লাল-সবুজে দাগানো

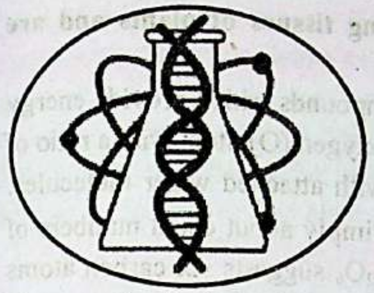
TEXT BOOK

Botany

UNMESH

Medical & Dental Admission Care

Chapter Three
Cell Chemistry



Organ, tissue and cell of an organism composed of different chemical compounds. Some of these chemicals are unique for life. The chemistry of the cell is very complex. Actually the ***secret of life*** remains concealed in these chemical compounds. So it is essential to know about the chemistry of cells for each science student. In this chapter a discussion has been made about the chemistry of the living cell.

Key words: Carbohydrates, monosaccharide, polysaccharide, deoxyribose, cellulose, starch, lipid, triglyceride, cholesterol, polypeptide, enzyme.

Period 8: After reading this chapter students should be able to (Learning output) -
❐ Explain the chemical composition of organism.
❐ Describe the classification of carbohydrate, protein and lipid.
❐ Analyze the role of carbohydrate, protein and lipid in organism's body.
❐ Explain the functional nature of enzyme.
❐ Describe the classification of enzyme.
❐ Explain the use of enzyme in different biological activities.

3.1 The chemical composition of organism

The body of a living organism composed of several chemical components. The structure and functions of the living organisms mostly based on the structure, arrangement and nature of these chemical components. These chemical components are known as **biomolecules**. Some of the biomolecules are very simple and small, called **macromolecules** and others are large and complex, called **macromolecules.** Ninety five percent (95%) of the cellular content comprises of only four molecules viz., Carbon (C), Hydrogen (H), Oxygen (O) and Nitrogen (N). Another 5% is comprised of 20 types of molecules as Calcium, Phosphorus, Chlorine, Sulfur, Sodium, Magnesium, Iodine, Iron, Copper, Cobalt, Zinc etc. Table 1 shows the prime chemical compound of a cell.

Table 1: Prime chemical compounds of the cell

Chemical compounds	%	Type
1. Water	80.00	Inorganic
2. Inorganic salts	1.00	
3. Carbohydrate	1.00	Organic
4. Lipid	0.50	
5. Protein	12.00	
6. Nucleic acid	2.00	
7. Other organi matter	0.50	

However, a brief description of carbohydrate, protein and lipid is given below:

1. CARBOHYDRATES

Carbohydrates are any of a class of organic compounds that are polyhydroxy aldehydes or polyhydroxy ketones, or change to such substances on simple chemical transformations, as hydrolysis, oxidation, or reduction, and that form the supporting tissues of plants and are important food for animals and people.

Carbohydrate comprises 1% of the living body. They are the compounds which provide energy to living cells. They are compounds of carbon (C), hydrogen (H) and oxygen (O) atom with a ratio of 1:2:1. The name carbohydrate means "**watered carbon**" or carbon with attached water molecules. Many carbohydrates have empirical formula, $C_n(H_2O)_n$ which would imply about equal numbers of carbon and water molecules. For example, the glucose formula $C_6H_{12}O_6$ suggests six carbon atoms and six water molecules. Carbohydrates are technically **hydrates of carbon**; structurally it is more accurate to view them as polyhydroxy aldehydes and ketones.

Sources

The main sources of carbohydrates are plants. Higher animals have trace amount of carbohydrates. In plants these are existing as cellulose and starch in the stem, fibres, barks, fruits, roots, seeds, sap, etc. In higher animals they stored as glycogen, lactic acid and lactogen in liver, muscle and milk respectively. Carbohydrates are granular, fibrous or crystal solid substance. They are sweet or tasteless in taste. Most of the carbohydrates are insoluble in water except monosaccharides. In excess heat they become ash. Carbohydrates form esters combined with acids.

Classification of Carbohydrates

(A) On the basis of taste the carbohydrates are of two types:

1. Sugar: These are sweet, granular and water soluble carbohydrates as glucose, fructose, sucruse etc. and

2. Non-sugar: These are non-sweet, agranular and water insoluble carbohydrate as cellulose, glycogen, sterch etc.

(B) On the basis of reducing capacity carbohydrates are of two types:

1. Reducing sugar: A reducing sugar is any sugar that is capable of acting as a reducing agent because it has a free **aldehyde group** (-CHO) or a free **ketone group** (>C=O). A *reducing sugar* is one that *reduces* another compound and is itself *oxidized*; that is, the carbonyl carbon of the sugar is oxidized to a carboxyl group. All monosaccharides are reducing sugars. This includes common monosaccharides like galactose, glucose, glyceraldehyde, fructose, ribose, and xylose.

2. **Non-reducing sugar**: A non-reducing sugar is any sugar that is unable to be oxidized and do not reduce other substances. These sugar do not have free aldehyde group (-CHO) or a free ketone group (>C=O). Major example of non reducing sugar is sucrose. Starch, Cellulose, Glycogen etc. are also non reducing sugar.

(C) On the basis of chemical complexity and behaviour on hydrolysis carbohydrates are classified in to three major classes. These are-

(1) Monosaccharides,
(2) Oligosaccharides and
(3) Polysaccharides.

1. Monosaccharides: (Gr-*mono*=single, *sacchar*=sugar)

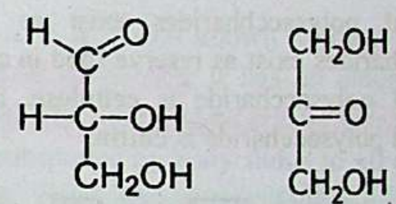
A monosaccharide is a simple sugar and is the simplest form of a carbohydrate. It cannot be broken down by water into a simpler sugar. The chemical formula of monosaccharide is $C_nH_{2n}O_n$. **Monosaccharides form the building blocks for more complex carbohydrates.** All monosaccharides are water soluble, sweet in taste and able to form callus. They possessing free aldehyde groups (-CHO) at their cabon 1 or free ketone groups (>C=O) at their cabon 2 and possess reducing properties. This reducing property is exhibited by Fehling's test where the Cu^{2+} ion in Fehling's sôlution is reduced to Cu^{+} ion. Hence all monosaccharides are called **reducing sugar**. Monosaccharides having aldehyde group called **aldose** and having ketone group called **ketose**.

On the basis of the number of carbon monosaccharides are of following types:

(i) Triose: A triose is a monosaccharide containing three carbon atoms in its primary chain. They exist as phosphate ester in plants. There are only three possible trioses: *L-Glyceraldehyde, D-Glyceraldehyde,* and *dihydroxyacetone*. Trioses are important in cellular respiration.

(ii) Tetrose: A tetrose is a monosaccharide containing four carbon atoms in its primary chain. They have either an aldehyde functional group in position 1 or a ketone functional group in position 2. Examples are- *erythrose, threose, erythrulose* etc.

(iii) Pentose: A pentose is a monosaccharide containing five carbon atoms in its primary chain. The pentose sugar ribose and deoxyribose are part of the nucleotides that make up the crucial nucleic acids like DNA and RNA. Other pentoses are *ribulose, xylulose, arabinose, lyxose* etc.



glyceraldehyde (aldose) dihydroxy acetone (ketose)

(iv) Hexose: A hexose is a monosaccharide with six carbon atoms, having the chemical formula $C_6H_{12}O_6$.

The hexose sugar *glucose* is the most abundant monosaccharide in nature and is the principal carbon and energy source for nearly all cells. Other hexoses are *fructose, manose, galactose* etc.

(v) Heptose: Heptose is any monosaccharide that has seven carbon atoms per molecule. There are few examples of C-7 sugars in nature, among which are: *Sedoheptulose* or D-*altro-heptulose*, an early intermediate in lipid A biosynthesis and *Mannoheptulose* found in avocados.

2. Oligosaccharides (Gr *oligo* =less; *sacchar*= sugar)

An oligosaccharide is a complex carbohydrate and contains 2 to 10 simple sugars. These are composed of several monosaccharide residues joined through *glycosidic linkage*, which can be hydrolyzed by acid to give the constituent monosaccharide units. Like monosaccharides oligosaccharides are water soluble, sweet in taste and able to form callus. Oligosaccharides may be disaccharides, trisaccharides, tetrasaccharides etc. All types of oligosaccharides occur naturally but most are the disaccharides.

(i) Disaccharides: These oligosaccharides are composed of two monosaccharides connected by a glycosidic bond. In disaccharide each glycosidic bond can be formed between any hydroxyl group on the component monosaccharides. Some common disaccharides are *lactose* (milk sugar), *maltose*, *sucrose* (table sugar) etc.

(ii) Trisaccharides: These oligosaccharides are composed of three monosaccharides with two glycosidic bonds connecting them as in disaccharides. Common trisaccharides are *raffinose, maltotriose, melezitose, maltotriulose* etc.

(iii) Tetrasaccharides: A tetrasaccharide is a carbohydrate which gives upon hydrolysis four molecules of the same or different monosaccharides. For example, *stachyose* upon hydrolysis gives one molecule each of *glucose* and *fructose* and two molecules of *galactose*. The general formula of a tetrasaccharide is typically $C_{24}H_{42}O_{21}$.

3. Polysaccharides (Gr *Poly*=many; *sacchar*=sugar)

Polysaccharides are long carbohydrate molecules of monosaccharide units joined together by glycosidic bonds. They range in structure from linear to highly branch. Polysaccharides are often quite heterogeneous, containing slight modifications of the repeating unit. Depending on the structure, these macromolecules can have distinct properties from their monosaccharide building blocks. They may be amorphous (**non-crystalline solid**) or even insoluble in water.

When all the monosaccharides in a polysaccharide are the same type, the polysaccharide is called a **homopolysaccharide** or **homoglycan,** but when more than one type of monosaccharide is present they are called **heteropolysaccharides** or **heteroglycans.** Considering that the repeating units in the polymer backbone are often six-carbon monosaccharides, the general formula can also be represented as $(C_6H_{10}O_5)_n$ where $10 \leq n \leq 3000$. Polysaccharides may be of structural or storage. Structural polysacchharides exist as primary structural components of cell and storage polysaccharides exist as reserve food in cell. In plants, the storage polysaccharide is **starch** and the structural polysaccharide is **cellulose.** In animals, the storage polysaccharide is **glycogen** and structural polysaccharide is **chitin.**

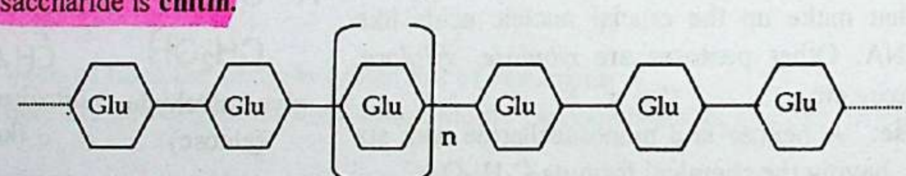
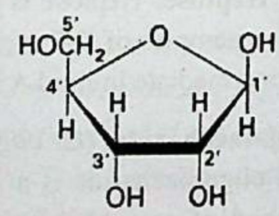


Fig 3.1 Simple structure of polysaccharide

Some Vital Carbohydrates

RIBOSE

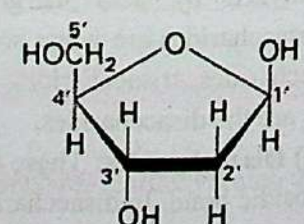
Ribose is a water-soluble aldopentose monosaccharide with five carbon atoms and aldehyde group that is an important component of nucleic acids, nucleotides, the vitamin riboflavin, and various co-enzymes. Ribose has the chemical formula $C_5H_{10}O_5$. It is also known as D-ribose which was first reported in 1891 by **Emil Fischer.** Ribose forms part of the backbone of RNA.



Ribose

DEOXYRIBOSE

Deoxyribose, also known as D-Deoxyribose and 2-deoxyribose, is an aldopentose monosaccharide containing five carbon atoms, and including an aldehyde functional group in its linear structure. **Phoebus Levene** in 1929 discovered the deoxyribose. Deoxyribose has the chemical formula $C_5H_{10}O_4$. Its name indicates that it is a deoxy sugar, meaning that it is derived from the sugar ribose by loss of an oxygen atom in the carbon 2.



Deoxyribose

Deoxyribose is a constituent of the nucleotide bases that form DNA. The absence of the 2' hydroxyl group in deoxyribose is apparently responsible for the increased mechanical flexibility of DNA compared to RNA, which allows it to assume the double-helix conformation, and also to be compactly coiled within the small cell nucleus. This ubiquitous sugar and its derivatives are fundamental to key biological processes throughout nature and reflect a commonality among all living organisms.

Differences between ribose and deoxyribose

Ribose	Deoxyribose
1. Ribose is found in RNA, is a "normal" sugar, with one oxygen atom attached to each carbon atom.	1. Deoxyribose is found in DNA, is a modified sugar, lacking one oxygen atom (hence the name "deoxy").
2. In ribose, carbon atom 2 carries one hydroxyl group.	2. In deoxyribose, carbon atom 2 carries a hydrogen atom instead of a hydroxyl group.
3. Its chemical formula of ribose sugar is $C_5H_{10}O_5$.	3. The chemical formula of deoxyribose sugar is $C_5H_{10}O_4$.
4. It produces furfural acid in reaction with heavy HCl.	4. It produces levulinic acid in reaction with heavy HCl.

