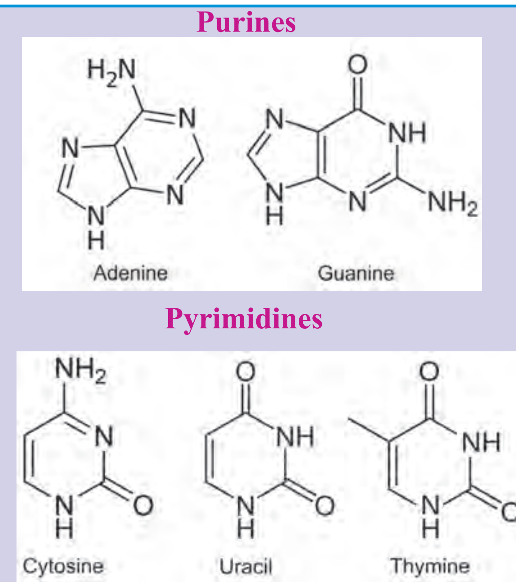


Fig. 6.10 Nitrogen bases in Nucleic acid

A single strand of DNA consists of several thousands of nucleotides linked one above the other. The phosphate group of the lower nucleotide attached with the 5th carbon atom of the deoxyribose sugar forms phospho-di-ester bond with that of the, 3rd carbon atom of the deoxyribose sugar of the nucleotide placed just above it.

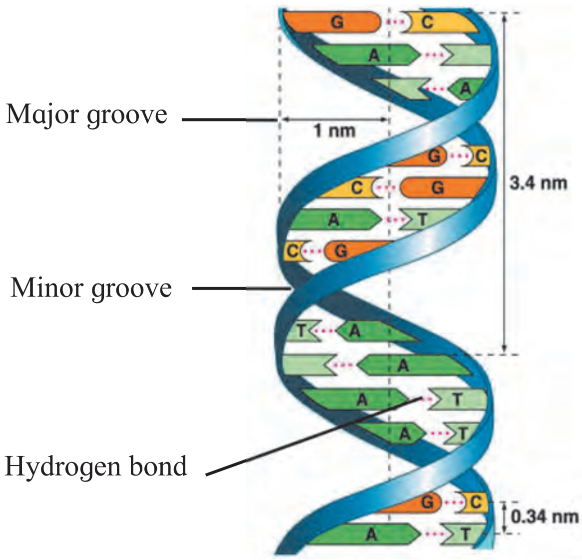


Fig. 6.11 Structure of DNA

Single long chain of polynucleotides of DNA consists of one end with sugar molecules not connected with another nucleotide having C-3 carbon not connected with phosphate group, similarly the other end having C-5 of the sugar is not connected with any more phosphate group. These two ends of the polynucleotide chain are called as 3' and 5' ends respectively. The single polynucleotide strand of DNA is not straight but helical in shape. The DNA molecule consists of such two helical polynucleotide chains which are complementary to each other. The two complementary polynucleotide chains of DNA are held together by the weak hydrogen bonds. Adenine always pairs with thymine, and guanine with cytosine (a pyrimidine with a purine). Adenine-thymine pair consists of two hydrogen bonds and guanine-cytosine pair consists of three hydrogen bonds (Thus, if the sequence of bases of a polynucleotide chain is known, that of the other can then be determined).

Do you know ?

Watson and Crick did not conduct any experiment on DNA. Crick was expert in physics, X-ray crystallography and Watson in viral and bacterial genetics. They only analyzed and comprehended the results of experiments performed by scientists like R. Franklin, M. Wilkins, etc.

DNA Model :

According to Watson and Crick, DNA molecule consists of two strands twisted around each other in the form of a double helix. The two strands i.e. polynucleotide chains are supposed to be in opposite direction (antiparallel) so end of one chain having 3' lies beside the 5' end of the other. One turn of the double helix of the DNA measures about 34Å . It consists paired nucleotides and the distance between two neighbouring pair nucleotides is 3.4Å . The diameter of the DNA molecule has been found be 20Å.

There are certain organisms like Bacteriophage φ x 174 and several bacterial viruses which possess single stranded DNA.

2. Ribonucleic Acid (RNA) :

Another nucleic acid found in the living organisms is Ribose nucleic acid. In most of the organisms it is not found to be hereditary material but in certain organisms like tobacco mosaic virus, it is the hereditary material. Like DNA, ribose nucleic acid also consists of polynucleotide chain with the difference that it consists of single strand. In some cases e.g. Reovirus and wound tumour virus, RNA is double stranded. The nucleotides of RNA have ribose sugar instead of the deoxyribose sugar as in the case of DNA.

