Consortium for
Educational
Communication

Module on

# Simple Sugars

By

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**Nomenclature and structural chemistry of carbohydrates:**

The name carbohydrate means hydrate of carbon. In earlier days, the carbohydrates were regarded as the hydrates of carbon with the general formula $C_n(H_2O)_m$, for example glucose *(blood sugar):* $C_6H_{12}O_6$ or alternatively $C_6 (H_2O)_6$, *Sucrose (table sugar):* $C_{12}H_{22}O_{11}$ or alternatively $C_{12} (H_2O)_{11}$.

However, all carbohydrates do not follow this general formula. Some contain too few oxygen atoms to fit this formula such as rhamnose ($C_6H_{12}O_5$), and some others contain too many oxygen atoms. Furthermore, there are other compounds like formaldehyde ($CH_2O$), acetic acid ($C_2H_4O_2$), etc. which are not and do not behave like carbohydrates but have the formula of hydrates of carbon. However, the term carbohydrate has become so firmly rooted in chemical nomenclature that, although not completely accurate, it persists as the name for this class of compounds. At the molecular level, most carbohydrates are polyhydroxyaldehydes, polyhydroxyketones, or compounds that yield either of these compounds after hydrolysis. Therefore, the chemistry of carbohydrates is essentially the chemistry of hydroxyl groups and carbonyl groups, and of the acetal bonds formed between these two functional groups.

Inspite of having predominantly only two types of functional groups, there exists a structural complexity in their chemistry. All but the simplest carbohydrates contain multiple chiral centres. Carbon atom that is surrounded by four different functional groups to satisfy its tetravalency is termed as chiral carbon. It is further said to satisfy the chirality if it can exist in two different spatial arrangements in space (configurations) that are non-superimposable mirror images of each other, for example, glucose, the most abundant carbohydrate in the biological world, contains one aldehyde group, one primary and four secondary hydroxyl groups that form four chiral centres. Working with molecules of this complexity presents enormous challenges to organic chemists and biochemists alike.

## 1. **Classification of carbohydrates:**

Several classifications of carbohydrates have been proven useful, as outlined below:

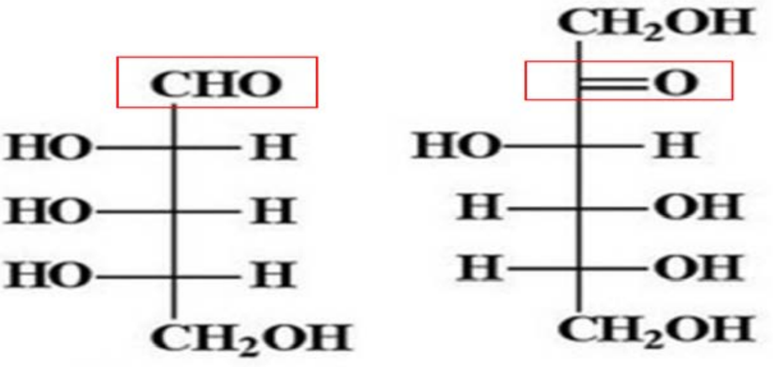
- Simple and complex sugars: Generally monosaccharides have been termed as simple sugars as these cannot be converted into simpler carbohydrates by hydrolysis for example glucose and fructose. While as, disaccharides, oligosaccharides and polysaccharides are termed as complex carbohydrates, as after hydrolysis these yield simpler carbohydrates.

- Size and number of carbon atoms: On this basis, carbohydrates are classified as trioses, tetroses, pentoses, hexoses, heptoses and octoses that contain three, four, five, six, seven and eight carbon atoms, respectively. Hexoses, like glucose are the most common in occurrence among all others.

- Presence of functional group: On basis of functional group, carbohydrates are classified as aldoses and ketoses. Sugars having an aldehyde functional group or its equivalent are termed as aldose, for example glucose. While the sugars having a ketone functional group or its equivalent are termed as ketoses, for example fructose, as shown in the diagram below (Fig 1).

- Reactivity: On the basis of reactivity, carbohydrates are classified as reducing sugars and non- reducing sugars. Reducing sugars are those that are oxidised by some oxidising agent like Tollen's reagent, Benedict's reagent, Fehling's reagents, etc. while as, non- reducing sugars do not get oxidised by these reagents, but require a very strong oxidising agent to show such property like potassium dichromate.

Fig. 1: The first being an aldose and the second being a ketose.



## 2. **Monosaccharides:**

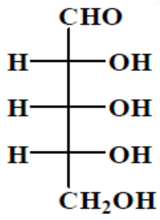
Monosaccharides are carbohydrate molecules that cannot be broken down to simpler carbohydrate molecules by hydrolysis, so they are sometimes referred to as simple sugars. They can be joined together to form larger structures, namely, oligosaccharides and polysaccharides. These have a general formula $C_nH_{2n}O_n$ with one of the carbons being the carbonyl group of either an aldehyde or a ketone. The most common monosaccharides have three to eight carbon atoms. The suffix -"ose" indicates that a molecule is a carbohydrate, and the prefixes tri-, tetr-, pent-, and so forth indicate the number of carbon atoms in the chain. Monosaccharides containing an aldehyde group are further classified as aldoses and those containing a ketone group are classified as ketoses. A ketose can also be indicated with the suffix "ulose", thus, a five- carbon ketose is also termed a Pentulose. Glucose and fructose are the example of monosaccharides. D-Glucose, the most abundant carbohydrate if all its combined forms are considered, is both a polyalcohol and an aldehyde with six carbon atoms (hexose). It is classified as an aldose, a designation for sugars containing an aldehyde group. Sucrose, however, is a disaccharide- a compound that can be converted by hydrolysis into two monosaccharides.

$$\text{Sucrose } (C_{12}H_{22}O_{11}) + H_2O \xrightarrow{\text{acid or certain enzyme}} \text{Glucose } (C_6H_{12}O_6) + \text{Fructose } (C_6H_{12}O_6)$$

