BIOMOLECULES

- The structure and function of different cell constituents are an interplay of their constituent chemicals, their arrangement and properties. Chemicals or molecules present in the living organism are known as **biomolecules.** The collection or sum total of different types of biomolecules, compounds and ions present in a cell is called the **cellular pool.**
- Biomolecules are of two types, **inorganic** and **organic.** Inorganic constituents of cellular pool are minerals, gases and water. Organic constituents are carbohydrates, lipids, amino acids, proteins, enzymes, nucleotides, nucleic acids, vitamins, etc.
- Thousands of organic compounds including fats and oils, nucleotides, amino acids, sugars, etc. are called **primary metabolites.** However, when analysing plant, fungal and microbial cells, it is seen that thousands of compounds other than these called primary metabolites; for example alkaloids, flavonoides, rubber, essential oils, antibiotics, coloured pigments, scents, gums, spices etc are formed. These are called **secondary metabolites.** Many of these are useful to 'human welfare' (*e.g.*, rubber, drugs, spices, scents and pigments). Some have ecological importance.
- Chemical compounds found in living organisms are of two types. One, those which have molecular weights less than one thousand dalton and are usually referred to as **micromolecules** or **simply biomolecules** while those which are found in the acid insoluble fraction are called **macromolecules** or **biomacromolecules.** The molecules in the insoluble fraction with the exception of lipids are **polymeric substances.** Lipids are small molecular weight compounds and are not strictly macromolecules.

