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Carbohydrates in food as important sources of energy.

Starch, found in plant-derived food such as pasta, consists of chains of linked glucose molecules. These chains are broken down into individual glucose molecules for eventual use in generation of ATP and building blocks for other molecules.

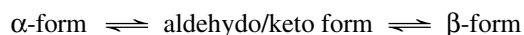
CHAPTER

6

Carbohydrates-II

Properties of Monosaccharides

Carbohydrates possess active groups which are responsible for their chemical behaviour. These groups are glycosidic OH, alcoholic OH and CHO (or CO). Most of the reactions of mutarotating sugars take place in aqueous solution so that all the 3 forms become available for the reaction.



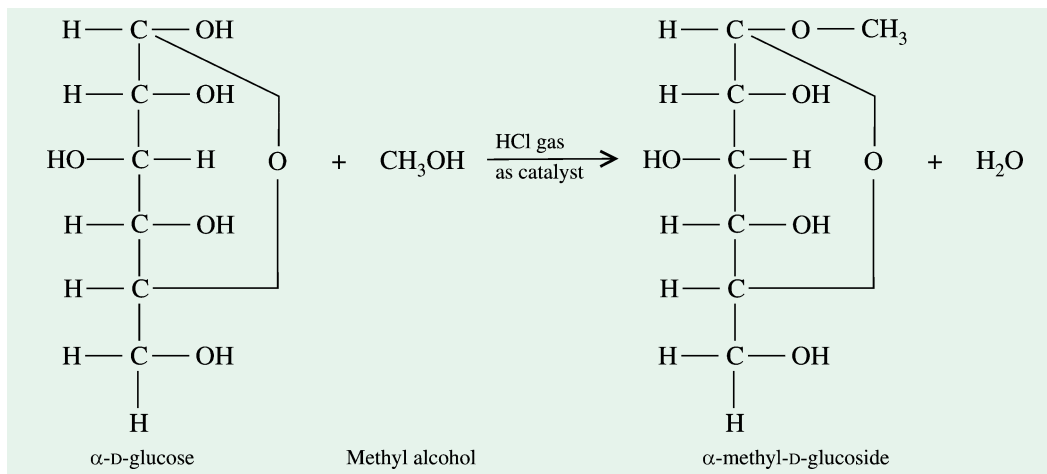
The above equilibrium is shifted in favour of the group which reacts. Some reagents, however, react with more than one group.

REACTION OF GLYCOSIDIC OH GROUP

Reaction with alcohol. The glycosidic OH group of mutarotating sugars react with alcohols to form α - and β -**glycosides** or **acetals**. Thus, glucose forms glucosides and fructose forms fructosides.

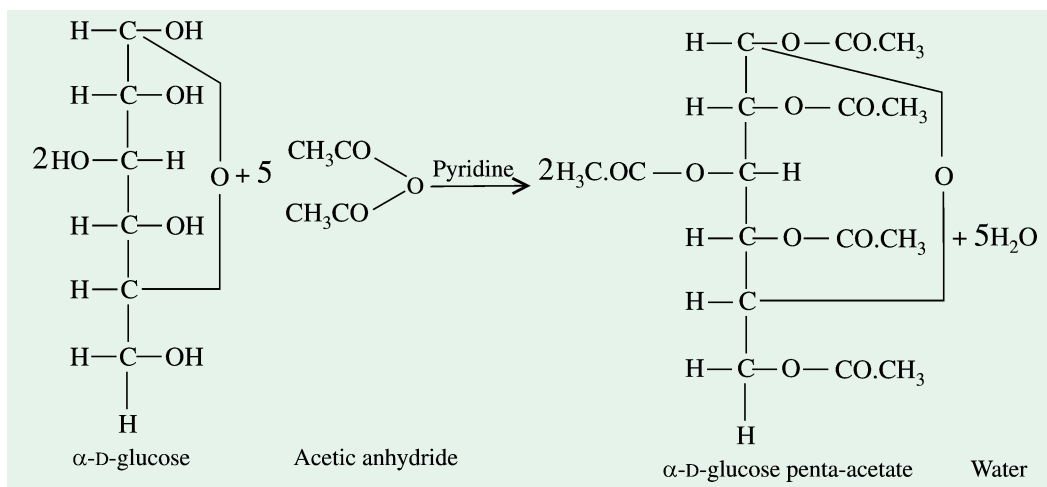
The glucosides, or glycosides in general, do not exhibit mutarotation as the aldehyde group in them is converted to the acetal group. A number of glycosides occur in nature, *e.g.*, *phlorhizin* (glucose + phloretin) in rose bark ; *digitonin* (4 galactose + xylose + digitogenin) in foxglove leaves; *amygdalin* (2 glucose + 2 mandelonitril) from bitter almonds and saponin (sugar + sapogenin) from soapwort. They are useful as medicaments.