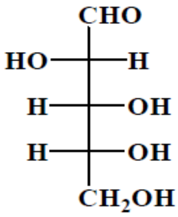
Disaccharides Monosaccharides

Some other examples of monosaccharides are given as under:

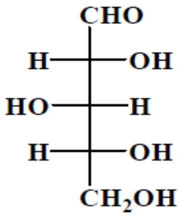
- Aldotriose (glyceraldehydes): $CH_2OH$. CHOH. CHO,
- Ketotriose (dihydroxyacetone): $CH_2OH$. CO. $CH_2OH$,
- Aldotetrose (erythrose): $CH_2OH$. $(CHOH)_2$. CHO,
- Ketotetrose (erythrulose): $CH_2OH$. CO. CHOH. $CH_2OH$.
- Aldopentose (xylose): $CH_2OH$. $(CHOH)_3$. CHO,
- Ketopentose (xylulose and rubilose): $CH_2OH$. CO. $(CHOH)_2$. $CH_2OH$.
- Aldohexose (glucose and mannose): $CH_2OH$. $(CHOH)_4$. CHO
- Ketohexose (fructose): $CH_2OH$. CO. $(CHOH)_3$. $CH_2OH$ etc.



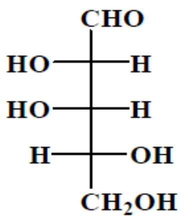
D-(-)-ribose



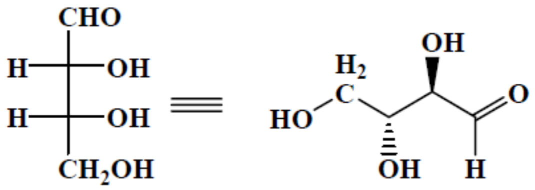
D-(-)-arabinose



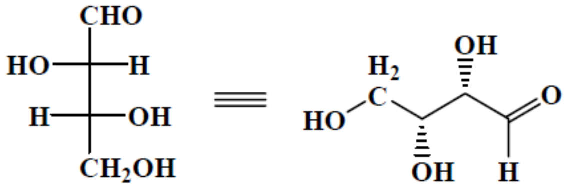
D-(+)-xylose



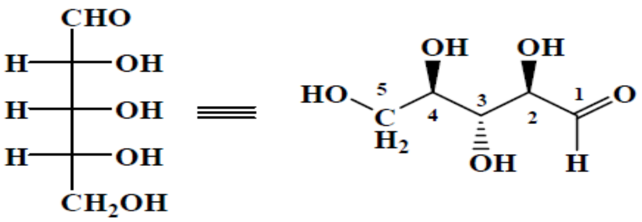
D-(-)-lyxose



D-(-)-Erythrose



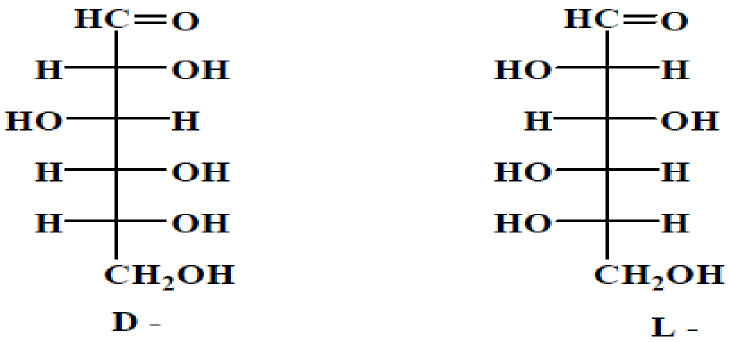
D-(-)-Threose



D-(-)-Ribose

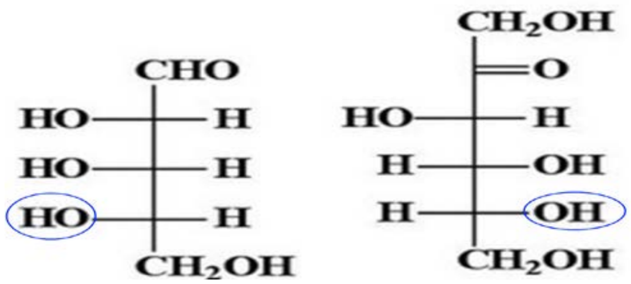
## 2.1. Monosaccharide configuration and isomerization:

Stereochemistry of carbohydrates will be discussed by the example of aldoses with six or fewer carbons. The aldoses with six or fewer carbons are given Fischer projections that are widely used in carbohydrate chemistry. Each of the monosaccharides has an enantiomer. An enantiomer is one of the two sterioisomers of a compound that are non-superimposible mirror images for example the two enantiomers of glucose have the following structures:

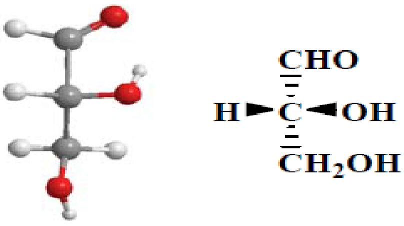


Enantiomers of glucose

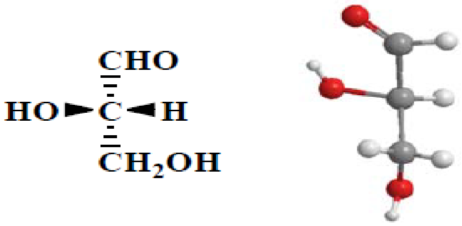
A monosaccharide is given D configuration if the hydroxyl group is to the right of the last stereocenter in a Fischer projection, whereas L configuration is given if the -OH is to the left o the last stereocenter carbon (as shown below). D or L is usually put in the beginning of the carbohydrate when naming the molecule.



The monosaccharide with three carbon atoms i.e., glyceraldehyde also contains a chiral centre and therefore exists as a pair of enantiomers as shown below:



D- glyceraldehyde



L- glyceraldehyde

Boelens et al. (1993) thoroughly working on such isomers, reviewed the information and concluded that three main categories of enantiomeric difference that can be identified:

- When sensory properties of the two enantiomers differ slightly in intensity or in quality (e.g. terpenoid hydrocarbons);
- When the enantiomers have the same main character but differ in secondary notes and intensity (such as for aliphatic and monoterpene alcohols);
- When the odours of the enantiomers differ in both quality and intensity (e.g. carvones, nootkatones).

