CHEMICAL CONSTITUENTS OF THE CELL AND CELL ORGANELLES

- Cells, tissues and organs are composed of chemicals, many of which are identical with those found in nonliving matter, while others are unique to living organisms.
- The study of chemical compounds found in living systems and reactions in which they take part is known as **biochemistry**.
- Studies of the structure and behaviour of individual molecules constitute **molecular biology**.

Composition of the living substance (protoplasm)

multitude of non-living constituents :

- proteins,
- nucleic acids,
- fats (lipids),
- carbohydrates,
- vitamins,
- minerals,
- waste metabolites,
- crystalline aggregates,
- pigments,
- and many others,

all of which are composed of molecules and their constituent atoms.

- The *protoplasm is alive because of the highly complex organization of these non-living substances and the way they interact with one another*.
- This is just like a watch which is a time piece only when all of its gears, springs, and bearings are organized in a particular way and interact with one another.
- Neither the gears of a watch nor the molecules in protoplasm can interact in any way that is contrary to universal physical laws.
- Consequently, the more completely we can understand the functioning of protoplasm and its constituents on the basis of chemical principles, the more completely we can understand the phenomenon of life.

PHYSICAL NATURE OF CYTOSOL (OR CYTOPLASMIC MATRIX)

- The cytosol (cytoplasmic matrix) is a colourless or greyish, translucent, viscid, gelatinous or jelly-like colloidal substance.
- It is heavier than water and capable of flowing.
- Proteins form stable colloids because, firstly, they are charged ions in solution that repel each other, and, secondly each protein molecule attracts water molecules around it in definite layers.

Phase Reversal: Cytosol (cytoplasmic matrix) like many colloidal systems, shows the property of **phase reversal**.

For example, gelatin particles (discontinuous phase) are dispersed through water (continuous phase) in a thin consistency that is freely shakable . Such a condition is called a **sol**.

When the solution cools, gelatin now becomes the continuous phase and the water is in the discontinuous phase. Moreover, now the solution has stiffened and becomes semisolid and is called a **gel**.

CHEMICAL ORGANIZATION OF CYTOSOL (OR CYTOPLASMIC MATRIX)

Chemically, the cytoplasmic matrix is composed of many chemical elements in the form of atoms, ions and molecules.

Chemical Elements

- Of the 92 naturally occurring elements, perhaps 46 are found in the cytosol (cytoplasmic matrix).
- Twenty four of these are considered essential for life (called **essential elements**), while others are present in cytosol only because they exist in the environment with which the organism interacts.
- Of the 24 essential elements, six play especially important roles in living systems.
- These **major elements** are carbon (C, 20 per cent), hydrogen (H, 10 per cent), nitrogen (N, 3 per cent), oxygen (O, 62 percent), phosphorus (P, 1.14 per cent) and sulphur (S,0.14 per cent). Most organic molecules are built with these six elements.
- Another five essential elements found in less abundance in living systems are calcium (Ca, 2.5 per cent), potassium (K, 0.11 per cent), sodium (Na, 0.10 per cent), chlorine (Cl, 0.16 per cent) and magnesium (Mg, 0.07 per cent).
- Several other elements, called **trace elements**, are also found in minute amounts in animals and plants but are nevertheless essential for life.
- These are iron (Fe, 0.10 per cent), iodine (I, 0.014 per cent), molybdenum (Mo), manganese (Mn), Cobalt (Co), zinc (Zn), selenium (Se), copper (Cu), chromium (Cr), tin (Sn), vanadium (V), silicon (Si), nickel (Ni), fluorine (F) and boron (B).

Ions

- The cytoplasmic matrix consists of various kinds of ions.
- The ions are important in maintaining osmotic pressure and acid-base balance in the cells.
- Retention of ions in the matrix produces an increase in osmotic pressure and, thus, the entrance of water in the cell.
- Cellular functions of certain ions have been
- tabulated in Table

Table 4-1. Cellular functions of certain ions. (Source : Sheeler and Bianchi, 1987).