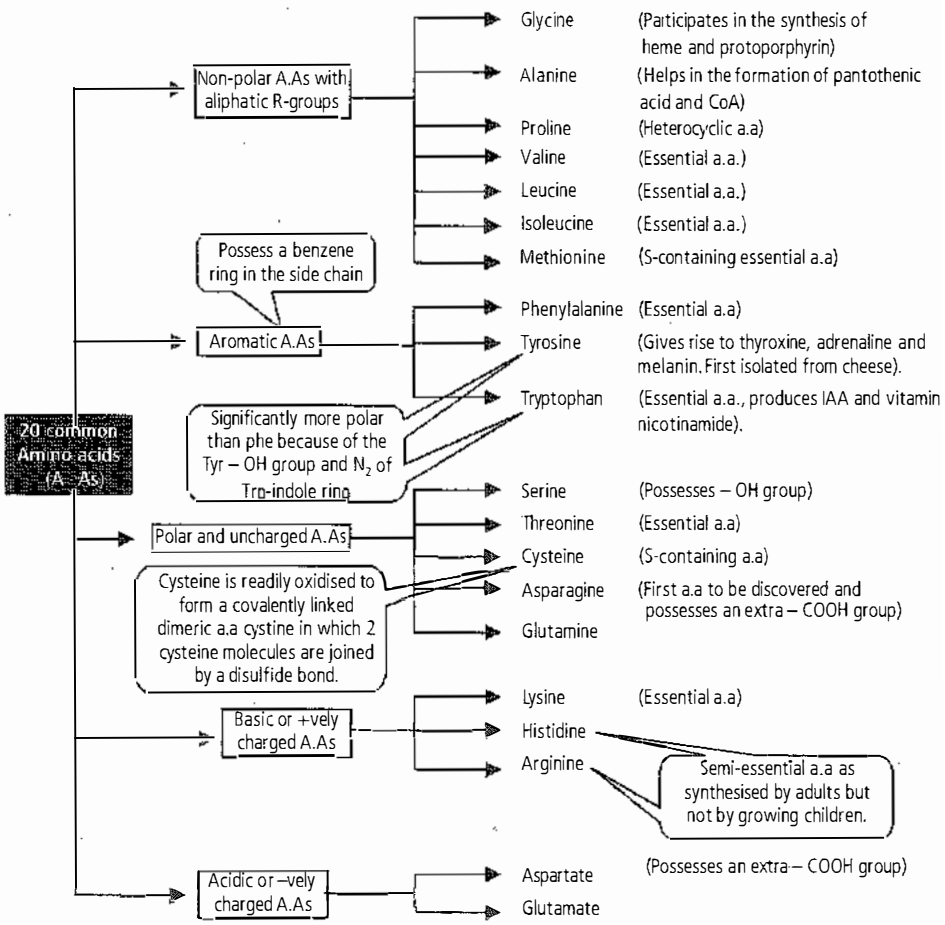


Table : Average composition of cells

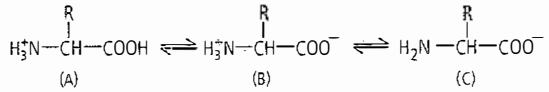
Component	% of the total cellular mass
Water	70 – 90
Proteins	10 – 15
Carbohydrates	3
Lipids	2
Nucleic acids	5 – 7
Ions	1

PROTEINS AND AMINO ACIDS

- Proteins are the most abundant biological macromolecules occurring in all cells and all parts of cells. These are heteropolymeric macromolecules having one or more polypeptides. They are linear chains of amino acids linked by peptide bonds.
- All proteins are constructed from the same ubiquitous set of **20 amino acids,** covalently linked by peptide bonds in characteristics linear sequences. Amino acids condense to produce **peptides.** The bond formed is called **peptide bond.**
- A chain containing two amino acids linked by a peptide bond is called **dipeptide.** There are three amino acids in a **tripeptide,** a few in **oligopeptide** and numerous in **polypeptide. Thus amino acids are the building blocks of proteins.**
- Structurally each amino acid consists of a centrally located carbon (α-carbon) to which four groups are attached, an **amino group, carboxylic group, hydrogen atom** and a **variable hydrocarbon** or **alkyl group (R).** With four different groups attached to it the α-carbon is said to be **asymmetric.**
- R can be **polar** with negative charge, *e.g.,* glutamic acid, polar uncharged *e.g.*, serine, polar with positive charge, *e.g.,* lysine or non polar uncharged, *e.g.*, alanine. Some

amino acids (proline and hydroxyproline) have –NH (**imino group**) instead of $-NH_2$, so they are called **imino acids.**

- Due to presence of two opposite electric charges the amino acids are **amphoteric** in nature. Amino acids are also called **zwitterions** as they can carry both positive and negative charges.



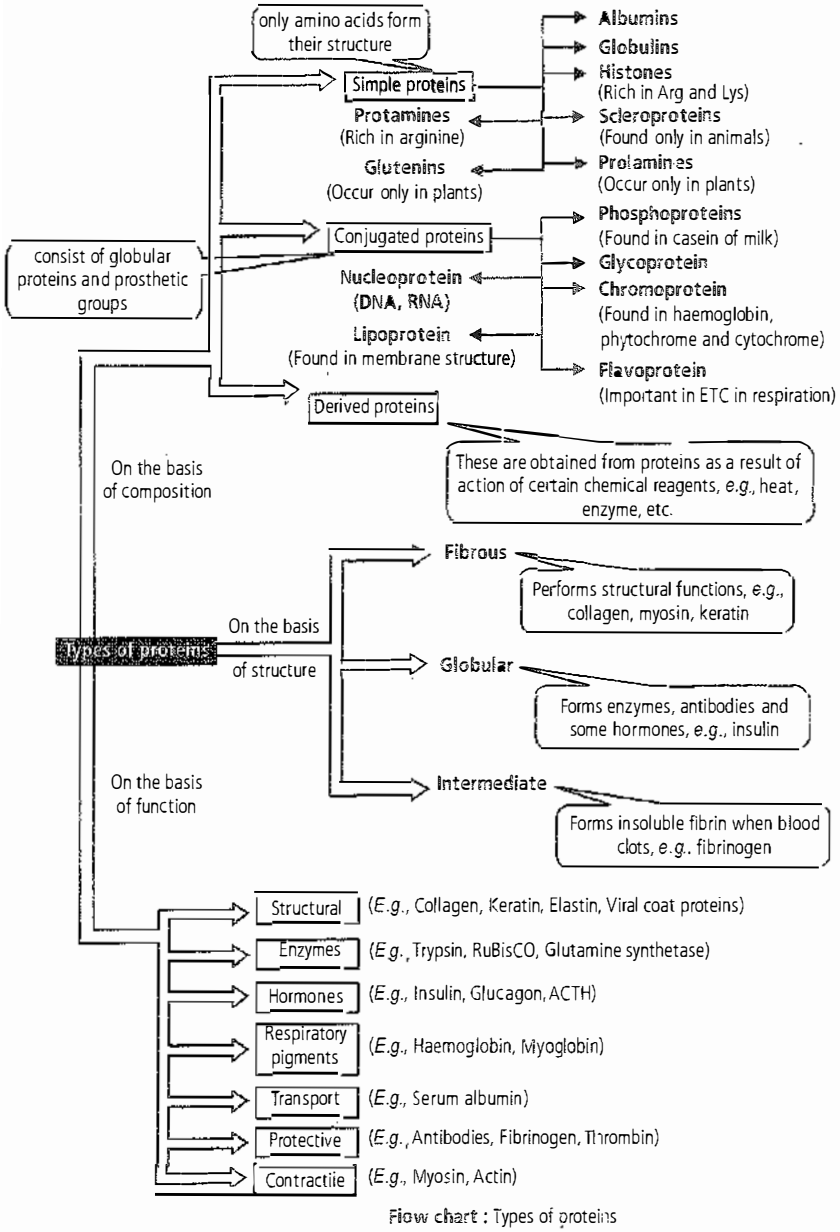
(A) (B) (C)