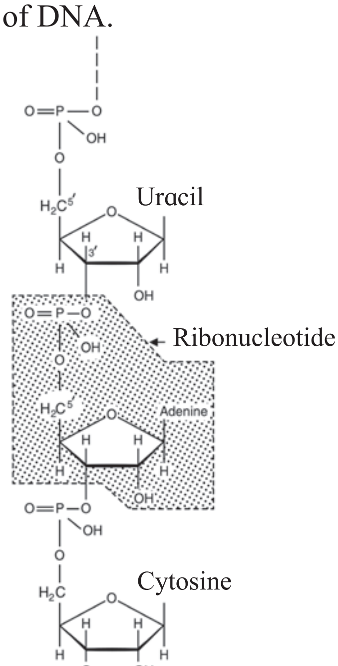


Fig. 6.12 Single strand of RNA

In case of RNA, Uracil substitutes thymine of DNA. Purine, pyrimidine equality is not found in RNA molecule because of its single stranded structure. RNA strand is usually found folded upon itself in certain regions or entirely. These foldings helps in stability of the RNA molecule. Most of the RNA polynucleotide chains start either with adenine or guanine. Three types of cellular RNAs have been distinguished: (a) messenger RNA (mRNA) or template RNA, (b) ribosomal RNA (rRNA), (c) transfer RNA (tRNA) or soluble RNA.

mRNA carries genetic information for arranging amino acids in definite sequence. It is a linear polynucleotide. It accounts 3% of total cellular RNA. Its molecular weight is several million. mRNA molecule carrying information to form a complete polypeptide chain is called cistron. Size of mRNA is related to the size of message it contains. Synthesis of mRNA begins at 5' end of DNA strand and terminates at 3' end.

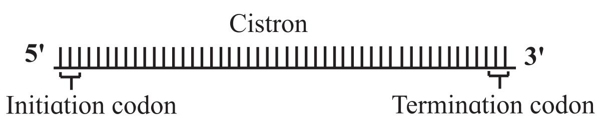


Fig. 6.13 The mRNA

rRNA form 50-60% part of ribosomes. It accounts 80-90% of the cellular RNA. It is synthesized in nucleus. Kurland (1960) discovered it. It gets coiled here and there due to intrachain complementary base pairing.

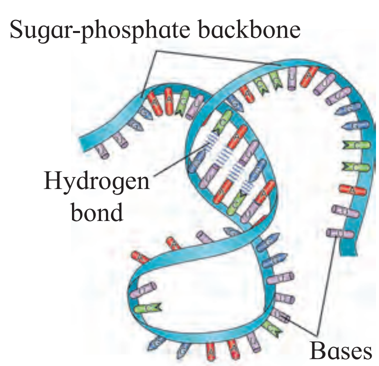


Fig. 6.14 The rRNA

tRNA molecules are much smaller consisting of 70-80 nucleotides.

It is also single stranded but folded due to number of complementary base sequences after pairing, it is shaped like clover-leaf (Holley,1965). Each tRNA can pick up particular amino acid. Following four parts can be recognized on tRNA 1) **DHU** arm (Dihydroxyuridine loop/amino acid recognition site 2) **Amino acid binding site** 3) **Anticodon loop** / codon recognition site 4) **Ribosome recognition site**. In the anticodon loop of tRNA, three unpaired nucleotides are present, called as anticodon which pair with complementary codon present on mRNA. The specific amino acids is attached at the 3' end in acceptor stem of clover leaf of tRNA.

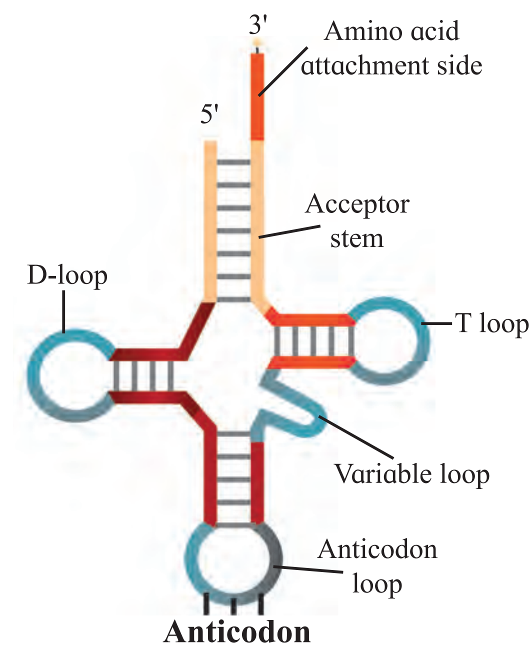


Fig. 6.15 The tRNA

Can you tell?