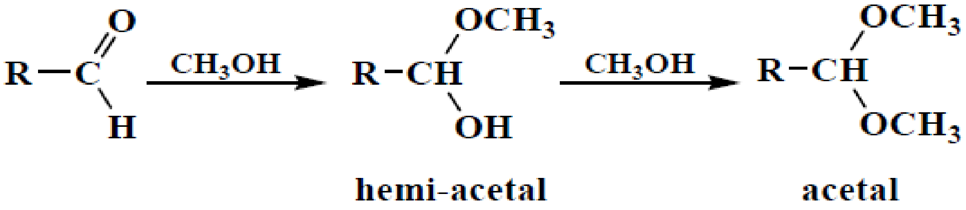
Marked differences in aroma-flavour characteristics and intensity (as assessed by threshold values) are common for isomers (Koppenhoefer *et al.,* 1994). For instance, L- and D-carvones have spearmint and caraway flavours, respectively, and out of the eight menthol isomers (due to its having three chiral esters) and analogues, such as menthones and menthyl acetates, only one has the prized combination of good mint flavour plus cooling sensations.

## 2.2. Physical Properties:

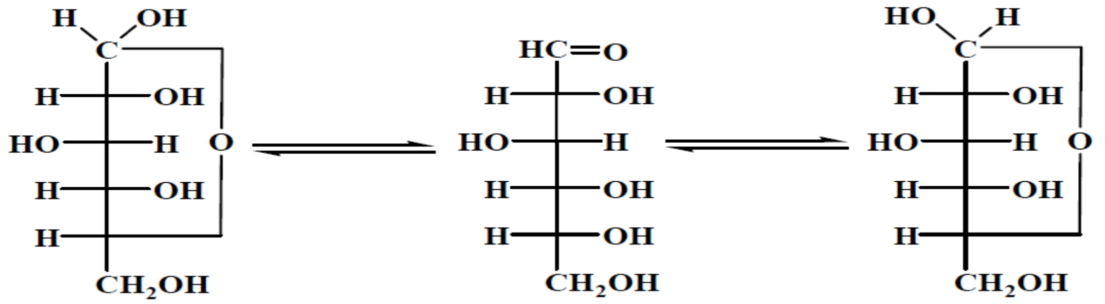
Monosaccharides are colourless crystalline solids that are sweet to the taste but they often crystallize with difficulty. All monosaccharides are soluble in water because of the presence of the polar -OH groups and possible hydrogen bonding with water molecule. They are only slightly soluble in ethanol and are insoluble in non-polar solvents such as diethyl ether, chloroform, and benzene.

## 2.3. Monosaccharides ring forms:

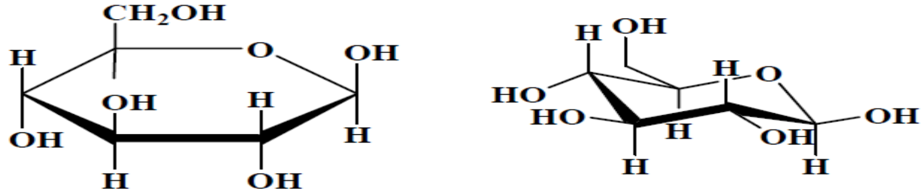
Carbonyl groups of aldehydes and ketones are reactive and easily undergo nucleophilic attack by the oxygen atom of an alcoholic hydroxyl group to produce a hemiacetal. The hydroxyl group of a hemiacetal can react further (by condensation) with a hydroxyl group of an alcohol to produce an acetal as shown below:



Hemiacetal formation can occur within the same aldose or ketose sugar molecule wherein the carbonyl group reacts with one of its own properly positioned hydroxyl groups, as illustrated below with D-glucose laid coiled on its side. The resulting six membered sugar ring is called a pyranose ring. It is important to note that for the oxygen atom of the hydroxyl group at C-5 to react to form the ring, C-5 must rotate to bring its oxygen atom upward. This rotation brings the hydroxymethyl group (C-6) to a position above the ring. These structures are represented by Haworth projection and are called D-glucopyranose ring in case of glucose and D-furanose ring in case of fructose. The example of glucopyranose is shown below:



α-D-Glucopyranose D-Glucose β-D-Glucopyranose



β-D-Glucopyranose
(β-D-Glucose)

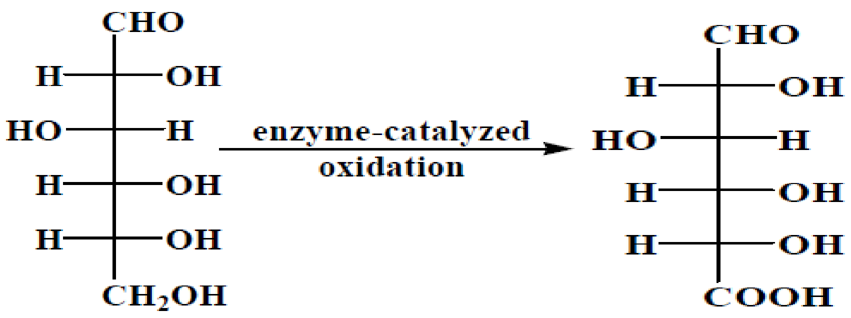
## 2.4. Monosaccharide Reactions:

### 2.4.1. Oxidation to Aldonic Acids and Aldonolactones:

Aldehyde group of aldoses (RCHO) are oxidized to carboxylic acids (RCOOH) by several oxidizing agents, including oxygen, $O_2$. Also the aldehyde group of an aldose can be oxidized, under basic conditions, to a carboxylate group. Oxidizing agents for this purpose include bromine in aqueous calcium carbonate ($Br_2$, $CaCO_3$, $H_2O$) and Tollen's solution [Ag $(NH_3)_2$+]. Any carbohydrate that reacts with an oxidizing agent to form an aldonic acid is classified as a reducing sugar (it reduces the oxidizing agent).