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REACTION INVOLVING BOTH GLYCOSIDIC AND ALCOHOLIC OH GROUPS

Reaction with acetic anhydride (Esterification). The glycosidic and alcoholic OH groups of monosaccharides and disaccharides react with acetylating agents (like acetic anhydride in pyridine) to form acetate derivatives called **esters**.

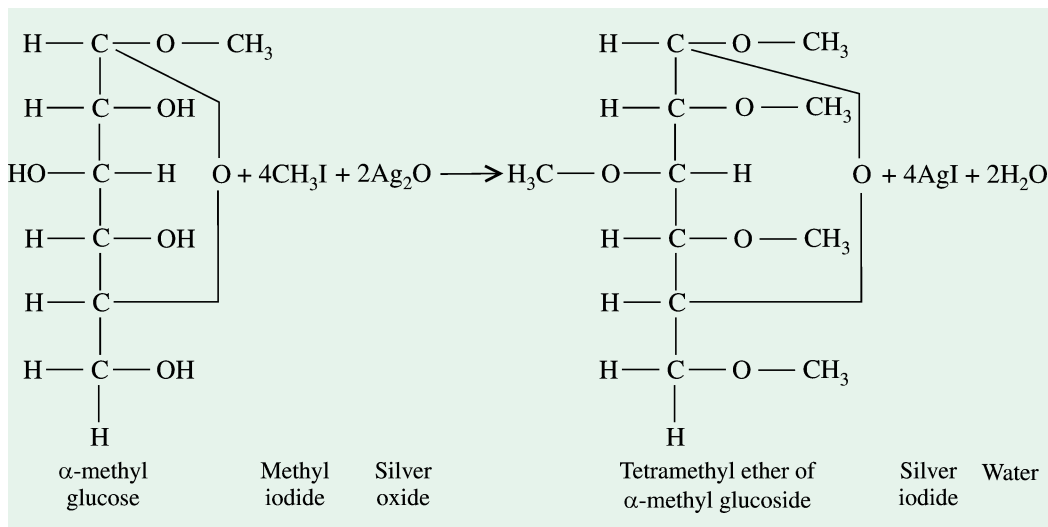


The ability of sugars to form esters indicates the presence of alcohol groups in their molecule. As glucose upon acetylation yields a penta-acetate derivative, it obviously contains 5 OH groups.

REACTION OF ALCOHOLIC OH GROUP

Reaction with methyl iodide (Etherification). The alcoholic OH groups of monosaccharides and disaccharides are converted to ether groups upon treatment with methylating agents.

[The glycosidic OH group of the sugars is, however, first protected with an R group by converting these sugars to glycosides which are, then, allowed to react with the methylating agent.]

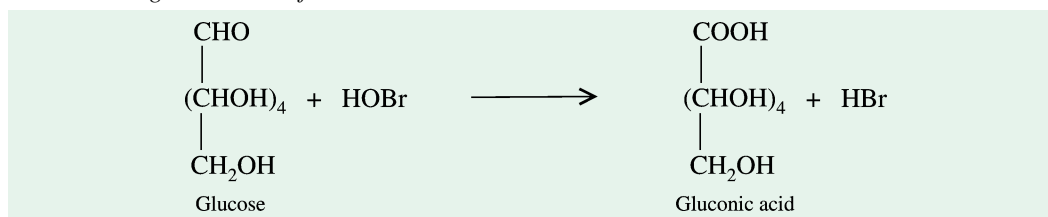


This reaction has been extensively used to ascertain which OH groups in a sugar are free and available for reaction. Thus, α -methyl glucoside is methylated at carbon 2, 3, 4 and 6 but not at carbon 5 which is involved in hemiacetal link.

REACTION INVOLVING BOTH ALCOHOLIC OH AND CHO/CO GROUPS

Oxidation with acids. The alcoholic OH group and CHO group (or CO group) are oxidized to carboxyl groups by certain oxidizing agents. The oxidation may be brought about under mild or vigorous oxidizing conditions.