GLUCOSE

Glucose is a aldohexose sugar with six carbon atom. It is is also known as **dextrose, grape sugar, corn sugar, D-glucose, etc**. Its chemical formula is $C_6H_{12}O_6$. It has an aldehyde group (–CHO) in its atomic structure, hence called **aldohexose**. Glucose is white crystal sweet chemical which is soluble in blood plasma and water and so it is transported by body fluids to all cells in the body. There are huge amount of glucose in ripen fruits, honey and grasps. Glucose is naturally produced in plant cells through the process of photosynthesis. Glucose is a basic form of fuel in all living things. In cells it is metabolized and releases energy. Sugar hydrolyzed into glucoses. Glucose can form polymer and stored as **starch** in the plant body. In living organisms it combined with protein and form glycoprotein. Glucose reacts with phosphoric acid and produces ester.

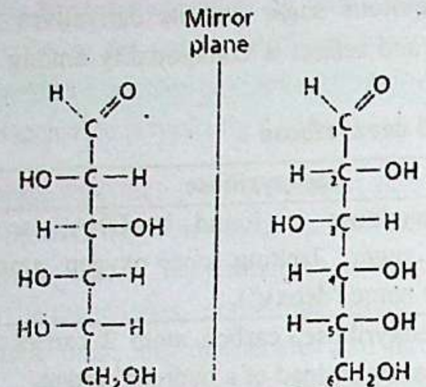
D Glucose and L Glucose Series

Based on the OH group on the single asymmetric carbon no. 5 in the chain configuration of glucose, it is named as *D glucose* and *L glucose.* If the OH group of glucose molecule lies towards right side, it called as **D- glucose** and if it is on left side, it will be **L-glucose**. According to **Fisher model** D and L glucose are mirror images of one another.

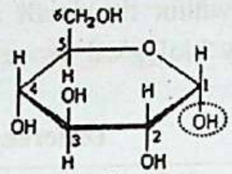
D-Glucose is optically active and its rotation phase is right (Latin, dexter =right)) to the chiral center. L-Glucose is also optically active and its rotation phase is left (Latin, laevus= left)) to the chiral center. (*A chiral center is defined as an atom in a molecule that is bonded to four different chemical species, allowing for optical isomerism*). All natural glucoses are D Glucose, but L-Glucose are developed artificially for diabetics treatment and endoscopic useses.

α-D Glucose and β-D Glucose

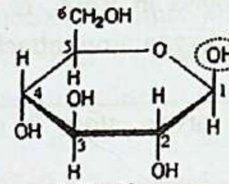
The D-glucose can exist in two forms α-D-glucose and β-D-glucose. They differ only in the direction that -H and -OH groups point on carbon 1. In cyclic configuration of D-glucose, when OH group is located over the carbon no.1 is called α-D-glucose and if it is under, it will be β–D-glucose. When α-glucose molecules are joined chemically to form a polymer **starch** is formed as a stored product of plant. When β-glucose molecules are joined to form a polymer **cellulose** is formed as a structural product of plant.



L Glucose D Glucose



α-D Glucose



β-D Glucose

Uses of Glucose

1. Glucose used as instant energy source for the patients.

2. D-glucose used in production of vitamin C or ascorbic acid through the Reichstein process. This process was devised by Nobel Prize winner **Tadeus Reichstein** and his colleagues in 1933

3. Glucose is used in fruit preservation; glucose-fructose syrups improve product conservation.

4. It can create or synthesize polysaccharides, which are complex sugars that can be used as energy storage in organisms as well.

5. Glucose also plays a role in the creation or synthesis of other substances like glycoproteins or glycolipids.

6.The glucose is very important substance in biology and in metabolism of all life forms.

7.Glucose is the main and preferred source of energy for all cells.

8. In pharmaceutical industry glucose can used for production of citric acid, sorbitol, gluconic acid, bio-ethanol etc.

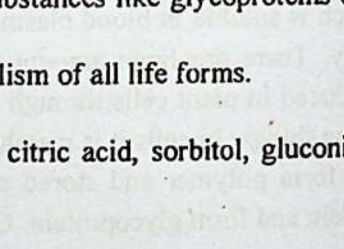
Dextrose:

Dextrose is a white soluble sweet-tasting crystalline solid that is the dextrorotatory isomer of glucose, occurring widely in fruit, honey, and in the blood and tissue of animals. It is commercially obtainable from starch by acid hydrolysis. Dextrose powder is sometimes used as a nutritional supplement by bodybuilders who are looking to increase weight and muscle. It may be prescribed when a person is dehydrated or has low blood sugar.

FRUCTOSE

Fructose is an isomer of glucose, *i.e,* six carbon hexos sugar. Fructose was discovered by French chemist **Augustin-Pierre Dubrunfaut** in 1847. Its molecular formula is $C_6H_{12}O_6$. It has a keto group (=CO) in its atomic structure, hence called **ketohexose.** It is also known as **laevulose or fruit sugar**. Like glucose, fructose has D and L configurations, *i.e.,* D-fructose and L-fructose.

Pure, dry fructose is a very sweet, white, odorless, crystalline solid and is the most water-soluble of all the sugars. Fructose is found in honey, tree and vine fruits, flowers, berries, and most root vegetables. Commercially, fructose is frequently derived from sugar cane, sugar beets, and corn. About 240,000 tonnes of crystalline fructose are produced annually.



Fructose

Uses: Fructose is used in huge amount in production of sweetmeat, beverage, cake, juice etc. Beside these fructose is used in laboratory for preparation of culture media of lactose bacteria.

Why is fructose bad for human body?

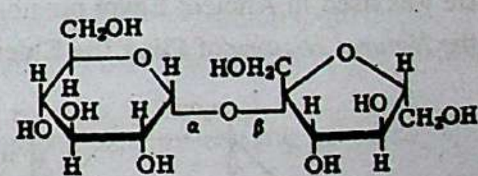
Glucose and fructose are metabolized very differently by the body. The key thing to realize, is that while every cell in the body can use glucose, the liver is the only organ that can metabolize fructose in significant amounts. When people eat a diet that is high in calories and high in fructose, the liver gets overloaded and starts turning the fructose into fat. Scientists believe that excess fructose consumption may be a key driver of many of the most serious diseases of today. These include obesity, type II diabetes, heart disease and even cancer.

Differences between glucose and fructose

Glucose	Fructose
1. Glucose is an aldohexose with an aldehyde group (−CHO)	1. Fructose is a ketohexose with a keto group (=CO)
2. Commonly called as blood sugar, dextrose, corn sugar, and grape sugar.	2. Commonly called as fruit sugar, levulose, D-fructose.
3. Glucose is sweet in taste.	3. Fructose is many times sweeter than glucose.
4. Its carbon is attached to a hydrogen atom by a single bond and an oxygen atom by a double bond.	4. Its carbon is attached only to an oxygen atom by a single bond.
5. Ring structure pyranose type with a 6 atom ring.	5. Ring structure furanose type with a 5 atom ring.
6. This breaking down process requires insulin.	6. It does not need insulin to be metabolized and therefore is a marginally better choice for diabetics.
7. Cells use glucose to fuel respiration. It is also used in Vitamin A production and for the synthesis of several substances, including starch and glycogen.	7. Fructose is used in respiration to produce ATP and to build glycogen. It can also produce fat to store energy.

SUCROSE

Sucrose also known as **saccharose** (Latin *sucrum* = sugar) is a disaccharide that yields from one molecule glucose and one molecule fructose on acidic hydrolysis. Its chemical formula is $C_{12}H_{22}O_{11}$.



Sucrose: [α-D-glucopyranosyl-(1→2)-β-D-fructofuranoside]

The word "sucrose" was coined in 1857 by the English chemist **William Miller** from the French *sucre* ("sugar") and the generic chemical suffix for sugars *-ose*.

Sucrose, ordinary table sugar, is probably the single most abundant pure organic chemical in the world and the one most widely known to nonchemists. Unlike most other disaccharides, sucrose is not a reducing sugar. Sucrose has an anomeric carbon which is not free since the carbon links glucose and fructose and fructose does not have free OH group to under reducing reaction and to open the ring so **sucrose is non reducing.** In the formation of sucrose *1,2 glycosidic bond* is formed between glucose and fructose. In the process, the keto group on Carbon 2 of the fructose molecule and the aldehyde group on Carbon 1 of the glucose molecule are altered. Keto group and aldehyde group give a monosaccharides and disaccharides the reducing properties.

Functions of Sucrose

(i) Sucrose is a sugar, the organic compound commonly known as table sugar, cane sugar, beet sugar or, usually, just sugar.

(ii) Sucrose is one of the main products of photosynthesis in plants, anc ...e most common form of carbohydrate transported from source to sink organs.

(iii) It also functions as a storage reserve, compatible solute and signal metabolite in plants.

(iv) Sucrose serves as a source of fixed carbon that can be distributed systemically throughout the plant.

Uses of Sucrose

(i) **Sweetener:** The primary characteristic of sucrose is its sweetness. Sugar has the ability to make foods more appealing by making them less tart or bitter.

(ii) **Preservative:** Like salt, sugar is a natural preservative because it draws moisture out of bacteria,

(iii) **Fermentation and Manufacturing:** Sugar acts as a food source for fungi. Fungi, in turn, speed up the fermentation process. People thus add sugar to any manufacturing process that requires fermentation.

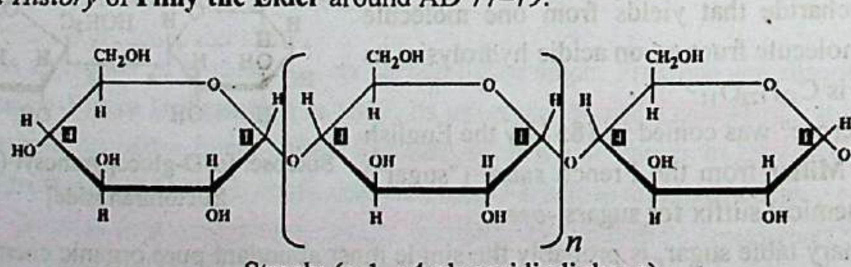
(iv) **Bait:** Insects like flies, ants and cockroaches are attracted to sugar. Sugar therefore is a nontoxic pest bait.

(v) **Gardening:** Sugar can also be a helpful additive to garden soil because it provides an inhospitable environment for nematodes (worm parasites) that attack garden plants.

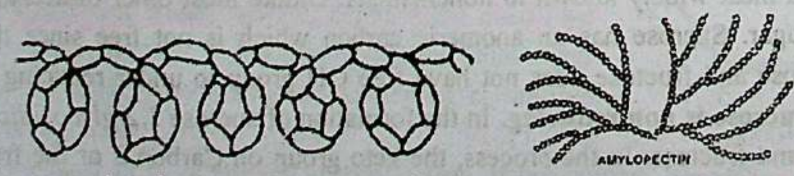
(vi) **Beauty and Cleansing:** Sugar acts as an abrasive agent, meaning that it has the capacity to wear away at something else. This makes it perfect for use as a cleansing agent.

STARCH

Starch (*sterchen* =stiffen) is a white, granular, organic chemical that is produced by all green plants. It is a complex homopolyscharide. The basic chemical formula of the starch molecule is $(C_6H_{10}O_5)_n$. Carbohydrates in plants are stored in the form of starches. The word "starch" is from a Germanic root with the meanings "strong, stiff, strengthen, stiffen". Pure extracted wheat starch paste was used in Ancient Egypt possibly to glue papyrus. The extraction of starch is first described in the *Natural History* of **Pliny the Elder** around AD 77–79.



Strach: (α,1→4 glycosidic linkage)



Amylase Amylopectin

The structure, shape and properties are varying in different plant species. Starch is composed of two different polysaccharides- unbranched **amylose** and branched **amylopectin**. Natural starches are mixtures of **amylose** (20-20%) and **amylopectin** (75-80%). Amyloses have 200 to 2000 1→4 linked D-glucoses monomers where as amylopectins have 2000 to 20,000 1→4 linked or α,1→4 linked D-glucoses monomers. Potato has the largest and rice has the smallest starch molecule, respectively.

Properties of Starch

1. It is insoluble, so doesn't draw water into cells by osmosis.
2. Won't easily diffuse out of cells because it is insoluble.
3. It can be stored in a small space because the tight coils make it compact.
4. Can be easily hydrolysed to give α-glucose, which can be used in respiration.

Functions of Starch

1. Most green plants use starch as their energy store.
2. Fruit, seeds, rhizomes, and tubers store starch to prepare for the next growing season.
3. Starch is the most common carbohydrate in the human diet and is contained in many staple foods. The major sources of starch intake worldwide are the cereals (rice, wheat, and maize) and the root vegetables (potatoes and cassava).

Commercial uses of starch

1. As food additive: As an additive for food processing, food starches are typically used as thickeners and stabilizers in foods.

2. In pharmaceutical industry: In the pharmaceutical industry, starch is also used as an excipient, as tablet disintegrant, and as binder.

3. In papermaking: Papermaking is the largest non-food application for starches globally, consuming millions of metric tons annually.