### 2.4.2. Oxidation to Uronic Acids:

Enzyme-catalyzed oxidation of the primary hydroxyl group at carbon 6 of a hexose yields uronic acid. Enzyme-catalyzed oxidation of D-glucose, for example, yields D-glucuronic acid, as shown below:

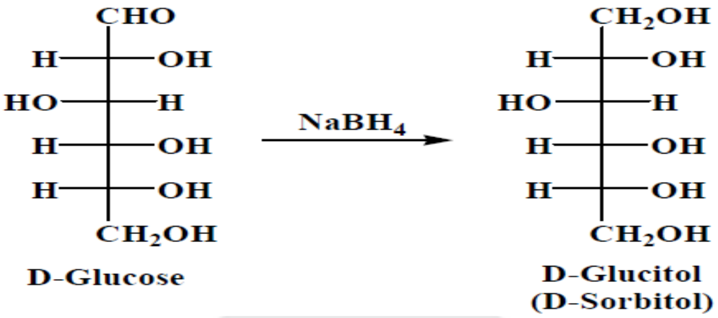


**D-glucose** **D-glucouronic acid**

D-Glucuronic acid is widely distributed in both the plant and animal world. In humans, it is an important component of the acidic polysaccharides of connective tissues. It is also used by the body to detoxify foreign hydroxyl-containing compounds, such as phenols and alcohols. In the liver, these compounds are converted to glycosides of glucuronic acid (glucuronides) and excreted in the urine. As the oxidizing agent is reduced in the process of oxidizing the aldehyde group of an aldose to the salt of a carboxylic acid group, aldoses are called reducing sugars. Ketoses are also termed as reducing sugars because, under the alkaline conditions of the Fehling test, ketoses are isomerized to aldoses. Benedict reagent, which is not alkaline, however, reacts with aldoses but not with ketoses.

### 2.4.3. Reduction of Carbonyl Groups:

Hydrogenation is the addition of hydrogen to a double bond. In case of carbohydrates, it most oftenly involves the addition of hydrogen to the double bond between the oxygen atom and the carbon atom of the carbonyl group of an aldose or ketose. Hydrogenation of D-glucose is easily accomplished with hydrogen gas under pressure in the presence of Raney nickel. The product is D-glucitol, commonly known as sorbitol, where the -itol suffix denotes a sugar alcohol (an alditol). Alditols are also known as polyhydroxy alcohols or polyols. D-glucitol (sorbitol) since derived from a hexose, is specifically named as hexitol. It is found widely distributed throughout the plant world, ranging from algae to higher orders where it is found in fruits and berries, but the amounts present are generally small. Commercially sold both as syrup and as crystals, it is 50% as sweet as sucrose and is used as a general humectant. Similarly, D-Mannitol can be obtained by hydrogenation of D-mannose. Commercially, it is obtained along with sorbitol from hydrogenolysis of sucrose.

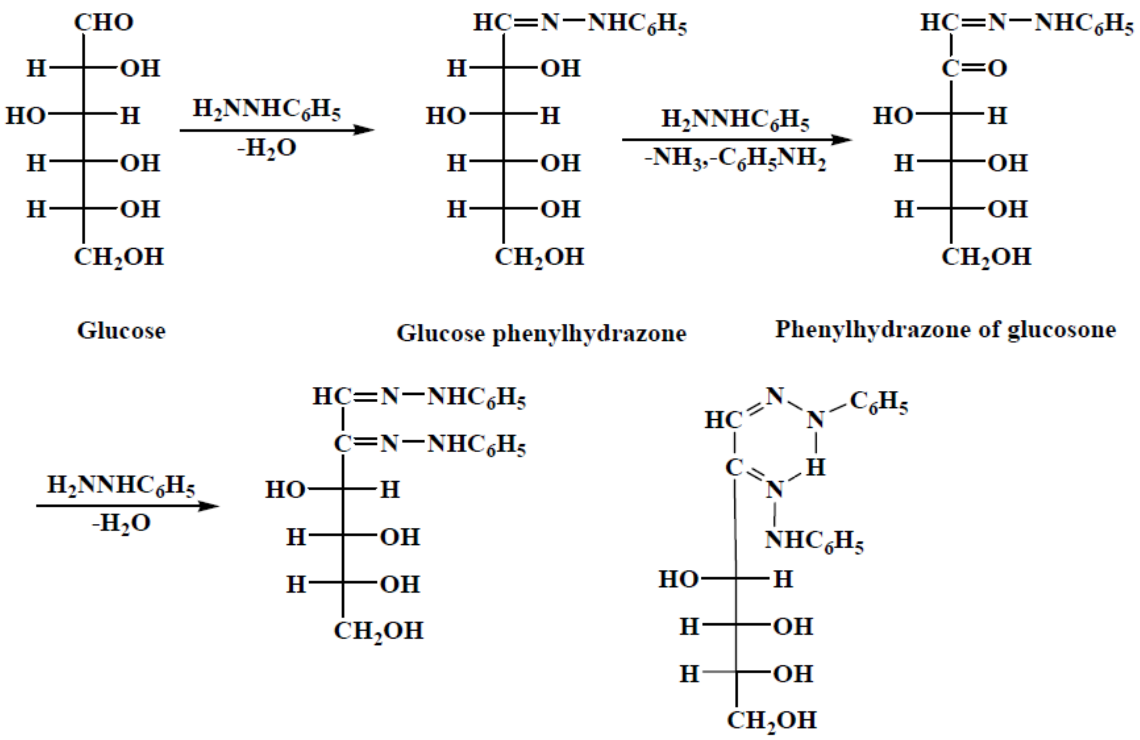


### 2.4.4. **Action of phenyl hydrazine:**

Cold phenyl hydrazine and other substituted hydrazine react with sugar to from hydrazones (osazones). These are valuable for the preparation of many sugar derivatives.