Element	Ionic form present	Functions
1. Molybdenum	MoO_4^{2-}	Cofactor or activator of certain enzymes (*e.g.*, nitrogen fixation, nucleic acid metabolism, aldehyde oxidation).
2. Cobalt	Co^{2+}	Constituent of vitamin B_{12}.
3. Copper	Cu^{+}, Cu^{2+}	Constituent of plastocyanin and cofactor of respiratory enzymes.
4. Iodine (Heaviest trace element)	I^{-}	Constituent of thyroxin, triiodothyronine and other thyroid hormones.
5. Boron	BO_3^{3-}, $B_4O_7^{2-}$	Activates arabinose isomerase.
6. Zinc	Zn^{2+}	Cofactor of certain enzymes (*e.g.*, carbonic anhydrase, carboxypeptidase).
7. Manganese	Mn^{2+}	Cofactor of certain enzymes (*e.g.*, several kinases, isocitric decarboxylase).
8. Iron	Fe^{2+}, Fe^{3+}	Constituent of haemoglobin, myoglobin and cytochromes.
9. Magnesium	Mg^{2+}	Constituent of chlorophyll; activates ATPase enzyme.
10. Sulphur	SO_4^{2-}	Constituent of coenzyme A, biotin, thiamine, proteins.
11. Phosphorus	PO_4^{3-}, $H_2PO_4^{-}$	Constituent of lipids, proteins, nucleic acids, sugar phosphates, nucleoside phosphates.
12. Calcium	Ca^{2+}	Constituent of plant cell walls; matrix component of bone tissue; cofactor of coagulation enzymes.
13. Potassium	K^{+}	Cofactor for pyruvate kinase and K^{+}- stimulated ATPase.

Electrolytes and Non-electrolytes

The matrix consists of both electrolytes and non-electrolytes.

(i) Electrolytes. The electrolytes play a vital role in the maintenance of osmotic pressure and acid base equilibrium in the matrix. Mg2+ ions, phosphate, etc., are good examples of the electrolytes.

(ii) Non-electrolytes.

- Some of minerals occur in matrix in non-ionizing state.
- The non-electrolytes of the matrix are Na, K, Ca, Mg, Cu, I, Fe, Mn, Fl, Mo, Cl, Zn, Co, Ni, etc.
- The iron (Fe) occurs in the haemoglobin, ferritin, cytochromes and some enzymes as catalase and cytochrome oxidase.
- The calcium (Ca) occurs in the blood, matrix and the bones.
- The copper (Cu), manganese (Mn), molybdenum (Mo), zinc (Zn) are useful as cofactors for enzymatic actions.
- The iodine and fluorine are essential for the thyroid and the enamel metabolism, respectively.

TYPES OF COMPOUNDS OF CYTOSOL

Chemical compounds are conventionally divided into two groups : **organic** and **inorganic**.
Organic compounds form 30 per cent of a typical cell, rest are the inorganic substances such as water and other substances.

INORGANIC COMPOUNDS

The inorganic compounds are those compounds which normally found in the bulk of the physical, non-living universe, such as elements, metals, non-metals, and their compounds such as water, salts and variety of electrolytes and non-electrolytes.

Water

- The most abundant inorganic component of the cytosol is the water (the notable exceptions are seeds, bone and enamel).
- Water constitutes about 65 to 80 per cent of the matrix. In the matrix the water occurs in two forms, *viz*., **free water** and **bound water**.
- The 95 per cent of the total cellular water is used by the matrix as the solvent for various inorganic substances and organic compounds and is known as **free water**.
- The remaining 5 per cent of the total cellular water remains loosely linked with protein molecules by hydrogen bonds or other forces and is known as **bound water.**
- The water contents of the cellular matrix of an organism depend directly on the age, habitat and metabolic activities.
- For instance, the cells of the embryo have 90 to 95 per cent water which decreases progressively in the cells of the adult organism.
- The cells of lower aquatic animals contain comparative high percentage of the water than the cells of higher terrestrial animals.
- Further the percentage of water in the matrix also varies from cell to cell according to the rate of the metabolism.

Table 4-2. The approximate percentage composition of the human body (Source : Roberts, 1986).

