Unit- III

i) **Glycogenesis, Glycogenosis and Gluconeogenesis**
ii) **Glycolysis**
iii) **Krebs Cycle**

Glycogenesis, Glycogenolysis and Gluconeogenesis

"Metabolism is defined as a series of biochemical reactions occurring in the cell of living organisms to release energy or to build up body tissues."

Metabolism includes two processes, namely Anabolism and Catabolism.

Anabolism is a synthetic process. In anabolism, large protoplasmic molecules are synthesized from smaller molecules by a serious of metabolic reactions.

Catabolism is a destructive process. During this process larger protoplasmic molecules are split into smaller ones for supply of energy.

Carbohydrate Metabolism:-

Carbohydrates metabolism represent the major source of energy for the animal kingdom. The one gram of Carbohydrate releases about 4.2 calories of energy.

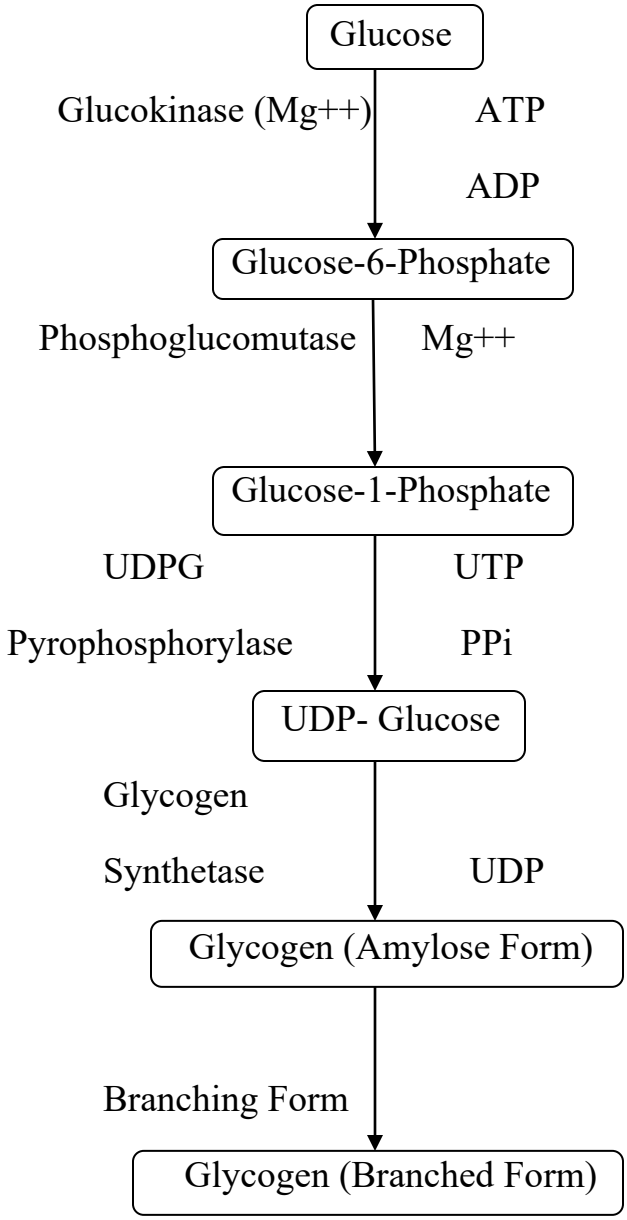
The metabolism of glucose involves the following steps.

1) Glycogenesis
2) Glycogenolysis
3) Glycolysis
4) Krebs Cycle
5) Pasteur effect
6) Gluconeogenesis
7) Cori cycle

1) Glycogenesis

The biosynthesis of glycogen from glucose is called Glycogenesis. The blood contains 1% glucose. When glucose level in the blood rises, Glycogenesis occurs. The excess sugars are stored in the form of glycogen. It is formed in the liver and muscles.

Glycogenesis:-



Step 1:- Glucose is phosphoraylated (addition of phosphate molecule) by ATP to glucose-6-Phosphate. This reaction is catalyzed by Glucokinase and MG++ ions.

Glucokinase, Mg++

Glucose ⟶ Glucose-6-Phoisphate + ADP

ATP

Step 2:- Glucose -6-phosphate is transformed into glucose-1-phosphate. This reaction is catalysed by Phosphoglucomutase.

Phosphoglucomutase

Glucose-6-Phoisphate ⟶ Glucose-1-Phoisphate

Mg++

Step 3:-Glucose -1-phosphate combines with uridine triphosphate in the presence of uridine diphosphate glucose Pyrophosphorylase (UDPG Pyrophosphorylase) to form uridine diphosphoglucose (UDPG) and inorganic phosphate (PPi).

UDPG

Glucose-1-Phoisphate +UTP ⟶ UDP Glucose+Pyrophosphate

Pyrophosphorylase

Step 4:- UDPG molecule under the action of glycogen synthetase transfers its glucose molecule to the end of a glycogen chain and the UDP itself is free.

One glucose unit is added to an existing glycogen. This glycogen is straight and unbranched and it is called amylose form of glycogen.

Glycogen

UDP Glucose ⟶ Glycogen (amylose form) +UDP

Synthetase

Step 5:- As soon as the glycogen attains the length of eight glucose units, it is subjected to the action of an enzyme called branching enzyme. This causes the tree-like branches of the glycogen molecule.

Glycogen (amylose form) $\xrightarrow[\text{Enzyme}]{\text{Branching}}$ Glycogen (branched form) + UDP

Step 6:- The UDP formed as a by product is converted into UTP in the presence of ATP. ATP is converted into ADP.

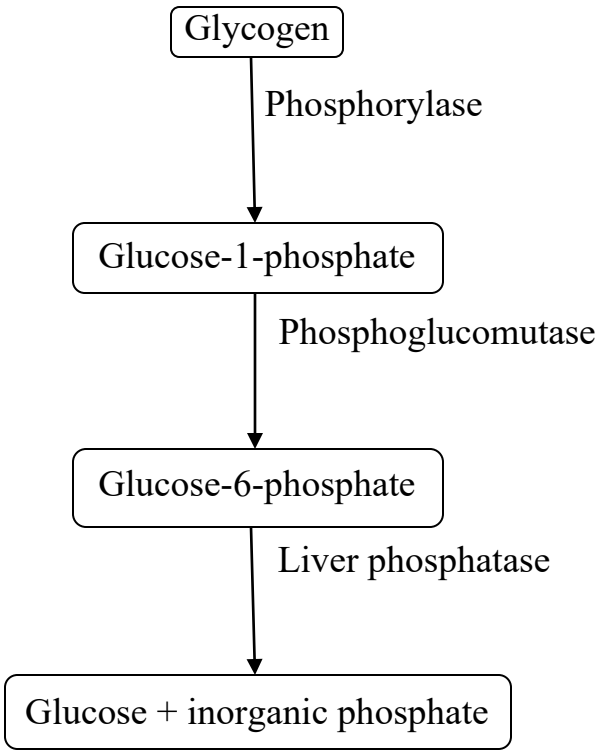
UDP + ATP ⟶ UTP + ADP

ATP ⟶ ADP

2) Glycogenolysis

The breakdown of glycogen into glucose is called Glycogenolysis. This occurs in the liver, when blood sugar level falls. Glycogenolysis involves the following steps:

i) During this process the terminal glucose of the glycogen molecule is split up into glucose-1-phosphate. This reaction is catalyzed by the enzyme phosphorylase.
ii) Glucose-1-phosphate is then converted into glucose-6-phosphate by the action of Phosphoglucomutase.
iii) Glucose-6-phosphate is then hydrolysed by glucose-6-phosphatase to free glucose from phosphates.
iv) Glycogenolysis cannot take place in the muscles because phosphatase is absent from muscles.



3) Gluconeogenesis

"Synthesis of carbohydrates from proteins and fats is called Gluconeogenesis."

When the diet is deficient in carbohydrates, carbohydrates are formed from body proteins dietary proteins and fats. The immediate products for the synthesis of carbohydrates are amino acid, glycerol and fatty acids.

Glycogenesis occurs in the liver and kidney. The most common gluconeogenic substances are lactic acid and glycerol. Besides this propionic acid, glutamic acid, glycine, aspartic acid, arginine, ornithine, α-ketoglutaric acid, oxaloacetic acid etc. are also converted into glucose. These substances occur as intermediate products in Glycolysis and Krebs cycle.

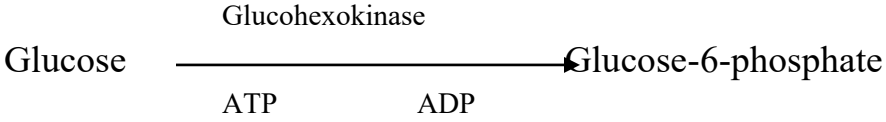
Glycolysis

Glycolysis is a process by which glycogen or glucose or other sugars are converted into pyruvic acid.

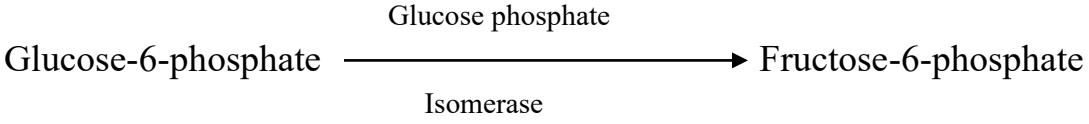
This process occurs in the cells. This process does not utilize oxygen. Hence Glycolysis is an anaerobic process. Glycolysis is also called Embden Meyerhof Pathway, since the various steps in Glycolysis have been worked out by the two German biochemists Embden and Meyerhof.

Steps involves in Glycolysis:-

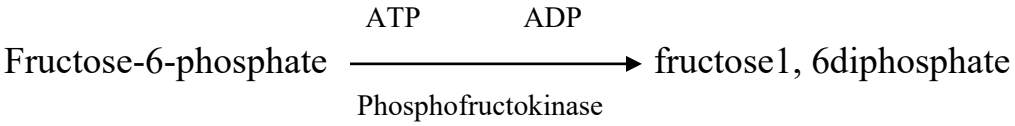
1) During Glycolysis glucose in the cells is phosphoraylated by ATP in the presence of glucohexokinase to form glucose-6-phosphate. Glycogen can also be converted into glucose-6-phosphate by Glycogenolysis.



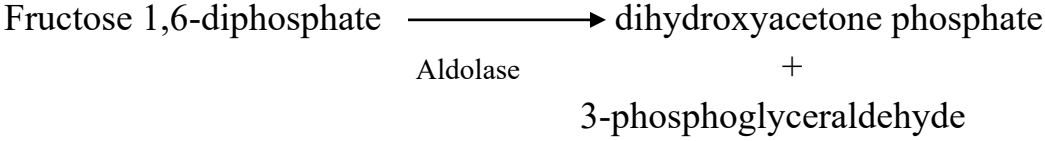
2) Glucose-6-phosphate is then converted into fructose-6-phosphate by the enzyme glucose phosphate isomerase.

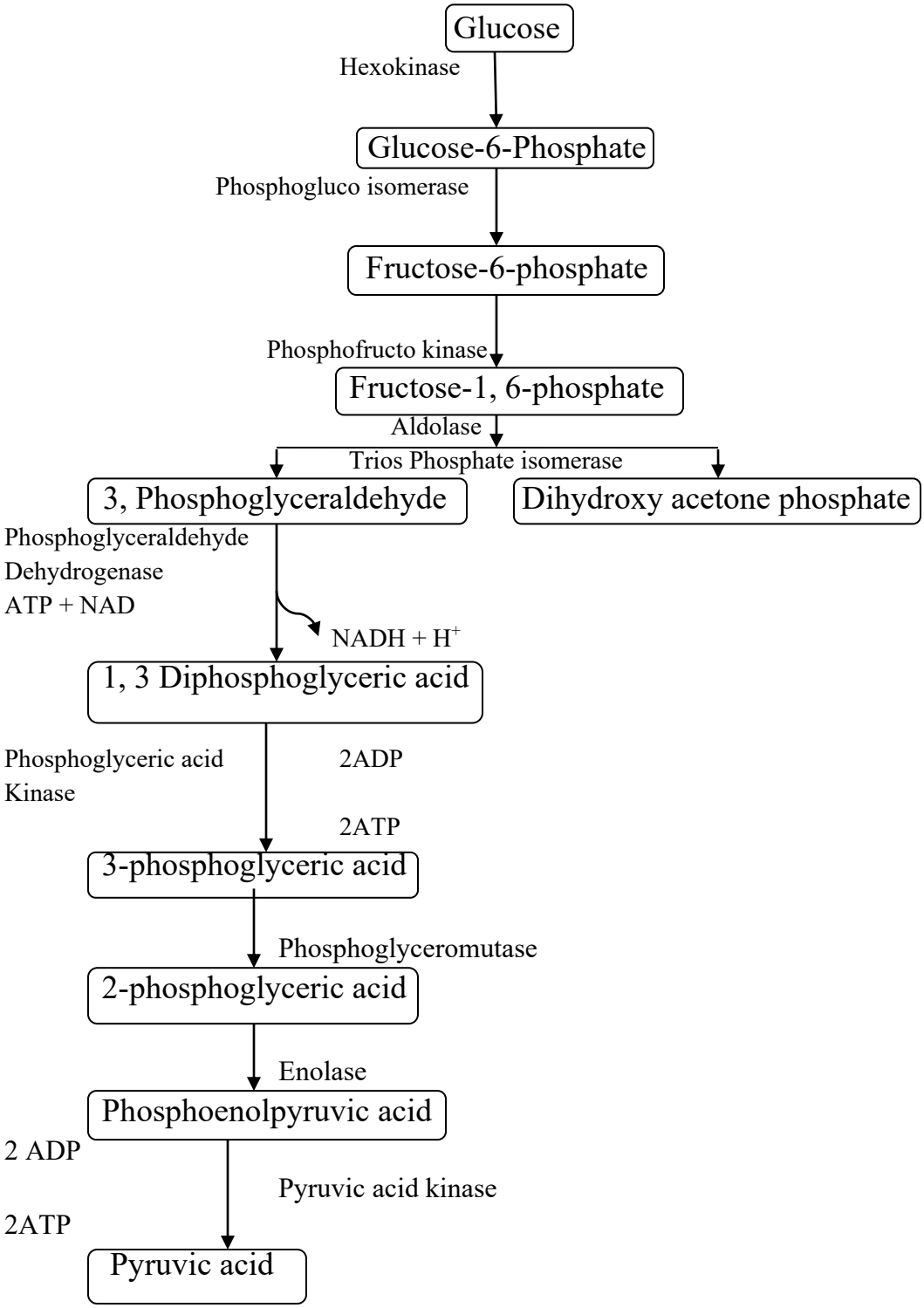


3) Fructose-6-phosphate is then phosphoraylated by ATP in the presence of phosphofructokinase to form fructose1, 6-diphosphate.