4. Corrugated board adhesives: Corrugated board adhesives are the next largest application of non-food starches globally.

5. Clothing starch: Clothing or laundry starch is a liquid prepared by mixing a vegetable starch in water (earlier preparations also had to be boiled), and is used in the laundering of clothes.

6. Other purposes:

(i) For body powder, powdered corn starch is used as a substitute for **talcum powder**, and similarly in other health and beauty products.

(ii) Starch is used to produce various bioplastics, synthetic polymers that are biodegradable.

(iii) Glucose from starch can be further fermented to **biofuel corn ethanol** using the so-called **wet milling process**.

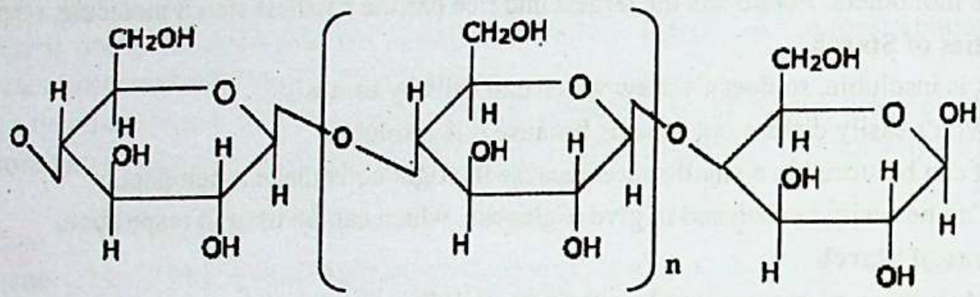
(iv) Textile chemicals like **warp sizing agents** are used to reduce breaking of yarns during weaving.

(v) In oil exploration, starch is used to adjust the viscosity of **drilling fluid**, which is used to lubricate the drill head and suspend the grinding residue in petroleum extraction.

CELLULOSE

Cellulose is an organic compound with the formula $(C_6H_{10}O_5)_n$ a polysaccharide consisting of a linear chain of 700 to over 10,000 β, 1→4 linked D-glucose monomers. Cellulose is an important structural component of the primary cell wall of green plants, many forms of algae and the oomycetes. Some species of bacteria secrete it to form biofilms. **Cellulose is the most abundant**

organic polymer on Earth. The cellulose content of cotton fiber is 90%, that of wood is 40–50% and that of dried hemp is approximately 45%. Cellulose was discovered in 1838 by the French chemist **Anselme Payen.** The compound was first chemically synthesized in 1992, by **Kobayashi and Shoda.**



Cellulose: (β, 1→4 glycosidic linkage)

Properties of Cellulose

(i) Cellulose has no taste, is odorless, is hydrophilic, insoluble in water and most organic solvents and is biodegradable.

(ii) Cellulose is crystalline and several different crystalline structures of cellulose are known.

(iii) It can be broken down chemically into its glucose units by treating it with concentrated mineral acids at high temperature.

Functions of Cellulose

(i) Cellulose makes up most of the tough cell walls surrounding plant cells and enables plants to stand upright. (***For this reason cellulose is called as skeletal system of plant***)

(ii) It is the major component of plants that makes the branches, stems and leaves very strong.

(iii) In animals cellulose supplements increased the bulk of the stools and had a laxative effect.

Commercial uses of Cellulose

(i) The strength of cellulose makes it useful in various synthetic products, including **plastics, fabrics, cosmetics, lotion** and **carpeting**.

(ii) Cellulose provides the raw material for the production of **paper, cellophane, celluloid** and **rayon** including various types of plastics.

(iii) Derivatives of cellulose such as **cellulose nitrate** are used in the manufacture of films, lacquers and explosives.

(iv) Cellulose derivatives especially **cellulose ethers** are widely used in production of bioadhesives and mucoadhesives.

(v) Cellulose is used in the laboratory as a stationary phase for **thin layer chromatography.**

(vi) It is the base material for the **celluloid** that was used for photographic and movie films until the mid-1930s.

(vii) **Cellulose insulation** made from recycled paper is becoming popular as an environmentally preferable material for building insulation.

(viii) Cellulose is used to make **water-soluble adhesives** and **binders** such as methyl cellulose which are used in wallpaper paste.

(ix) Cellulose is the raw material in the manufacture of **nitrocellulose** which is used in smokeless gunpowder.

Cellulose importance to human diet

Despite the fact that humans cannot digest cellulose, cellulose is nonetheless a very important part of the healthy human diet. This is because it forms a major part of the dietary fiber that we know is important for proper digestion. Since we cannot break cellulose down and it passes through our systems basically unchanged, it acts as what we call bulk or roughage that helps the movements of our intestines

Why does cellulose can't be digested by humans?

No mammal makes the necessary enzymes to break down cellulose. Those mammals that eat a lot of cellulose, like cows, need to keep symbiotic bacteria in their digestive tracts to help them digest the cellulose. Even termites have symbiotic bacteria in their digestive tracts to help them digest cellulose. Humans cannot digest cellulose because we lack the enzymes that are required to break the β, 1→4 glycosidic linkage that hold the glucose monomers together.

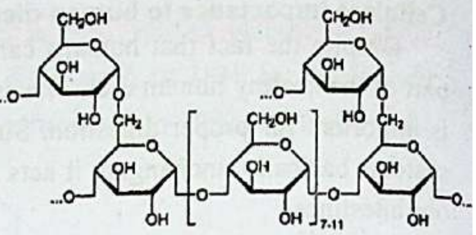
Differences between Starch and Cellulose

Starch	Cellulose
1. Starch is the polymeric form of glucose in which 2000 to 20,000 glucose units are linked by α, 1→4 glycosidic linkage.	1. Cellulose is the polymeric form of glucose in which700 to 10,000 glucose units are linked by β, 1→4 glycosidic linkage.
2. The chain of glucose molecules which forms the starch could be linear, mix or branched.	2. Cellulose is mostly linear chains of glucose molecules.
3. Starch is mainly a storage polysaccharide.	3. Cellulose is a structural polysaccharide
4. Starch occurs in the form of amylopectin and amylose.	4. Cellulose occurs in nature as pure cellulose, lignin or hemicellulose.
5. Starch can be broken down to maltose and then finally to glucose by the enzymes present in humans.	5. Cellulose cannot be digested properly in the absence of the cellulase enzymes.
6. The main function of starch is as food and supplying the body with energy and helps in its proper metabolism	6. Cellulose has a more significant use in the clothing industry and in the production of important materials like cellophane and rayon.

GLYCOGEN

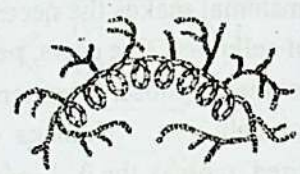
Glycogen is a polysaccharide that is the principal storage form of glucose in animal and human cells. Hepatocytes (liver cells) have the highest concentration of it - up to 8% of the fresh weight in well fed state, or 100-120 gm in an adult. Small amounts of glycogen are found in the kidneys, and even smaller amounts in certain glial cells in the brain and white blood cells. Glycogen is the analogue of starch, a glucose polymer in plants, and is sometimes referred to as ***animal starch***, having a similar structure to amylopectin but more extensively branched and compact than starch.

Glycogen is a highly-branched polymer of about 30, 000 glucose residues and has a molecular weight between 10^6 and 10^7 daltons . Glucoses linked together linearly by α (1→4) glycosidic bonds from one glucose to the next.



Glycogen

Glycogen was discovered by French physiologist **Claude Bernard** in 1857. It is amorphous and water soluble. Glycogen is found in the form of granules in the cytoplasm in many cell types, and plays an important role in the glucose cycle. The most common disease in which glycogen metabolism becomes abnormal is **diabetes,** in which, because of abnormal amounts of insulin, liver glycogen can be abnormally accumulated or depleted



Glycogen polymer

Functions of Glycogen

(i) Glycogen is stored and produced by the hepatocytes in the animal liver. The main function of glycogen is as a secondary long-term energy-storage molecule.

(ii) In **skeletal and cardiac muscle**, glucose from glycogen stores remains within the cell and is used as an energy source for muscle work.

(iii) The **brain** contains a small amount of glycogen, suggesting its functional role in the conscious brain.

(iv) Glycogen has a specialized role in fetal lung **type II pulmonary cells**. At about 23 weeks of gestation these cells start to accumulate glycogen and then to synthesize pulmonary surfactant, using it as a major substrate for the synthesis of surfactant lipids.

CHITIN

Chitin $(C_8H_{13}O_5N)_n$ is the second most important natural polymer in the world. Chitin is a polysaccharide containing ***N*-acetylglucosamine**, is a derivative of glucose, in which monomers occur with the glycosidically linked components β, 1→4. Chitin was first isolated and characterized in 1811 by the chemist and botanist **Henry Braconnot**. It is the same coupling as glucose with cellulose, however in chitin the hydroxyl group of the monomer is replaced with an acetyl amine group. The resulting, stronger hydrogen bond between the bordering polymers makes chitin harder and more stable than cellulose.

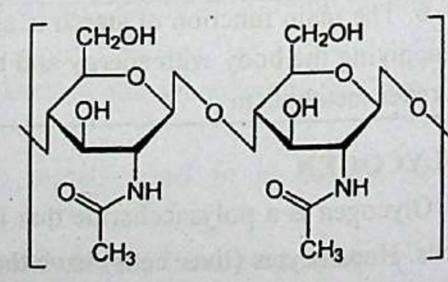


Fig: Chitin-Haworth structure

Chitin occurs in the exoskeleton of animals such as shrimp, crabs, krill, squid and insects or in cell walls of fungi, yeast and other microorganisms.

Chitin insoluble in water, organic solvents, weak acids and lyes. It is soluble in concentrated formic acid and methane sulfonic acid. Strong acids split chitin into acetic acid and D-amino glucose (monomer of chitin), strong lyes split chitin into acetic acid and chitosan.

In terms of function, it may be compared to the protein keratin. Chitin has proved useful for several medicinal, industrial and biotechnological purposes.

Carbohydrate derivatives

Carbohydrate derivatives are sugar molecules that have been modified with substituents other than hydroxyl groups. Most sugar derivatives occur naturally and have important biological functions.

Some of few instances are as below:

1. Chondroitin sulfate is an important structural component of cartilage and provides much of its resistance to compression.

2. Sugar alcohols are still have sweet taste widely used as sugar replacement in diet and health-oriented foods especially for individuals with diabetes.

3. Amino sugar heparin occurs in intracellular granules of mast cells that line arterial walls and, when released, inhibits blood clotting.

4. Glycosylamine adenosine is an important part of DNA and RNA structure.

5. Galactosamine is one of eight essential amino acids that function in cell to cell interaction.

6. Glucosamine, is a very popular and relatively well-known amino sugar that our bodies use to produce glycosylated lipids and proteins.

7. Sialic Acid is a very important sugar amine necessary to our bodies' mental and physical well being.

8. Ascorbic acid is most commonly known by the name Vitamin C has been used for curing scurvy (a lack of vitamin C in the body).

9. Saccharin, also known as Sweet-N-Low is one of the oldest artificial sweeteners. It is 300 times as sweet as sucrose.

10. Sucralose, more popularly known as **Splenda,** is 600 times sweeter than sucrose. It is very similar to the disaccharide structure of sucrose.

Due to wide application of sugar derivatives in different areas many of them are commercially synthesized.

Roles of Carbohydrates in Organisms

Vital roles of carbohydrate in organisms are listed below:

1. As biofuel: Most of the energy for the metabolic activities of the cell in all organisms is derived from the oxidation of carbohydrate. Carbohydrate functions as an energy source of the body and acts as biofuel. Carbohydrates contain about 4 calories per gram.

2. As storage food: All animals derive the major portion of their food calories from the different types of carbohydrates in their diets. Different forms of carbohydrate are stored in living organism as storage food-

- Polysaccharide starch acts as storage food for plants.
- Glycogen stored in liver and muscles acts as storage food for animals.
- Inulin acts as storage food of dahlias, onion and garlic.

3. As framework in body: Different carbohydrates especially polysaccharides act as framework in living organism.

- Cellulose forms cell wall of plant cell along with hemicelluloses and pectin.
- Chitin forms cell wall of fungal cell and exoskeleton of arthropods.
- Peptidoglycan forms cell wall of bacteria and cyanobacteria.

4. As anticoagulant: Heparin is a polysaccharide which acts as anticoagulant factor and prevents intravascular clotting.

5. **As antigen:** Many antigens are glycoprotein in nature and give immunological properties to the blood.

6. **As hormone:** Many hormones like FSH (Follicular Stimulating Hormone) and LH (Leutinizing Hormone) are glycoprotein and help in reproductive processes.

7. **Other Functions**

- Agar is polysaccharide used in culture media, laxative and food.
- Cellulose acts as roughage of food. It stimulates peristalsis movement and secretion of digestive enzymes.
- Hyaluronic acid found in between joints acts as synovial fluid and provides frictionless movement.
- Carbohydrates form DNA, RNA, and co-enzyme (ATP, FAD, NAD)

2. LIPIDS

Lipids are any of a group of organic compounds, composed of Hydrogen (H), Oxygen (O) and Carbon (C), are insoluble in water but soluble in alcohol, benzene, hexen, ether, chloroform etc., and together with carbohydrates and proteins constitute the principal structural material of living cells.