Substance	Percentage
1. Water	65
2. Protein	18
3. Fat	10
4. Carbohydrate	5
5. Other organic	1
6. Inorganic	1

ORGANIC COMPOUNDS

- The chemical substances which contain carbon (C) in combination with one or more other
- elements as hydrogen (H), nitrogen (N), sulphur (S), etc., are called **organic compounds**.
- The organic compounds usually contain large molecules which are formed by the similar or dissimilar unit structure known as the **monomers**.
- A monomer (Gr., *mono*=one, *meros*=part) is the simplest unit of the organic molecule which can exist freely.
- Some organic compounds such as carbohydrates occur in the matrix as the monomers.
- The monomers usually link with other monomers to form **oligomers** (Gr., *oligo*=few or little, *meros*=part) and **polymers** (Gr., *poly*=many, *meros*=part).
- The oligomers contain small number of monomers, while the polymers contain large number of monomers.
- The oligomers and polymers contain large-sized molecules or macromolecules.
- When a polymer contains similar kinds of monomers in its macromolecule it is known as **homopolymer** and when the polymer is composed of different kinds of monomers it is known as the **heteropolymer**.
- The main organic compounds of the matrix are the carbohydrates, lipids, proteins, vitamins, hormones and nucleotides.

Carbohydrates

- The carbohydrates (L., *carbo*=carbon or coal, Gr.,*hydro*=water) are the compounds of the carbon, hydrogen and oxygen.
- They form the main source of the energy of all living beings.
- Only green part of plants and certain microbes have the power of synthesizing the carbohy-drates from the water and CO2 in the presence of sunlight and chlorophyll by the process of
- photosynthesis.
- All the animals, non-green parts of the plants (*viz*., stem, root, etc.), non-green plants
- (*e.g*., fungi), bacteria and viruses depend on green parts of plants for the supply of carbohydrates.
- Chemically the carbohydrates are polyhydroxy aldehydes or ketones and they are classified as
- follows :
- Monosaccharides (Monomers), B. Oligosaccharides (Oligomers), and C. Polysaccharides
- (Polymers).

A. Monosaccharides. The monosaccharides are the simple sugars with the empirical formula
C*n* (H2O)*n*. They are classified and named according to the number of carbon atoms in their molecules
as follows :

(i) Trioses contain three carbon atoms in their molecules, *e.g*., glyceraldehyde and dihydroxy acetone.

(ii) Tetroses contain four carbon atoms in their molecules, *e.g*.,erythrulose and erythrose.

(iii) Pentoses contain five carbon atoms in their molecules, *e.g.*, ribose, ribulose, deoxyribose, arabinose and xylulose.

(iv) Hexoses contain six carbon atoms in their molecules, *e.g*., glucose, mannose, fructose and galactose.

(v) Heptoses contain seven carbon atoms in their molecules, *e.g.*, sedoheptulose.

- . The pentoses and hexoses are the most abundantly occurring monosaccharides of the

- matrix.
- The pentose sugar, **ribose** is the important constituent molecule of the ribonucleic acid (RNA)
- and certain coenzymes as nicotinamide adenine dinucleotide (NAD), NAD phosphate (NADP), adenosine triphosphate (ATP) and coenzyme A (CoA). Another pentose sugar the **deoxyribose** is the important constituent of the deoxyribonucleic acid (DNA).
- The **ribulose** is a pentose sugar which is necessary for photosynthetic mechanism.
- The **glucose**, a hexose sugar, is the primary source of the energy for the cell.
- The other important hexose sugars of the matrix are the fructose and galactose.

B. Oligosaccharides. The oligosaccharides consist of 2 to 10 monosaccharides (monomers) in their molecules. The monomers remain linked with each other by the **glycosidic bonds** or **linkages**.

Certain important oligosaccharides are as follows : **(i) Disaccharides** contain two monomers, *e.g.,* sucrose, maltose, lactose, etc.

(ii) Trisaccharides contain three monomers, *e.g.,*reffinose, mannotriose, rabinose, rhaminose, gentianose and melezitose.

(iii) Tetrasaccharides contain four monomers, *e.g.,*stachyose and scordose.

(iv) Pentasaccharides contain five monomers, *e.g.,* verbascose.