(B) is called zwitterionic form

- Two amino acids can join through amino group of one and carboxylic group of the other forming a **– CO – NH – linkage** or **peptide bond.**
- **Essential amino acids** are those which are taken from plants and not synthesised in animal body. Other amino acids may be synthesised in the body, and are not required to be supplied from outside. They are called as **non-essential amino acids.**

Structures of protein

- A description of all covalent bonds linking amino acid residues in a polypeptide chain is its **primary structure.**
- The most important element of primary structure is the sequence of amino acid residues.
- **Secondary structure** refers to particularly stable arrangements of amino acids giving rise to recurring structural patterns.
- The peptide chain is of two types - **right handed α-helix** and **β-pleated sheets.** Former is the most common.
- α-helix proteins are common in **keratin** in hair, **myosin** and **tropomyosin** in muscles. **The helical structures serve a mechanical role in forming stiff bundles of fibres.**
- **Tertiary structure** describes all aspects of **3-D folding** of a polypeptide.
- When a protein has two or more polypeptide sub-units, there arrangement in space is referred to as **quaternary structure.**
- The forces that stabilise these aggregates are hydrogen bonds and electrostatic bonds.
- **Haemoglobin** is an excellent example of quaternary structure. It consists of four peptide chains of two pairs each of α and β chains ($\alpha_2\ \beta_2$).