Lipid comprises 0.5% of the living body. Lipid includes the fats, oils, waxes, sterols, and triglycerides. Lipids are a naturally occurring substance in the body used for energy storage. Fatty type foods are good sources of dietary sources for lipids. Nuts, eggs, cheese, salad dressings, skim milk, real cream butter, all help the body's lipids to do their job. The term lipid was first used by the German biochemist **Bloor** in 1943.

Properties of lipid

(i) Lipids are colourless, smell less and test less organic substances.
(ii) Lipids are insoluble in water but soluble in alcohol, benzene, hexen, ether, chloroform etc.
(iii) Lipids are lighter then water and have no specific smelting point.
(iv) In general temperature (20°C) solid lipids are called **fats** and liquid lipids are called **oils.**
(v) Generally lipids exist as esters of fatty acids.
(vi) Lipids hydrolyze into fatty acid and glycerol.

Chemical tests for lipid

1. **Salkowski test:** Sample dissolve in chloroform and add equal volume of concentrated H_2SO_4. To produce bluish-red to cherry to cherry-red colour.

2. **Liebermann-Burchard test:** Sample is dissolve in chloroform in a dry test tube. Add few drop of acetic anhydride and few drop of concentrated H_2SO_4. The solution becomes red, then blue and finally bluish- green in colour.

Classification of Lipid

Lipids are classified in different ways.

□ **A. On the basic of reaction with NaOH / KOH lipids are two types:**

1. **Saponifiable lipids:** A saponifiable lipid is one with an ester functional group that can be hydrolyzed under basic conditions. These include triglycerides, phospholipids, glycolipids, sphingolipids, and the waxes.

2. **Non saponifiable:** A non-saponifiable lipid is one without an ester functional group and that cannot be hydrolyzed under basic conditions. These include prostoglandens, steroids, and terpenes.

B. On the basis to products of hydrolysis lipids are following types:

1. Simple Lipids: Simple lipids are defined as those that on hydrolysis yield at most two types of primary product per mole. On hydrolysis they give fatty acids and alcohol. Simple lipids are of two types: (a) Triglycerides and (b) Wax.

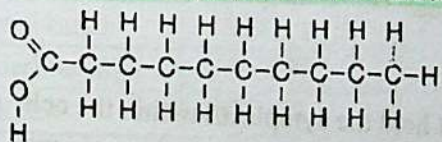
(a) Triglycerides: A triglyceride (TG) is an ester derived from a glycerol and three fatty acids. Triglycerides are blood lipids that help enable the bidirectional transference of adipose fat and blood glucose from the liver. In the human body, high levels of triglycerides in the bloodstream have been linked to **atherosclerosis** and, by extension, the risk of heart disease and stroke. The main triglycerides are:

(i) Fats: The triglyderides produced **saturated fatty acids** are called fats. Saturated fats have a higher melting point (70°C) and are more likely to be solid at room temperature (20°C). Common saturated fatty acids are *lauric acid, palmitic acid, stearic acid, behenic acid, myristic acid, lignoceric acid* etc. Foods containing a high proportion of saturated fat include animal fats such as cream, cheese, butter, and ghee; suet, tallow, lard, and fatty meats; as well as certain vegetable products such as coconut oil, cottonseed oil, palm kernel oil, chocolate, and many prepared foods.

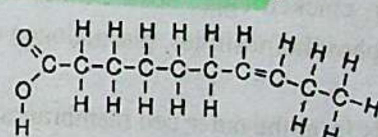
(ii) Oils: The triglyderides produced **unsaturated fatty** acids are called oils. Unsaturated oils have a lower melting point (5°C) and are more likely to be liquid at room temperature. Common unsaturated fatty acids are *palmitoleic acid, oleic acid, gadoleic acid, erucic acid, linoleic acid, linolenic acid, arachidonic acid* etc. Foods containing unsaturated fats include avocado, nuts, and vegetable oils such as canola and olive oils.

Fatty acids

A fatty acid consists of a straight chain of an even number of carbon atoms, with hydrogen atoms along the length of the chain and at one end of the chain and a carboxyl group (−COOH) at the other end. If the carbon-to-carbon bonds are all single, the acid is **saturated**; if any of the bonds is double or triple, the acid is **unsaturated** and is more reactive.



Saturated fatty acids



Unsaturated fatty acids

Functions of fat and oil/Triglycerides:

- Fat and oil are concentrated source of energy. These provide backup energy source when carbohydrates are not available.
- Some types of vitamins rely on fat and oil for absorption and storage. Vitamins A, D, E and K, called fat-soluble vitamins, cannot function without adequate daily fat intake.
- Fat cells, stored in adipose tissue, insulate our body and help sustain a normal core body temperature.
- Fat and oil remain as reserve food in fruit and seeds of plants.
- During germination reserve fat and oil transformed into carbohydrates and supply nutrition to the growing embryos.
- Fat and oil provide our body with fatty acids, which play key metabolic and structural roles in physiology.

■ Fatty acids work as signaling molecules, helping your cells communicate with each other to ensure proper body function.

■ Saturated fatty acids (fats) raise LDL (low-density lipoprotein) cholesterol levels in the blood. This increases the chances for developing cardiovascular disease.

■ Unsaturated fatty acids (oil) fats lower LDL levels and reduce the risk for disease.

(b) Wax: A wax is a simple lipid which is an ester of a long-chain monohydric alcohol and a fatty acid. The alcohol may contain from 12-32 carbon atoms. Waxes are more likely to be solid at room temperature. Waxes are insoluble in water but soluble in organic, nonpolar solvents. Natural waxes of different types are produced by plants and animals and occur in petroleum. In waxes of plant origin, characteristic mixtures of unesterified hydrocarbons may predominate over esters. Those of animal origin typically consist of wax esters derived from a variety of carboxylic acids and fatty alcohols

Functions of wax:

■ Many plants have leaves and fruits with wax coatings to help prevent water loss.

■ Some animals also have wax-coated fur or feathers to repel water.

■ Candles and perfumes are produced from wax.

2. Compound lipid: Compound lipids defined as those that on hydrolysis yield three or more primary product per mole. On hydrolysis it gives phosphoric acid, various sugars, sphingosine, ethanolamine and serine in addition to fatty acids and glycerol. Compound lipid are of following four types:

(a) Phospholipid: A phospholipid (phosphatide) is composed of two fatty acids, a glycerol unit, a phosphate group and a polar molecule. Phospholipids are a major component of all cell membranes as they can form lipid bilayers. Common sources of industrially produced phospholipids are soya, rapeseed, sunflower, chicken eggs, bovine milk, fish eggs etc. Examples of phospholipids include lecithin, cephalins, phosphoinositides, plasmalogen etc.

Functions:

■ Phospholipids form the outer cell membranes that hold the cytoplasm within the cell.

■ It prevents the diffusion of larger molecules such as glucose, water and charged ions.

■ Phospholipids help the cell maintain its internal structures and environment, a process called **homeostasis.**

■ In plants, **phospholipids** serve as a raw material to produce Jasmonic acid, a plant hormone that mediates defensive responses against any disease causing agents.

■ It acts as a prosthetic group in case of some enzymes.

■ It helps in blood clotting.

(b) Glycolipid: Glycolipids are any of a group of lipids containing a carbohydrate group, commonly glucose or galactose. Glycolipids are part of the cell membrane and help to make up what is known as the **glycocalyx.** Chloroplast membranes of green plants enriched with glycolipid. These are also found in sunflower and cotton seeds.

Functions:

■ The main function of glycolipids in the body is to serve as recognition sites for cell–cell interactions.

- Glycolipipds are responsible for immune responses, notably the recognition of viruses within the body.
- Glycolipipds are also responsible for blood grouping of human.

(c) Lipoprotein: A lipoprotein is a biochemical assembly that contains both proteins and lipids. The lipids or their derivatives may be covalently or non-covalently bound to the proteins. Many enzymes, transporters, structural proteins, antigens, adhesins and toxins are lipoproteins. Lipoproteins enable fats and cholesterol to move within the water-based solution of the bloodstream. In order of size, largest to smallest, lipoproteins are of five types:

(i) Chylomicrons,
(ii) Very-low-density lipoprotein (VLDL),
(iii) Intermediate-density lipoproteins (IDL),
(iv) Low-density lipoprotein (LDL) and
(v) High-density lipoprotein (HDL)

LDL particles are often informally called **bad cholesterol** because they can transport their content of many cholesterols. Each LDL bears more or less 1500 cholesterol esters. HDL particles, on the other hand, is frequently referred to as **good cholesterol or healthy cholesterol**, because they can bear little amount of cholesterol. The high level of HDL in human blood is not harmful but high level of LDL in blood is very risky which leads **hypertension** and **heart disease**. When LDL exceeds its normal level (<100 mg/dl) in blood, gradually there is build up of cholesterol and fats in the artery walls creating a complex disease **coronary thrombosis** or **atherosclerosis.**

Lipid profile

Lipid profile or *lipid panel* is a panel of blood tests that serves as an initial broad medical screening tool for abnormalities in lipids, such as cholesterol and triglycerides.

Know your lipid profile (mg/dl=milligram/deciliter)

Interpretation	TG (mg/dl)	LDL(mg/dl)	HDL(mg/dl)	Total cholesterol (TC)
Normal range	< 150	< 100	>145	>200
Borderline-high	150 - 199	130 - 159	90-145	200 - 239
High risk .	200 -499	160 - 189	< 90	< 240
Very high risk	> 500	>190	< 40	< 240
TC=HDL + LDL + 20% of triglyceride (TG) level				

(d) Sulpholipids: A glycolipid which bears sulfur molecule is called as sulpholipid. This is abundant in chloroplast.

(e) Sphingolipids: Sphingolipids are a type of lipid found in cell membranes, particularly nerve cells and brain tissues. They do not contain glycerol, but retain the two alcohols with the middle position occupied by an amine. Sphingolipids are named after the **Spinx** in Greek mythology, part woman and part lion, which devoured all who could not answer her riddles. Spingolipids appeared to **Johann Thudichum** in 1874 as part of the dangerous riddle of the brain.

3. Derived lipid: Hydrolytic products of simple and compound lipids are known as **derived lipids.** Derived lipids include steroids, terpins, rubber, ketone bodies, hydrocarbons, fatty acids, fatty alcohols, mono and diglycerides etc.

(a) Steroids: Steroids are naturally occurring or synthetic fat-soluble derived lipids having as a basis 17 carbon atoms arranged in four rings. **Sterols** are forms of steroids with a hydroxyl group at position three and a skeleton derived from cholestane. Steroids include such well known compounds as cholesterol, sex hormones, birth control pills, cortisone and anabolic steroids. Hundreds of steroids are found in plants, animals and fungi. All steroids are manufactured in cells from the sterols lanosterol (animals and fungi) or cycloartenol (plants).

Biological significance of steroid

- Steroids and their metabolites often function as signalling molecules and steroids and phospholipids are components of cell membranes.
- Steroids such as cholesterol decrease membrane fluidity.
- Similar to lipids, steroids are highly concentrated energy stores. However, they are not typically sources of energy.
- Steroids play critical roles in a number of disorders, including malignancies like **prostate cancer,** where steroid production inside and outside the tumour promotes cancer cell aggressiveness.

Cholesterol

The best known and most abundant steroid in the body is **cholesterol.** Cholesterol is formed in brain tissue, nerve tissue, and the blood stream. It is the major compound found in gallstones and bile salts. Cholesterol also contributes to the formation of deposits on the inner walls of blood vessels. These deposits harden and obstruct the flow of blood. This condition, known as **atherosclerosis** or **coronary thrombosis,** results in various heart diseases, strokes, and high blood pressure.

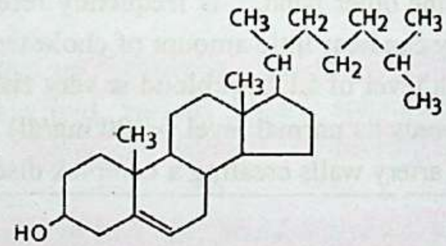
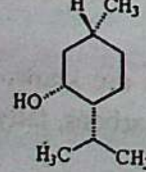


Fig 3.2: Cholesterol

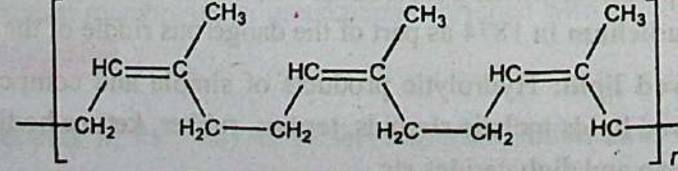
(b) Terpenes: Terpenes are one of the most important derived lipids and components of the resin and essential oils of many types of plants and flowers. Their molecules contain isoprene units (C_5H_8) and have the general formula $(C_5H_8)_n$. Terpenes derived from oranges, lemons, other citrus, lavender, thyme, cedar wood, pine, and other plants and more rarely by insects (termites or swallowtail butterflies). When terpenes are modified chemically, the resulting compounds are generally referred to as **terpenoids.** Terpenes and terpenoids are the primary constituents of the **essential oils** of many types of medicinal plants and flowers. Terpenes are also major constituents of *Cannabis sativa* plants, which contain at least 120 identified compounds.