- **Formation of Osazones:**

During osazone formation the hydroxyl group adjacent to the carbony1 group is oxidized to keto group which is then attacked by phenyl hydrazine to from osazone. During this oxidation the hydrazine is reduced to aniline and ammonia.



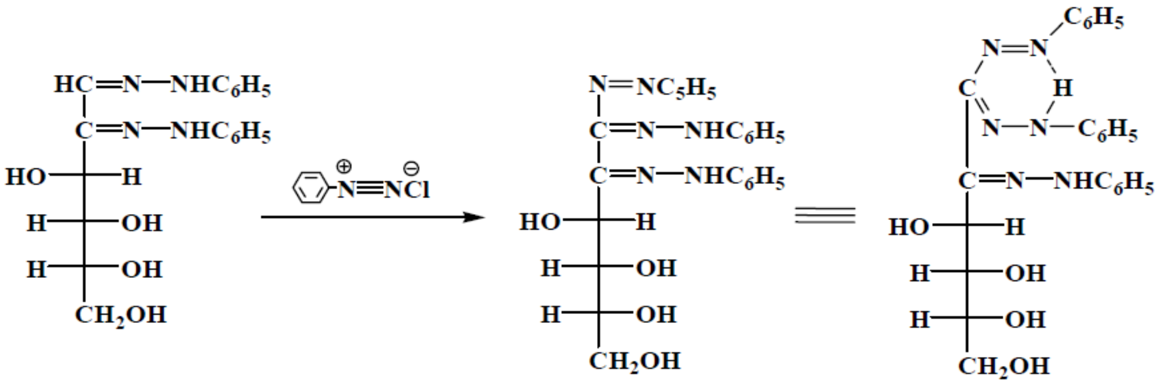
- **Reactions of osazones:**

a) Conversion into the corresponding osatriazoles:

Hudson found that when osazones are refluxed with aqueous copper sulphate, they are converted into the osatriazoles. In this reaction, other oxidizing agents such as ferric salts and bromine water can also be used for glucose phenyl osatriazole formation. The reaction will proceed in two steps; first involving the oxidation to an unstable intermediate and later conversion into the osatriazoles.

b) Foramazan:

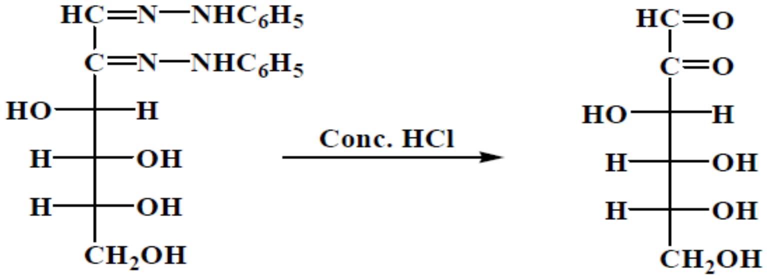
The reaction of carbohydrate phenyl-osazone with aryldiazonium compound yields formazan as shown below:



Glucose phenylosazone Formazone

c) Conversion of osazones into osones:

This reaction was first carried out by E. Fischer using conc. Hydrochloric acid, but it is now performed with aromatic aldehydes. e.g. benzaldehyde because benzald- phenylhydrazone is precipitated leaving the ozone in solution. Osones react with phenylhydrazine in cold to form osazones.

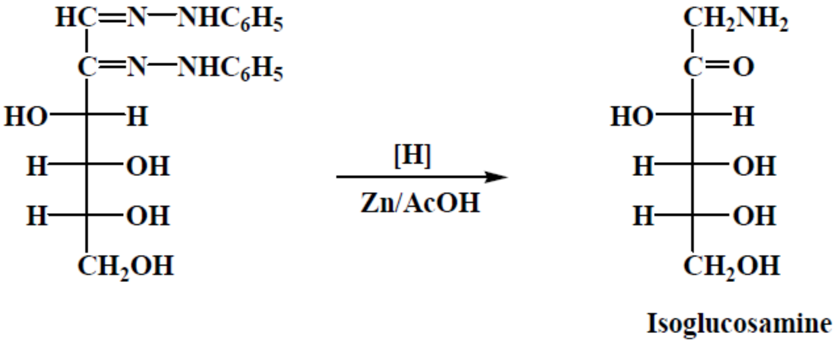


Glucose phenylosazone Glucosone

The osones are available starting materials for the synthesis of ascorbic acid which is its homologous. They can also be reduced to give the corresponding ketoses. So we can convert the aldoses to ketoses through the reduction of osones. An example is the conversion of glucose to fructose.

d) Reduction of Osazones:

When osazones are reduced, for example with nacent hydrogen in presence of a catalyst, they give iso-glucosamine. Isoglucosamine can be converted into fructose by nitrous acid, affording another way for converting aldoses into ketoses.



Isoglucosamine

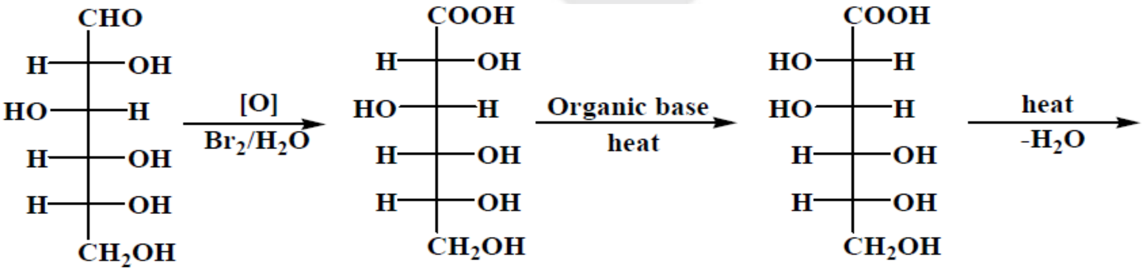
### 2.4.5. Action of Alkalies:

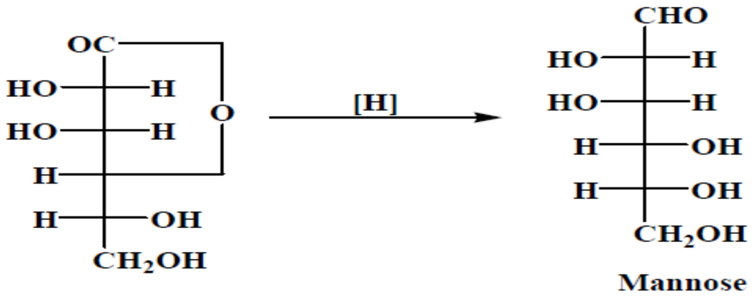
The sugar molecule is unstable toward alkalies. It undergoes a series of isomerisation and degradation leading to a number of compounds. Thus more than 100 different compounds have been isolated from the reaction product of glucose and sodium hydroxide.