1. Describe the structure of DNA molecule as proposed by Watson and Crick.
2. Difference between DNA and RNA is because of
   a. sugar and base
   b. sugar and phosphate
   c. phosphate and base
   d. sugar only
3. Differentiate between DNA and RNA.
4. What is nucleotide? How is it formed? Mention the names of all nucleotides.

E. Enzymes :

Thousands of different chemical reactions take place automatically at a given time in a tiny living cell. The reactions take place at the body temperature. If these enzymes were not present in the cell, either the reactions would not occur or if they occur they would occur at a very very slow rate.

Know the scientists

German chemist Edward Buchner discovered enzymes by accident. Buchner discovered that living cells were not necessary but that yeast extract could bring about fermentation. He then coined the term Enzyme (Gk. En = in, zyma = yeast i.e. in yeast). This term is now commonly used for all biocatalysts.

Each enzyme catalyzes a small number of reactions, specifically perhaps only one. The substance upon which an enzyme acts is termed as the substrate. The enzymes which act within the cell in which they are synthesized are known as endo-enzymes e.g., enzymes produced in the chloroplast and mitochondria, if they act outside the cell in which they are synthesized, they are known as exo-enzymes e.g., enzymes released by many fungi. These enzymes, synthesised by living cell, retain their catalytic property even when extracted from cells.

Do you know ?

Rennet tablets used for coagulating milk protein casein (cheese) contain renin enzyme that is obtained from the stomach of calf.

Nature of Enzymes :

On the basis of chemical composition, enzymes can be put into two categories.

(i) **Purely proteinaceous enzymes** e.g. proteases that spilt protein (ii) **Conjugated enzymes** are made up of a protein to which a non-protein prosthetic group is attached.

The prosthetic group is firmly bound to the protein component by chemical bonds and is not removed by hydrolysis. If the prosthetic group is removed the protein part of the enzyme becomes inactive. Proteinous part of enzyme is called apoenzyme. Apoenzyme with prosthetic group together forms, holoenzyme.

There are enzymes which require certain organic compounds and inorganic ions for their activity. The organic compounds that are tightly attached to the protein part are called co-enzymes whereas the inorganic ions which are loosely attached to the protein part are called co-factors. Some of the organic co-enzymes are nicotinamide-adenine-dinucleotide (NAD) and flavin mononucleotide (FMN). Inorganic ions of metals which act as co-factors include magnesium, copper, zinc, iron, manganese etc. Iron (Fe^{++}) is a co-factor of enzyme catalase, manganese is a co-factor of peptidases. Often metal co-factors are referred to as enzyme activators.

Properties of Enzymes :

Proteinaceous Nature : All enzymes are basically made up of protein except ribozymes.

Three-Dimensional conformation : All enzymes have specific 3-dimensional conformation. They have one or more active sites to which substrate (reactant) combines. The points of active site where the substrate joins with the enzyme is called substrate-binding site.

Catalytic Property : Enzymes are like inorganic catalysts and influence the speed of biochemical reactions but themselves remain unchanged. After completion of the reaction and release of the product they remain active to catalyse again.

A small quantity of enzymes can catalyse the transformation of a very large quantity of the substrate into an end product. For example, sucrase can hydrolyse 100000 times of sucrose as compared with its own weight.

Specificity of action : The ability of an enzyme to catalyse one specific reaction and essentially no other is perhaps its most significant property.

Each enzyme acts upon a specific substrate or a specific group of substrates. Enzymes are very sensitive to temperature and pH. Each enzyme exhibits its highest activity at a specific pH, called optimum pH. Any increase or decrease in pH causes decline in enzyme activity e.g. enzyme pepsin (secreted in stomach) shows highest activity at an optimum pH of 2 (acidic). Trypsin (in duodenum) is most active at an optimum pH of 9.5 (alkaline). Both these enzymes viz. pepsin and trypsin are protein digesting enzymes.

Temperature : Enzymes are denatured or destroyed at higher temperature of 60-70°C. Below 4°C temperature they are not destroyed but become inactive. This inactive state is temporary and the enzyme can become active at suitable temperature. Most of the enzymes work at an optimum temperature between 20°C and 35°C.

Nomenclature of Enzymes :

There are various ways of naming enzymes. Enzymes are named by adding the suffix-'ase' to the name of the substrate on which they act e.g. protease, sucrase, nuclease etc. which break up proteins, sucrose and nucleic acids respectively.