Functions

- Terpenes often have a strong odor and may protect the plants that produce them by deterring herbivores and by attracting predators and parasites of herbivores.
- Terpenes are use in production of perfumes, insect repellants, cosmetics, cleaners, air fresheners etc.



Terpenes



Cis-isopren

(c) Rubber: Rubber is a derived lipid of highly elastic solid substance, light cream or dark amber in colour, polymerized by the drying and coagulation of the latex or milky juice of rubber trees and plants, species of the *Hevea brasiliensis, Palaquium gutta, Ficus elastica, Castilla elastica* and *Taraxacum officinale* species. The major commercial source of natural rubber latex is the Pará rubber tree, *Hevea brasiliensis*. This species is preferred because it grows well under cultivation. A properly managed tree responds to wounding by producing more latex for several years. Chemically it is composed of 3000-6000 isopren (C_5H_8) units. **Natural rubber** is susceptible to degradation by a wide range of bacteria. Rubber is also produced artificially reffered as **gum rubber**.

Functions

- Natural rubber is used extensively in many applications and products, either alone or in combination with other materials.
- In most of its useful forms, it has a large stretch ratio and high resilience, and is extremely waterproof.

Roles of lipids in living organisms

Lipids are vitally important in living organisms. They have many functions, some of which are listed below:

1. **Structuring cell membranes.** Phospholipids act as building blocks of the biological cell membranes in virtually all organisms. The lipid membrane allows for fluid movement and transport of vital molecules in and out of cells.
2. **Energy storage.** For many organisms, lipids (Triglycerides) are the primary means of storing energy for later use. The structure of lipids allows more energy to be stored in less space.
3. **Hormone:** Lipids form the base from which hormones are built. Plants and animals alike use hormones to perform numerous important functions like regulating stress responses, sugar levels and energy processing, as well as the production of sex cells. Lipid hormones, like steroids and eicosanoids, also mediate communication between cells.
4. **Absorbing vitamins:** Many necessary vitamins are carried out of the intestines by the aid of lipids, and are stored in fatty tissues. Vital fat-soluble vitamins include vitamins A, D, E and K.
5. **Protection:** Many organisms use lipids for protecting their surfaces, which are exposed to the elements. Plants have waxy coatings on their leaves to prevent drying out, much like the oils found on skin, hair and nails in mammals.
6. **Buoyancy:** In aquatic mammals, the fat is less dense than water, so it acts as a buoyancy aid.
7. **Electrical insulators:** In nerve fibers, the myelin sheath contains lipids which act as electrical insulators.
8. **Fluidity and permeability of cell membrane:** Cholesterol regulates membrane fluidity over a wider range of temperatures. It is also maintain the permeability of the plasma membrane.
9. **Transporter:** Phospholipids play an important role in the transport of fat between gut and liver in mammalian digestion.
10. **Colouration:** Carotin, xanthophylls, chlorophylls etc. of lipid derivative are responsible for colouration of plants.
11. **Odor:** Terpenes produced perfumes in plants.
12. **Photosynthesis:** Glycolipids help in photosynthesis process in plants.

3. PROTEINS

Proteins are any of a class of nitrogenous organic compounds which have large molecules composed of one or more long chains of amino acids and are an essential part of all living organisms, especially as structural components of body tissues such as muscle, hair, etc., and as enzymes and antibodies.

Protein comprises 12% of the living body. Proteins are the "**workhorse**" molecules of life, taking part in essentially every structure and activity of life. They are building materials for living cells, appearing in the structures inside the cell and within the cell membrane. Proteins were first described by the Dutch chemist **Gerardus Johannes Mulder** and named by the Swedish chemist **Jons Jacob Berzelius** in 1838.

Properties of Protein

1. Proteins are colloidal organic substances with high molecular weight.
2. Protein contains carbon, hydrogen, and oxygen like the carbohydrates and lipids, but they also contain nitrogen and often sulfur and phosphorus.
3. They are fundamental components of all living cells and include many substances, such as enzymes, hormones, and antibodies, that are necessary for the proper functioning of an organism.
4. They are essential in the diet of animals for the growth and repair of tissue and can be obtained from foods such as meat, fish, eggs, milk, and legumes.
5. When hydrolyzed by acids, alkalis or enzymes, proteins yield amino acids or their derivatives.

Sources of Protein

Protein can be found in a wide range of food. Meat, eggs and fish are sources of complete protein. Milk and milk-derived foods are also good sources of protein. Whole grains and cereals are another source of proteins. Vegetarian sources of proteins include pulses, nuts, seeds and fruits.

Abundance in cells

It has been estimated that average-sized bacteria contain about 2 million proteins per cell (e.g. *E. coli* and *Staphylococcus aureus*). Yeast cells were estimated to contain about 50 million proteins and human cells on the order of 1 to 3 billion.

Structure of Protein

Protein molecules are often very large and are made up of hundreds to thousands of amino acid units. There are 20 types of amino acid units in a protein molecule are held together by **peptide bonds** (–CO–NH–) and form chains called **polypeptide chains**. In polypeptide bond the amine group ($-NH_2$) is attached to the carbon atom adjacent to the –COOH (the **α carbon atom**). The amino acids are called **amphoteric organic acids** because they contain the basic amine group, $-NH_2$ and the carboxylic acid group –COOH.

The shortest peptides are **dipeptides**, consisting of 2 amino acids joined by a single peptide bond, followed by **tripeptides, tetrapeptides**, etc. Short polypeptides, containing less than 20–30 2 amino acids, are commonly called **oligopeptides**. A linear chain with more than 50 amino acid residues is called a polypeptide. A protein contains at least one long polypeptide. The sequence of amino acid residues in a protein is defined by the sequence of a gene, which is encoded in the genetic code.

Both end of a polypeptide chain always remain open. These are called N end and C end of amine and carboxyl radical respectively. The nature of protein depends of the diversification of polypeptide chain. Proteins are synthesis in the ribosome of the cell.

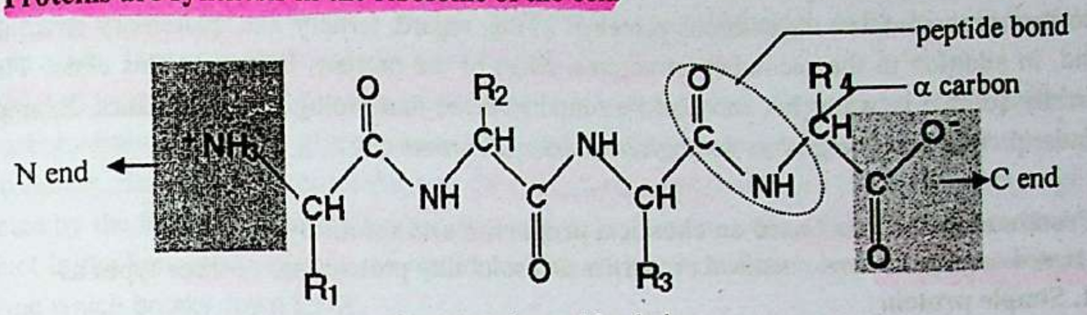


Fig 3.3 Polypeptide chain

However, biochemists often refer to four distinct aspects of a protein's structure:

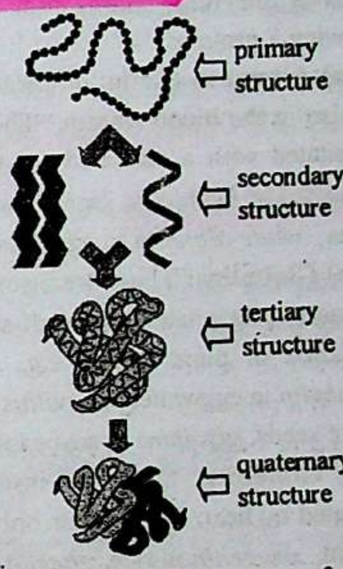


Fig 3.4: Different structure of protein

1. **Primary structure:** The linear sequence of amino acids joined together by peptide bonds is termed as the primary structure of protein. *Insulin* is an example of a protein with a primary structure.

2. **Secondary structure:** Secondary structure refers to the regular folding of regions of the polypeptide chain. Most common types of secondary structure are α-helix (a spiral) and β-pleated (folds) e.g. keratin, silk.

3. **Tertiary structure:** Tertiary structure refers to 3-dimentional arrangement of all amino acids in the polypeptide chain. e.g. Fibrinogen.

4. **Quaternary structure:** In quaternary structure protein consists of more than one polypeptide chains are held together by covalent (disulphide bonds) or non covalent interactions (hydrogen bondings). e.g. Hemoglobin made up of 4 polypeptide chains, two α-chains and two β-chains.

Classification of protein

A. Protein classification based on biological activities

On the basis of biological activities proteins are two types:

1. **Structural protein:** Structural protein is usually a protein that provides scaffolding or give the cell or one of its organelles shape. Examples of structural proteins are ***keratin*** (skin, horn, nail, hoolf, feather etc.), ***collagens*** (bone, tendon, connective tissue etc.), ***fibrin*** (silk, spider web), ***sclerotin*** (exoskeleton of insect), ***chondrin*** (cartilage), ***sein*** (bone).

2. **Functional protein:** Functional protein is usually a protein that catalyzes a reaction of some kind or participates in different metabolic reaction of organism. These are also called as **regulatory proteins**. Examples of functional protein are enzymes, hormones, vitamins, respiratory pigments etc.

B. Protein classification based on shape

On the basis of their shape, proteins may be divided into two classes: fibrous and globular.

1. **Fibrous or Fibrillar proteins:** They have primarily mechanical and structural functions, providing support to the cells as well as the whole organism. These proteins are insoluble in water as

they contain, both internally and on their surface, many hydrophobic amino acids. Examples of fibrous proteins are *fibroin, collagen, α-keratins, elastin* etc.

2. Globular or Corpuscular Proteins: They have a compact and more or less spherical structure, more complex than fibrous proteins. In this regard, tertiary and quaternary structures are found, in addition to the secondary structures. Most of the proteins belong to this class. They are generally soluble in water but can also be found inserted into biological membranes. Examples of globular proteins are *myoglobin, hemoglobin,* and *cytochrome C*.

C. Protein classification based on chemical properties and solubility

Based on physical and chemical properties and solubility proteins are of three types as-

1. Simple protein

Simple protein consists of only amino acids or their derivatives. When hydrolyzed by acids, alkalis or enzymes, simple proteins yield only amino acids or their derivatives. They include the following 7 groups:

(a) Albumins (Latin: *albumen*=white): These are water soluble-proteins found in all body cells and also in the blood stream. These are soluble in water and dilute solutions of acids, bases and salts. Precipitated with a saturated solution of an acid salt like $(NH_4)_2SO_4$ or a neutral salt like Na_2SO_4. Coagulated by heat. e.g. *lactoalbumin* in milk, *β amylase albumin* in barley, *serum albumin* in blood plasma, *white albumin* in egg, *leucosine* in cereals, *legumeline* in legumes and *myosin* of muscles.

(b) Globulins: These are insoluble in water but are soluble in dilute salt solutions of strong acids and bases. Precipitated with half saturated solution of $(NH_4)_2SO_4$ and coagulated by heat. These are abundance in plant seeds. e.g. *serum globulin* in blood plasma, *alphaglobin* in blood serum. *ovoglobulin* in eggwhite, *phosvitins* in yolk, *lactoglobulin* in milk, *myosinogen* in muscle, *ologlobulin* in plant seeds, *glycinine* in soybeans, *legumine* peas, *pomeline* in oranges, *tuberin* in also potato etc.

(c) Glutelins: These are insoluble in water but are soluble in dilute acids and alkalis. Not coagulated by heat. They occur only in plant material. These are abundance in cereals. e.g. *glutenin* in wheat, *orygenin* in rice, *glutelin* in corn etc.

(d) Prolamines: These are insoluble in water and dilute salt solutions but soluble in dilute acids and alkalies and also in 60 – 80% alcohol solutions. They can hydrolyze into prolin and ammonia. Not coagulated by heat. They are found only in plant material. They include *gliadin* from wheat, *hordein* from barley and *zein* from maize.

(e) Scleroproteins: Scleroproteins are insoluble in all neutral solvents and in dilute alkalis and acids. They are found in connective tissues, hair and nails and commonly known as the **'animal skeleton proteins'**. They are not attacked by enzymes. e.g *keratin* in skin, hair and nails, *collagen* in white fibers of areolar tissue, *elastin* in ligaments, *fibroin* of silk etc.

(f) Histones: These are water soluble proteins in which alkaloid amino acids are predominant. They are rich in arginine or lysine. Not coagulated by heat. e.g. *nucleohistones* in nucleus, *globin* in hemoglobin.

(g) Protamines: These are water soluble basic polypeptides with a low molecular weight (about 4,000 Daltons). They are very rich in the amino acid arginine. Protamines are found bound to DNA in spermatozoa of some fishes. e.g. *clupeine* in herring sperm, *salmine* in salmon sperm, *sturine* in sturgeon, *cyprinine* in carp etc.

2. Conjugated proteins

These consist of simple proteins in combination with some non-protein component. The non-protein groups are called **prosthetic groups.** Conjugated protein includes the following group:

(a) Nucleoproteins: (Protein + nucleic acid). Nucleoproteins are proteins in combination with nucleic acids. These are water soluble and found in chromosomes.