### 2.4.6. Epimerisation:

When glucose is treated with very dilute alkalies such as pyridine or quincline, epimerization is said to take place, that is, sugar epimers are obtained. Thus glucose yields a mixture of mannose, fructose and unreacted glucose. This reaction is useful in the preparation of rare sugars from their epimers. The mechanism of this reaction was suggested by Lobrg de Druyn and Van Ekenstein involving the formation of an intermediate enediol.

The reaction is best carried out by the epimerization of aldonic acids which are more stable towards alkaline medium. Thus, the aldose is first oxidized to the aldonic acid say gluconic acid, which is then heated with an organic base like pyridine or quinoline and converting it to mannonic acid which is then lactonised and reduced to give mannose.





### 2.4.7. **Action of acids:**

Although sugar molecule is very stable towards dilute acids, but with concentrated acids it is distorted. Some examples are given below:

a) *Conc. Sulphuric acid* removes the elements of water and converts the sugar into carbon.

b) *Conc. Nitric acid* oxidizes the aldose into dicarboxylic acid.

c) *Conc. Hydrochloric acid* reacts with aldoses giving different products:

I. With pentoses it yields furfural which is steam volatile and can therefore be used for the estimation of pentoses (this reaction is used in wood analysis).

II. With methyl pentoses we obtain methyl furfural which is steam volatile.

III. With hexoses the reaction proceeds in 2 steps first hydroxymethyl-furfuraldehyde is obtained but this rapidly decomposes giving levolinic acid which is not steam volatile, this affords a means for the estimation of pentoses in the presence of hexoses.

### 2.4.8. **Non enzymatic browning:**

When aldoses or ketoses are heated in solution with amines, a variety of reactions ensue, producing numerous compounds, some of which are flavors, aromas, and dark-colored polymeric materials. The flavors, aromas, and colors may be either desirable or undersirable. They may be produced by frying, roasting, baking, or storage.

The reducing sugar reacts reversibly with the amine to produce a glycosylamine. This undergoes a reaction called the Amadori rearrangement to give, in the case of D-glucose, a derivative of 1-amino-1-deoxy-D-fructose. Reaction continues, especially at pH 5 or lower, to give an intermediate that dehydrates. Eventually a furan derivative, that froms HMF, a hexose (5-hydroxymethyl-2-furaldehyde) is formed. Under less acidic conditions (higher than pH 5), the reactive cyclic compounds (HMF and others) polymerize quickly to a dark-colored, insoluble material containing nitrogen.

Maillard browning products, including soluble and insoluble polymers, are found where reducing sugars and amino acids, proteins, and/or other nitrogen-containing compounds are heated together, such as in soy sauce and bread crusts. Maillard reaction products are important contributors to the flavor of milk chocolate. The Maillard reaction is also important in the production of caramels, toffees, and fudges, during which reducing sugars also react with milk proteins.

Browning reactions are some of the most important phenomena occurring in food during processing and storage. They represent an interesting research for the implications in food stability and technology as well as in nutrition and health. The major groups of reactions leading to browning are enzymatic phenol oxidation and since it involves no enzymes, it is called non-enzymatic browning.

### *L-Ascorbic acid (Vitamin C):*

The structure of L-ascorbic acid (vitamin C) resembles that of a monosaccharide. In fact, this vitamin is synthesized both biochemically by plants and some animals and commercially from D-glucose. Humans do not have the enzymes required for this synthesis and, therefore, we must obtain it in the food we eat or as a vitamin supplement. It is an important water soluble biological reducing agent that complements lipid soluble antioxidants such as vitamine E. It functions in the living tissues as a hydrogen carrier. L-Ascorbic acid is very easily oxidized to L-dehydroascorbic acid, a diketone. Both L-ascorbic acid and L- dehydroascorbic acid are physiologically active and are found together in most body fluids.

### 3. Disaccharides and Oligosaccharides:

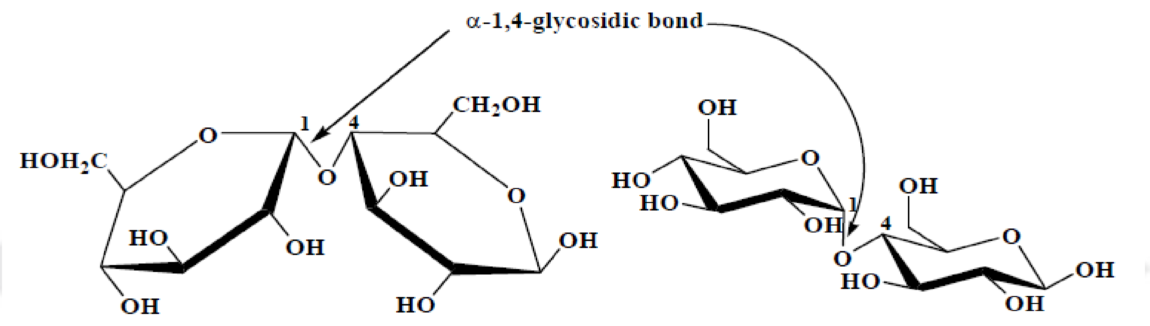
Most carbohydrates in nature contain more than one monosaccharide unit. Those that contain two units are called disaccharides, those that contain three units are called trisaccharides, and so forth. The general term oligosaccharide is often used for carbohydrates that contain from four to ten monosaccharide units. Carbohydrates containing larger numbers of monosaccharide units are called polysaccharides. However, according to some authors, an oligosaccharide contains 2 to 20 sugar units joined by glycosidic bonds. When a molecule contains more than 20 units, it is a polysaccharide. Only a few oligosaccharides occur in nature and most are produced by hydrolysis of polysaccharides into smaller units.