The enzymes can be named according to the type of function they perform e.g. dehydrogenase remove hydrogen, carboxylase add CO_2 decarboxylases remove CO_2, oxidases helping in oxidation etc.

Some enzymes are named according to the source from which they are obtained e.g. papain from papaya, bromelain from the member of Bromeliaceae family, pineapple.

According to international code of enzyme nomenclature, the name of each enzyme ends with an -ase and consists of double name. The first name indicates the nature of substrate upon which the enzyme acts and the second name indicates the reaction catalysed e.g. pyruvic decarboxylase catalyses the removal of CO_2 from the substrate pyruvic acid. Similarly, the enzyme glutamate pyruvate transaminase catalyses the transfer of an amino group from the substrate glutamate to another substrate pyruvate.

Classification of Enzymes :

Oxidoreductases : These are enzymes catalyzing oxidation and reduction reactions by the transfer of hydrogen and/or oxygen. e.g. alcohol dehydrogenase

$$\text{Alcohol} + NAD^+ \xrightarrow[\text{dehydrogenase}]{\text{alcohol}} \text{Aldehyde} + NADH_2$$

Transferases : These enzymes catalyse the transfer of certain groups between two molecules. e.g. glucokinase

$$\text{Glucose} + \text{ATP} \xrightarrow{\text{Glucokinase}} \text{Glu-6-Phosphate} + \text{ADP}$$

Hydrolases: These are enzymes catalyse hydrolytic reactions. This class includes amylases, proteases, lipases etc. eg. Sucrase

$$\text{Sucrose} + H_2O \xrightarrow{\text{Sucrase}} \text{Glucose} + \text{Fructose}$$

Lyases : These enzymes are involved in elimination reactions resulting in the removal of a group of atoms from substrate molecule to leave a double bond. It includes aldolases, decarboxylases, and dehydratases, e.g fumarate hydratase.

$$\text{Histidine} \xrightarrow[\text{decarboxylase}]{\text{Histidine}} \text{Histamine} + CO_2$$

Isomerases : These enzymes catalyze structural rearrangements within a molecule. Their nomenclature is based on the type of isomerism. Thus these enzymes are identified as racemases, epimerases, isomerases, mutases, e.g. xylose isomerase.

$$\text{Glu-6-Phosphate} \xrightarrow{\text{Isomerase}} \text{Fructose-6-Phosphate}$$

Ligases or Synthetases : These are the enzymes which catalyse the covalent linkage of the molecules utilizing the energy obtained from hydrolysis of an energy-rich compound like ATP, GTP e.g. glutathione synthetase, Pyruvate carboxylase.

$$\text{Pyruvate} + CO_2 + \text{ATP} \xrightarrow{\text{Pyruvate carboxylase}} \text{Oxaloacetate} + \text{ADP} + \text{Pi}$$

Can you tell?

1. Which enzyme is needed to digest food reserve in caster seed?
   a. amylase b. diastase
   c. lipase d. protease
2. Co-enzyme is ---------
   a often a metal b. often a vitamin
   c. always as organic molecule
   d. always an inorganic molecule
3. List the important properties of enzymes.
4. Name the chemical found in the living cell which has necessary message for the production of all enzymes required by it.

Try this

To demonstrate the effect of heat on the activities of inorganic catalysts and enzymes.

Procedure : Take 2 ml of hydrogen peroxide (H_2O_2) in two test tubes, Add a pinch of manganese dioxide (MnO_2) powder to one and a small piece of potato (to provide enzyme catalase) or fresh liver (to provide enzyme peroxidase) to other test tube. Keep the tubes at room temperature in summer and at 38°C in winter. You will find that bubbles of oxygen evolve in both the test tubes. Both MnO_2 and cellular enzymes (catalase or peroxidase) cause breakdown of H_2O_2 and evolution of oxygen. Now take two fresh test tubes and repeat the experiment. This time, use boiled and cooled manganese dioxide and the liver/potato piece. You will find that oxygen evolves in the hydrogen peroxide solution containing boiled and cooled manganese dioxide. But oxygen does not evolve in the other tube containing boiled and cooled liver/potato piece. This activity confirms that heat does not affect catalytic action of inorganic catalyst but inactivates the enzyme.

Mechanism of enzyme action :

The basic mechanism by which enzymes catalyze chemical reactions begins with the binding of the **substrate** (or substrates) to the active site on the enzyme. The active site is the specific region of the enzyme which combines with the substrate.