(b) Glycoproteins or Mucoproteins: (Protein+Carbohydrate): Glycoproteins are proteins link to carbohydrate. In most glycoproteins the linkage is between asparagines and N-acetyl-D-glocosamine. Examples glycoproteins are: *Plasma glycoproteins* secreted by the liver, *thyroglobulin* secreted by the thyroid gland, *immunoglobins* secreted by plasma cells, *ovoalbumins* secreted by the oviduct in the hen, *ribonuclease,* the enzyme which breaks down RNA, and *deoxyribonuclease,* the enzyme which breaks down DNA.

(c) **Phosphoproteins** (Protein+phosphate): Phosphoproteins are proteins in combination with a phosphate-containing radical other than a nucleic acid or a phospholipid. Examples of phosphoproteins are *caseinogen* of milk and *ovovitelline* in eggs.

(d) **Chromoproteins:** These are proteins in combination with a proshetic group that is a pigments. Examples are the respiratory pigments *haemoglobin* and *haemocyanin,* visual purple or *rhodopsin* found in the rods of the eye, *flavoproteins* and *cytochromes.*

(e) **Lipoproteins:** These are proteins conjugated with lipids. These are structural components of all cellular membrane.

(f) **Metalloproteins:** These are proteins conjugated to metal ion (s) which are not part of the prosthetic group. They include *caeruloplasmin*, an enzyme with oxidase activity that may transport copper in plasma, and *siderophilin* that is found to iron.

3. Derived proteins

Derived protein is a small protein obtained by enzymatic or chemical hydrolysis of a larger protein source.

(a) Proteans. Insoluble in water; appear as first product produced by the action of acids, enzymes or water on proteins. e.g., edestan derived from edestin and myosan derived from myosin.

(b) Metaproteins or Infraproteins. Insoluble in water but soluble in dilute acids or alkalies; produced by further action of acid or alkali on proteins at about 30–60°C. e.g. , acid and alkali metaproteins.

(c) Coagulated Proteins. Insoluble in water; produced by the action of heat or alcohol on proteins. e.g., coagulated eggwhite.

(d) Proteoses. Soluble in water; coagulable by heat; produced when hydrolysis proceeds beyond the level of metaproteins.. e.g., albumose from albumin; globulose from globulin.

(e) Peptones. Soluble in water; noncoagulable by heat; produced by the action of dilute acids or enzymes when hydrolysis proceeds beyond proteoses.

(f) Polypeptides. These are combinations of two or more amino acid units. In fact, the proteins are essentially long chain polypeptides.

Roles of protein in living organisms

Proteins are very important molecules in living cells. They are involved in virtually all cell functions. Some of the main functions carried out by proteins include:

1. **Structural support:** There are structural proteins, which are frequently fibrous and stringy and provide support. Examples include keratin, collagen, and elastin.

2 **Transport:** The protein *hemoglobin* carried by red blood cells, plays a key role in respiratory gases (oxygen and carbondioxide) transport. The protein *cytochromes* operate in the electron transport chain as electron carrier proteins.

3. **Catalyzers:** All enzymes are made of protein. As *catalysts enzymes* facilitate biochemical reactions and speed them up enormously, making them as much as a million times faster.

4. **Defense:** The protein *lysozyme* which is an important defensive enzyme found in tears, saliva, and mucus. Lysozyme destroys the bacterial polysaccharide by cleaving it into pieces.

5. **Immunity:** *Antibodies* are defensive proteins that have binding sites whose three-dimensional structure allows them to identify and bind to very specific foreign molecules.

6. **Body contraction:** There are contractile proteins, such as *actin* and *myosin*, that provide movement in muscles and movement within single cells.

7. **Plant Growth:** Plants store proteins in embryo and vegetative cells to provide carbon, nitrogen, and sulfur resources for subsequent growth and development.

8. **Blood clotting:** *Fibrinogen* is a glycoprotein which helps in healing of wounds. Thus it prevents the blood loss and inhibits the passage of germs.

9. **Control metabolic activity:** Many *hormones* are protein in nature; hormones control growth and metabolic activities of the body.

10. **Source of energy:** Protein is only used in the body as fuel when carbohydrates and lipid resources are low. Per gram protein can produce 4.1 calories of energy.

11. **Signal receptors:** Many proteins are embedded in the cell's membranes or span the entire lipid bilayer where they play an important role in recognition, signaling, and transport.

Daily Protein Requirements

You need protein for your muscles, bones, and the rest of your body. Exactly how much you need changes with age:

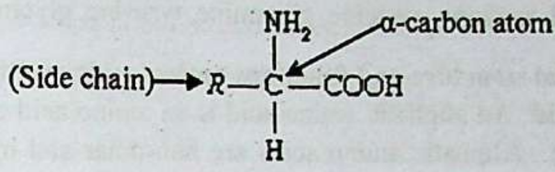
- Babies need about 10 grams a day.
- School-age kids need 19-34 grams a day.
- Teenage boys need up to 52 grams a day.
- Teenage girls need up to 46 grams a day.
- Adult men need about 56 grams a day.
- Adult women need about 46 grams a day.
- Pregnant or breastfeeding women need about71 grams a day.

Amino acids

Amino acid, any of a group of organic molecules that consist of a basic amino group ($-NH_2$), an acidic carboxyl group ($-COOH$), and an organic R group (or side chain) that is unique to each amino acid. Each molecule of amino acid contains a central carbon (C) atom, termed the **α-carbon,** to which both an amino and a carboxyl group are attached. The remaining two bonds of the α-carbon atom are generally satisfied by a hydrogen (H) atom and the R group. The formula of an amino acid comprises, bound to a carbon (alpha carbon):

- a carboxyl group -COOH
- an amine group -NH2

- an atom of hydrogen -H
- a variable radical -R, that is the functional group of the amino acid.



Here, R = H or different radicals or groups with carbon atom

The amino acids differ from each other in the particular chemical structure of their R group or side chain. The name, abbreviation, molecular and linear formula of 20 common amino acids which take part in protein formation, are mention in the **Table-1**. These amino acids combined and arranged in different ways to form millions of protein in the living organisms.

Amino acids and proteins are the building blocks of life. In 1902, **Emil Fischer and Franz Hofmeister** proposed that proteins are the result of the formation of bonds between the amino group of one amino acid with the carboxyl group of another, in a linear structure that Fischer termed **peptide.**

Properties of amino acid

1. Amino acids are colourless, tasteless, sweet or bitter substances.
2. Amino acids are water soluble in nature but insoluble in alcohol.
3. Amino acid produces salt with light acids or alkali.
4. They have high power of melting.
5. Proteins were found to yield amino acids after enzymatic digestion or acid hydrolysis.
6. One or more types of amino acids are bonded together with peptide bonds to form protein molecule.
7. The amine and carboxylic acid functional groups found in amino acids allow them to have amphiprotic properties.
8. Carboxylic acid groups (–COOH) can be deprotonated to become negative carboxylates ($-CO_2^-$), and α-amino groups (NH_2-) can be protonated to become positive α-ammonium groups ($^+NH_3-$). This molecular state is known as a **Zwitterion,** from the German **Zwitter** meaning *hermaphrodite* or *hybrid.*

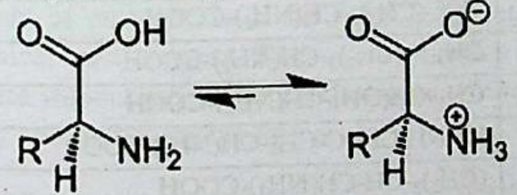


Fig 3.5: An amino acid contains both acidic (carboxylic acid fragment) and basic (amine fragment) centers. The isomer on the right is a **zwitterion.**

Classification of Amino Acid

Although over 100 amino acids exist in nature, the human body requires 20 amino acids, called **standard amino acids**, for normal functioning. These amino acids are classified in different ways.

A. On the basis of necessity of human body, amino acids are classified into two groups:

1. Essential amino acids: Essential amino acids cannot be made by the body. As a result, they must come from food. The **9 essential amino acids** are: histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine.

2. Nonessential amino acids: Nonessential means that our bodies produce an amino acid, even if we don't get it from the food we eat. The **11 nonessential amino acids** are: alanine, asparagine, aspartic acid, glutamic acid, arginine, cysteine, glutamine, tyrosine, glycine, proline, and serine.

B. On the basis of chemical structure and functions amino acids are three types-

1. Aliphatic amino acid: An aliphatic amino acid is an amino acid containing an aliphatic side chain functional group (R). Aliphatic amino acids are non-polar and hydrophobic. Examples are: alanine, glycine, valine, leucine, isoleucine, glutamic acid, aspertic acid, lysine, arginine, serine, threonine, cistine, cysteine and methionine.

2. Aromatic amino acid: An aliphatic amino acid is an amino acid containing an aromatic (benzene) side chain functional group (R). Aromatic amino acids are relatively nonpolar. Examples are tyrocine and phenylalanine.

3. Heterocyclic amino acid: Amino acids that have the structurally different components from the above mentioned are called heterocyclic amino acids. Examples are proline, hydroxyproline, histidine and tryptophan.

C. On the basis of protein formation amino acids are two types-

1. Proteinogenic amino acids: These are broadly defined as the amino acids that are used to form proteins. There are 20 amino acids mentioned in the Table-1 are proteogenic type.

2. Non-proteinogenic amino acids: These are not required to build proteins. However, this doesn't mean that they are not important. These amino acids have a vital role as metabolic intermediates. There are approximately 700 known non-proteinogenic amino acids, of which around 300 are plant derived.

Table: The name, abbreviation, molecular and linear formula of 20 Proteinogenic amino acids

No.	Amino acid	Abbreviations	Molecular formula	Linear formula
		Essential amino acid		
1.	Histidine	His	$C_6H_9N_3O_2$	$NH-CH=N-CH=C-CH_2-CH(NH_2)-COOH$
2.	Isoleucine	Ile	$C_6H_{13}NO_2$	$CH_3-CH_2-CH(CH_3)-CH(NH_2)-COOH$
3.	Leucine	Leu	$C_6H_{13}NO_2$	$(CH_3)_2-CH-CH_2-CH(NH_2)-COOH$
4.	Lysine	Lys	$C_6H_{14}N_2O_2$	$H_2N-(CH_2)_4-CH(NH_2)-COOH$
5.	Methionine	Met	$C_5H_{11}NO_2S$	$CH_3-S-(CH_2)_2-CH(NH_2)-COOH$
6.	Threonine	Thr	$C_4H_9NO_3$	$CH_3-CH(OH)-CH(NH_2)-COOH$
7.	Tryptophan	Trp	$C_{11}H_{12}N_2O_2$	$Ph-NH-CH=C-CH_2-CH(NH_2)-COOH$
8.	Valine	Val	$C_5H_{11}NO_2$	$(CH_3)_2-CH-CH(NH_2)-COOH$
9	Phenylalanine	Phe	$C_9H_{11}NO_2$	$Ph-CH_2-CH(NH_2)-COOH$
		Nonessential amino acids		
10	Cysteine	Cys	$C_3H_7NO_2S$	$HS-CH_2-CH(NH_2)-COOH$
11	Glutamine	Gln	$C_5H_{10}N_2O_3$	$H_2N-CO-(CH_2)_2-CH(NH_2)-COOH$
12	Glutamic acid	Glu	$C_5H_9NO_4$	$HOOC-(CH_2)_2-CH(NH_2)-COOH$
13	Glycine	Gly	$C_2H_5NO_2$	NH_2-CH_2-COOH
14	Alanine	Ala	$C_3H_7NO_2$	$CH_3-CH(NH_2)-COOH$

15	Arginine	Arg	$C_6H_{14}N_4O_2$	HN=C(NH$_2$)-NH-(CH$_2$)$_3$-CH(NH$_2$)-COOH
16	Asparagine	Asn	$C_4H_8N_2O_3$	H$_2$N-CO-CH$_2$-CH(NH$_2$)-COOH
17	Aspartic acid	Asp	$C_4H_7NO_4$	HOOC-CH$_2$-CH(NH$_2$)-COOH
18	Proline	Pro	$C_5H_9NO_2$	NH-(CH$_2$)$_3$-CH-COOH
19	Serine	Ser	$C_3H_7NO_3$	HO-CH$_2$-CH(NH$_2$)-COOH
20	Tyrosine	Tyr	$C_9H_{11}NO_3$	HO-Ph-CH$_2$-CH(NH$_2$)-COOH

Functions of amino acid

1. They are essentially the building blocks of proteins, and proteins are essentially the building blocks of life.

2. They play an important role in hormone and enzyme synthesis.

3. Amino acids are responsible for breaking down food, repairing tissue, building muscle, intermediating metabolism, growth, and performing various other body functions.

3.2 Enzyme

Enzymes are any of numerous proteins substances that are produced by living cells and catalyze specific biochemical reactions at body temperatures. Enzymes are usually very selective in the molecules that they act upon, called **substrates,** often reacting with only a single substrate. Enzymes are also known as organic catalysts, mocatalysts, cell ferments, bio-regulators, catalysts of life or 'agents of life'.

Wilhelm Kuhne
(1837–1900)

The first enzyme discovered was ***amylase***, which catalyses the conversion of starch to maltose, in 1833 by two French chemists **Payen and Persoz.** However, it was not well-known until 1878 when **Wilhelm Kuhne**, the distinguished German biochemist, proposed the term *enzyme*. The term enzyme comes from *zymosis,* the Greek word for fermentation, a process accomplished by yeast cells. In 1897 German scientist, **Eduard Buchner** recognized *zymase* enzyme which responsible for sugar fermentation. In 1907, he received the Nobel Prize in Chemistry for his biochemical research and his discovery of cell-free fermentation.