### 4. Disaccharides:

In a disaccharide, two monosaccharide units are joined together by a glycosidic bond between the anomeric carbon of one unit and an OH of the other. Three important disaccharides are sucrose, lactose, and maltose. On hydrolysis, disaccharides yield two molecules of monosaccharide. Disaccharides can be homodisaccharides or heterodisaccharides. Homodisaccharides are those disaccharides that are made up of two similar monosaccharide units, e.g. maltose which is made up of two α-glucose molecules linked by α-(1-4) glucosidic bonds and cellobiose which is formed of two β-glucose molecules linked by β-(1-4) glucosidic bond. On the other hand, heterodisaccharides are made up of two different monosaccharides, e.g. Lactose which is made up of one β- glucose and one β- galactose molecule linked by β-(1-4) glucosidic bonds and sucrose which is made up of one α-glucose and one β-fructose molecule linked together by α-(1,2) glycosidic bond.

#### 4.4.1. Maltose:

Maltose derives its name from its presence in malt, the juice from sprouted barley and other cereal grains (from which beer is brewed). It consists of two molecules of D-glucopyranose joined by an α-(1-4)-glycosidic bond between carbon 1 (the anomeric carbon) of one unit and carbon 4 of the other unit. Maltose is a disaccharide which can be obtained by hydrolysis of starch. Maltose is a reducing sugar because its aldehyde group is free to react with oxidants and, in fact, to undergo almost all reactions as though it were present as a free aldose. Maltose is readily produced by hydrolysis of starch using the enzyme β-amylase. It occurs only rarely in plants, and even then, it results from partial hydrolysis of starch. Maltose is produced during malting of grains, especially barley. It is commercially produced by the specific enzyme-catalyzed hydrolysis of starch using β-amylase from *Bacillus* bacteria, although the β-amylases from barley seed, soybeans, and sweet potatoes may also be used. Maltose is used sparingly as a mild sweetner for foods.



## 1.1.2. **Lactose:**

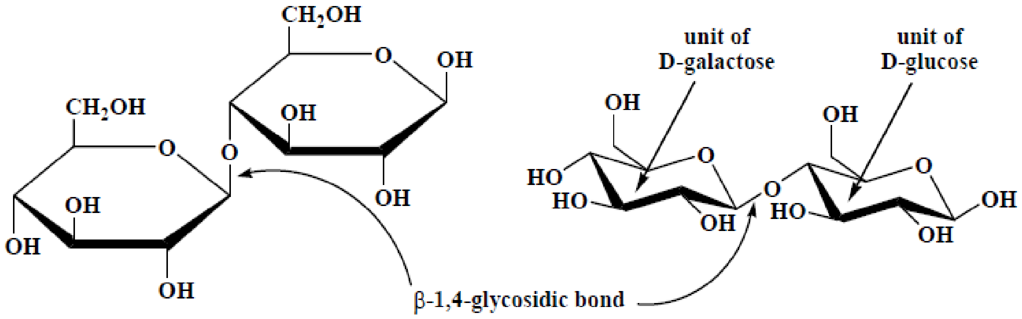
Lactose is the principal sugar present in milk. It is the primary carbohydrate source for developing mammals. It occurs mainly free, but to a small extent as a component of higher oligosaccharides. It makes up about 5-8% of human milk and 4-6% of cow's milk. It consists of D-galactopyranose bonded by a β-(1-4) glycosidic bond to carbon-4 of D-glucopyranose.

Lactose is a reducing sugar which constitutes 40% of the energy consumed during nursing. Utilization of lactose for energy must be preceded by hydrolysis to the constituent monosaccharides, D-glucose and D-galactose. Milk also contains 0.3–0.6% of lactose-containing oligosaccharides, many of which are important as energy sources for growth of a specific variant of Lactobacillus bifidus, which, as a result, is the predominant microorganism of the intestinal flora of breast-fed infants.

Lactose is ingested along with milk and other unfermented dairy products, such as ice- cream. Fermented dairy products, such as most yogurt and cheese, contain less lactose because during fermentation some of the lactose is converted into lactic acid. Lactose stimulates intestinal absorption and retention of calcium. Lactose is not digested until it reaches the small intestine, where the hydrolytic enzyme lactase is secreated. Lactase (a β-galactosidase) is a membrane-bound enzyme located in the brush border epithelial cells of the small intestine. It catalyzes the hydrolysis of lactose into its constituent monosaccharides, D-glucose and D-galactose. Of the carbohydrates, only monosaccharides are absorbed from the intestines. Both D-glucose and D-galactose are rapidly absorbed and enter the blood stream.

If for some reason the ingested lactose is only partially hydrolyzed, that is, only partially digested, or is not hydrolyzed at all, a clinical syndrome called lactose intolerance results. If there is a deficiency of lactase, some lactose remains in the lumen of the small intestine. The presence of lactose tends to draw fluid into the lumen by osmosis. This fluid produces abdominal distention and cramps. From the small intestine, the lactose passes into the large intestine (colon) where it undergoes anaerobic bacterial fermentation to lactic acid (present as the lactate anion) and other short-chain acids. The increase in the concentration of molecules, that is, the increase in osmolality, results in still greater retention of fluid. In addition, the acidic products of fermentation lower the pH and irritate the lining of the colon, leading to an increased movement of the contents. Diarrhoea is caused both by the retention of fluid and the increased movement of the intestinal contents. The gaseous products of fermentation cause bloating and cramping. Lactose intolerance is not usually seen in children until after about 6 years of age. However, both the incidence and the degree of lactose intolerance vary by ethnic group, indicating that the presence or absence of lactase is under genetic control.