The binding of the substrate to the enzyme causes changes in the distribution of electrons in the chemical bonds of the substrate and ultimately causes the reaction that lead to the formation of products. The products are released from the enzyme surface to regenerate the enzyme for another reaction cycle. There are two models to explain the mechanism of forming Enzyme-Substrate complex, as described below:

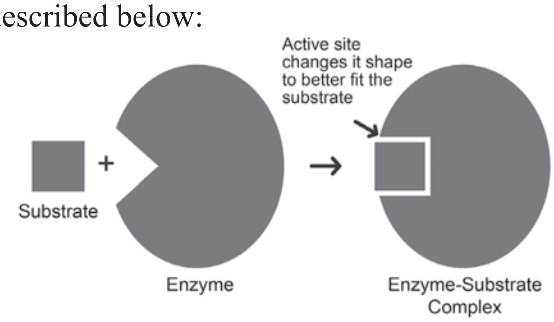


Fig. 6.16 Mechanism of enzyme action

Lock and Key model:

The specific action of an enzyme with a single substrate can be explained using a Lock and Key analogy first postulated in 1894 by Emil Fischer. In this analogy, the lock is the enzyme and the key is the substrate. Only the correctly sized key (substrate) fits into the key hole (active site) of the lock (enzyme).

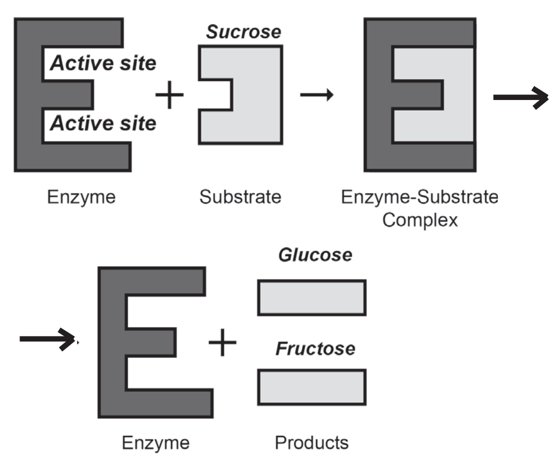


Fig. 6.17 Lock and key model

Induced Fit model (Flexible Model):

Koshland (1959) proposed the induced fit theory, which states that approach of a substrate induces a conformational change in the enzyme. It is the more accepted model to understand mode of action of enzyme. Unlike the lock-and-key model, the induced fit model shows that enzymes are rather flexible structures in which the active site continually reshapes by its interactions with the substrate until the time the substrate is completely bound to it (it is also the point at which the final form and shape of the enzyme is determined).

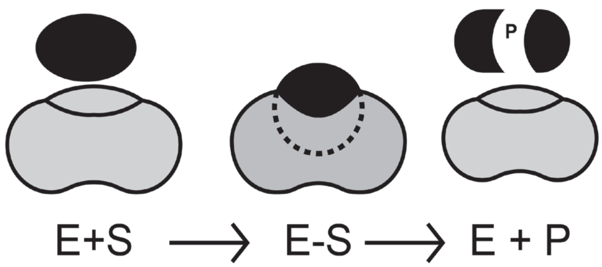


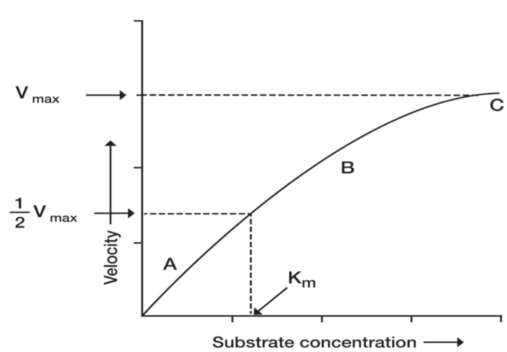
Fig. 6.18 Complex Flexible model

Factors Affecting Enzyme Activity :

Following factors affect enzyme activity :

1. Concentration of Substrate :

Increase in the substrate concentration gradually increases the velocity of enzyme activity within the limited range of substrate levels. A rectangular hyperbola is obtained when velocity is plotted against the substrate concentration. Three distinct phases (A, B and C) of the reaction are observed in the graph. Where V = Measured velocity, V_{max} = Maximum velocity, S = Substrate concentration, K_m = Michaelis-Menten constant.