In 1926, **James B. Sumner** crystallized enzyme *urease* from the plant and proved it as protein. The study of enzymes is called ***enzymology.*** Enzymes are known to catalyze more than 5,000 biochemical reaction types. Enzymes are present in trace amount in living body. No reaction of the body held without any enzyme. Thousands of enzymes catalyzed different biochemical reaction in the body and continuing the life.

Chemical structure of enzyme

Enzymes are composed primarily of proteins, which are polymers of amino acids. Each enzyme is made of between a hundred and upwards of a million amino acids placed like pearls on a string. In most enzymes the string is coiled and folded thousands of times to form a highly complex three-dimensional structure. The vast majority of enzymes are made of only 20 different kinds of amino acid. The structure and function of the enzyme is determined by the order of the amino acids.

A small number of enzymes are not proteins, but consist of small catalytic RNA molecules. These RNA biocatalysts have come to be known as **ribozymes.** Many enzymes catalyze reactions without help, but some require an additional non-protein component called a **co-factor.** Co-factors may be inorganic ions such as Fe^{2+}, Mg^{2+}, Mn^{2+}, or Zn^{2+}, or consist of organic or metalloorganic molecules known as **co-enzymes.**

Activeness of enzyme

Some enzymes secrete as active condition called **zymase.** *Ptyalin* is a zymase enzyme. But some enzymes secrete as inactive condition. They require a biochemical change for to become an active enzyme. These are called **zymozens** or **proenzymes.** *Pepsinozen, trypsinogen* etc. are notable zymogens.

Characteristic of enzymes

1. Enzymes are biological catalysts which speed up a reaction without being used up. They are recovered back after a chemical reaction.
2. Enzymes act on specific substances and catalyze specific reactions.
3. All known enzymes are proteins. They are high molecular weight compounds made up principally of chains of amino acids linked together by peptide bonds.
4. The catalytic power of enzymes limited to specific pH value.
5. The enzymatic reactions are reversible and held within the range of 35°C to 45°C.
6. The functional activities of enzyme are determined by their three dimensional structure.
7. They can be denatured /destroyed by excessive heat (100°C), ultraviolet rays etc.
8. Most of the enzymes are diluted in water, glycerol and low concentration alcohol except some lypolytic enzymes.
9. Enzymes are sediment by ammonium salphate, sodium chloride, picric acid etc.
10. They can perform their functions in both alkali and acidic media.
11. The rate of reaction increase by the presence of co-enzyme, co-factors etc.
12. The enzymes are larger than the molecules of the substrate.

Nomenclature of Enzyme

Except for some of the originally studied enzymes such as pepsin, rennin, and trypsin, most enzyme names end in 'ase'. Generally enzymes get their name in following three common ways:

1. Most often enzymes are named by adding a suffix '*ase*' to the root word of the substrate. For example,

Lipid + ase = Lipase
Protein + ase = Protease
Sucrose + ase = Sucrase

2. Some enzymes are named by adding a suffix '*ase*' to the name of chemical reaction. For example,

Oxidation + ase = Oxidase
Reduction + ase = Reductase
Hydrolysis + ase = Hydrolase

3. Some enzymes are named by adding a suffix '*ase*' to the combined name of chemical reaction and substrate. For example,

Alchohol dehydration + ase = Alchohol dehydrogenase
Cytochrome oxidation + ase = Cytochrome oxidase
Nitrate reuction + ase = Nitrate reductase

Classification of enzymes

A. Based on the function sites, enzymes are broadly of two types:

1. Intracellular or Endoenzymes: They are functional within cells where they are synthesized. *e.g.*, enzymes of Krebs cycle (inside mitochondria), enzymes of glycolysis (inside cytoplasm).

2. Extracellular or Exoenzymes: These enzymes are active outside the cells. *e.g.*, enzymes present in digestive juices, lysozyme of tears

B. Based on the molecular structure, enzymes are of two types:

1. Simple enzymes: They consist of only proteins, *e.g.* urease, lysozyme, pepsin, trypsin etc.

2. Conjugated enzymes: These enzymes consist of proteinous part called **apoenzyme** and non-proteinous part called **co-factor.**

C. Based on catalyzing reactions, the nomenclature committee of the **International Union of Biochemistry and Molecular Biology** (IUBMB) recommended the following classification:

1. Oxidoreductases: This enzyme catalyze oxidation or reduction reactions; transfer of H and O atoms or electrons from one substance to another. They are very important enzymes, which are vital for many metabolic processes, particularly in aerobic and anaerobic respiration. Common names include *dehydrogenase, oxidase, reductase* and *catalase*. The basic reaction can be shown as:

$$AH + B \rightarrow A + BH \text{ (reduced)};\ A + O \rightarrow AO \text{ (oxidized)}$$

$$\text{Succinic acid} + \text{FAD} \xrightleftharpoons{\textit{Dehydrogenase}} \text{Fumaric acid} + FADH_2$$

2. Transferases: These transfer of a functional group from one substance to another. The group may be methyl-, acyl-, amino- or phosphate group. Common names include *acetyltransferase, methylase, protein kinase and polymerase*. The basic reaction can be shown as:

$$AB + C \rightarrow A + BC$$

$$\text{Glutamic acid} + \text{Oxalo acetic acid} \xrightleftharpoons{\textit{Transamylase}} \alpha\text{-ketoglutamic acid} + \text{Aspertic acid}$$

3. Hydrolases: Formation of two products from a substrate by hydrolysis. Common examples are *Proteases, Nucleases, Phosphatase*. The basic reaction can be shown as:

$$AB + H_2O \rightarrow AOH + BH$$

$$\text{Sucrose} + H_2O \xrightleftharpoons{\textit{Sucrease}} \text{Glucose} + \text{Fructose}$$

4. Lyases: Non-hydrolytic addition or removal of groups from substrates. C-C, C-N, C-O or C-S bonds may be cleaved. These are often referred to as synthetase enzymes. Common names include *decarboxylase* and *aldolase*. The basic reaction can be shown as:

$$RCOCOOH \rightarrow RCOH + CO_2 \quad \text{or} \quad [X\text{-}A\text{-}B\text{-}Y] \rightarrow [A{=}B + X\text{-}Y]$$

$$\text{L-malate} \xrightleftharpoons{\textit{Malatehydrolyage}} \text{Fumarate} + \text{Water}$$

5. Isomerases: Isomerases are enzymes that can catalyze structural changes within a molecule. There is only one substrate and one product with nothing gained or lost, so they represent only a change in shape. Examples include *rotamase, protein disulfide isomerase* (PDI), *epimerase* and *racemase*. The basic reaction can be shown as:

$$AB \rightarrow BA$$

$$\text{Glucose-6-phosohate} \xrightleftharpoons{Isomerase} \text{Fructose -6-phosphate}$$

6. **Ligases:** Ligases are responsible for the catalysis of ligation; the joining of two substrates. Usually chemical potential energy is required, so the reaction is coupled to the hydrolysis of a disphosphate bond in a nucleotide triphosphate such as ATP. Examples include *peptide synthetase, aminoacyl-tRNA synthetase, DNA ligase* and *RNA ligase*. The basic reaction can be shown as:

$$X + Y + ATP \rightarrow XY + ADP + Pi$$

$$ATP + \alpha\text{-glutamate} + NH_3 \xrightleftharpoons{Synthetase} ADP + \text{Orthrophosphate} + \alpha\text{-Glutamine}$$

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. There are two different models to explain the mechanism of enzyme action. These are:

1. 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). Smaller keys, larger keys, or incorrectly positioned teeth on keys (incorrectly shaped or sized substrate molecules) do not fit into the lock (enzyme). Only the correctly shaped key opens a particular lock. Lock-and-key is the model such that active site of enzyme is good fit for substrate that does not require change of structure of enzyme after enzyme binds substrate.

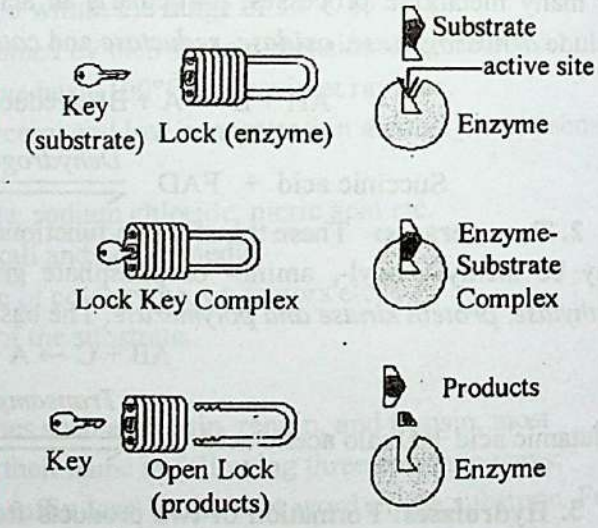


Fig 3.6 Lock and Key model

2. Induced fit theory:

Not all experimental evidence can be adequately explained by using the so-called rigid enzyme model assumed by the lock and key theory. For this reason, a modification called the induced-fit theory has been proposed by **Daniel E. Koshland** in 1958.

The induced-fit model involves the changing of the conformation of the active site to fit the substrate after binding. Also, in the induced-fit model, it was stated that there are amino acids that aid the correct substrate to bind to the active site which leads to shaping of the active site to the complementary shape. Induced fit is the model such that structure of active site of enzyme can be easily changed after binding of enzyme and substrate.

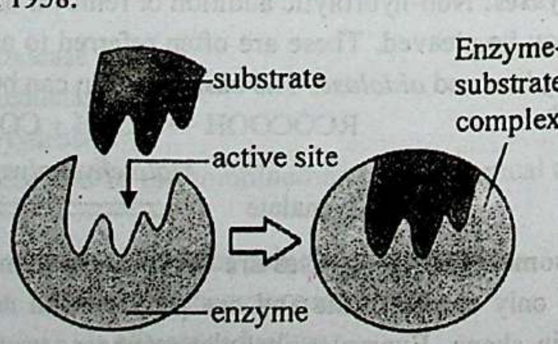


Fig 3.7 Induced fit model

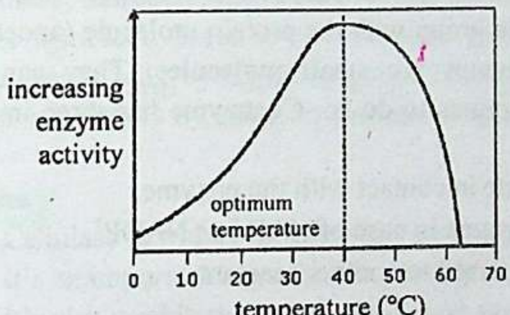
Factors affecting enzyme activities

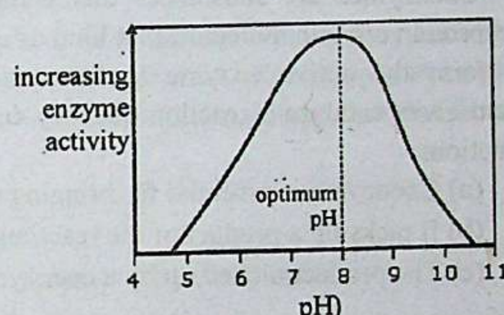
The activity of an enzyme is affected by its environmental conditions. Changing these alter the rate of reaction caused by the enzyme. In nature, organisms adjust the conditions of their enzymes to produce an optimum rate of reaction, where necessary, or they may have enzymes which are adapted to function well in extreme conditions where they live.

1. Temperature: As the temperature increases, so does the rate of reaction. The enzyme activity gradually increases with temperature until around 37°C, or body temperature. But very high temperatures denature enzymes.

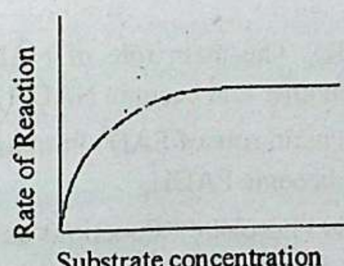
2. pH: Changes in pH alter an enzyme's shape. Different enzymes work best at different pH values. The optimum pH for an enzyme depends on where it normally works. Any change in pH above or below the optimum will quickly cause a decrease in the rate of reaction.

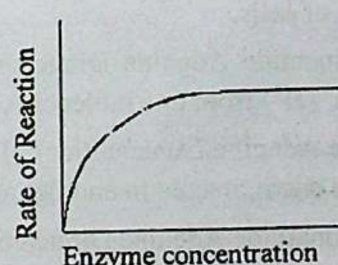
3. Enzyme concentration: Increasing enzyme concentration will increases substrate molecules. However, this too will only have an effect up to a certain concentration, where the enzyme concentration is no longer the limiting factor increase the rate of reaction, as more enzymes will be colliding with.





4. Substrate concentration: Increasing substrate concentration increases the rate of reaction. However, after a certain concentration, any increase will have no effect on the rate of reaction.





5. Co-factors: These are chemical compounds (Cl^-, Mg^{++}, Ca^{++}, Mn^{++}) which bind to enzymes and which are needed by the enzyme to work on substrate molecules. They are often called helper molecules.