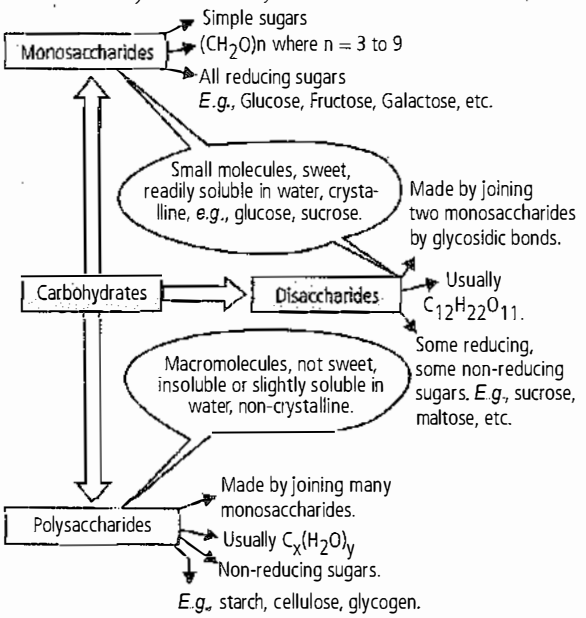


Flow chart : Types of proteins

CARBOHYDRATES

- **Carbohydrates** are hydrates of carbon. They are compounds containing carbon, hydrogen and oxygen which generally occur in the ratio of 1 : 2 : 1. They are also called **saccharides** as their basic component is sugar. The **most important carbohydrate** occurring in animals is **glucose** and in plants is **starch.**
- Carbohydrates are broadly classified into 3 groups – monosaccharides, oligosaccharides and polysaccharides.
- **Monosaccharides** are simplest sugar (monomers) which cannot be hydrolysed further into smaller units. On the basis of number of C-atoms, the monosaccharides are of different types as **trioses** (3C), *e.g.*, glyceraldehyde and dihydroxyacetone; **tetroses** (4C), *e.g.*, erythrose and erythrulose; **pentoses** (5C), *e.g.*, ribose, ribulose, xylose and xylulose, arabinose; **hexoses** (6C), *e.g.*, glucose, fructose, mannose, galactose; and **heptoses** (7C), *e.g.*, sedoheptulose.
- The hexoses are divided into **aldoses** or **ketoses** according to whether they contain an **aldehyde or keto group.** All hexoses are aldoses **(glucose, galactose** and **mannose),** except **fructose** which is a ketose. **Glucose is stored as glycogen in liver and muscles.**

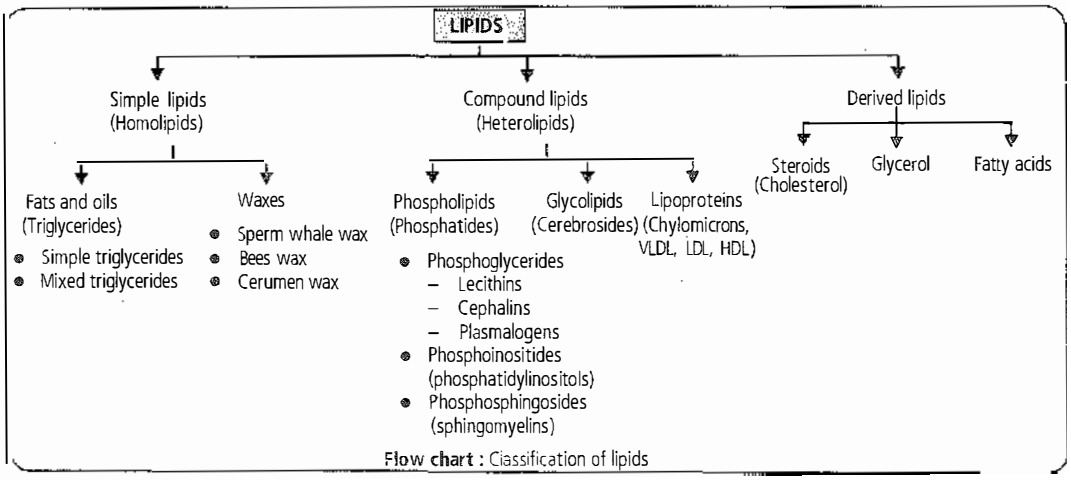
- **Oligosaccharides** are formed by condensation of 2-9 monosaccharides units. These are crystalline, sweet in taste and are readily soluble in water. **Disaccharides** are oligosaccharides with a combination of two molecules of monosaccharides. The common oligosaccharides (or disaccharides) are sucrose, maltose and lactose.