4) The fructose1, 6-diphosphate is split by enzyme Aldolase into two substances, namely glyceraldehydes-3-phosphate and dihydroxyacetone phosphate. These two substances are inter-convertible in the presence of triose phosphate isomerase.




Glucose
Hexokinase
Glucose-6-Phosphate
Phosphogluco isomerase
Fructose-6-phosphate
Phosphofructo kinase
Fructose-1, 6-phosphate
Aldolase
Trios Phosphate isomerase
3, Phosphoglyceraldehyde
Dihydroxy acetone phosphate
Phosphoglyceraldehyde
Dehydrogenase
ATP + NAD
NADH + H+
1, 3 Diphosphoglyceric acid
Phosphoglyceric acid
Kinase
2ADP
2ATP
3-phosphoglyceric acid
Phosphoglyceromutase
2-phosphoglyceric acid
Enolase
Phosphoenolpyruvic acid
2 ADP
Pyruvic acid kinase
2ATP
Pyruvic acid

5) The two molecules of 3-phosphoglyceraldehyde are phosphoraylated and oxidized into two molecules of 1, 3- Diphosphoglyceric acid, catalyzed by the enzyme 3, Phosphoglyceraldehyde dehydrogenase. NAD and inorganic phosphates are required.

3-phosphoglyceraldehyde $\xrightarrow{\text{3, Phosphoglyceraldehyde dehydrogenase}}$ 1, 3- Diphosphoglyceric acid

6) 1, 3-diphosphoglyceric acid is converted into 3-phospho glyceric acid, by means of 3, phosphoglycerate kinase in the presence of Mg++.

1, 3- Diphosphoglyceric acid $\xrightarrow{\text{3, phosphoglycerate kinase}}$ 3-phospho glyceric acid

7) 3-phosphoglyceric acid is converted into 2-phosphoglyceric acid by the enzyme Phosphoglyceromutase utilizing 2, 3-diphosphoglycerate as coenzyme.

3-phospho glyceric acid $\xrightarrow{\text{Phosphoglyceromutase}}$ 2-phosphoglyceric acid

8) 2-phosphoglyceric acid is converted into phosphoenol-pyruvic acid by dehydration in the presence of Enolase. It contains a high energy bond.

2-phosphoglyceric acid $\xrightarrow{\text{Enolase}}$ phosphoenol-pyruvic acid+ H_2O

9) The phosphoenol pyruvic acid now transfers its energy rich phosphate to ADP under the influence of phosphopyruvate kinase and in the presence of Mg++ and K+ forming enolpyruvic acid and ATP.

Phosphoenol-pyruvic acid $\xrightarrow{\text{Phosphopyruvate kinase}}$ enolpyruvic acid

10) The enolpyruvic acid is spontaneously transformed into pyruvic acid

Enolpyruvic acid $\longrightarrow$ pyruvic acid

Function of Glycolysis:-

1) It is an obligatory to glucose metabolism because; in this process only glucose is converted into pyruvic acid.
2) The intermediate products formed in Glycolysis are utilized for the synthesis of fat.
3) Finally Glycolysis also yield energy in the form of ATP.

Energetic of Glycolysis:-

During Glycolysis of each glucose molecule, 2 ATP molecules are utilized and 10 molecules of ATP are synthesized. Hence there is a net gain of 8 molecules of ATP (10-2=8) duvering Glycolysis

1) Glucose:- Fructose 1,6 diphosphate = -2 ATP
2) 1,3 diphosphoglyceric acid :- 3-phosphoglyceric acid+ 2DPNH=+2Atp
3) Phosphoenol pyruvic acid:- Enolpyruvic acid= +2ATP

2NADH:- +6ATP

Krebs cycle

The oxidation of pyruvic acid into CO_2 and water is called Krebs cycle. This cycle is also called citric acid cycle, because the cycle begins with the formation of citric acid. The citric acid is a carboxylic acid containing three COOH group.

Hence this cycle also called tricarboxylic acid cycle. This cycle was first described by Krebs in 1936. This cycle occurs only the presence of oxygen. Hence it is an aerobic process. The Krebs cycle takes place mainly in the mitochondria.

The following steps involves in Krebs cycle as

1) Formation of citric acid
2) Dehydration
3) Hydration-I
4) Dehydrogenation-I
5) Decarboxylation
6) Oxidative decarboxylation
7) Oxidation
8) Hydration-II
9) Dehydrogenation-II

1) Formation of citric acid: - The acetyl-COA combines with oxaloacetic acid to form citric acid. It contains 6 carbon atoms. This reaction is catalyzed by an enzyme called citric acid synthetase.
2) Dehydration: - Citric acid undergoes dehydration and forms cis-aconitic acid. This reaction is catalyzed by the enzyme aconitase
3) Hydration-I: - The cis-aconitic acid is hydrated and it forms iso-citric acid. This reaction is catalyzed by the enzyme aconitase.
4) Dehydrogenation-I: - Isocitric acid under goes dehydrogenation in the presence of Isocitric acid dehydrogenase to form oxalosuccinic acid. In this reaction two hydrogen atoms are released. They are accepted by NAD to form $NADH^{+} + H^{+}$
5) Decarboxylation: - The oxalosuccinic acid under goes decarboxylation to form α- ketoglutaric acid. This reaction is catalyzed by oxalosuccinic acid decarboxylase. In this reaction, one CO_2 is eliminated. Hence the- ketoglutaric acid has only 5 carbon atoms.
6) Oxidative decarboxylation: - Duvering oxidative decarboxylation α-ketoglutaric acid is converted into succinyl COA. This reaction is catalyzed by α- ketoglutaric acid dehydrogenase. Two hydrogen atoms are released and they are transferred to NAD. This NAD is converted into $NADH_2$.

   In the next step, the succinyl CoA is decarboxylated to succinic acid. This step is catalyzed by succinic acid thiokinase. CoA is liberated.
7) Oxidation: - succinic acid is oxidized to fumaric acid by the removal of two hydrogen atoms. The reaction is catalyzed by succinic acid dehydrogenase. The hydrogen atoms are accepted by FAD and it forms $FADH_2$.
8) Hydration-II: - Fumaric acid then undergoes hydration to form malic acid. This reaction is catalyzed by fumarase.
9) Dehydrogenation-II: - it is the final step in Krebs cycle. Oxaloacetic acid is regenerated from malic acid by a process of dehydrogenation. This reaction is catalyzed by malic acid

dehydrogenase in the presence of NAD. The two hydrogen removed are accepted by NAD it forms $NADH_2$.

The oxaloacetic acid formed in the above reaction condenses with the acetyl CoA to form citric acid again and thus the cycle is repeated.

The Energetic of Krebs cycle in Glucose Metabolism:-

Oxidative decarboxylation: 1 $NADH_2$ = 3 ATP

Oxidation of iso-citric acid to oxalosuccinic acid 1NAD^+ = 3 ATP

Oxidation of α- ketoglutaric acid to Succinyl CoA 1NAD^+ = 3 ATP

Oxidation of succinic acid to fumaric acid 1FAD = 2 ATP

Oxidation of Malic acid to Oxaloacetic acid 1NAD^+ = 3 ATP

Conversion of succinyl CoA to succinic acid = 1 ATP

The total ATP molecules produced for each pyruvic acid = 15 ATP

Unit- IV Protein Metabolism

i) Deamination and Transamination
ii) Ornithine Cycle
iii)

Protein Metabolism:-

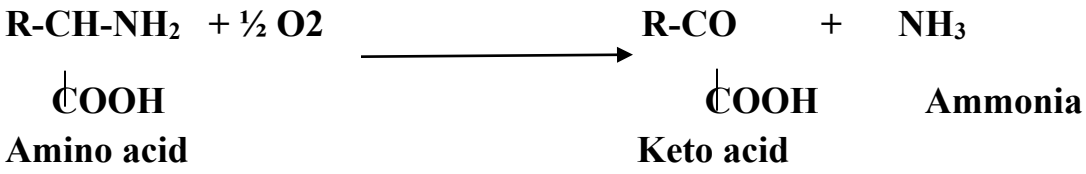
Duvering digestion, proteins are split into amino acids. They are absorbed into the blood and are transported to various parts of the body. The metabolism of amino acid takes place through the following process.

1) Deamination
2) Transamination
3) Decarboxylation
4) Transmethylation
5) Ornithine cycle
6) Krebs cycle
7) Ketogenesis
8) Gluconeogenesis
9) Amino acid synthesis
10) Protein synthesis

1) Deamination:-

The first stage in the breakdown of amino acids is the removal

Of their nitrogenous group as ammonia. The removal of amino group from the amino acid is called deamination. Deamination converts the amino acids into keto acids. This process occurs in the liver.



Disposal of Ammonia:-

The ammonia produced by deamination is highly toxic and must be disposed off. In aquatic animals, NH_3 is disposed off as such by diffusion. These animals are called ammonotelic.

In elasmobranch fishes, amphibians and mammals, ammonia is converted into urea by ornithine cycle and is eliminated. These animals are called ureotelic.

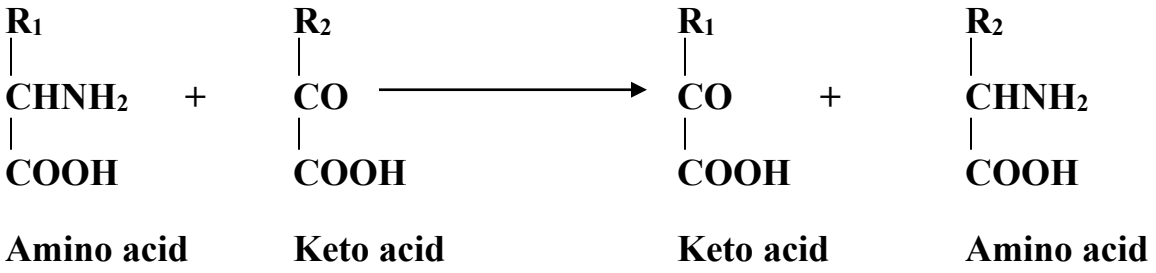
Disposal of Keto acids:-

Amino acids are converted into keto acids by deamination. For example, glutamic acid on deamination gives rise to keto glutaric acid. Alanine is deaminated to give rise to pyruvic acid.

2) Transamination:-

It is very common method for the conversion of amino acid into Keto acid. It involves "the transfer of an amino group from one amino acid to a keto acid under the influence of Transaminase or aminotransferase and coenzyme pyridoxol phosphate."

In this reaction, the donor amino acid becomes a keto acid and the recipient keto acid becomes an amino acid.



In this reaction of Transamination the shifting of group takes place which give the result that the basic group of Amino acid shifted towards keto acid and keto acids basic group shifted towards Amino acid.

Amino group shifted in this reaction due to this reaction called as Transamination.

This Transamination reaction beneficial for protein metabolism as well as in the various chemical reactions which are take place in the cell related to protein metabolism.

Ornithine cycle

Urea is a nitrogenous waste product. Most of the ammonia formed by deamination and Transamination are transformed into urea.

The synthesis of urea occurs in the liver. The reactions involved in the synthesis of urea were discovered by Krebs. Hence the reactions constitute Krebs Urea Cycle. It is also called Ornithine cycle because ornithine is involved in this reaction. This cycle has the following steps:

Step 1:-

The ornithine cycle starts with the combination of CO_2 and NH_3. The resulting compound is called carbamyl phosphate. This reaction is catalyzed by the enzyme carbamyl phosphate synthetase in the presence of two molecules of ATP and MG^{++}

Carbamyl Phosphate Synthetase

CO_2 + NH_3 + 2ATP ⟶ Carbamyl Phosphate + 2ADP

Step 2:-

In the second stage, carbamyl phosphate reacts with ornithine to form citrulline and inorganic phosphate (Pi).

Carbamyl phosphate + ornithine ⟶ citrulline

Step 3:-

In the third stage, citrulline condenses with Aspartic acid to form an intermediate addition compound called Arginosuccinic acid.

Citrulline + Aspartic acid ⟶ Arginosuccinic acid

Step 4:-

In the fourth stage, arginosuccinic acid is cleaved into arginine and fumaric acid. This reaction is catalyzed by the enzyme Arginosuccinase.

Arginosuccinic acid ⟶ Arginine + Fumaric acid

Step 5:-

In the final stage, arginine is cleaved by arginase into ornithine and urea. Ornithine repeats the cycle by accepting another molecule of carbamyl phosphate.

Arginine ⟶ **Ornithine + Urea**

Enzyme

- ✓ Amylase is an enzyme to degrade starch. It is produced from Bacillum subtilis, Bacillus polymya (bacteria) as well as Aspergillus niger, Aspergillus oryzae, Rhizopus oryzae (fungi). Amylase is widely used pharmaceutical, beverage, textile confectionary industries.
- ✓ Protease is an enzyme to degrade proteins. It is produced by Morsierellarenispora, Aspergillus sp, Bacillus sp. Its use extends to beverage, detergent baking and photographic industry.
- ✓ Lactases obtained from saccharomyces fragilis and Torula cremaris and lipases obtained from Candida crypolytica are useful in diary industry.

Enzyme Nomenclature: different kinds of enzymes are named in different ways.

- ➢ Most often enzymes are named by adding a suffix 'ase' to the root word of the substrate. e.g., Lipase (fat hydrolysing enzyme), Sucrase (breaking down sucrose).
- ➢ Sometimes the enzymes are named on the basis of the reaction that they catalyse. Example: Polymerase (aids in polymerisation), Dehydrogenase (removal H atoms).
- ➢ Some enzymes have been named based on the source from which they were first identified. For example, Papayin from papaya.
- ➢ The names of some enzymes ends with an 'in' indicating that they are basically proteins.For example, Pepsin, Trypsin etc.

Properties of enzymes: Enzymes possess the following properties

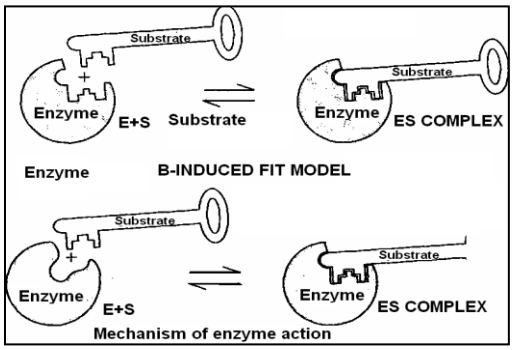
1. ***Catalytic activity:*** Their catalytic activity is high since a very small amount of enzyme can bring about a change in a large amount of the substrate. e.g. one molecule of the enzyme brings the decomposition of about 600 thousand molecules of hydrogen peroxide / sec to water and oxygen at body temperature.
2. ***Specificity***: They show specificity i.e. only a specific enzyme can act on a particular substrate. According to the degree of specificity, the specificity of an enzyme is of three types:
   a) **Absolute specificity**: means when an enzyme acts on one substrate.
   b) **Relative specificity:** when an enzyme acts on a group of related compounds.
   c) **Stereo specificity:** When an enzyme action depends on the stereo-chemical configuration ie. if it acts on only one of a pair of optical isomers it is called stereo specificity. e.g. D-amino acid oxidase oxidises D-amino acids & not L-amino acid.
3. ***Thermosensitivity***: They are sensitive to temperature changes. The temperature at which an enzyme works at its best is called optimum temperature. Several enzymes lies between 25°-45°c. At low temperatures the enzyme is ineffective. At high temperatures i.e. above 65°c they are destroyed. Hence enzymes are said to be thermolabile*.