6. Enzyme inhibitors: These are molecules (e.g. Ag, Zn, Hg, Cu) which bind to enzymes, reducing their activity (many drugs are enzyme inhibitors).

Biological Functions of Enzyme

Thousands of enzymes involve in different physiological activities in living organisms. Actually no chemical reaction in the body could not held without any enzyme. There are important functions of enzyme are mention below:

1. They are major components in signal transduction and cell regulation, kinases and phosphatases help in this function.

2. They take part in movement with the help of the protein myosin which aids in muscle contraction.

3. Enzymes in the cell membrane act as ion pumps in active transport mechanism.

4. Enzymes present in the viruses are for infecting cell.

5. Enzymes play important role in the digestive activity of the organisms.

6. Amylases and proteases are enzymes that breakdown large molecules into absorbable molecules.

7. Various enzymes work together in an order forming metabolic pathways. Example: Glycolysis.

8. Enzymes take part in oxidation, reduction, isomeration, energy production reaction of the body.

❑ Coenzyme

Coenzymes are substances that enhance the action of an enzyme. Coenzymes are organic nonprotein organic moleculesthat bind as a prosthetic group with the protein molecule (apoenzyme) to form the active enzyme (holoenzyme). Coenzymes are small molecules. They cannot by themselves catalyze a reaction but they can help enzymes to do so. Coenzyme has three important functions:

(a) Coenzyme is essential for bringing the substrate in contact with the enzyme,

(b) It picks up a product of the reaction, e.g., hydrogen in case of NAD^+ or $NADP^+$.

(c) The product picked up by a coenzyme is transferred to another reactant.

Some essential coenzymes of living organism are cited below:

- **ATP** (Adenosine Tri Phosphate): One molecule of adenine, one molecule of ribose sugar and three molecules of phosphate combined to form an ATP molecule. It supplies energy to the metabolic reactions of cells.
- **NAD** (Nicotinamide Adenine Dinucleotide): The main role of NAD^+ in metabolism is the transfer of electrons (H^+) from one molecule to another and become $NADH_2$
- **FAD** (Flavine Adenine Dinucleotide): The main role of FAD^+ in metabolism is the transfer of electrons (H^+) from one molecule to another and become $FADH_2$
- **NADP** (Nicotinamide Adenine Dinucleotide Phosphate): Functions as like as NAD.
- **FADP** (Flavine Adenine Dinucleotide Phosphate): Functions as like as FAD.
- **Co-A:** Coenzyme A or Co-A is synthesized from the vitamin B, pyrophosphate and adenylic acid. It is notable for its role in the synthesis and oxidation of fatty acids, and the oxidation of pyruvate in the citric acid cycle.
- **Cytochrome**: Cytochromes are hemeproteins containing *heme* groups and are primarily responsible for the generation of ATP via electron transport.

Differences between Enzyme and Co-enzyme

Enzyme	Co-enzyme
1. Enzymes are biological catalysts which accelerate chemical reactions.	1. Co-enzymes are organic molecules which help enzymes to catalyze the chemical reactions.

2. All enzymes are proteins.	2. Co-enzymes are non-proteins.
3. Enzymes are not altered due to the chemical reaction.	3. Co-enzymes become chemically altered as a result of the reaction.
4. Enzymes are specific.	4. Co-enzymes are not specific.
5. Enzymes are larger molecules with atomic weight 12000-10,00,0000 Daltons.	5. Co-enzymes are smaller molecules with atomic weight about 500 Daltons.
6. Amylase, proteinase, and kinase are examples of enzymes.	6. NAD, ATP, coenzyme A, and FAD kinase are examples of co-enzymes.

Some biologically important enzymes

■ Cellulase

Cellulase is a class of enzymes produced by the fungi, bacteria, protozoans and certain termites. that generate **cellulolysis.** This process is actually the hydrolysis of cellulose and of some related polysaccharides. The activity of cellulase is commonly to break down cellulose and convert it into **beta-glucose.** The specific reaction involved is the hydrolysis of the *1,4-beta-D-glycosidic linkages* in **cellulose, hemicellulose, lichenin,** and **cereal beta-D-glucans.**

The symbiotic bacteria of herbivores generate this form of cellulase. Thus, they take their overall energy only by ingesting grass. Humans cannot generate cellulase. Thus, they can break it down only partially by using fermentation and they are not able to utilize the energy from the fibrous plants.

Uses

1. Cellulase is widely utilized for processing the coffee.
2. It's an important ingredient in laundry detergents, cleaning and washing agents.
3. It's also used in the paper, textile and pulp industries.
4. This beneficial enzyme also has various pharmaceutical applications.
5. Cellulase may be used to produce various beverages like fruit juices.

■ Protease

Protease refers to a group of enzymes whose catalytic function is to hydrolyze proteins into amino acids. They are also called **proteolytic enzymes** or **systemic enzymes.** Proteases are very important in digestion as they breakdown the peptide bonds in the protein foods to liberate the amino acids needed by the body. Normal living cells are protected against lysis by the inhibitor mechanism. Proteolytic enzymes are most abundant in animals but also present in bacteria, archaea, certain types of algae, some viruses, and plants.

Uses

1. Proteases are used in industry, medicine and as a basic biological research tool.
2. They are also used extensively in the bread industry in bread improver.
3. A variety of proteases are used medically in controlling blood clotting.

■ Amylases

Amylase, any member of a class of enzymes that catalyze the hydrolysis of **starch** into smaller carbohydrate molecules such as **sugar.** Two categories of amylases, denoted alpha and beta, differ in the way they attack the bonds of the starch molecules. All amylases are glycoside hydrolases and act on *α-1,4-glycosidic* bonds. Amylase is present in the **saliva** and **pancreatic juice** in animals.

Uses

1. Amylases are important in brewing beer and liquor made from sugars derived from starch.

2. Amylases are used in bread making and to break down complex sugars, such as starch into simple sugars.

3. Amylase also has medical applications in the use of *Pancreatic Enzyme Replacement Therapy* (PERT).

4. Amylase is also used in clothing and dishwasher detergents to dissolve starches from fabrics and dishes.

■ Lipase

A lipase is any enzyme that catalyzes the hydrolysis of **fats** or **lipids.** Lipases perform essential roles in the digestion, transport and processing of dietary lipids (e.g. triglycerides, fats, oils) in most living organisms. Lipases are generally animal sourced, but can also be sourced microbially. Some lipases are expressed and secreted by pathogenic organisms during an infection. Most lipases act at a specific position on the glycerol backbone of a lipid substrate.

Uses

1. Lipases serve important roles in human practices as ancient as yogurt and cheese fermentation.

2. Use in applications such as baking, laundry detergents and even as biocatalysts.

3. Blood tests for lipase may be used to help investigate and diagnose acute pancreatitis and other disorders of the pancreas.

4. Lipase can also assist in the breakdown of fats into lipids in those undergoing pancreatic enzyme replacement therapy (PERT).

■ Zymase

Zymase is an enzyme complex that catalyzes the fermentation of sugar into ethanol and carbon dioxide. It occurs naturally in yeasts. The overall chemical reaction for alcoholic fermentation is:

$$C_6H_{12}O_6 + \text{Zymase} \rightarrow 2C_2H_5OH + 2\,CO_2$$

The reaction takes places at temperatures between 25°C and 37°C.

Zymase activity varies among yeast strains. Zymase was first isolated from the yeast cell in 1897 by a German chemist named **Eduard Buchner** who fermented sugar in the laboratory without living cells, leading to 1907 Nobel Prize in Chemistry.

Uses

Zymase enzyme is used in commercial alcohol manufacturing.

■ Catalase

Catalase is an enzyme that brings about (catalyzes) the reaction by which hydrogen peroxide is decomposed to water and oxygen. Found extensively in organisms that live in the presence of oxygen. Catalase prevents the accumulation of and protects cellular organelles and tissues from damage by peroxide, which is continuously produced by numerous metabolic reactions. In mammals, catalase is found predominantly in the liver.

Uses

1. Catalase is used in the food industry for removing hydrogen peroxide from milk prior to cheese production.

2. Another use is in food wrappers where it prevents food from oxidizing.

3. Catalase is also used in the textile industry, removing hydrogen peroxide from fabrics to make sure the material is peroxide-free.

4. A minor use is in contact lens hygiene a few lens-cleaning products disinfect the lens using a hydrogen peroxide solution.

Applications of enzymes in different biological activities

Enzymes are used in the chemical industry and other industrial applications when extremely specific catalysts are required. Some industrial applications of enzyme are cited below:

1. **In food processing: Amylases** enzymes from fungi and plants are used in production of sugars from starch in making corn-syrup. **Catalyze** enzyme is used in breakdown of starch into sugar, and in baking fermentation process of yeast raises the dough. **Proteases** enzyme help in manufacture of biscuits in lowering the protein level.

2. **In baby foods: Trypsin** enzyme is used in pre-digestion of baby foods.

3. **In brewing industry:** Enzymes from barley are widely used in brewing industries. **Amylases, glucanases, proteases, betaglucanases, arabinoxylases, amyloglucosidase, acetolactatede carboxylases** are used in production of beer industries.

4. **In fruit juices:** Enzymes like **cellulases, pectinases** help are used in clarifying fruit juices.

5. **Indairy industry: Renin** is used in manufacture of cheese. *Lipases* are used in ripening blue-mold cheese. **Lactases** break down lactose to glucose and galactose.

6. **In meat tenderizes: Papain** is used to soften meat.

7. **In starch industry: Amylases, amyloglucosidases** and **glycoamylases** converts starch into glucose and syrups. **Glucose isomerases** production enhanced sweetening properties and lowering calorific values.

8. **In paper industry:** Enzymes like **amylases, xylanase, cellulase** and **liginase** lower the viscosity, and removes lignin to soften paper.

9. **In biofuel industry:** Enzymes like **cellulases** are used in breakdown of cellulose into sugars which can be fermented.

10. **As biological detergent: Proteases, amylases, lipases, cellulases** assist in removal of protein stains, oily stains and acts as fabric conditioners.

11. **In rubber industry: Catalase** enzyme used to generate oxygen from peroxide to convert latex into foam rubber

12. **In photographic industry: Protease** (ficin) enzyme dissolve gelatin off scrap film, allowing recovery of its silver content.

13. **In medical science: Ureage** and **urecase enzyme** used in clinical analysis of blood urea and uric acid. **Trypsin** enzyme used in surgery of eye cateract. **Urobilase** enzyme used to declotting of blood from brain and artery. **Proteases** enzyme used to remove proteins on **contact lens to prevent** infections

14. **In genetic engineering**: ***Restriction enzymes, DNA ligase*** and ***polymerases*** are used in genetic engineering, pharmacology, agriculture, medicine, PCR techniques, and are also important in forensic science

Did You Know?

- All living things need food for the energy to make all the other body processes happen, such as growth, movement, and repair.
- Most important biological molecules are polymers. Biological polymers include proteins, carbohydrates and lipids. Polymers are made from smaller molecules called monomers.
- Proteins contribute to the genetic characteristics of human body such as characteristics of hair, eye colour, skin colour height etc. therefore ultimate controllers of cellular functions.
- Fiber is a complex carbohydrate that cannot be broken down. A diet that's high in fiber has been shown to lower cholesterol and help protect the body against heart disease and some forms of cancer.
- Eating a lot of saturated fat can put you at an increased risk of heart disease and cancer. That's why eating lipids that are unsaturated are much better for you. These lipids can be found in fish, nuts, and many different types of vegetables.
- While the body does produce some enzymes on its own, these are not enough for a healthy metabolism. Some enzyme supplied with enzyme rich food. Cooking destroys the enzymes in food. For these reason salad and ripen fruits are good for health.

Excercise

Multiple Choice Questions (Sample)

1. Which one is not the pentose sugar?
   a. Ribose b. Ribulose c. Fructose d. Deoxyribose
2. Which bond liked monosaccharides to form a disaccharides?
   a. Phosphate b. Glycosidic c. Hydrogen d. Carbon
3. Which one is purine base?
   a. Adenine b. Thymine c. Cytosine d. Uracil
4. Starch stored as: i. Seed, ii. Fruit, iii. Tuber-Which one of the following is correct?
   a. i and ii b. ii and iii c. i and iii d. i, ii and iii
5. Fish, meat, eggs, pulses etc. are the protein foods. These are essential for-
   i. Growth of the boby, ii. Catalize cellular chemical reactions, iii. Used as main source of fuel in celllar respiration-Which one of the following is correct?
   a. i and ii b. ii and iii c. i and iii d. i, ii and iii

There are some organic compounds which are present in trace amount in living body and no reaction of the body held without such compounds. They are biological catalysts which speed up a reaction without being used up. They are recovered back after a chemical reaction. Answer the question 6 and 7 on the basis of above stem-

6. Which are those compound mentions in the stem?
   a. Hormones b. Enzymes c. Vitamins d. Minerals
7. The chemical nature of those compound mention in the stem-
   i. They can be destroyed by excessive heat, ii. are diluted in water, glycerol and low concentration alcohol, iii. They can perform their functions only in alkaline media. -Which one of the following is correct?
   a. i and ii b. ii and iii c. i and iii d. i, ii and iii
8. Which compound shows th peptide bond?
   a. Carbohydrate b. Lipid c. Protein d. Vitamin