- The most abundant oligosaccharides of the animal and plant cells are the disaccharides
- such as sucrose, maltose and lactose.
- The sucrose and maltose occur mainly in the matrix of plant cells, while the lactose occurs exclusively in the matrix of animal cells.

.

C. Polysaccharides.

- The polysaccharides are composed of ten to many thousands monosaccharides as the monomers in their macromolecules.
- Their empirical formula is $(C6H10O6)n$.
- The molecules of the polysaccharides are of colloidal size having high molecular weights.
- The polysaccharides can be hydrolysed into simple sugars.
- Polysaccharides can be divided into two main functional groups : the structural polysaccharides and the nutrient polysaccharides.
- The **structural polysaccharides** serve primarily as extracellular or intracellular supporting elements.
- Included in this group are **cellulose** (found in plant cell wall), **mannan** (a homopolymer of mannose found in yeast cell walls), **chitin** (in the exoskeleton of arthropods and the cell walls of most fungi and some green algae), **hyaluronic acid**, **keratin sulphate** and **chondroitin sulphate** (these three are found in cartilage and other connective tissues) and the **peptidoglycans** (in
- bacterial cell wall).
- The **nutrient polysaccharides** serve as reserves of monosaccharides and are in continuous metabolic turnover.
- Included in this group are **starch** (plant cells and bacteria), **glycogen** (animal cells), *-+9qq**inulin** (plants such as artichokes and dandelions) and**paramylum** (an unbranched nutrient and storage homopolymer of glucose found in certain protozoa, *e.g., Euglena*).
- Molecules of some polysaccharides are **unbranched** (*i.e.,* linear) chains whose structure may be

- ribbon-like or helical (usually a left-handed spiral).
- Other polysaccharides are **branched** and, like many proteins, assume a globular form.
- On the chemical basis, the polysaccharides can be divided into two broad classes : the homopolysaccharides and the heteropolysaccharides.

Homopolysaccharides.

- The homopolysaccharides contain similar kinds of monosaccharides in their molecules.
- The most important homopolysaccharides of the matrix are the starch, glycogen, paramylum and cellulose.

Heteropolysac-charides.

- The polysaccharides which are composed of different kinds of the monosaccharides and amino-nitrogen or sulphuric or phosphoric acids in their molecules are known as heteropolysac-charides.
- The most important heteropolysaccharides are as follows:

Hyaluronic acid, keratin sulphate and chondroitin sulphate.

Glycoproteins (or **glycosaminoglycans** or **mucopolysaccharides**).

- In these molecules, the carbohydrate portion consists of much shorter chains which are often branched.
- Glycoproteins serve diverse roles in cells and tissues and include certain enzymes, hormones, blood groups, saliva, gastric mucin, ovomucoids, serum, albumins, antibodies or immunoglobins .

Glycolipids.

- These molecules are covalent combinations of carbohydrate and lipid.
- The carbohydrate portion may be a single monosaccharide or a linear of branched chain. Glycolipids form the component of most cell membranes, *e.g.*, cerebrosides and gangliosides.

Lipids (Fats)

- The lipids (Gr., *lipos*=fats) are the organic compounds which are insoluble in the water but soluble in the non-polar organic solvents such as acetone, benzene, chloroform and ether.
- The cause of this general property of lipids is the predominance of long chains of aliphatic hydrocarbons or benzene ring in their molecules.
- The lipids are non-polar and hydrophobic.
- The common examples of lipids are cooking oil, butter, ghee, waxes, natural rubber and cholesterol.
- Like the carbohydrates, lipids serve two major roles in cells and tissues :
  1. They occur as constituents of certain structural components of cells such as membranous organelles; plant pigments such as **carotene** found in carrots

and **lycopene** that occurs in tomatoes; vitamins like A, E and K; menthol and eucalyptus oil; and (2) they may be stored within cells as reserve energy sources.