4. ***pH sensitivity***: They are highly sensitive to pH changes. They are active at a particular range of pH only. It ranges between 6 to 7.5.
5. ***Reversibility of enzyme reaction:*** They catalyses reactions in both ways i.e. They act in either direction. It may catalyze the splitting of one molecule into two or unite two molecules into one.
6. ***Team activity:*** They usually work in co-ordination with each other i.e. In teams. thermolabile : sensitive to heat

Classification of enzymes: With the exception of the originally studied enzymes such as pepsin, rennin and trypsin, most enzyme names end in "ase". Enzymes are generally classified on the basis of the type of reactions that they catalyses. 6 groups of enzymes can be recognized on this basis. According to this system enzymes are classified into six major classes based on their functions.

1) ***Oxidoreductases or oxidation-reduction enzymes*** : They catalyze the addition or removal of hydrogen or oxygen to or from a substrate. E.g. Dehydrogenases catalyse the removal of two atoms of hydrogen.
2) ***Hydrolases or hydrolytic enzymes*** : They catalyze reactions which involves the addition of water molecule to a bond of the substrate. Hydrolases are further classified into peptidases, glycosidases, esterases, etherases, etc. E.g. Peptidases catalyse the hydrolysis of peptide bonds ; Glycosidases catalyse the hydrolysis of glycosidic bonds.
3) ***Transferases*** : They catalyse the transfer of a group from a donor to an acceptor. E.g. Transaminase catalyses the transfer of amino group from alanine to oxaloacetic acid.
4) ***Lyases***: They catalyse either the removal or addition of a group of atoms from the substrate without hydrolysis, oxidation or reduction. E.g. Decarboxylases, aldolases etc.
5) ***Ligases***: They catalyse reactions which involve the union of two molecules by the breaking of the pyrophosphate bond of ATP to ADP. E.g. Synthetases, carboxylases etc.
6) ***Isomerases***: They catalyse reactions which involve changes in the geometry or structure of a molecule. E.g. Epimerases, recemases etc

Mechanism of Enzyme Action: The action of enzymes is to lower the activation energy or threshold of their substrates which, therefore, become activated and react with the other reactants. The specific amino acid sequence and molecular shape of the enzyme are of primary importance in this function, but its mechanism is not yet properly understood. Two main views have been expressed to explain this mechanism:



Mechanism of enzyme action

A-LOCK-AND-KEY MODEL

1. "Lock-and-key", or "Template" Hypothesis: Emil Fischer (1894) hypothesized that each enzyme molecule has a specific and rigid active site on itssurface. A reactant molecule (substrate) having a matching geometrical conformation only can fit into this active site of enzyme like "a key fitting into a lock", forming an unstable "enzyme-substrate complex (ES complex)". This linkage activates the substrate molecule to react readily with the other reactant of the reaction (Fig).
2. "Induced-fit Model" Hypothesis: The Lock-and-key" model has been modified by Koshland (1971) and his co-workers who have suggested that the active site of an enzyme molecule is flexible. As the specific substrate molecule links with the enzyme molecule, the latter undergoes conformational changes (Fig.) so that the "fit" is improved and the reactive groups of enzyme molecule move to their proper sites.

Enzyme Regulation: To avoid wastage in metabolism, cells have devices to regulate enzyme activities by a "genetic control" and a "control of catalysis". Genetic control implies increasing or decreasing the amount of enzymes and rate of their synthesis by switching on or off the transcription of relevant genes. The control of catalysis is quicker and involves a change in enzyme activity without a change in enzyme synthesis. In this the end product of a reaction itself acts as an activator or inhibitor of one of the enzyme molecules participating in the reaction pathway. The activator or inhibitor binds with a non-active site of enzyme molecule and brings about conformational changes in it. The enzyme molecule may, therefore, become more active or inactive. This phenomenon is called feedback regulation or allosteric modulation of the enzymes. The following table lists the 6 groups of enzymes along with example.

Factors Affecting Enzyme Activity: The activity of enzyme is affected by a number of factors such as temperature, pH, enzyme concentration and substrate concentration.

1) **Effect of Temperature on Enzymes:** The rate of enzyme action increases with increase of temperature upto 40^0C. The temperature, at which the enzyme action is “maximum”, is called the optimum temperature. For most of the enzymes the optimum temperature lies between 30^0C and 40^0C. At low temperature, the enzyme is ineffective. At high temperature, for example at 60^0C the enzyme becomes inactive. This is because the enzyme is denatured or destroyed by high temperature. Thus enzymes are said to be thermolabile.
2) **Effect of pH on Enzymes:** The rate of enzyme action increases with increase in the H ion concentration up to a certain pH when the enzyme action is maximum. This pH is called the optimum pH. Increased H ion c concentration beyond this peak point will destroy the enzymes, because of their protein nature, and bring down the enzyme action. Most of the enzymes act effectively in a pH range of 5.0 to 9.0. But some enzymes like pepsin are active even at pH value between 1.2 and 1.8.

3) **Effect of Enzyme Concentration:** An enzyme works even when it is present in low quantity. The velocity of the reaction increases with the increase in the concentration of enzymes. The velocity (V) of a reaction is proportional to the concentration of enzyme (E). When the enzyme concentration is doubled, the velocity is also doubled. This is because when Concentration is doubled as much as twice the active sites become available to combine with the substrate.

4) **Effect of Substrate Concentration:** An increase of substrate concentration results in a very rapid increase in the velocity of reaction. As the substrate concentration continues to increase, the increase in the rate of reaction begins to slow down; with a large substrate concentration, no further rise in velocity occurs. Thus upto a certain point reaction rate is proportional to the substrate concentration.

5) **Coenzymes:** Since coenzymes are chemically changed as a consequence of enzyme action, it is useful to consider coenzymes to be a special class of substrates, or second substrates, which are common to many different enzymes. For e.g., about 700 enzymes are known to use the coenzyme NADH. Coenzymes are usually continuously regenerated and their concentrations maintained at a steady level inside a cell: for e.g., NADPH is regenerated thro' pentose phosphate pathway and S-adenosylmethionine by methionine adenosyltransferase. This continuous regeneration means that even small amounts of coenzymes are used very intensively. For e.g., the human body turns over its own weight in ATP each day.

Carbohydrates

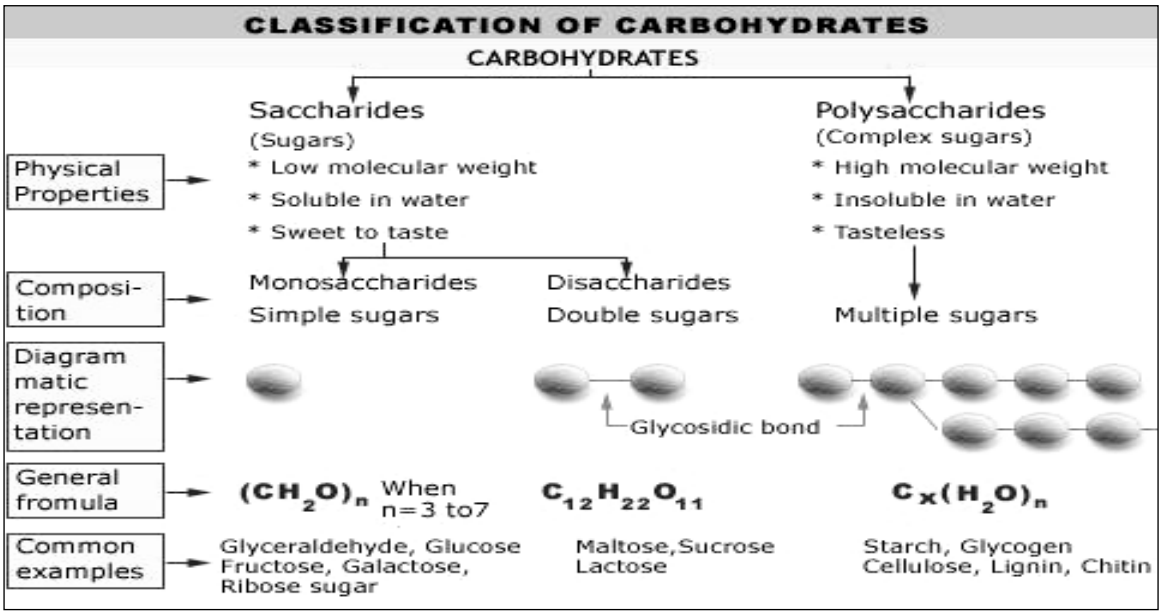
Carbohydrates (L: carbo-coal; G: hydra-water) are naturally occurring **organic compounds** which are widely distributed in both plant and animal kingdom. Plants can synthesize carbohydrates by photosynthesis while animals derive it from plants. Carbohydrates are primarily made up of carbon, hydrogen and oxygen. Generally, hydrogen and oxygen are combined in a similar ratio as in water i.e. **2:1** hence the name **hydrates** (however, it is a misnomer as the structure does not contain any water molecule as such). Moreover there are certain carbohydrates which have nitrogen and sulphur too, and yet the name carbohydrates is still applied. Carbohydrates are represented by the general formula $\mathbf{C_n(H_20)_n}$ where **'n'** is for 2 or more.

Definition: Chemically, carbohydrates are either aldoses containing aldehyde group or ketoses containing ketone group along with several hydroxyl groups. Hence, carbohydrates are defined as 'polyhydroxy aldehydes or ketones and that which yield one of these on hydrolysis'.

Classification: The carbohydrates are classified into three main categories based on their structure.

1. ***Monosaccharides***
2. ***Oligosaccharides***

3. Polysaccharides



Monosaccharides (mono-single; saccharide-sugar): They are the simplest members of carbohydrates and are referred to as simple sugars. They form the basic fundamental units or the monomers of large sugars. They cannot be hydrolysed further to yield simple sugars.

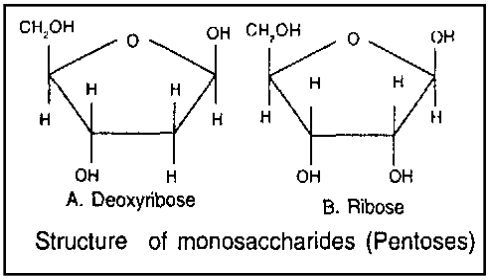
Structurally, the monosaccharides having more than four carbon atoms are represented either in a chain form or in a cyclic form. The chain structure fails to explain certain properties of monosaccharides hence the cyclic form is more commonly used.

Classification: The monosaccharides are classified into several groups based on the number of carbon atoms as given below in the table.

Monosaccharide	Number of carbon atoms	General formula	Examples
Triose	**3**	**$C,(H_20)_3$**	**glyceraldehyde, dihydroxyacetone**
Tetrose	**4**	**$c_4(h_20)_4$**	**threose, erythrose,**
Pentose	**5**	**$c_5(H_20)_5$**	**ribose, arabinose, lyxose, xylose**
Hexose	**6**	**$c_6(H_20)_6$**	**glucose, mannose, galactose, fructose**
Heptose	**7**	**$c_7(H_20)_7$**	**glucoheptose, sedoheptulose**

Table: *Classification of monosaccharides based on the number of carbon atoms.*

Among these, the **pentoses** and the **hexoses** are the most common in the biological system. In our body they need no digestion and are absorbed readily.



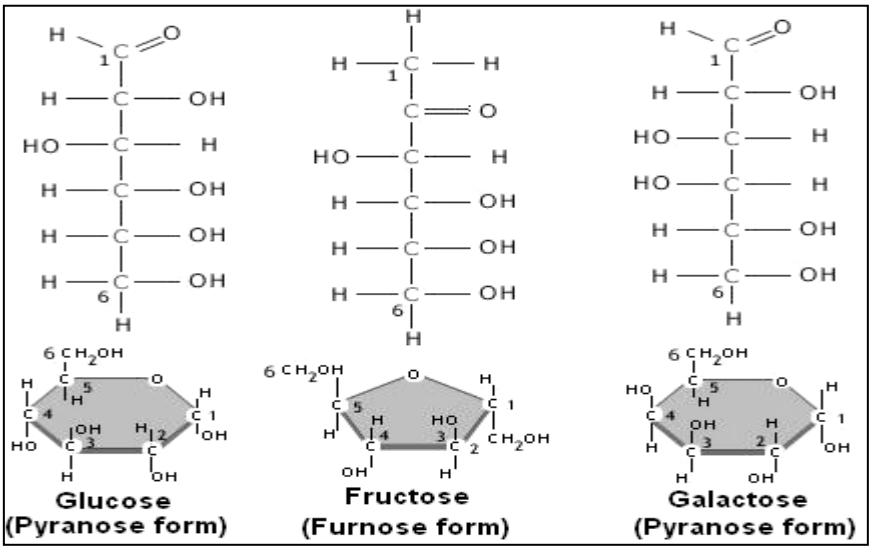
Structure of monosaccharides (Pentoses)

I. **Pentoses:** They are characterized by the presence of five carbon atoms and are the main constituents of nucleic acids. They occur as deoxyribose in DNA

II. **Hexoses:** They are characterized by the presence of six carbon atoms. They are important from the nutritional point of view and are termed as dietary sugars. E.g. glucose, fructose and galactose.

1) **Glucose:** It is also called **grape sugar** or **dextrose.** It is found in fruits and honey along with fructose. It occurs widely in living systems. All carbohydrates taken in the form of food are finally broken into glucose and forms the immediate source of energy for the body cells to function. In the human blood the standard level of glucose ranges between 80 to 120mg. If it is higher than 120mg / 100ml, it indicates a disorder called **diabetes.**

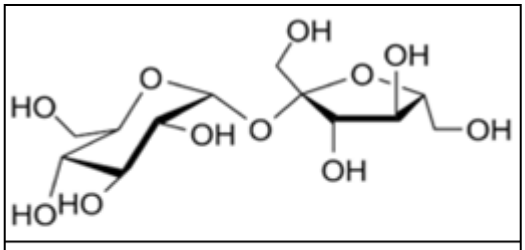
2) **Fructose:** It is also called **fruit sugar** or **revulose** and is one of the constituent of fruit juices, honey, nectar etc. It has a similar composition to glucose but is less readily digested or absorbed than glucose. It forms one of the **end products** of carbohydrate digestion in animals.



3) **Galactose:** It is a

constituent of a cell wall material called **'agar'** of certain marine algae. It also forms one of the **end products** of carbohydrate digestion in animals.