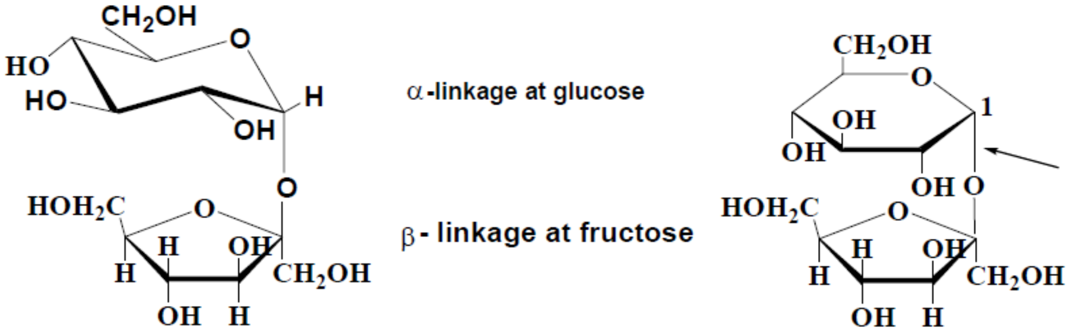
There are two ways to overcome the effects of lactase deficiency. One is to remove the lactose by fermentation; that produces yogurt and buttermilk products. Another is to produce reduced-lactose milk by adding lactase to it. However, both the products of hydrolysis, i.e., D-glucose and D-galactose, are sweeter than lactose, and at about 80% hydrolysis, the taste change becomes too evident. Therefore, most reduced-lactose-milk has the lactose reduced as close as possible to the 70% government-mandated limit for a claim. In a technology under development, live yogurt cultures are added to refrigerated milk. The bacteria remain dormant in the cold and do not change the flavour of the milk, but upon reaching the small intestine, release lactase.



### 1.1.3. **Sucrose:**

Sucrose is the most abundant disaccharide in the biological world. The per person daily utilization of sucrose, usually called simply sugar or table sugar, in the United States averages about 160 g. Sucrose is, however, also used extensively in fermentations, in bakery products where it is also largely used up in fermentation, and in pet food, so the actual average daily amount consumed by individuals in foods and beverages in about 55 g (20 kg or 43 Ib/year). It is obtained principally from the juice of sugar cane and sugar beets. Also present in sugar beet extract are a trisaccharide, raffinose, which has a D-galactopyranosyl unit attached to sucrose, and a tetrasaccharide, stachyose, which contains another D-galactosyl unit. These oligosaccharides also found in beans, are non-digestible, and are the source of the flatulence associated with consumption of beans.

In sucrose, carbon 1 of α-D-glucopyranose is joined to carbon 2 of β-D-fructofuranose by an α-1,2-glycosidic bond. Sucrose is composed of a D-glucopyranosyl unit and a β-D-fructofursanosyl unit linked head to head (reducing end to reducing end) rather than by the usual head-to-tail linkage, as shown below. Since it has no reducing end, it is a non-reducing sugar. Commercial brown sugar is made by treating white sugar crystals with molasses to leave a coating of desired thickness. Grades range from light yellow to dark brown. Confection, or powdered, sugar is pulverized sucrose. It usually contains 3% corn starch as an anti-caking agent. To make fondant sugar, which is used in icings and confections, very fine sucrose crystals are surrounded with a saturated solution of invert sugar, corn syrup, or maltodextrin.

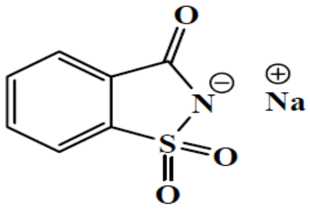


The sucrase of the human intestinal tract catalyzes hydrolysis of sucrose into D-glucose and D-fructose, making sucrose one of the three carbohydrates (other than monosaccharides) that humans can utilize for energy, the other two being lactose and starch. Monosaccharides (D-glucose and D-fructose being the only significant ones in our diets) do not need to undergo digestion before absorption.

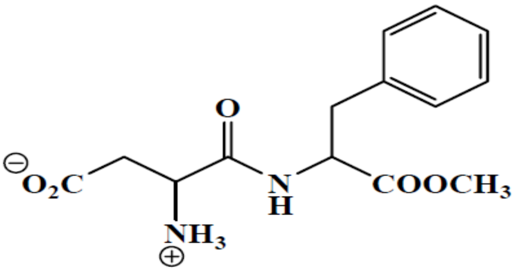
***Relative Sweetness of Some Carbohydrate and Artificial Sweeteners:***

Although all monosaccharides are sweet to the taste, some are sweeter than others (Table 4). D-Fructose tastes the sweetest, even sweeter than sucrose. The sweet taste of honey is attributable largely to D-fructose and D-glucose. Lactose has almost no sweetness. It occurs in many milk products and is sometimes added to foods as a filler.

The sweetening power of sugars is undoubtedly their most important characteristic, insofar as the public is concerned. If the sweetness of sucrose is taken as a standard, then other sweet tasting compounds may be ranked accordingly, as shown below where saccharin and aspartame are synthetic sweeteners and others are natural sugars.



**Sacchrin**



**Aspartame**

***Table 4: Relative Sweetness of Some Carbohydrates and Arificial Sweetening Agents:***

| Carbohydrate | Sweetness Relative to Sucrose | Artificial Sweetener | Sweetness Relative to Sucrose |
|---|---|---|---|
| **Fructose** | 1.74 | Saccharin | 450 |
| **Invert sugar** | 1.25 | Aspartame | 160 |
| **Sucrose (table sugar)** | 1.00 | | |
| **Honey** | 0.97 | | |
| **Glucose** | 0.74 | | |
| **Maltose** | 0.33 | | |
| **Galactose** | 0.32 | | |
| **Lactose (milk sugra)** | 0.16 | | |