- Natural fats and oils are compounds of **glycerol** (*i.e.*, glycerine or propane- 1, 2, 3 triol) and **fatty acids**.
- They are esters which are formed due to reaction of organic acids with alcohols.
- **Fatty acids.** A fatty acid molecule is **amphipathic** and has two distinct regions or ends: a long **hydrocarbon chain**, which is **hydrophobic** (water insoluble) and not very reactive

chemically, and a **carboxylic acid group** which is ionized in solution (COO–), extremely **hydrophilic**

- (water soluble) and readily forms esters and amides.
- A fatty acid molecule may be either saturated or unsaturated. The **saturated fatty acids** consist
- of long hydrocarbon chains terminating in a carboxyl group and conform to the general formula : $CH_3 – (CH_2)_n – COOH$
- In nearly all naturally occurring fatty acids, *n* is an even number from 2 to 22.
- In the **saturated fatty acids**, most commonly found in animal tissues, *n* is either 12 (*i.e.*, **myristic acid**), 14 (*i.e.*, **palmitic acid**) or 16 (*i.e.*, **stearic acid**).
- In **unsaturated fatty acids**, at least two but usually no more than six of the carbon atoms of the hydrocarbon chain are linked together by double bonds (– C = C –), *e.g.*, **oleic acid**, **linoleic**, **linolenic, arachidonic** and **clupanadonic acids**.

Essential fatty acids. Some animals, especially mammals, are unable to synthesize certain fatty acids and, therefore, require them in their diet. They are called **essential fatty acids** and include linoleic acid, linolenic acid and arachidonic acid. Such essential fatty acids have to be obtained from plant material by the animal.

Types of lipids. The lipids are classified into three main types : 1. simple lipids, 2. compound lipids and 3. derived lipids.

1. Simple lipids. The simple lipids are alcohol esters of fatty acids :

$$\text{Triglyceride} \xrightarrow{\text{Lipase}} \text{Glycerol} + 3 \text{ Fatty acids.}$$

Simple lipids are also of following two types :

(a) Neutral fats (Glycerides or triglycerides).

(b) Waxes.

2. Compound lipids. The compound lipids contain fatty acids, alcohols and other compounds as phosphorus, amino-nitrogen carbohydrates, etc., in their molecules. E.g

i) **Phospholipids (or Glycerophos-phatides).**
ii) **Sphingolipids.**
iii) **Glycolipids.**

Proteins

- Of all the macromolecules found in the cell, the proteins are chemically and physically more diverse.
- They are important constituents of the cell forming more than 50 per cent of the cell's
- dry weight.
- The term protein was coined by Dutch chemist **G.J. Mulder** (1802—1880) and is derived from Greek word *proteios*, which means "of the first rank".
- Proteins serve as the chief structural material of protoplasm and play numerous other essential roles in living systems.
- They form enzymes—globular proteins specialized to serve as catalysts in virtually all biochemical activities of the cells.
- Other proteins are antibodies (immunoglobulins), transport proteins, storage proteins, contractile proteins, and some hormones.
- In every living organism, there are thousands of different proteins, each fitted to perform a specific functional or structural role.
- Indeed, a single human cell may contain more than 10,000 different protein molecules. Chemically, proteins are polymers of amino acids.

- There are about 20 different amino acids which occur regularly as constituents of naturally occurring proteins.
- An organic compound containing one or more amino groups (–NH2) and one or more carboxyl groups (—COOH) is known as amino acid.

.

2. Formation of proteins.

- Because a molecule of the amino acid contains both basic or amino (—NH2) and acidic or carboxyl (—COOH) group, it can behave as an acid and base at a time.
- The molecules of such organic compounds which contain both acidic and basic properties are known as **amphoteric molecules**.
- Due to amphoteric molecules, the amino acids unite with one another to form complex and large protein molecules.
- When two molecules of amino acids are combined then the basic group (—NH2) of one amino acid molecule combines with the carboxylic (—COOH) group of other amino acid and the loss of a water molecule takes place.
- This sort of condensation of two amino acid molecules by —NH—CO linkage or bond is known as **peptide linkage** or **peptide bond**.
- A combination of two amino acids by the peptide bond is known as **dipeptide**.
- When three amino acids are united by two peptide bonds, they form **tripeptide**. Likewise, by condensation of few or many amino acids by the peptide bonds the **oligopeptides** and **polypeptides** are formed respectively.