Disaccharides: Two joined monosaccharides are called a disaccharide and these are the simplest polysaccharides. Examples include sucrose and lactose. They are composed of two monosaccharide units bound together by a covalent bond known as a glycosidic linkage formed via a dehydration reaction, resulting in the loss of a hydrogen atom from one monosaccharide and a hydroxyl group from the other. The formula of unmodified disaccharides is $C_{12}H_{22}O_{11}$. Although there are numerous kinds of disaccharides, a handful of disaccharides are particularly notable.



Sucrose, also known as table sugar, is a common disaccharide. It is composed of two monosaccharides: D-glucose (left) and D-fructose (right).

Sucrose, pictured to the right, is the most abundant disaccharide, and the main form in which carbohydrates are transported in plants. It is composed of one D-glucose molecule and one D-fructose molecule. The systematic name for sucrose, O-α-D-glucopyranosyl-(1→2)-D-fructofuranoside, indicates four things:

- ✓ Its monosaccharides: glucose and fructose
- ✓ Their ring types: glucose is a pyranose, and fructose is a furanose
- ✓ How they are linked together: the oxygen on carbon number 1 (C1) of α-D-glucose is linked to the C2 of D-fructose.
- ✓ The -o side suffix indicates that the anomeric carbon of both monosaccharides participates in the glycosidic bond.

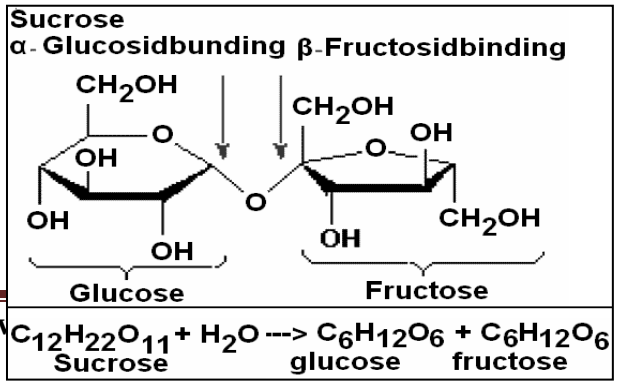
Lactose, a disaccharide composed of one D-galactose molecule and one D-glucose molecule, occurs naturally in mammalian milk. The systematic name for lactose is O-β-D-galactopyranosyl-(1→4)-D-glucopyranose.

Other notable disaccharides include maltose (two D-glucoses linked α-1,4) and cellulobiose (two D-glucoses linked β-1,4). disaccharides can be classified into two types.They are reducing and non-reducing disaccahrides if the functional group is present in bonding with another sugar unit it is called as reducing disaccharide.

Properties of Disaccharides: All the disaccharides are crystalline solids, soluble in water and fall in two classes, reducing sugar and non-reducing sugars. A number of common disaccharides occur in nature , e.g sucrose,maltose and lactose.

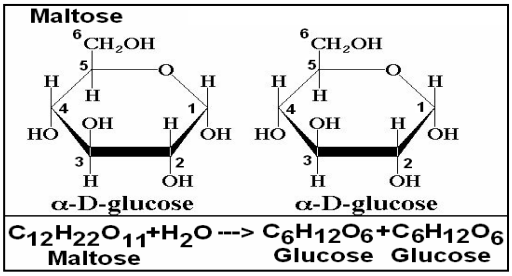
The disaccharide is formed when two monosaccharides undergo condensation reaction with a loss of molecule of water and formation of glycosidic bond.

Sucrose (table Sugar): Sucrose is one of the most important disaccharide commercially and is obtained from sugar cane and sugar beet. Sucrose is a white crystalline solid, soluble in water with melting point 180° C. When heated above its melting point, it forms a brown

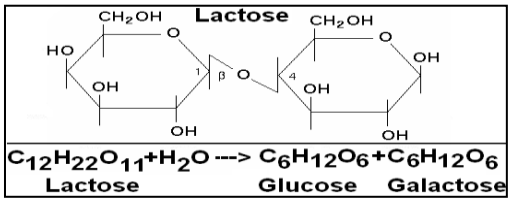


substance known as caramel. Sucrose is dextrorotatory. On hydrolysis with dilute acids sucrose yield an equimolecular mixture of D(+)glucose and D(-)fructose.

Maltose (beer Sugar): It is a white crystalline solid, soluble in water with melting point 160°-165° C and it is dextrorotatory.When it is hydrolysed with dilute acid it yields two molecules of D(+) glucose .It is a reducing sugar. Maltose is a important component in the process of creating fermented barley which can be used to brew beer.



Lactose (milk Sugar): Lactose occur in the milk of all animals. Lactose is a white crystalline solid with melting point 203°C, soluble in water and is dextrorotatory.It is a reducing sugar formed by one molecule of D(+) glalactose and one molecule of D(-) glucose coupled by a beta linkage.



Besides maltose, lactose and sucrose, another disaccharide of some importance is trehalose. It is abundantly found in young mushrooms and is a major component of haemolymph (circulatory fluid) of insects, serving as energy-storage compound. It is also a homodisaccharide whose molecule is formed by glycosidic linkage between the aldehyde groups of two D-Glucose molecules.

Oligosaccharides: Common hexose (6-carbon) monosaccharides (glucose, fructose, mannose and galactose) and pentose (5-carbon) monosaccharides (ribose and xylose) act as monomelic subunits *(building blocks)* of higher carbohydrates, called *compound carbohydrates.* By linking in linear chains, molecules of these monosaccharides polymerize to form oligosaccharides and polysaccharides.

Oligosaccharides (Gr. *Oligo*=few) are short-chain carbohydrate molecules formed by polymerization of a few (2 to 10) monosaccharide monomers. These are, therefore, small, commonly sweet and soluble micromolecules of low molecular weights. According to the number of monosaccharide subunits, oligosaccharides are disaccharides, trisaccharides, tetrasaccharides, pentasaccharides, and so on.

Glycosidic bond*:* The covalent bond by which monosaccharide molecules link in polymerization is called a glycosidic bond. The polymerization occurs only in solution and only the cyclic or ring forms of monosaccharide molecules participate in it. In a glycosidic linkage, the *aldehyde* or *ketone* part of one monosaccharide molecule condenses with an alcoholic *(hydroxyl,* —OH) group of another monosaccharide molecule, yielding a molecule of water. Thus, this linkage is chemically a *dehydration-condensation synthesis.* Obviously, this reaction is reversible; the monosaccharide monomers can be easily split apart by *hydrolysis* if the compound molecule is boiled in dilute acids, or with the help of enzymes as occurs in digestion.

GLYCOSIDIC BOND: $C_6H_{12}O_6 + C_6H_{12}O_6 \rightarrow C_{12}H_{22}O_{11} + H_20$

Other oligosaccharides and their functions: Some important oligosaccharides other than disaccharides are as follows:

1. ***Disaccharides*** are made up of 2 monosaccharide units. Examples include Sucrose, Lactose, Trehalose, Cellubiose, Maltose, Gentiobiose etc.
2. ***Trisaccharides*** contain 3 monosaccharides. E.g.:- Maltotriose and Raffinose.
3. ***Tetrasaccharide*** are Stachyose, Nystose, Acarbose etc.
4. ***Pentaglyceride*** - Verbascose

Of these oligosaccharides, only trisaccharides may be found free in cells. All others are found covalently bound to protein or lipid molecules, forming complexes which are respectively called glycoproteins and glycolipids. Natural sources of these examples of oligosaccharides include **I.** *legumes*, **II.** *Beans*, **III.** Sources of FOS include *asparagus, leeks, chicory, onions, burdocks* etc. IV. *Soyabeans* are main source of GOS. All of these are plant food sources of oligosaccharides.

Polysaccharides: are the largest carbohydrates. They are formed by the polymerization of a large number of monosaccharides united by glycosidic linkages. The number of monomers involved is several hundred or even thousands. The molecules of some polysaccharides are *linear chains;* others are *branched chains.* All of them can be broken down by acids or enzymes to yield their constituent monosaccharides.

Classification of Polysaccharides: - Polysaccharides are classified on two criteria namely; based on chemical composition and based on Biological function.

- ✓ ***Homoplysaccharides-*** They are made up of single type of mono saccharides. *Example- Glycogen, Starch, Cellulose, all made up of Glucose molecules.*
- ✓ ***Heteropolysaccharides-*** are composed of more than one type of monosaccharide, *Ex: Chondroitin sulphate, Hyaluronic acid, Keratan sulfate, & Dermatan sulfate.*

Based on the functionality the polysaccharides are classified in to two types viz,

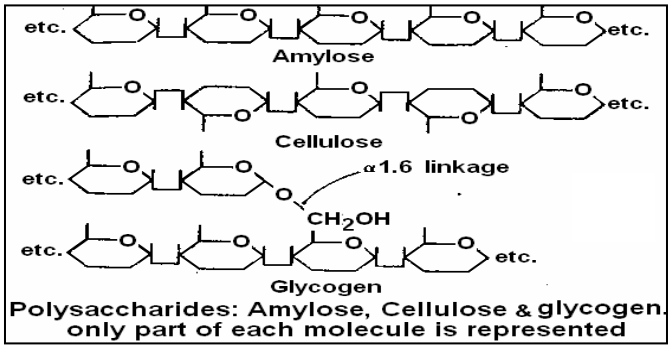
- ✓ ***Storage polysaccharides-***Which helps in storing food materials in plants (starch) and animals(Glycogen)
- ✓ ***Structural polysaccharides-***These helps in maintaining mechanical shape and rigidity of the living cell in plants (cellulose in plant cell wall) and animals (Chitin in exoskeleton of Arthropods like Crabs).

The most common monosaccharide found in a polysaccharide is as follows.

(i) ***Starch:*** Starch is the storage product of plants. It is a mixture of two polysaccharides, namely, branched chains of *amylopectin* and unbranched chains of *amylase.* There is usually 20% to 28% amylose and the rest is amylopectin. Both are polymers of the hexose, glucose. While in amylose, a glucose units are joined by i, 4 glycosidic bonds, in amylopectin, they are joined by 1.6 glycosidic bonds. Starch is commonly found in most cereals, tubers

(potato) and unripe fruits of apples and bananas. Starch in insoluble in cold water, when a suspension is heated, it swells and forms a colloid. Starch gives a blue colour with iodine, chiefly because of amylose. *Dextrins* are produced by partial hydrolysis of starch. Dextrins with larger molecular weights are called *erythrodextrins.* They give a red colour with iodine. Dextrins with low molecular weights are named *achroodextrins.* They do not give colour with iodine.

(ii) ***Glycogen:*** is often called "animal starch". It is a storage form of glucose of animal cells &fungi. The chemical structure of glycogen is similar to that of amylopectin of starch; it is a branched chain formed by linking of 100s of glucose molecules. In animals, muscles & liver contain a lot of glycogen. Glycogen gives a red colour with iodine. The colour disappears on boiling & reappears on cooling.



Polysaccharides: Amylose, Cellulose & glycogen. only part of each molecule is represented

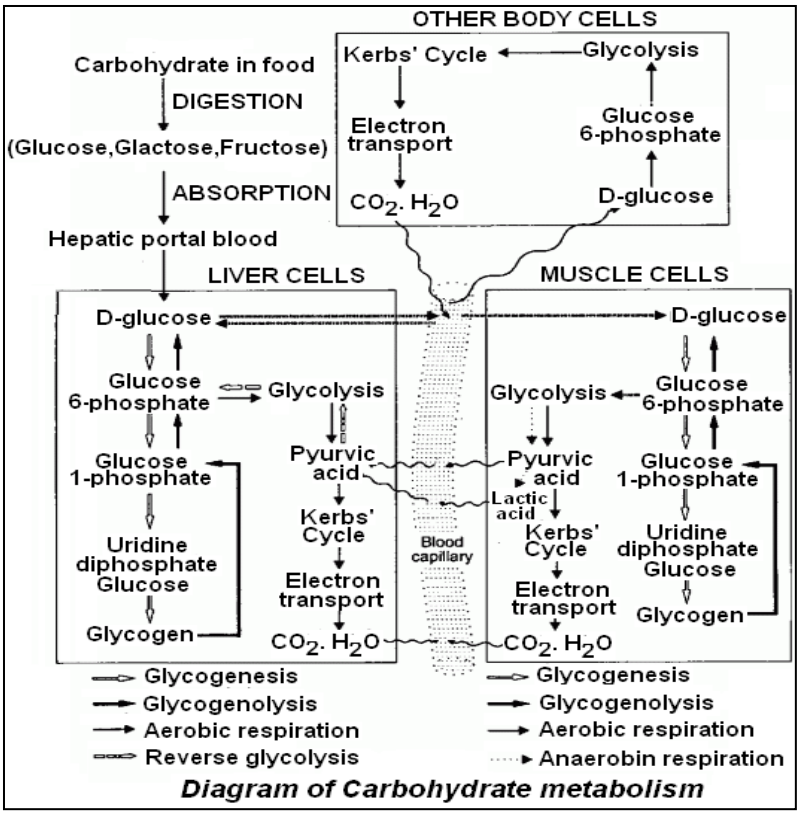
(iii) ***Cellulose:*** Cellulose is another polymer of glucose, held together by p14 glycosidic bonds. Humans do not possess enzymes capable of hydrolyzing these bonds. Hence cellulose represents indigestible part of human diet. In ruminating (cud-chewing) mammals like cattle, symbionts in the gut produce the enzyme cellulase which digests cellulose. Cellulose is the most common homopoly-saccharide on earth as it forms the cell wall material of plants. It gives rigidity to plant cells and distinguishes them from animal cells. Wood is 50% and cotton and paper pulp are 100% cellulose.

(iv) ***Pectins:*** are produced by a combination of galacturonic acid monomers. They are acidic & slimy. Calcium pectate, and to some extent, magnesium pectate are major constituents of the middle lamella of cell walls of a plant tissue. During fruit ripening the cell wall pectins are hydrolyzed into their constituent sugars. In the presence of citric acid pectin forms a gel. This is the basis of preparations of jams & jellies.

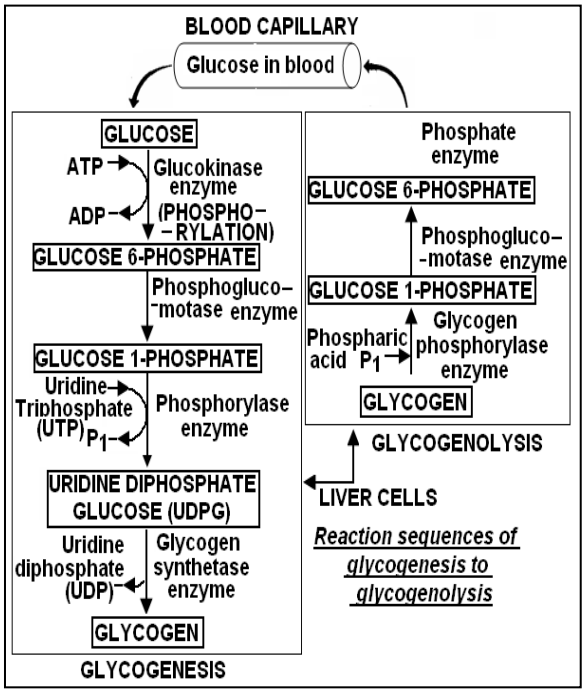
(v) ***Chitin:*** comes next to cellulose in abundance. It composes the cell walls of some fungi and the tough exoskeletons of lobsters & crabs & insects. In lobsters & crabs the chitin is impregnated with calcium carbonate. Chitin yields two products on hydrolysis: glucosamine & acetic acid.