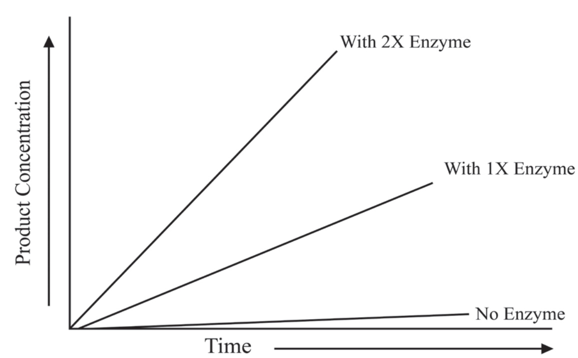
Graph 6.19 Effect of substrate concentration on enzyme activity

K_m or the Michaelis-Menten constant is defined as the substrate concentration (expressed in moles/lit) to produce half of maximum velocity in an enzyme catalysed reaction. It indicates that half of the enzyme molecules (i.e. 50%) are bound with the substrate molecules when the substrate concentration equals the K_m value.

K_m value is a constant and a characteristic feature of a given enzyme. It is a representative for measuring the strength of ES complex. A low K_m value indicates a strong affinity between enzyme and substrate, whereas a high K_m value reflects a weak affinity between them. For majority of enzymes, the K_m values are in the range of 10^{-5} to 10^{-2} moles.

2. Enzyme Concentration :

The rate of an enzymatic reaction is directly proportional to the concentration of the substrate. The rate of reaction is also directly proportional to the square root of the concentration of enzymes. It means that the rate of reaction also increases with the increasing concentration of enzyme. And the rate of reaction can also decreased by decreasing the concentration of enzyme.

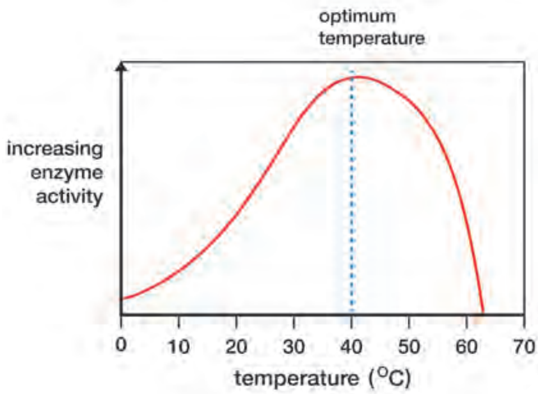


Graph 6.20 Effect of enzyme concentration

3. Temperature :

The enzymatic reaction occurs best at or around 37°C which is the average normal body temperature in homeotherms. The rate chemical reaction is increased by a rise in temperature but this is true only over a limited range of temperature. Enzymes rapidly denature at temperature above 40°C.

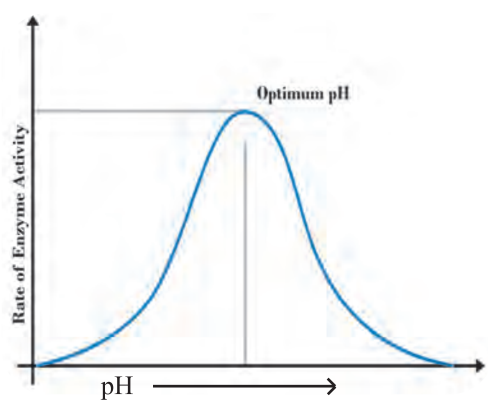
The activity of enzymes is reduced at low temperature. The temperature at which the enzymes show maximum activity is called Optimum temperature.



Graph 6.21 Effect of temperature on enzyme activity

4. Effect of pH :

Similar to temperature, there is also pH at which an enzyme will catalyze the reaction at the maximum rate. Every enzyme has different optimum pH value. The enzyme cannot perform its function beyond the range of its pH value.



Graph 6.22 Effect of pH on enzyme activity

5. Other Substances :

The enzymes action is also increased or decreased in the presence of some other substances such as co-enzymes, activators and inhibitors. Most of the enzymes are combination of a co-enzyme and an apo-enzyme. Activators are the inorganic substances which increase the enzyme activity. Inhibitor is the substance which retards the enzyme activity.

Concept of Metabolism: Metabolism is the sum of the chemical reactions that take place within each cell of a living organism and provide energy for vital processes and for synthesizing new organic material.

It involves continuous process of breakdown and synthesis of biomolecules through chemical reactions. Each of the metabolic reaction results in a transformation of biomolecules. Most of these metabolic reactions do not occur in isolation but are always linked with some other reactions.

In living systems, cells are 'work centres' where metabolism involves two following types of pathways. (Fig 6.22).

a. Catabolic pathways lead to formation of simpler structure from a complex biomolecules e.g. when we eat wheat, bread or chapati, our gastrointestinal tract digests (hydrolyses) the starch to glucose units with help of enzymes and releases energy in form of ATP (Adenosine triphosphate).

b. Anabolic pathway is called biosynthetic pathway that involves formation of a more complex biomolecules from a simpler structure, e.g., synthesis of glycogen from glucose and protein from amino acids. These pathways consume energy.