- **Polysaccharides** are complex carbohydrates formed by condensation of a number of monosaccharides (more than 10). They are tasteless, amorphous and insoluble in water. They are also called glycans as they are formed from sugars. Structurally, they are of two types, **homopolysaccharides** and **heteropolysaccharides. Starch, cellulose** and **glycogen** are homopolysaccharides. **Chitin, pectin, hemicellulose** are heteropolysaccharides.
- In a polysaccharide the individual monosaccharides are linked by a **glycosidic bond.** This bond is formed by dehydration. This bond is formed between two carbon atoms of two adjacent monosaccharides.
- **Storage polysaccharides** are reserve foods which can be hydrolysed to produce monosaccharide sugars, *e.g.*, glycogen, starch, inulin. **Structural polysaccharides** are fibrous polysaccharides forming **exoskeleton** in arthropods, cell walls of fungi and plants, *e.g.*, chitin, cellulose.
- In a polysaccharide chain (say glycogen), the right end is called the **reducing end** and left end is called the **non-reducing end.** Starch forms helical secondary structures. In fact, starch can hold I_2 molecules in the helical portion. The starch-I_2 is blue in colour. Cellulose does not contain complex helices and hence cannot hold I_2. Paper made from plant pulp and cotton fibres are cellulose. **Inulin** (Dahlia starch) is a **fructose polymer** (30-50 units) having 2-1 β linkage with glucose residue at one end. It gets precipitated in alcohol. **Pectin** is a polymer of **galacturonic acid, arabinose,** and **galactose.** It is soluble in hot water.

LIPIDS

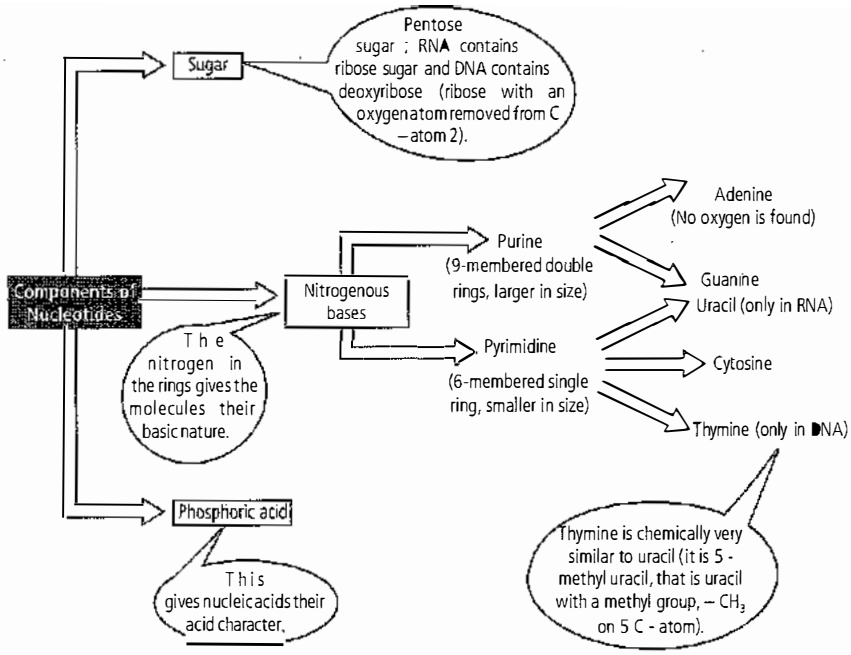
- Lipids are generally **water insoluble.** They could be simple fatty acids. A fatty acid has a carboxyl group attached to an R group. The R group could be a methyl ($-CH_3$), or ethyl ($-C_2H_5$) or higher number of $-CH_2$ groups (1 carbon to 19 carbons). For example, palmitic acid has 16 carbons including carboxyl carbon.
- Broadly lipids can be classified into three types as given below in the flow chart.
- Fatty acids are either **saturated** (all carbon-carbon bonds are single bonds) or **unsaturated** (with one or more double bonds in the hydrocarbon chain). If a fatty acid has **only one double bond** (pahnitic acid and oleic acid) it is said to be **monounsaturated fatty acid (MUFA).** If a fatty acid has **more than one double bond** (2 in linolenic acid, 3 in linoleic acid and 4 in arachidonic acid), is said to be **polyunsaturated fatty acid (PUFA).** Edible oils having PUFA are **safflower** and **sunflower oils.**
- **Fats** and **oils** are esters derived from glycerol (an alcohol) and fatty acids. Depending upon the number of fatty acids, they are called **mono, di or triglycerides.**
- **Phospholipid** is amphipathic molecule with both hydrophilic (water soluble) and hydrophobic (water insoluble) regions. The major phospholipids are esters of glycerol and a **mixture of fatty acids and phosphoric acid.** Phospholipids are important cell membrane constituents because they contain both polar and non-polar portions.