(vi) ***Agar:*** is a polysaccharide composed of galactose molecules and hence is a galactan. It is extracted from the red algae, *Gelidium* and *Gracilaria.* It is also a mucopolysaccharide. It is acidic & slimy & is used as a solidifying agent, different kinds of agar media are prepared for culturing different types of bacteria.

Carbohydrate Metabolism: The end products of carbohydrate digestion, absorbed into the blood and taken to the liver by hepatic portal vein, are four monosaccharide sugars (isomers of $C_6H_{12}O_6$), viz, glucose, fructose, mannose and galactose. Liver cells readily convert fructose, mannose and galactose into D-glucose. Hence, D-glucose circulates in the blood. Normal glucose concentration in human blood is 100 mg/100 ml of blood, i.e., about 0.1% of blood. After meals, blood sugar level may raise upto 0.14% depending on the amount of carbohydrates digested from food. During fasting, glucose level in blood falls to about 60 to 70mg/100ml of blood. Glucose is transported into the cells across the plasma membrane by facilitated diffusion through carrier proteins. The cellular metabolism of carbohydrates in the body is divisible into 5 main aspects, glycogenesis, glycogenolysis, anabolism & lipogenesis, gluconeogenesis & catabolic breakdown (Fig.).



(1) *Glycogenesis*: This is an anabolic process in which glucose is polymerized into glycogen by the sequence of reactions. Some glycogenesis occurs in all body cells, but its main sites are liver and skeletal muscles. Liver and muscle cells remove excess glucose from blood and polymerize it into glycogen for storage. About 400 grams of storage glycogen (= animal starch) is normally found in human body. This is an anabolic process in which uridine diphosphate plays a vital role as shown.



(2) *Glycogenolysis*: It is breakdown of glycogen to glucose by means of the reaction series. Like glycogenesis, it also occurs in all body cells, but mainly in liver and muscle cells, to yield glucose required for energy-production. Muscle cells use this glucose

themselves, but liver cells, release it into the blood to replenish the amount of glucose that is being constantly taken up by body cells from the blood. Thus, glycogen storage of liver serves to maintain normal blood sugar level in between meals. It is, thus a "reserve fuel". A fasting or starving person first consumes this liver glycogen. All of it is consumed in 12 to 24 hrs if not replenished by another meal.

Glycogenesis & glycogenolysis are regulated by a double control—nervous as well as hormonal. Hormonal control involves five main hormones—insulin hormone of pancreas, growth hormone of pituitary and Cortisol of adrenal cortex stimulate glycogenesis, whereas glucagon of pancreas and adrenaline (= epinephrine) of adrenal medulla stimulate glycogenolysis.

Glycolysis: Glycolysis is almost universal central pathway of glucose catabolism. It occurs in cell cytoplasm. The overall equation for glycolysis is:

Glucose + 2NAD + + 2ADP + 2Pi → 2 pyruvate + 2NADH + 2H+ + 2ATP + $2H_2O$

Glycolysis can be divided into "preparatory" and "payoff" phase.

Preparatory Phase of Glycolysis: Glucose is first phosphorylated at the hydroxyl group on C-6. The D-glucose 6-phosphate thus formed is converted to D-fructose 6-phosphate, which is again phosphorylated, this time at C-1, to yield D-fructose 1,6- bisphosphate. For both phosphorylations, ATP is the phosphoryl group donor. Fructose 1, 6-bisphosphate is split to yield two three-carbon molecules, dihydroxyacetone phosphate and glyceraldehyde 3-phosphate; this is the "lysis" step that gives the pathway its name.

The dihydroxyacetone phosphate is isomerized to a second molecule of glyceraldehyde 3-phosphate, ending the first phase of glycolysis. Thus in the preparatory phase of glycolysis the energy of ATP is invested, raising the free-energy content of the intermediates, and the carbon chains of all the metabolized hexoses are converted into a common product, glyceraldehyde 3-phosphate.

Payoff Phase of Glycolysis: Each molecule of glyceraldehydes 3-phosphate is oxidized and phosphorylated by inorganic phosphate to form 1,3-bisphosphoglycerate. Energy is then released as the two molecules of 1,3-bisphosphoglycerate are converted to two molecules of pyruvate.

Steps in Glycolysis: Glycolysis is a process that results in the conversion of a molecule of glucose to two molecules of pyruvic acid. The term glycolysis is derived from two Greek words glycos-sugar and lysis-dissolution and thus the term glyco; lysis means- "Splitting of Sugar". Glucose 6-phosphate is a principal compound in the metabolism of glucose. The two major pathways of glucose 6-phosphate metabolism are the 1. anaerobic or glycolytic pathway-followed by the 2. aerobic pathway or Krebs' cycle. The largest proportion of energy available from the oxidation of the glucose molecule is liberated from the Krebs' cycle, but the glycolytic pathway is essential as pyruvic acid used in the Krebs' cycle is formed only by glycolysis. Glycolysis is a primitive metabolic pathway since it

operates in even the simplest and archaic cells. The overall balanced equation for glycolysis is

This simple equation does not reveal the complexity of the glycolytic pathway which involves a sequence of 10 enzyme catalyzed reactions, where a molecule of glucose yields two molecules of pyruvic acid. The enzymes involved in glycolysis are found in the extra mitochondrial soluble fraction of the cells and hence glycolysis occurs in the cytoplasm of the cells outside the mitochondria.

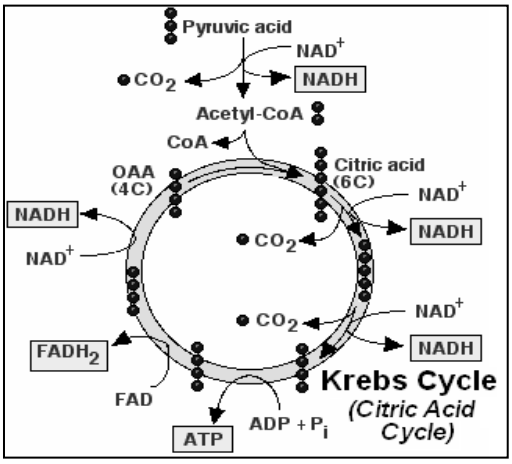
Introduction to TCA cycle *(tricarboxylic acid cycle)*: TCA cycle is the 2nd stage of cellular respiration in which acetyl CoA is enzymatically oxidizes to CO_2 and energy released is conserved in the reduced electron carriers NADH and $FADH_2$. TCA is also called citric acid cycle or the Krebs cycle. Glycolysis, the first stage produces two molecules of pyruvate from one glucose molecule. Pyruvate is oxidized to acetyl-CoA and CO_2 by the pyruvate dehydrogenase (PDH) complex, a cluster of enzymes—multiple copies of each of three enzymes—located in the mitochondria of eukaryotic cells and in the cytosol of prokaryotes. The overall reaction catalyzed by the pyruvate dehydrogenase complex is an oxidative decarboxylation, an irreversible oxidation process in which the carboxyl group is removed from pyruvate as a molecule of CO_2 and the two remaining carbons become the acetyl group of acetyl-CoA. NAD acts as electron acceptor.

Although the TCA cycle is central to energy-yielding metabolism its role is not limited to energy conservation. 4 and 5 carbon intermediates of the cycle serve as precursors for a wide variety of products. Oxaloacetate and *α* -ketoglutarate, for e.g., are produced from aspartate & glutamate, respectively, when proteins are degraded. To replace intermediates removed for this purpose, cells employ anaplerotic (replenish) reactions. In eukaryotes, the entire reactions of the citric acid cycle takes place in mitochondria.

Steps of TCA Cycle:

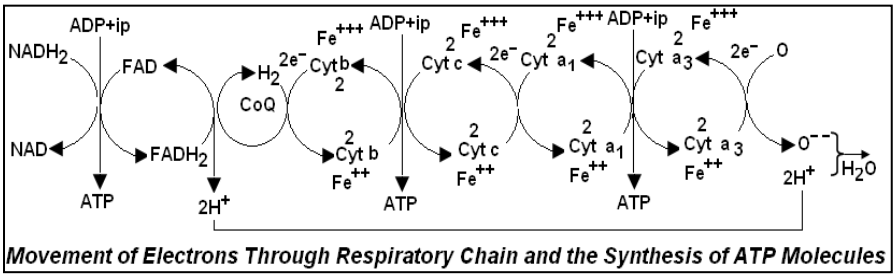
1. ***Formation of Citrate*** The 1st reaction of TCA cycle is condensation of acetyl-CoA with oxaloacetate to produce citrate. This is catalyzed by citrate synthase that join the methyl carbon of the acetyl group to the carbonyl group (C-2) of oxaloacetate.
2. ***Formation of Isocitrate via cis-Aconitate****:* The enzyme aconitase or aconitate hydratase catalyzes the reversible transformation of citrate to isocitrate**,** through the intermediary formation of tricarboxylic acid *cis*-aconitate**.**
3. ***Oxidation of Isocitrate to α-Ketoglutarate and CO_2***: Enzyme isocitrate dehydrogenase catalyzes oxidative decarboxylation of isocitrate to form ***α*** – ketoglutarate**.** There are two different forms of isocitrate dehydrogenase in all cells, one require NAD^+ as electron acceptor & other require $NADP^+$. In eukaryotic cells, the NAD^+ dependent enzyme is found in the mitochondrial matrix and serves in the TCA cycle. The main function of the $NADP^+$ dependent enzyme, found in both the mitochondrial matrix and the cytosol, may be the generation of NADPH, which is essential for reductive anabolic reactions.

4. ***Oxidation of α -Ketoglutarate to Succinyl-CoA and CO2*:** In next step *α* -ketoglutarate is converted to succinyl-CoA and CO2*α* -ketoglutarate dehydrogenase complex; NAD+ serves as electron acceptor and CoA as the carrier of the succinyl group.



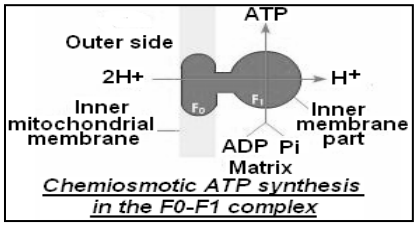
5. ***Conversion of Succinyl-CoA to Succinate**:* In the next step succinyl-CoA synthetase or succinic thiokinase catalyzes cleavage of s*uccinyl-CoA to succinate &* use of release energy in formation of GTP from GDP.
6. ***Oxidation of Succinate to Fumarate**:* The succinate formed from succinyl-CoA is oxidized to fumarate by the flavoprotein succinate dehydrogenase. FAD acts as electron acceptor in this reaction.
7. ***Hydration of Fumarate to Malate**:* The reversible hydration of fumarate to L-malate is catalyzed by fumarase**.**
8. ***Oxidation of Malate to Oxaloacetate**:* In the last reaction of TCA cycle, NAD-linked L-malate dehydrogenase catalyzes the oxidation of L-malate to oxaloacetate.

Oxidative phosphorylation: The whole process, by which oxygen effectively allows the production of ATP by Phosphorylation of ADP, is called oxidative phosphorylation.



Movement of Electrons Through Respiratory Chain and the Synthesis of ATP Molecules

It is the synthesis of energy rich ATP molecules with the help of energy liberated by oxidation of reduced coenzymes, NADH2 and FADH2 produced during respiration. The enzyme required for their synthesis is called ATP synthatase. It is present in F1 or head piece of F0 - F1 particle in mito chondrial membrane. The enzyme ATP synthatase becomes active in ATP formation whenever there is a proton gradient.



Chemiosmotic ATP synthesis in the F0-F1 complex

Transport of 2 electrons from $NADH_2$ by the electron transport chain, simultaneously, transfers 3 pairs of protons to the outer compartment. One high energy ATP bond is produced per pair of protons returning to the matrix through the inner membrane particles. When one molecule of NADH molecule is oxidised, 3 molecules of ATP are synthesized. When one molecule of FADH is oxidised, only 2 ATP molecules are synthesised, as the latter donates its electron further down the chain.

Proteins:

Proteins are the most abundant organic molecules of the biological system. The name is justified because nearly half of the dry weight of an organism is formed of protein. They are complex organic nitrogenous compounds made up of carbon, oxygen, hydrogen, nitrogen and sulphur. Some proteins also contain phosphorus, iron, copper in varying proportions.

Definition: Proteins can be defined as complex organic nitrogenous compounds whose building blocks are amino acids.

Proteins are classified into two types. Simple proteins and Conjugated proteins

Simple proteins: Simple proteins are those which yield only amino acids on hydrolysis. e.g. albumins, gobulins, histones, actins, myosin, keratin etc.

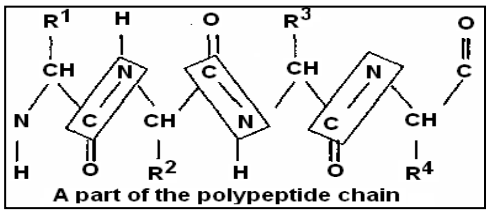
Albumins: These are soluble in water, dilute salt solutions dilute acids and bases. They occur in all body cells and in blood. Example: ova albumin of egg, serum albumin of blood, lacto albumin of milk, leucocin of barley, wheat etc. Albumins perform diverse functions for e.g.

- ✓ Lactoalbumin provides nutrition for young animals. It contains adequate amount of all amino acids.
- ✓ Serum albumin constitutes about 60% of the serum proteins and plays a significant role in maintaining blood volume and osmotic pressure.
- ✓ Several biochemically important compounds like bilirubin, steroid hormones, calcium, copper etc are bound to albumin while being transported in the blood.
- ✓ Albumins serve as a source of amino acids during tissue protein synthesis.

Globulin: These are bigger in size than albumin, insoluble in water but soluble in dilute salt solution. Eg. ovo globulin of egg, serum globulin of blood, lactoglobulin of milk etc. Blood serum contains a variety of globulins and perform diverse functions. There are specialized group of plasma globulins, actively involved in defence system called immunoglobulins**.**

Histones:

- ✓ These are soluble in water and dilute acids.
- ✓ Like albumin and globuins they do not coagulate* when heated.
- ✓ They are stable molecules. Eg. Proteins in nucleoproteins are histones.