Metabolic pool : It is the reservoir of biomolecules in the cell on which enzymes can act to produce useful products as per the need of the cell. The concept of metabolic pool is significant in cell biology because it allows one type of molecule to change into another type e.g. carbohydrates can be converted to fats and vice-versa.

Catabolic chemical reaction of glycolysis and Krebs cycle not only provide ATP but also makes available metabolic pool of biomolecules that can be utilized for synthesis of many important cellular components. The metabolites can be added or withdrawn from this pool according to the need of the cell. The balance between catabolism and anabolism maintain homeostasis in the cell as well as in the whole body.

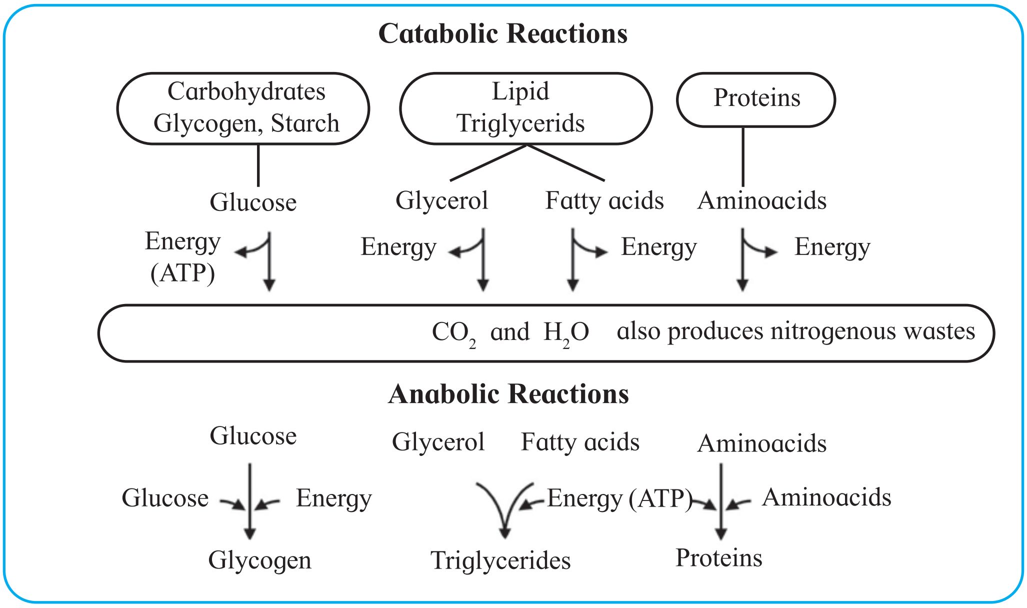


Fig. 6.22 Catabolic and anabolic reactions

Secondary metabolites (SMs) : Secondary metabolisms are small organic molecules produced by organisms that are not essential for their growth, development and reproductions. Several types of bacteria, fungi and plants produce secondary metabolites.

Secondary metabolites can be classified on the basis of chemical structure (e.g. SMs containing rings, sugar), composition (with or without nitrogen), their solubility in various solvents, or the pathway by which they are synthesized (e.g.phenylpropanoid produces tannins). A simple way of classifying secondary metabolites includes three main groups such as,

1. **Terpenes :** Made from mevalonic acid that is composed mainly of carbon and hydrogen
2. **Phenolics :** Made from simple sugars containing benzene rings, hydrogen and oxygen.
3. **Nitrogen-containg compounds :** Extremely diverse class may also contain sulphur.

Economic importance -

Secondary metabolites :

1. Secondary metabolites from natural sources have made a significant contribution for millennia. In modern medicine, drugs developed from secondary metabolites have been used to treat infectious diseases, cancer, hypertension and inflammation.
2. Morphine was the first alkaloid isolated from plant *Papaver somniferum*. It is used as pain reliever and cough suppressant.
3. SMs like alkaloids nicotine and cocaine and the terpenes cannabinol are widely used for recreation and stimulation.
4. Flavours of secondary metabolites improve our food preference.
5. Characteristic flavours and aroma of cabbage and its relatives are caused by nitrogen and sulphur-containing chemicals, glucosinolates, protect these plants from many pests.
6. Tannins are added to wines and chocolate for improving astringency.
7. Since most of secondary metabolites are having antibiotic properties, they are also used as food preservatives.