Flow chart : Classification of lipids

NUCLEIC ACIDS

- Nucleic acids, like proteins are essential for life. They form the **genetic material of all living organisms, including the simplest viruses.** Two types of nucleic acids are found in the cells of all living organisms. These are :-
  - Deoxyribonucleic acid – DNA
  - Ribonucleic acid – RNA
- The nucleic acid was first isolated by **Frederich Miescher** in 1868 from the nuclei of **pus cells** and was named **nuclein.**
- Nucleic acids are made up of units called **nucleotides** which are arranged to form extremely long molecules known as **polynucleotides.** A nucleotide has three components, a 5-carbon sugar, a nitrogenous base and a phosphoric acid.
- The combination of a sugar with a base by glycosidic bond at its 1 C-atom gives nucleoside which is accomplished by elimination of water. A nucleotide is formed by further condensation with phosphoric acid. The phosphoric acid molecule is linked to number 3 and 5 C-atoms of deoxyribose molecules by an **ester linkage.**



ENZYMES

- **Enzymes are a group of catalysts functioning in biological system.** They are usually **proteinaceous substances** produced by living cell that catalyse biochemical reactions without themselves being changed in the process. Enzymes occur in colloidal state and are often produced in inactive form called **proenzymes** or **zymogens.** These are converted to active enzymes in the presence of specific factor like pH, substrate, etc.
- **With few exception, all known enzymes are proteins** but **all proteins are not enzymes.** Ribozyme, ribonuclease-P and peptidyl transferase are three non protein enzymes.
- Enzymes are simple if they are made entirely of protein only (*e.g.*, pepsin, trypsin) while **conjugate enzymes** or **holoenzymes** possess two parts - a large thermolabile protein part **(apoenzyme)** and a small dialysable thermostable non protein part **(cofactor)** *e.g.*, dehydrogenase, oxidase, catalase.
- **Cofactor** may remain unchanged or is regenerated after the reaction through another process. These are of three types - **inorganic ions** (enzyme activator like Zn, Mg), **prosthetic group** (organic substance firmly attached to apoenzyme, *e.g*, haem, biotin) and **coenzyme** (organic in nature, as NAD^+, $NADP^+$ etc).
- Coenzyme picks up small chemicals or products from one substrate and hand it to another substrate. Prosthetic groups are functional in transfer of small chemicals and electron.
- Each enzyme has an **active site** in the form of a pit that attracts and holds substrate molecule as well as facilitate their chemical change. **Allosteric enzymes** possess both regulatory or allosteric site and active site. Regulatory site can act as an activator site (allosteric activator) or as an inhibitor site (allosteric inhibitor).
- Previously, naming of enzymes were based on group activity or characteristics of enzyme, *e.g.*, pepsin (Gk *pepsis*-digestion) but present day names end in suffix - *ase* and are used on two criteria (i) **after substrate** – amylase (acting on amylose starch) **after chemical action** – dehydrogenase (perform dehydrogenation).
- According to **IUB**, each enzyme has 4 digit classification *i.e.* class, subclass, subdivision of subclass and serial number. Broadly there are six classes-**oxidoreductase, transferase, hydrolases, lyases, isomerases** and **ligases.**
  - **Oxidoreductases/dehydrogenases:** Enzymes which catalyse oxidoreduction between two substrates S and S'.
  - **Transferases:** Enzymes catalysing transfer of a group, G (other than hydrogen) between a pair of substrate S and S').
  - **Hydrolases:** Enzymes catalysing hydrolysis of ester, ether, peptide, glycosidic, C-C, C-halide or P-N bonds.
  - **Lyases:** Enzymes that catalyse removal of groups from substrates by mechanisms other than hydrolysis leaving double bonds.
  - **Isomerases:** Includes all enzymes catalysing inter-conversion of optical, geometrical or positional isomers.
  - **Ligases:** Enzymes catalysing the linking together of 2 compounds, *e.g.*, enzymes which catalyse joining of C-O, C-S, C-N, P-O, etc. bonds.