A part of the polypeptide chain

- ✓ Protein part of haemoglobin is a histone. Histones along with DNA forms the chromosomes. Chromosomes are the vehicles of heredity.

Actin:

- ✓ These are contractile proteins present in the myofibrils of muscles forming the thick filament.

- ✓ Actin has a striking property of existing in two forms. Globular (G actin) and fibrous actin (F actin)
- ✓ Each whole actin molecule (fibrous actin) is made up of two helical strands of globular actin molecule.
- ✓ Actin along with myosin is responsible for the contractile nature of the muscles.

Myosin:

- ✓ These are contractile proteins present in the myofibrils of muscles forming the thin filament.
- ✓ Each myosin molecule consists of a rod and a head. The head consists of two similar body parts.
- ✓ Myosin along with actin is responsible for the contractile nature of the muscles.

Keratins:

- ✓ These are fibre like in shape, insoluble in all neutral solvents as well as weak acids and weak alkalis. They are resistant to digestion.
- ✓ They are found in the vertebrate skin, especially in the region which is subjected to abrasion like buccal cavity or wear and tear like sole, palm etc.
- ✓ In vertebrate skin keratinized region is said to be cornified. The cornified layer becomes modified to produce nails, claws, hooves, antlers, hair etc. of which kertain is the main component.

Conjugated proteins: Conjugated proteins are those proteins which on hydrolysis yield amino acid and a non protein group. The non protein group is called the prosthetic group (if the addition is organic) or co-factor (if the addition is inorganic*) Example: chromoproteins, glycoproteins, phosphoproteins, lipoproteins.

1. **Chromoproteins**: These are proteins in combination with pigments. Example. Haemoglobin
    - Coagulate : form into a mass
    - Inorganic : substance without carbon
    - **Haemoglobin (Hb)**
        - ✓ Haemoglobin is the respiratory pigment found in the blood. In vertebrates it is present in the RBC, while in invertebrates like Annelids it is present in blood plasma. It is made up of two units Haem and globin. Haem is a prosthetic group while globin is a protein factor. Haemoglobin performs two important biological functions.
        - ✓ It transports oxygen from the lungs to the tissues.
        - ✓ It transports carbon dioxide from tissues to the lungs for elimination.
2. **Glycoproteins**: These are proteins in combination with carbohydrates. Example: mucin of saliva
    - **Mucin of saliva**
        - ✓ The mucin sereted by the salivary glands moistens and lubricates the food and makes it easier to swallow.

- ✓ It also protects the wall of the buccal cavity from the action of acids and pungent food.

3. **Phosphoproteins**: These are proteins in combination with phosphorous group. Example :casein of milk
   - **Casein of milk:** Casein of milk forms about 85% of milk proteins. These are associated with feeding of young ones. It has a high nutritive value.
4. **Lipoproteins** : These are proteins in combination with lipids. Example: Lipovitelline of egg yolk.
   - **Lipovitelline**: It is one the e99 Proteins rich in essential amino acids that are necessary for growth. They are easily digested, absorbed and utilized.

Derived Proteins: These are divided into primary and secondary protein derivatives. Primary protein derivatives are those that have been slightly modified by the incipient action of water, very dilute acids, or enzyms, or are the result of the action of acids and alkalies whereby products soluble in weak acids and alkalies are formed. Coagulated proteins resulting from the action of heat and alcohol are classed in this division.

Secondary protein derivatives are those in which the modifying changes (hydrolytic or the taking up of water), through the action of acids or enzyms, have proceeded beyond the incipient stage with the formation of bodies that are soluble in water. In this division, the most important compounds are the proteoses and the peptones, the latter having suffered a greater change by hydrolysis than the former.

Primary Protein Derivatives
Proteans and Metaproteins

When proteins are acted upon by acids or alkalies, they are modified in proportion to the strength of the reacting acid or alkali and the length of time that the action continues. With acid or alkalies of sufficient strength, there are formed products soluble in weak acids and alkalies.

Table: ***Summery*** *of Proteins*

Classification	**On hydrolysis**	**Examples**	**Occurrence**
Simple protein	On hydrolysis yield only amino acids	Albumin	Serum albumin of blood, Locto albumin of milk etc.
		Globulin	Lactoglobulin of milk ovoglobulin of egg
		Histone	DNA
		Actin	Myofibril of muscle
		Myosin	Myofibril of muscle
		Kertain	Hair, nail, connective tissue
Conjugated protein	On hydrolysis yield amino acids plus non protein group called prosthetic group.	Chromoprotein	Respiratory pigments like haemoglobin,haemocyanin
		Glycoprotein	Mucin of salivary gland
		Phosphoprotein	Casein of milk
		Lipoprotein	Lipovitelline of egg yolk

Structure of Proteins: Every polypeptide chain is synthesized by polymerization of amino acid monomers in a specific sequence in accordance with the genetic information encoded in a molecule of mRNA which brings the information transcribed from a gene. The process of polymerization takes place on ribosomes, and is called translation of mRNA. As it is synthesized, each type of polypeptide chain undergoes bending and folding in a specific pattern to assume its distinctive 3-dimensional protein structure called its native conformation. Only then, the protein becomes capable of its specific function. This pattern of bending and folding is genetically inherent in the amino acid

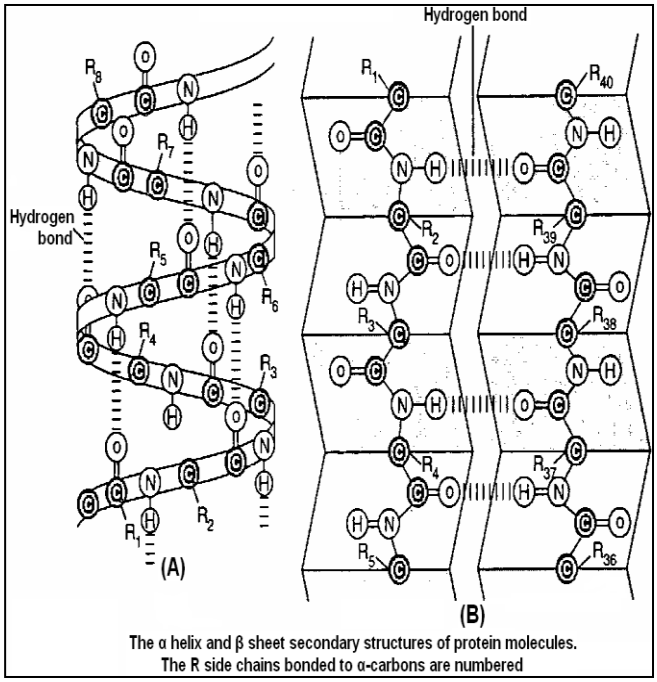
sequences of respective proteins. The 3-dimensional native conformations of all the immensely diverse proteins can be considered on basis of four basic hierarchial levels of organization, *viz.,* primary, secondary, tertiary and quaternary protein structures.

The primary, secondary and tertiary levels of structural organization involve only single polypeptide chains, but the quaternery organization involves interactions between two or more polypeptide chains which associate to form a protein molecule.

(1) Primary structure: The specific linear sequence of peptide-bonded amino acids constituting a polypeptide chain represents the primary structure of a protein. Only two of its component amino acid residues, viz. methionine and cysteine contain sulphur in their R group side chains, and only in cysteine, the sulphur occurs in a sulfhydryl group (SH). Even as a polypeptide chain is being formed, it bends and curves at specific places due to formation of covalent disulphide bonds (—S= S—) between the distantly situated cysteine residues. Thus, these disulphide bonds may be regarded a part of primary protein structure.

(2) Secondary structure: The polypeptide chains become folded into two types of secondary structures, called alpha helix (a helix) and beta sheet (fi sheet). Both of these structures are generated only by hydrogen bonding between the O_2 of carbonyl (—C=O) group of one peptide bond and the hydrogen of the amide (—NH) group of the other.

In a helix structure, one or more segments of a polypeptide chain become coiled in regular spirals in springlike fashion because, throughout the length of such a segment, the cabonyl (—C—O) oxygen of each amino acid becomes hydrogen bonded to the amide (—NH) hydrogen of the fourth amino acid along the chain (Fig.).



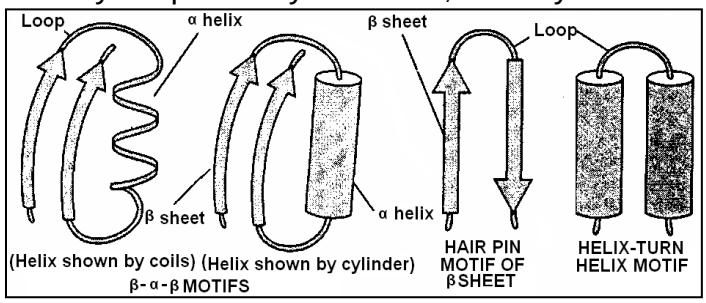
The α helix and β sheet secondary structures of protein molecules. The R side chains bonded to α-carbons are numbered

In the (3 sheet structure, two different segments of a polypeptide chain come to lie side by side and are held together by hydrogen bonds formed between carbonyl oxygen (—C=O) and amino hydrogen (—NH) of all amino acid residues of the opposing segments (Fig.). Thus, an extended sheet like structure is formed.

Because the alpha carbon (a-carbon) atoms, which form the backbone of a polypeptide chain, and to which the R side chain of each amino acid is attached,

are successively located a little above or a little below the plane of the (3 *sheet,* the sheet structure becomes zig-zag, giving the appearance of folds in a cloth. That is why, (3 *sheet* structure is commonly called pleated (3 sheet conformation.

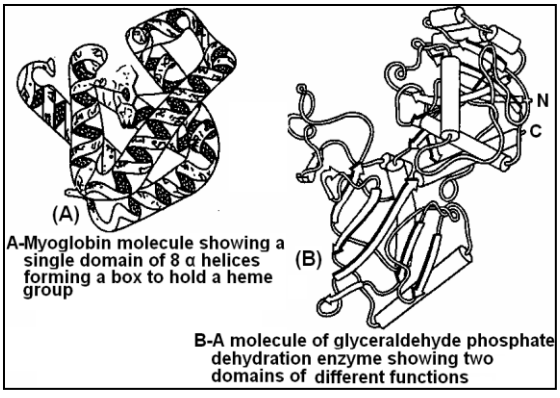
In multimeric (multisubunit) proteins, composed of two or more polypeptide chains, (3 sheet structures may also form due to interactions between segments of different chains. A polypeptide chain may acquire only a helical, or only P sheet conformation, or a combination of both in its different segments. The intermediate regions of simple amino acid sequences, connecting the modified segments, often become loop-like. Thus, at the secondary level, a polypeptide chain is often a combined unit of modified segments interconnected by nonmodified loop-like portions.



It is, therefore, called a super-secondary structure or motif. In a motif, the helix segments are shown by cylinders or coils, fisheetby flat arrows, and connecting loops by narrow ribbons (Fig.). Both a helix and (3 sheet segments occur in molecules of most proteins, but their relative contents are widely variable. For example, the molecules of fibroin protein of silk fibres consist almost entirely of |3 sheets. This renders the silk fibres strong and virtully nonstretchable. Contrarily, the molecules of keratin protein of hair and wool consist almost entirely of helices, rendering hair and wool quite stretchable. Obviously, both fibroin and keratin are fibrous proteins. All fibrous proteins occur in the form of extended fibres and acquire only secondary protein structure. These occur in cells in small amounts only as structural materials.

(3) Tertiary structure: Most proteins of cells occur as compact and roughly spherical or globular molecules (globular proteins) which form by acquiring tertiary and quaternary protein structures.

To attain *tertiary level of protein structure,* a polypeptide chain undergoes further folding to pack its secondary structures close together, forming localized regions of compact folding known as domains. In the formation of domains, the R-group side chains of distant amino acid residues come close together to play their decisive roles in protein function. Thus, the domains represent the *active sites* of globular proteins.



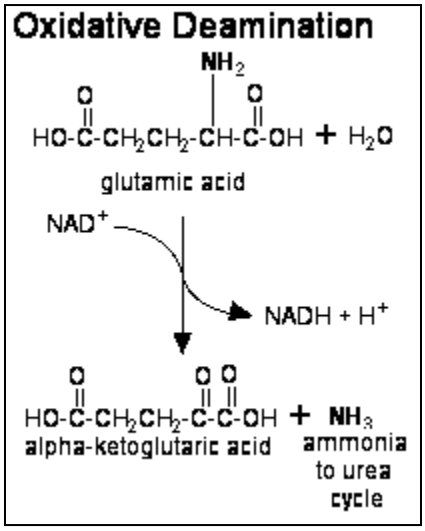
Small proteins, like myoglobin, cytochrome c, lysozyme, etc., are folded into a single domain (Fig.). Larger proteins may have more than one, and upto dozens of domains which may have different functions. Contrarily, similar domains in different proteins may have similar functions. Domains may obviously be of three types—those formed only of helices, or only of P sheets, or of a mixture of both.

Whereas the folding of a polypeptide chain into secondary structures depends only on hydrogen bonds between carboxyl (— C = O) and amino (—NH) groups of peptide bonds, the folding for tertiary conformation depends on five types of interactions between the R group side chains of amino acid residues. These interactions are **(a)** disulphide bonds, **(b)** electrostatic (ionic) bonds, **(c)** hydrogen bonds, **(d)** van der Waal's forces, and **(e)** hydrophilic or hydrophobic attractions.

(4) Quaternary structure: Whereas the secondary and tertiary protein structures are characteristics of single polypeptides, the quaternary protein structure occurs only in multimeric proteins in which two or more (upto dozens or even hundreds) of polypeptides of tertiary level associate and interact to form a protein molecule. Most cellular proteins are enzymes and most enzymes and all other multimeric proteins *(e.g.* insulin, heamoglobin, etc.) are globular proteins of quaternary structure.

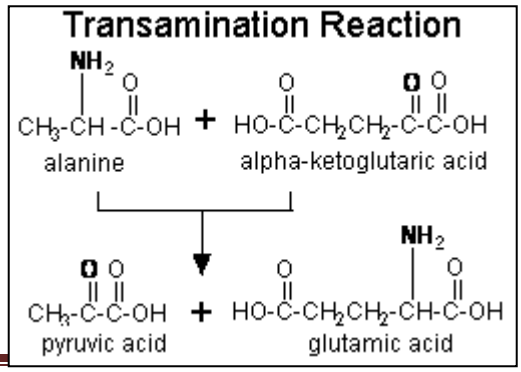
The component polypeptides, *i.e.* the multimeric subunits in quaternary proteins are held together by the same interactions which are responsible for tertiary structures in single polypeptides. Once a protein is folded into its native conformation, it can also associate non-covalently with other proteins, nucleic acids, lipids, etc., to form supramolecular complexes, such as viruses, multifunctional enzyme complexes, chromosomes, cyto-skeletal structures, ribosomes, biomembranes, etc.