Types of proteins. Many different methods have been used to classify proteins, no method of their classification being entirely satisfactory :

(1) Classification based on biological functions. According to their biological functions, proteins are of two main types :

1. Structural proteins which include **keratin**, the major protein component of hair (cortex), wool, fur, nail, beak, feathers, hooves and cornified layer of skin; and **collagen**, abundant in skin, bone, tendon, cartilage and other connective tissues.

2. Dynamic or functional proteins which include the enzymes that serve as catalysts in metabolism, hormonal proteins, respiratory pigments, etc.

(2) Classification based on shape of proteins. According to the shape or conformation, two major types of proteins have been recognized :

(a) Fibrous proteins.

- Fibrous proteins are water-insoluble, thread-like proteins having greater
- length than their diameter.
- They contain secondary protein structure and occur in those cellular or extracellular structures, where strength, elasticity and rigidity are required,
- *e.g.*, collagen, elastin, keratin, fibrin (blood-clot proteins) and myosin (muscle contractile proteins).

(b) Globular proteins

- **.** Globular proteins are water-soluble, roughly spheroidal or ovoidal in shape.
- They readily go into colloidal suspension. They have tertiary protein structure and are usually functional proteins, *e.g.*, enzymes, hormones and immunoglobulins (antibodies).

(3) Classification based on solubility characteristics.

(A) Simple proteins. These proteins contain only amino acids in their molecules and they are of following types :

(i) Albumins. These are water soluble proteins found in all body cells and also in blood stream, *e.g.*, **lactalbu min**, found in milk and **serum albumin** found in blood.
(ii) Globulins. These are insoluble in water but are soluble in dilute salt solutions of strong acids and bases, *e.g.*, **lactoglobulin** found in milk and **ovoglobulin**.
(iii) Glutelins. These plant proteins are soluble in dilute acids and alkalis, *e.g.*, **glutenin** of wheat.
(iv) Prolamines. These plant proteins are soluble in 70 to 80 per cent alcohol, *e.g.*, **gliadin** of wheat and **zein** of corn.
(v) Scleroproteins. They are insoluble in all neutral solvents and in dilute alkalis and acids, *e.g*., keratin and collagen.
(vi) Histones. These are water soluble proteins which are rich in basic amino acids such as arginine and lysine. In eukaryotes histones are associated with DNA of chromosomes to form nucleoproteins.
(vii) Protamines. These are water soluble, basic, light weight, **arginine** rich polypeptides. They are bound to DNA in spermatozoa of some fishes, *e.g.*, **salmine**, of salmon and **sturine** in sturgeons.
(B) Conjugated proteins. These proteins consist of simple proteins in combination with some non-protein components, called **prosthetic groups**. The prosthetic groups are permanently associated
with the molecule, usually through covalent and/or non-covalent linkages with the side chains of certain amino acids. Conjugated proteins are of following types :
(i) Chromoproteins. Chromoproteins are a heterogeneous group of conjugated proteins which are in combination with a prosthetic group that is a pigment, *e.g*., respiratory pigments such as **haemoglobin**, **myoglobin** and **haemocyanin**; **catalase**, **cytochromes**, **haemerythrins**; visual purple or **rhodopsin** of rods of retina of eye and yellow enzymes or **flavoproteins**.
(ii) Glycoproteins. Glycoproteins are proteins that contain various amounts (1 to 85 per cent) of carbohydrates.
(iii) Lipoproteins. Lipid containing proteins are called **lipoproteins.** Their lipid contents are 40 to 90 per cent of their molecular weight and this tends to affect the density of the molecule.
(iv) Nucleoproteins. Nucleoproteins are proteins in combination with nucleic acids (DNA and RNA). However, these proteins are not true conjugated proteins since the nucleic acid involved cannot be regarded as prosthetic groups. .
(v) Metalloproteins. Metalloproteins are proteins conjugated to metal ions which are not part of the prosthetic group, *e.g.*, **carbonic anhydrase** enzyme contains zinc ions and amino acids in its molecule; **caeruloplasmin**, an oxidase enzyme containing copper; and **siderophilin** contains iron.
(vi) Phosphoproteins. Phosphoproteins are proteins in combination with a phosphate group, *e.g*., casein of the milk and ovovitellin of eggs.