Enzyme action

- Enzymes with three dimensional structures including an 'active site', convert a substrate (S) into a product (P). Symbolically, this can be depicted as: S → P. There is an obligatory formation of an **'ES' complex.** This complex formation is a transient phenomenon.
- During the state where substrate is bound to the enzyme active site, anew structure of the substrate called **transition state** structure is formed. Very soon, the product is released from the active site. If 'P' is at a lower level than 'S' the reaction is an **exothermic reaction** and is not supplied energy (by heating) in order to form the product. However, whether it is an **exothermic** or **spontaneous reaction** or an **endothermic** or energy requiring reaction, the 'S' has to go through a much **higher energy** state or transition state. The difference in average energy content of 'S' from that of this transition state is called **'activation energy'.** Enzymes eventually bring down this **energy barrier** making the transition of 'S' to 'P' more easy.

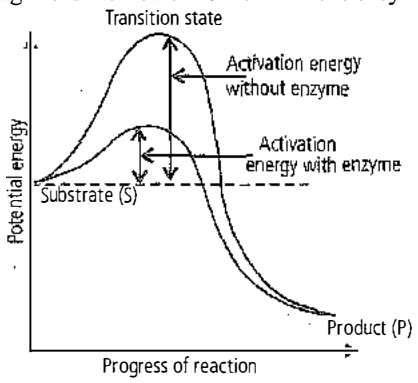


Fig. : Concept of activation energy.

Factors affecting enzyme activity

- The activity of an enzyme can be affected by a change in the conditions which can alter the tertiary structure of the protein. These include **temperature, pH,** change in **substrate concentration** or binding of specific chemicals that regulate its activity.

Temperature and pH

- **Optimum temperature** for enzyme activity is 30°C – 40°C in animal and 20°C – 30°C in plant. High temperature (above 45°C) **denatures enzymes** due to degradation of linkages in its polypeptide chain whereas low temperature inactivate them due to reduction in speed of molecular movement.
- A bell shaped curve will represent the relationship of enzyme activity to pH, which has its peak at **optimum pH.** Most intracellular enzymes function near neutral pH with the exception of several digestive enzymes which work either in acidic or alkaline range of pH.

Concentration of substrate

- With the increase in substrate concentration, the velocity of the enzymatic reaction rises at first. The reaction ultimately reaches a maximum velocity (V_{max}) which is not exceeded by any further rise in concentration of the substrate. This is because the enzyme molecules are fewer than the substrate molecules and after saturation of these molecules, there are no free enzyme molecules to bind with the additional substrate molecule.
- To determine the effect of substrate concentration in enzymatic reaction **Lesnor Michaelis** and **Maud Menten** (1913) proposed a mathematical model and derived a relationship which is mathematically expressed as

$$V=\frac{V_{max}[S]}{K_m+[S]};$$

where, K_m = Michaelis – Menten constant, *i.e.,* the substrate concentration to produce half maximum velocity.

V = Velocity of reaction

V_{max} = Maximum velocity

[S] = Substrate concentration

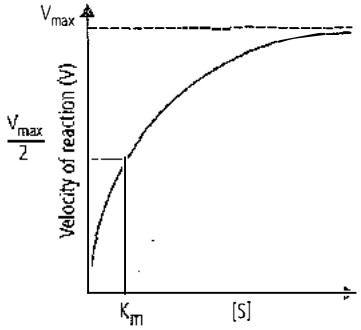


Fig.: Effect of change in concentration of substrate on enzyme activity.