Deamination: Introduction: Deamination is also an oxidative reaction that occurs under aerobic conditions in all tissues but especially the liver. During oxidative deamination, an amino acid is converted into the corresponding keto acid by the removal of the amine functional group as ammonia and the amine functional group is replaced by the ketone group. The ammonia eventually goes into the urea cycle.



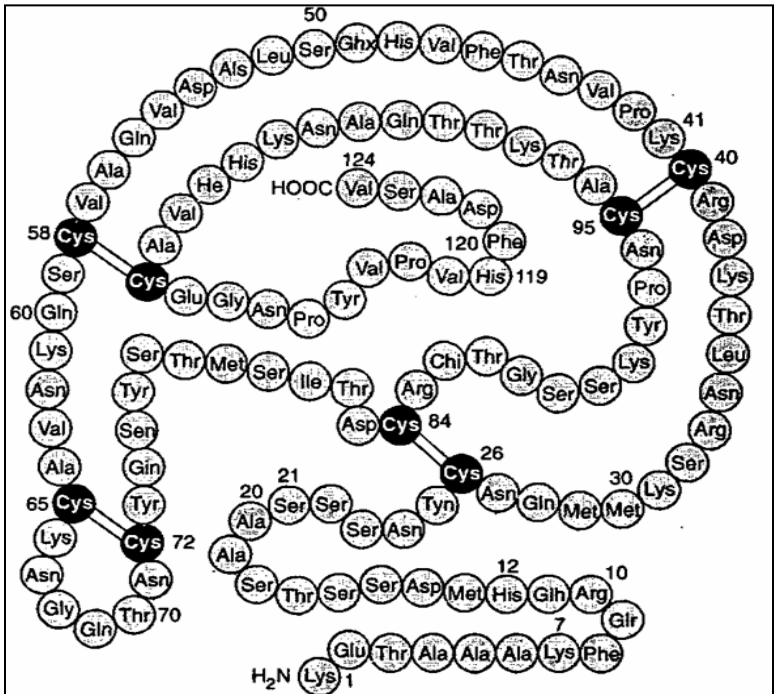
Oxidative deamination occurs primarily on glutamic acid because glutamic acid was the end product of many transamination reactions. The glutamate dehydrogenase is allosterically controlled by ATP and ADP. ATP acts as an inhibitor whereas ADP is an activator.

Transamination: **Introduction:** Transamination as the name implies, refers to the transfer of an amine group from one molecule to another. This reaction is catalyzed by a family of enzymes called transaminases. Actually, the transamination reaction results in the exchange of an amine group on one acid with a ketone group on another acid. It is analogous to a double replacement reaction. The most usual and major keto acid



involved with transamination reactions is alpha-ketoglutaric acid, an intermediate in the citric acid cycle. A specific example is the transamination of alanine to make pyruvic acid and glutamic acid. Other amino acids which can be converted after several steps through transamination into pyruvic acid include serine, cysteine, and glycine.

Denaturation: Proteins when subjected to high temperature, radiation, action of acids and alkalis, unfold and loose their specific three dimensional shape and coagulate. This process is called denaturation of proteins. This change may be temporary or permanent. When a protein is denatured, its amino acid sequence remains unaffected, but the shape gets altered and can no longer perform its biological function. Sometimes the *protein* may spontaneously refold itself into Its original structure. This *reversal* process Is known as renaturation



A polypeptide chain bent and curved due to four disulphide bonds

LIPIDS

1) Fats are simple lipids. They are solid lipids. They are the esters of fatty acids with glycerol. They are found in liver, seeds, fruits, etc.
2) Fats are solids or semisolids at room temperature.
3) They form reserve food in animal.
4) They form insulation to temperature loss,
5) A fat is made up of a glycerol molecule and 3 fatty acids. It is called a triglyceride.
6) If the 3 molecules of fatty acids are same, the fat is a simple glyceride.
7) If the fatty acids are different, then the fat is a mixed glyceride?
8) If the glycerides have no free acid or basic groups the fat is termed as neutral fat.
9) Fats have high percentage of saturated fatty acids like palmitic and stearic acid.
10) Fats have high melting points.
11) Fats are of two types, namely animal fats and plant fats.
12) Fats are insoluble in water.

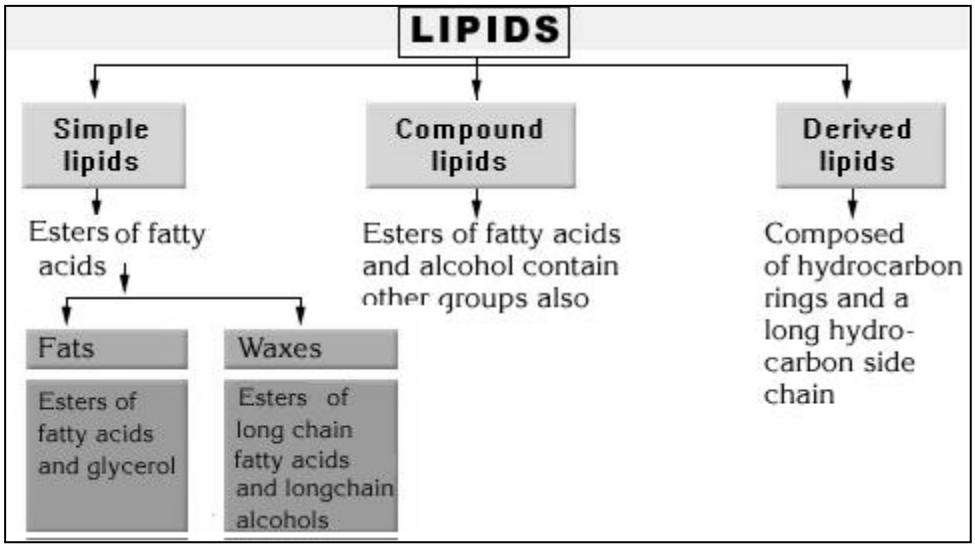
13) They float on water.

14) They form soap with alkali. The process of formation of soap is called saponification.

15) They develop unpleasant odor on aging. It is called rancidity,. Rancidity is caused by oxidation and hydrolysis.

Classification of Lipids: Lipids are organic compounds containing carbon, hydrogen and oxygen. However, hydrogen and oxygen occur in a ratio much higher than in water. Lipids form about 3.5% of the total chemical composition of a cell. Lipids are generally insoluble in water but soluble in organic solvents like ether and chloroform. Lipids are generally classified into three types.

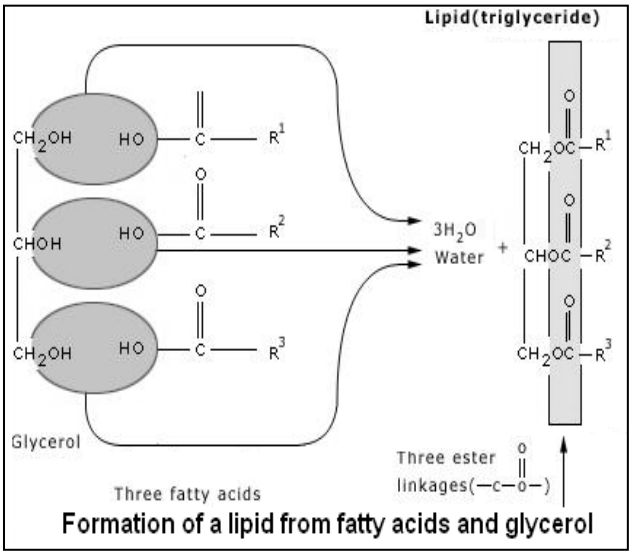
I. Simple lipids or homolipids **II.**Compound lipids or heterolipids **III.** Derived lipids



Simple Lipids: Simple lipids are alcohol esters of fatty acids and include neutral fats and waxes. These are long chain fatty acid esters of trihydric alcohol glycerol. These fatty acids contain even number of carbon atoms and are both saturated and unsaturated carboxylic acids. Simple lipids are known as *triglycerides/ triacyl glycerols.* Some of these are solids at room temperature, while others are liquids. Solids are known as fats and liquids are known as oils. The structure is represented as

Fats are esters of fatty acids and glycerol. A fatty acid is an organic acid with a hydrocarbon chain ending in a carboxyl (COOH) group. Most fatty acids have an even number of carbon atoms ranging between 14 to 22 (most commonly 16 or 18). The carbon and hydrogen atoms form a long hydrocarbon tail that is hydrophobic (having no affinity for water).

Glycerol is a type of alcohol having 3 hydroxyl (-OH) groups. A fatty acid is described as saturated if there are no double bonds between carbons of the molecular chain, for e.g. palmitic acid (16 carbons) & stearic acid (18 carbons).



A fatty acid is described as unsaturated if one (mono) or more (poly) double bonds occur between the carbon atoms of the chain. The 18 carbon unsaturated fatty acids are oleic acid, linoleic acid and linolenic acid with one, two and three double bond respectively. Fats that are generally liquids at room temperature are called oils. They are rich in unsaturated fatty acids. For example, Groundnut oil, sunflower oil, safflower oil and so on. Waxes are esters of long chain fatty acids with long chain alcohols in place of glycerol. Waxes are of common occurrence in both plants and animals. They form a waterproof protective coating on animal furs and plant leaves and stem. Cutin in the cuticle of leaves, suberin in the endodermis of root, sebum in the hairs of mammals, cerumin in the wax glands of ear, bee wax produced by bees, are some common examples.

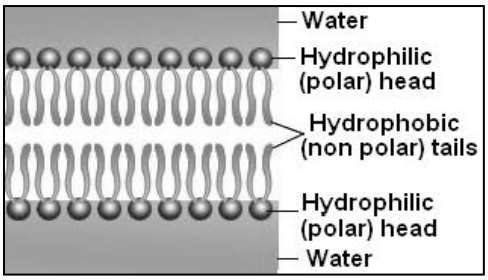
Some important fatty acids in fats are:

Acid	C-atoms	Formula	Nature	Fat

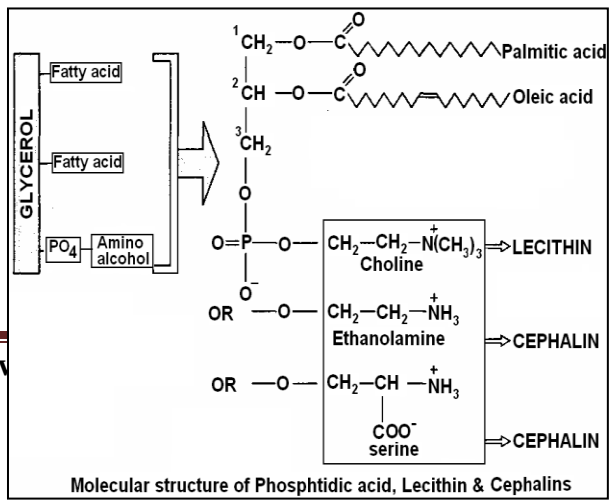
Butyric acid	4	$CH_3(CH_2)2COOH$	Saturated	Butter
Caproic acid	6	$CH_3(CH_2)4COOH$	Saturated	Butter oil
Caprylic acid	8	$CH_3(CH_2)6COOH$	Saturated	Coconut oil
Capric acid	10	$CH_3(CH_2)8COOH$	Saturated	Coconut oil
Palmitic acid	16	$CH_3(CH_2)14COOH$	Saturated	Animal fat
Stearic acid	18	$CH_3(CH_2)16COOH$	Saturated	Animal fat
Arachidic acid	20	$CH_3(CH_2)18COOH$	Saturated	Groundnut oil
Cerotic acid	26	$CH_3(CH_2)24COOH$	Saturated	Wool fat
Linolenic acid	18	$CH_3(CH_2)4CH=CH2OH$	Unsaturated	Cotton seed oil
Oleic acid	18	$= CH(CH_2)7COOH$ $CH_3(CH_2)7CH=$ $CH(CH_2)7COOH$	Unsaturated	Animal fat

Compound (Conjugated) Lipids: These are compounds composed of alcohol, fatty acids and some other substances. Functionally, these are structural lipids which are the basic components of biological membranes. Remember that each cell has a covering of plasma membrane which separates it from its surroundings. A similar membrane surrounds most cell organelles (nucleus, endoplasmic reticulum, mitochondria, Golgi bodies, lysosomes, chloroplasts, etc.), separating the organelles from the cytosol and thus, establishing an intracellular compartmentalization of cellular metabolism into distinct units. In order to construct biomembranes, compound lipids must be more strongly amphipathicthan ordinary fats, with usual fatty acid "tails" but with large hydrophilic "heads" to present a greater surface to aqueous phase. The increased affinity for water is obtained by incorporating an additional, charged group to the polar "head group" of fat molecules. Cellular pool includes a variety of two main categories of compound lipids, viz. phospholipids and sphingolipids.

Phospholipids (Phosphoglycerides, or Glycerophospholipids): A variety of phospholipids are formed in cells from a common precursor called phosphatide acid. A molecule of this acid consists of two nonpolar (hydrophobic) fatty acid "tails" ester-linked to C 1 and C 2 of the glycerol backbone of a hydrophilic "head", and a negatively charged phosphate group (PO4) linked to the C 3 of glycerol. The phosphate group is the basis of these lipids being termed phospholipids. These include lecithins, cephalins, and cardiolipins andplasmalogens as follows:



Lecithins and Cephalins: These are the most common phospholipids in biomembranes. These also occur in blood plasma, egg yolk, etc. Molecules of these contain a large "head" formed due to linking of an amino alcohol with the phosphate group of phosphatidic acid by means of a phosphodiester bond. This additional "head



Molecular structure of Phosphtidic acid, Lecithin & Cephalins

group" bears a positive charge. In addition to enlarging the "head" it also renders the head amphoteric, making it strongly hydrophilic. The amino alcohol linked to the phosphate group is choline in lecithin, and ethanolamine or serine (an alcoholic amino acid) in cephalins (Fig.).

Cardiolipins: These belong to a different category of phospholipids in which the additional "headgroup", linked to the C 3 of glycerol backbone through the phosphate group, is another molecule of glycerol. These phospholipids form about 20% of inner mitochondrial membrane.

Plasmalogens : In these phospholipids one of the two "tail" fatty acids links to the glycerol head, not by an ester linkage, but by an ether linkage. Biomembranes in vertebrate cardiac muscles, ciliate protists and certain cells of invertebrates are rich in plasmalogens. One of the plasmalogens is platelet-activating factor (PAF) which is released from basophils (a kind of WBC, in vertebrates) to stimulate the blood platelets.