Enzymes

- The cytoplasmic matrix and many cellular organelles contain very important organic compounds known as the **enzymes**.
- The word enzyme (Greek. “in yeast”) had been proposed by **Kuhne** in 1878. The enzymes are the specialized proteins and they have the capacity to act as catalysts in chemical reaction.

- Like the other catalysts of chemical world, the enzymes are the catalysts of the biological world and they influence the rate of a chemical reaction, while themselves remain quite unchanged at the end of the reaction.
- The substance on which the enzymes act is known as **substrate**.
- The enzymes play a vital role in various metabolic and biosynthetic activities of the cell such as synthesis (anabolism) of DNA, RNA and protein molecules and catabolism of carbohydrates, lipids, fats and other chemical substances.

The enzymes of the matrix and cellular organelles are classified as follows :

1. **Oxireductases.**

➢ The enzymes catalyzing the oxidation and reduction reaction of the cell are known as oxireductases.

➢ These enzymes transfer the electrons and hydrogen ions from the substrates, *e.g.*, hydrogenases or reductases, oxidases, oxygenases and peroxidases.

2. Transferases.

➢ The enzymes which transfer following groups from one molecule to other are known as transferases :

➢ one carbon, aldehydic or ketonic residues, acyl, glycosyl, alkyl, nitrogenous, phosphorus containing groups and sulphur containing groups.

3. Hydrolases.

➢ These enzymes hydrolyse a complex molecule into two compounds by adding

➢ the element of the water across the bond which is cleaved.

➢ These enzymes act on the following bonds– ester, glycosyl, ether, peptide, other C–N bonds, acid anhydride, C–C, halide and P–N bonds.

➢ Certain important hydrolase enzymes are the proteases, esterases, phosphatases, nucleases and phosphorylases.

4. Lysases.

➢ The lysase enzymes add or remove group to or from the chemical compounds containing the double bonds.

➢ The lysases act on C–C, C–O, C–N, C–S and C–halide bonds.

5. Isomerases. These enzymes catalyse the reaction involving in the isomerization or intramolecular rearrangements in the substrates, *e.g.*, intramolecular oxidoreductases, intramolecular transferases, intramolecular lysases, cis-trans-isomerases, racemases and epimerases.

6. Ligases or synthetases. These enzymes catalyze the linkage of the molecules by splitting a phosphate bond.

The synthetase enzymes form C–O, C–S, C–N and C–C bonds.

According to the chemical nature of the substrate the enzymes have also been classified as follows:

1. Carbohydrases, 2. Proteases (endopeptidases and exopeptidases), 3. Amylases, 4. Esterases,
5. Dehydrogenases, 6. Oxidases, 7. Decarboxylases, 8. Hydrases, 9. Transferases, and 10. Isomerases.

Isoenzymes

- Recently, it has been investigated that some enzymes have similar activities and almost similar molecular structures. These enzymes are known as **isoenzymes**.

Vitamins

- The vitamins are organic compounds of diverse chemical nature. They are required in minute amounts for normal growth, functioning and reproduction of cells.
- The vitamins play an important role in the cellular metabolism and act as the enzymes or other biological catalysts in the various chemical activities of the cell.
- The animal cell cannot synthesize the vitamins from the standard food and so they are taken along with the food.

Hormones

- Hormones are the complex organic compounds which occur in traces in the cytoplasm and regulate the synthesis of mRNA, enzymes and various other intracellular physiological activities.
- The most important hormones are growth hormones, estrogen, androgen, insulin, thyroxine, cortisone, and adrenocortical hormones, etc.
- These hormones are synthesized by the ductless or endocrine glands and transported to various cells of multicellular organisms by blood vascular system.

Nucleic Acids

- The nucleic acids are the complex macromolecular organic compounds of immense biological
- importance.
- They control the important biosynthetic activities of the cell and carry hereditary informations from generation to generation.
- There occur two types of nucleic acids in living organims, *viz*., **Ribonucleic acid (RNA)** and **Deoxyribonucleic acid (DNA)**.
- Both types of nucleic acids are the polymers of the nucleotides.