Exercise

1. Choose correct option

A. Sugar, amino acids and nucleotides unite to their respective subunits to form--------
a. bioelements b. micromolecules
c. macromolecules d. each of these

B. Glycosidic bond is found in ---------------.
a. Disaccharide b. Nucleosides
c. Polysaccharide d. each of these

C. Amino acids in a polypeptide are joined by ---------------bond.
a. Disulphide b. glycosidic
c. hydrogen bond d. none of these

D. Lipids associated with cell membrane are ------------.
a. Spingomyelin b. Isoprenoids
c. Phospolipids d. Cholesterol

E. Linoleic, Linolenic and -------------------- acids are referred as essential fatty acids since they cannot be synthesized by the body and hence must be included in daily diet.
a. Arachidonic b. Oleic
c. Stearic d. Palmitic

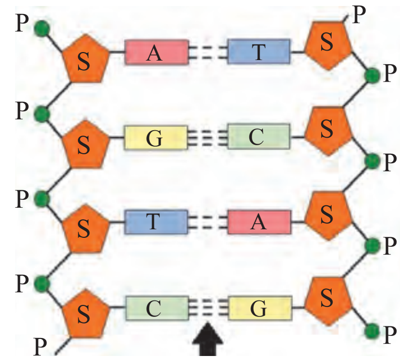
F. Haemoglobin is a type of -------------- protein, which plays indispensible part in respiration.
a. simple b. derived
c. conjugated d. complex

G. When inorganic ions or metallo-organic molecules bind to apoenzyme, they together form------
a. isoenzyme b. holoenzyme
c. denatured enzyme d. none of these

H. In enzyme kinetics, Km= Vmax/2. If Km value is lower, it indicates ----------------
a. Enzyme has less affinity for substrate
b. Enzyme has higher affinity towards substrate
c. There will be no product formation
d. All active sites of enzyme are saturated.

2. Solve the following questions:

A. Observe the following figure and name the type of bond shown by arrow in the structure.



3. Answer the following questions

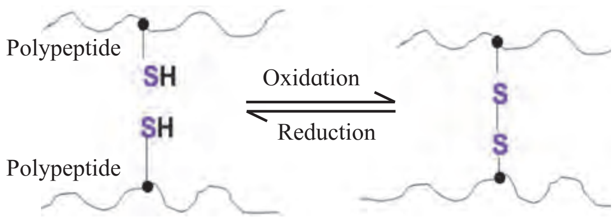
A. What are building blocks of life?
B. Explain the peptide bond.
C. How many types of polysaccharides you know?
D. Enlist the significance of carbohydrates.
E. What is a reducing sugar?
F. What is the basic difference between saturated and unsaturated fatty acid?
G. Enlist the examples of simple proteins and give their significance.
H. Explain the secondary structure of protein with examples.
I. Explain the induced fit model for mode of enzyme action.
J. What is RNA? Enlist types of RNA.
K. Describe the concept of metabolic pool.
L. How do secondary metabolites are useful for mankind?

4. Solve the following questions:

A. Complete the following chart.

Protein	Physiological role
Collagen	....
....	Responsible for muscle contraction
Immunoglobulin IgG	....
....	Significant in respiration
Fibrinogen	....

B. Answer the questions with reference to the following figure.



i. Name the type of bond formed between two polypeptides.

ii. Which amino acid is involved in the formation of such bond?

iii. Amongst I, II, III and IV structural levels of protein, which level of structure includes such bond?

C. Match the following items given in column I and II.

Column I	Column II
i. RNA	a. Induced fit model
ii. Yam plant	b.Flax seeds
iii. Koshland	c. Hydrolase
iv. Omega-3-fatty acid	d. Uracil
v. Sucrase	e. Anti-fertility pills

5. Long answer questions

A. What are biomolecules? Explain the building blocks of life.

B. Explain the classes of carbohydrates with examples.

C. Describe the types of lipids and mention their biological significance.

D. Explain the chemical nature, structure and role of phospholipids in biological membrane.

E. Describe classes of proteins with their importance.

F. What are enzymes? How are they classified? Mention example of each class.

G. Explain the properties of enzymes.

H. Describe the factors affecting enzyme action.

I. What are nucleic acids? Enlist the point of differences among DNA and RNA.

J. What are the types of RNA? Mention the role of each class of RNA.

K. What is metabolism? How metabolic pool is formed in the cell.

6. If double stranded DNA has 14% C (cytosine) what is percentage of A (adenine), T(thymine) and G (gaunine) would you expect?

7. Name

i. The term that describes all the chemical reactions taking place in an organism.

ii. The form in which carbohydrate is transported in a plant.

iii. The reagent used for testing of reducing sugar.

Practical / Project :

1. Perform an experiment to study starch granules isolated from potato.

2. Study the action of enzyme urease on urea.