Table: *Summary of lipids*

Classification	On hydrolysis	Types	Occurrence
Simple lipid	On hydrolysis yield fatty acid and glycerol only	Oils	Vegetable oils, fish oil
		Fats	Glycerides of animals
		Waxes	Bee wax, spermaceti of sperm whale
Conjugated lipid	On hydrolysis yield fatty acid, glycerol plus non lipid group, like glucose, phosphorous etc	Phosphoilips	Cell membranes, egg yolk
		Sphingolipids	Brain and nervous tissue
Related Compounds	On hydrolysis yield fatty acid and alcohol other than glycerol.	Steroids	Hormones like testosterone, estrogen, progesterone
		Sterols	Cholesterol, Vit D, etc
		Prostaglandins	Prostanoids

Derived Lipids

Introduction to the derived lipids: Lipids or Fats are greasy materials disturbing extensively in nature. They are normally insoluble in water but soluble in fat solvents. They includes substances like,

Naturally occurring fats e.g. butter and oils.

Substances which are chemically linked to fats but vary in definite ordinary properties like lecithin (waxy substance which is soluble in fat solvents and mixing with water to form a colloidal solution).

Substance, which are related to fats, because of certain common properties like solubility and biological origin, but differ from fat in appearance and chemical nature, e.g. cholesterol.

Oils which are liquid at room temperature.

Biological significance of derived lipids:

The lipid forms one of the three main types of food stuffs. As an necessary dietary ingredient, it does the significant purpose of supplying fuel to the body. It give ups extra heat and energy than carbohydrates.

Certain normal breakdown products of fatty acids in the body, such as acetic acid and bile acids form important building blocks of biologically active and complex materials like cholesterol, sex hormone and steroids.

Another function of derived lipids is to supply the essential dietary constituent, known as the Essential fatty acids (EFA). They resemble vitamins in that they cannot be synthesized by the body and therefore should be supplied in the diet in small quantities for optimal growth.

Deposits of fat underneath the skin insulating effect to the body. They protect the body from excessive heat or cold.

Vitamins D, K, E, and A are fat soluble vitamins which are nutritional essentials.

Lipid Beta Oxidation: Beta oxidation is the metabolism of fatty acid. In β oxidation fatty acids are split into acetyl CoA. Oxidation is defined as the oxidation of fatty acid at the 0 carbon atom (second carbon atom from the carbpxyl group) and split into acetyl Co A and a fatty acid having two carbon atoms less. Oxidation of fatty acid occurs in mitochondria. β oxidation takes place with the following steps:

1. **Activation of fatty acid:** Fatty acid combines with coenzyme A with the help of ATP to form fatty acyl CoA. Reaction is catalyzed by enzyme acyl - CoA synthetase
2. **Dehydrogenation I:** Dehydrogenation occurs in the 'a' and 'p' carbon atoms of the fatty acyl CoA. This reaction is catalyzed by the enzyme acyl-CoA dehydrogenase in the presence of FAD- A double bond is created and leads to the formation of a, (β unsaturated acyl CoA).
3. **Hydration:** In the next step water molecule is added to the double bond of a, P unsaturated acyl CoA to form - P hydroxyacyl CoA. The enzyme involved in this reaction is aacyl - CoA hydratase.
4. **Dehydrogenation II:** P - hydroxyacyl - CoA is dehydrogenated to form P - ketoacyl - CoA by the action of the enzyme P - ketoacyl - CoA dehydrogenase. This reaction requires the presence of NAD+
5. **Cleavage:** The last step of the fatty acid oxidation cycle is catalyzed by the enzyme thiolase. A free coenzyme A is added to P ketoacyl. CoA and results in the splitting to form acetyl CoA and a fatty acyl CoA with less 2 carbon fragment. The resulting acetyl CoA enters the Krebs cycle. The fatty acyl CoA reenters the (β oxidation cycle and it releases another acetyl CoA. The cycle is repeated till the fatty acid is completely split up into acetyl CoA. If the starting fatty acid contains even number of carbon atoms, the final cleavage results in two molecules of acetyl "CoA. If the fatty acid contains odd number of carbon atoms, tlfe final cleavage produces one acetyl CoA and one molecule of propionyl Co A.

Synthesis of cholesterol: Liver is the major place for synthesis of cholesterol and other locations are intestine, sex organs and adrenal glands. HMG CoA is the condensed product of Acetyl CoA and acetoacetyl CoA, which undergoes further reactions to form cholesterol. HMG CoA reductase is the regulating enzyme.

Functions of Cholesterol: As a constituent of cell membrane, cholesterol maintains its fluidity and keeps it structure intact. The hydroxyl group of cholesterol interacts with hydrophilic groups and the bulky group is studded in the plasmalemma, which reduces its permeability of ions. Its plays a major role in intracellular transport, signal transduction and nerve signals. It is a beginning molecule for synthesis of bile in liver. Fat-soluble vitamins like vitamin A, E, D and K are made soluble by bile. It helps in synthesis of adrenocorticoids and sex hormones like testosterone and progesterone. It has an essential function in clathrin-coated endocytosis. It assists in the formation of lipid rafts that are involved in cell signalling.

Disorders Caused by Abnormal Cholesterol Levels

1) **Hypercholesterolemia:** As the term indicates high levels of cholesterol that is high levels of LDL and low levels of HDL leads to atherosclerosis (a cardiac disorder).
2) **Hypocholesterolemia:** Similarly low cholesterol levels may aggravate depression, hemorrhage.

The HDL and LDL levels in blood are measured by fasting lipid profile test. The conditions like 200mg/dL or more of cholesterol or HDL levels <40mg/dL are considered as abnormal.

Some Important Vitamins: Vitamins are complex organic substances. These are required for various metabolic reactions within cells of the body. They do not occur freely and Eire found in various food substances. Vitamins are not synthesized in the animal's body except some which are synthesized by bacteria of intestine. They are synthesized in plants and hence one depends upon plants for vitamins. Vitamins are not generally stored in the animal's body, except some which can be stored in liver (e.g., vitamin D). Hence, they are excreted with urine after digestion.

Classifications Vitamins are classified into two groups:

Water-soluble vitamins: *and* **Fat-soluble vitamins.**

Water-soluble vitamins:

Vitamin C: This is a water soluble non-B complex vitamin known as Ascorbic acid. Intake of vitamin C cures common cold. Animals can synthesize ascorbic acid while man cannot synthesize due to the lack of an enzyme - gluconolactone oxidase. Vitamin C is helpful in wound healing process and bone formation. It is also useful in Tryptophan metabolism, Tyrosine metabolism, Fatty acid metabolism and cholesterol metabolism. Vitamin C reduces cataract formation and also prevents chronic diseases.

Sources: Rich sources are citrus fruits and gooseberry. Good sources are Guava, green vegetables, tomatoes and potatoes. Milk is a poor source of ascorbic acid.

Deficiency: The disease caused due to the deficiency of vitamin C is scurvy. This disease causes spongy and sore gums, loose teeth, fragile blood vessels, swollen joints, etc. The main characteristic of this disease is anaemia. Intake of vitamin C cures common cold. Intake of mega doses of vitamin C leads to urinary tract infections.

Thiamine (Vitamin B1): This is a water soluble vitamin with a specific coenzyme Thiamine pyrophosphate (TPP). This coenzyme TPP function is connected to carbohydrate metabolism. Thiamine is non toxic. The requirement of thiamine in a body depends on the intake of carbohydrate. Many enzymatic reactions in carbohydrate metabolism are dependent on TPP. For e.g., pyruvate dehydrogenase, Transketolase, -ketoglutarate dehydrogenase, etc.

Sources: Good sources are cereals, pulses, nuts and yeast. Thiamine is mostly found in outerlayer of cereals. It is also found in liver, heart, kidney, milk, etc.

Deficiency: The disease caused due to the deficiency of Thiamine is beri-beri. Early symptoms of this deficiency are weakness, constipation, mental depression, loss of appetite, etc. Two types of Beri-Beri are observed. They are Dry beri-beri, wet beri-beri. Dry beri-beri causes neurological manifestations. Muscles become weak and walking becomes difficult and the individual become bed ridden. Wet beri-beri causes breathlessness & palpitation. Heart becomes weak & death occurs due to heart failure.

Riboflavin (B_2): This is also a water soluble vitamin which helps in the oxidation - reduction reactions through its coenzymes. The two coenzymes of

this vitamin are Flavin mononucleotide (FMN) and Flavin adenine dinucleotide (FAD). Enzymes that use flavin coenzymes are called as flavo proteins. Flavo proteins containing metal atoms are called as metallo flavo proteins.

Sources: Rich sources are milk and its products, meat, eggs, liver and kidney. Cereals, fruits, vegetables and fish contain moderate amounts of riboflavin.

Deficiency: The deficiency of this vitamin is uncommon and is observed mostly in chronic alcoholics. Deficiency of this vitamin causes Dermatitis, Glossitis and Cheilosis. Intake of large doses of riboflavin doesn't affect the body. It is excreted in feces.

Pyridoxine (B_6): Pyridoxine is a water soluble vitamin with pyridine derivatives. These are pyridoxine, pyridoxal and pyridoxamine. Pyridoxine is a primary alcohol, pyridoxal is an aldehyde and pyridoxamine is an amine form. Pyridoxine can be converted to pyridoxal and pyridoxamine where as they cannot form pyridoxine. Pyridoxal phosphate is the coenzyme of B_6. It participates in reactions like transamination, deamination, condensation, etc.

Sources: Rich sources of vitamin B_6 are egg, fish, milk and meat. Wheat, corn, cabbage, roots and tubers are some other sources of vitamin B_6.

Deficiency: The deficiency of vitamin B_6 causes depression, irritability, nervousness and mental confusion. Severe deficiency of this vitamin causes convulsions and peripheral neuropathy. Demyelination of neurons, decrease in Haemoglobin levels are also observed due to this vitamin deficiency.

Fat-soluble vitamins:

Vitamin A: This is a fat soluble vitamin which is present mostly in animals. Its provitamins carotenes are found in plants. Vitamin A is necessary for vision and proper growth. It is necessary for maintenance of proper immune system to fight various infections. Cholesterol synthesis requires vitamin A. The carotenoids act as antioxidants and reduce risk of cancers.

Sources: Dark green vegetables & fruits are good sources of carotenes. E.g., carrots, spinach, amaranthus, papaya, pumpkins, etc. The animal sources are liver, kidney, egg, milk & its products like cheese & butter. Fish is very rich source of vitamin A.

Deficiency: The deficiency of vitamin A is related to eyes, skin and growth. The major deficiency manifestations are related to eyes. It causes xerophthalmia i.e., hardening of cornea of eye. This is one of the deficiencies caused in many individuals. They have a difficulty to see in dim light. This is the earliest stage of deficiency. If this prolongs it causes the destruction of cornea, causing total blindness. This is called Keratomalacia. The other manifestations caused due to the deficiency are growth retardation, dryness of skin, bacterial infections of urinary tract, etc.

Vitamin D: This is also a fat soluble vitamin. Ergo calciferol and cholecalciferol are the provitamins of vitamin D. Ergocalciferol is vitamin D_2 formed from ergosterol. Cholecalciferol is vitamin D_3 found in animals. Vitamin D is stored in liver and other tissues. Calcitrol is the biologically active form of vita D. It is produced in kidney. Acts on intestines and bones.

Sources: Fish, fish liver oils, Egg yolk are the rich sources of vitamin D. Exposure of skin to sunlight is a way through which vitamin D is provided to the body.

Deficiency: The deficiency of this vitamin leads to demineralization of bones. It causes rickets in children and osteomalacia in adults. Rickets is characterized by bone deformities. It results in soft and pliable bones and delays in teeth formation. In osteomalacia bones become softer and cause fractures. Higher consumption of vitamin D causes hyper vitaminosis D. This leads to formation of stones in kidneys. More consumption of vitamin D causes loss of appetite, increased thirst, etc.

Vitamin E: This vitamin is named as tocopherol. Nearly about 8 tocopherols are identified - a, b, g etc. Among these -tocopherol is most active. Vitamin E is stored in adipose tissue, liver and muscle. It acts as a scavenger and is essential for membrane structure, cellular respiration and storage of creatine in skeletal muscle. It protects liver from being damaged.

Sources: Vegetable oils are the rich sources of vitamin E. It is present in small amounts in meat, milk, butter and eggs. Sunflower oil, wheat germ oil, cotton seed oil and corn oil are the good sources of vitamin E.

Deficiency: The deficiency of this vitamin occurs mainly in animals. It causes sterility, megaloblastic anaemia. It also causes changes in central nervous system. Compared with animal's deficiency of vitamin E is not severe in humans. In humans it causes increased fragility, minor neurological disorders. Major defect is observed in fat absorption and transport.

Vitamin K: This is the only fat soluble vitamin which has a coenzyme function. It exists in different forms - K_1, K_2, and K_3. Vitamin K_1 called phylloquinone is found in plants. Vitamin K_2 called menaquinone is found in intestinal bacteria and some animals. K_3 is called menadione which is a synthetic form. Main function of vitamin K is with blood clotting process. It is required for carboxylation of glutamic acid residues. Vitamin K acts as coenzyme in this carboxylation process. It also involves in electron transport chain and oxidative phosphorylation.

Sources: Good sources of vitamin K are green vegetables, cabbage, cauliflower, tomatoes and spinach. It is also present in meat, liver and dairy products.

Deficiency: The deficiency of this vitamin effects blood clotting mechanism. The blood clotting time increases and the individual bleeds heavily even for minor injuries. Deficiency of vitamin K leads to lack of prothrombin. Excess administration of vitamin K causes jaundice in infants. Heparin acts as anticoagulant.

Niacin: This is also called as Nicotinic acid. The coenzymes are Nicotinamide dinucleotide (NAD) and Nicotinamide dinucleotide phosphate (NADP). These coenzymes participate in oxidation - reduction reactions and in almost all the metabolisms.

Sources: Rich sources of Niacin are liver, yeast, whole grains, cereals and pulses. Milk, fish, eggs and vegetables are the moderate sources of niacin.

Deficiency: The disease caused due to the deficiency of this vitamin is pellagra. The symptoms of pellagra are dermatitis, diarrhea, and dementia. These are referred as three D's. If the patient is not treated it may lead to death. Dermatitis is observed on skin that is exposed to sunlight. Diarrhea is in form of loose stools with blood and mucus. Prolonged diarrhea leads to weight loss. Symptoms of dementia are anxiety, poor memory, etc.

B12 (Cyanocobalamin): This is the only vitamin with a complex structure. The empirical formula of vitamin B_{12} is $C_{63}H_{90}N_{14}O_{14}PCO$. Vitamin B_{12} is also known as anti pernicious anemia vitamin. This is stored in liver to meet the body requirements.

Sources: Rich sources of liver, kidney, milk, eggs, fish, pork and chicken. Vitamin B_{12} is synthesized in micro-organisms and hence B_{12} is found only in animal foods and absent in plant foods.

Deficiency: The disease caused due to the deficiency is pernicious anemia. Symptoms of this disease are low haemoglobin levels, decreased number of erythrocytes and neurological manifestations. The deficiency of B_{12} also causes numbness and tingling of fingers and toes. If the deficiency is severe it causes confusion, etc.