- The activity of an enzyme is also sensitive to the presence of specific chemicals that bind to the enzyme. When the binding of the chemical shuts of enzyme activity, the process is called **inhibiition** and the chemical is called **inhibitor.** Enzyme inhibition is broadly of two categories **reversibility** and **competitiveness.**
- On the basis of **reversibility,** enzyme inhibition is of two types – **reversible** and **irreversible inhibition. Reversible inhibition** is temporary and is overcome by increased concentration of substrate, dilution and dialysis. **Irreversible inhibition** is of permanent nature, in which the inhibitor combines with a specific functional group of enzyme through covalent bond.
- On the basis of **competitiveness** enzyme inhibition can be divided into – competitive inhibition, non-competitive inhibition and uncompetitive inhibition.
- **Competitive inhibition** is reversible and is due to the presence of substrate or enzyme analogues which block the active site. Malonate inhibits succinate dehydrogenase activity because its structure is similar to succinate. Competitive inhibition is temporary and can be reduced or overcome by dilution, dilation and excess availability of substrate or enzyme. In this K_m is increased but V_{max} remains the same and more substrate is needed to achieve 1/2 V_{max}.
- In **non-competitive inhibition** inhibitor forms a complex with the enzyme at a place other than the active site. In this V_{max} of the reaction decreases as the inhibition cannot be overcome by increasing the concentration of the substrate. This type can result in the change in enzyme structure.

- In **uncompetitive inhibition** (rarely encountered) an inhibitor also binds at a site distinct from the substrate. However, an uncompetitive inhibitor will bind **only to the ES complex.** On the other hand noncompetitive inhibitor binds to **either free enzyme** or the **ES complex.** In uncompetitive inhibition, apparent V_{max} and K_m both decreases.
- **Allosteric modulation** or **feedback inhibition** is an enzyme regulatory mechanism where a product or intermediates of a reaction functions as a temporary allosteric inhibitor, (which combines with a regulatory site) if its concentration crosses the threshold value. The end product inhibitor functions as negative modulator and the enzymes inactivated is called allosteric enzyme. **Michaelis- Menten or Km constant is not applicable in allosteric enzymes.**

CONCEPT MAP

Biomolecules

Carbohydrates
- Hydrates of carbon, units are linked by glycosidic bond.

→ **Monosaccharides**
Simple sugars; all reducing sugars.

→ **Oligosaccharides**
Condensation of 2-9 monosaccharides. Disaccharides are the common oligosaccharides.

→ **Polysaccharides**
Made by joining many monosaccharides.

Proteins
- Most abundant biomacromolecules.
- Synthesized from amino acids linked by peptide bonds.
- 20 amino acids(a.a's).

→ **Primary structure**
Sequence of amino acids linked by peptide bonds.

→ **Secondary structure**
Stable arrangement to form structural patterns.

→ **Tertiary structures**
3-D folding of polypeptide.

→ **Quaternary structure**
Two or more polypeptides.

Lipids
- Water insoluble; carboxyl group attached to an R group.

→ **Simple lipids (homolipids)**
Triglycerides and waxes

→ **Compound lipids (heterolipids)**
Phospholipids, glycolipids, lipoproteins.

→ **Derived lipids**
Steroids, glycerol, fatty acid.

Nucleic acids
- Genetic material of all living organisms.
- Deoxyribonucleic acid (DNA) and Ribonucleic acid (RNA).

→ **Sugar (pentose sugar)**
Ribose (RNA); Deoxyribose (DNA).

→ **Nitrogenous base**
Purine (G & A)
Pyrimidine (T/U & C)

→ **Phosphoric acid**
Forms ester linkage during condensation with other phosphoric acids.

Enzymes
- Proteinaceous substances.
- Holoenzyme is made up of apoenzyme (protein part) and cofactor (non protein part).
- Cofactor are of three types– inorganic ions (Zn, Mg), prosthetic group (haem, biotin) and coenzyme (NAD^+, $NADP^+$)

Competitive inhibition
- Reversible.
- Due to substrate or enzyme analogue.
- K_m ↑s but V_{max} remains the

Non-competitive inhibition
- Inhibitor forms a complex with enzyme other than the active site.

Uncompetitive inhibition
- Inhibitor binds to ES complex.

Feedback inhibition
- End product or intermediates functions as temporary inhibitor which combines with a regulatory site of the enzyme and thus functions as negative modulator.