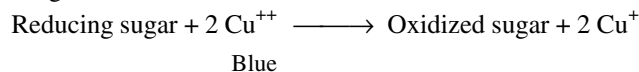
(a) With mild oxidants (like HOBr) – Only the aldehyde group is oxidized to produce **monocarboxylic acids**. Ketoses, however, do not respond to this reaction. Hence, *this reaction is used to distinguish aldoses from ketoses*.



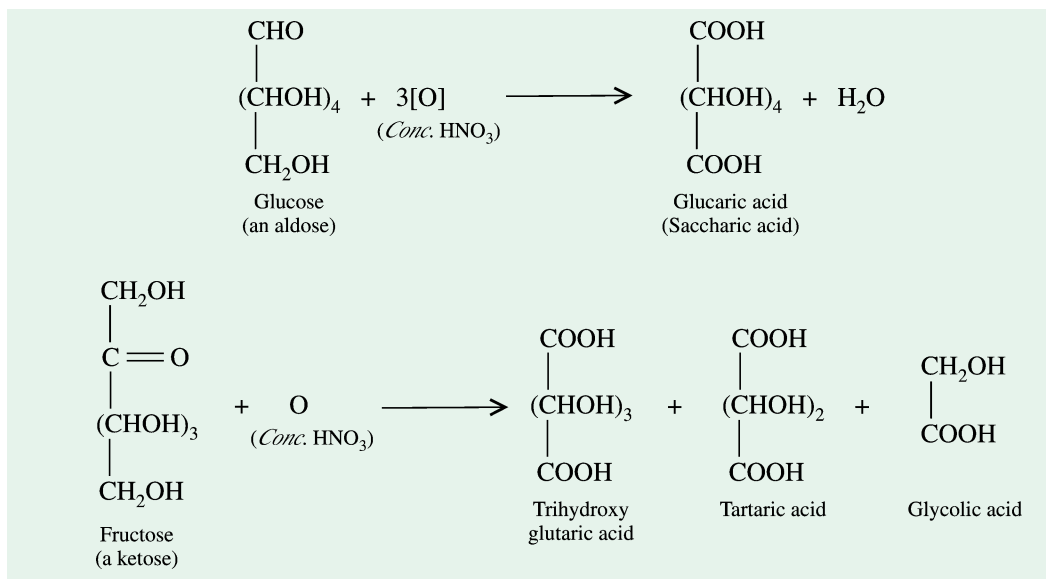
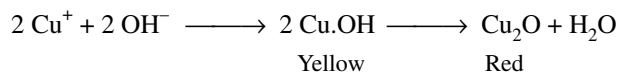
(b) With strong oxidants (like conc. HNO_3) – Both the aldehyde group (or ketone group) and the primary alcohol group are oxidized to yield **dicarboxylic acids**. With aldoses, acids with same number of carbon atoms are obtained whereas ketoses react to produce acids with fewer number of carbon atoms.

REACTIONS OF CHO/CO GROUP

1. Oxidation with metal hydroxides. Metal hydroxides like $\text{Cu}(\text{OH})_2$, AgOH and $\text{Bi}(\text{OH})_3$ oxidize the free aldehyde (or ketone) group of mutarotating mono- and di-saccharides and are, at the same time, themselves reduced to the lower oxides or to the free metals. Thus, $\text{Cu}(\text{OH})_2$ is reduced to Cu_2O and AgOH and $\text{Bi}(\text{OH})_3$ are reduced to the free metal, Ag and Bi. The reaction with cupric hydroxide is given below :



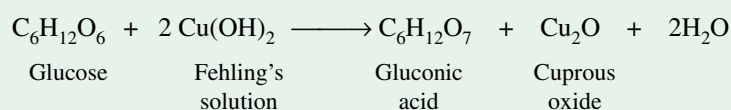
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Cupric ion (Cu^{++}) is, in fact, the most common oxidizing agent of these. It is the active ingredient in Fehling's, Benedict's and Barfoed's reagents.

Fehling's reagent consists of 2 solutions : *solution A* contains 7% Cu.SO_4 and *solution B* contains 25% KOH and 35% sodium potassium tartarate. When the two solutions are mixed in equal amounts, a clear blue solution results for the tartarate forms a soluble complex with the copper hydroxide produced. This solution is widely used as an oxidizing agent preferably in quantitative sugar determinations.

With Fehling's reagent, the overall reaction occurs as follows :



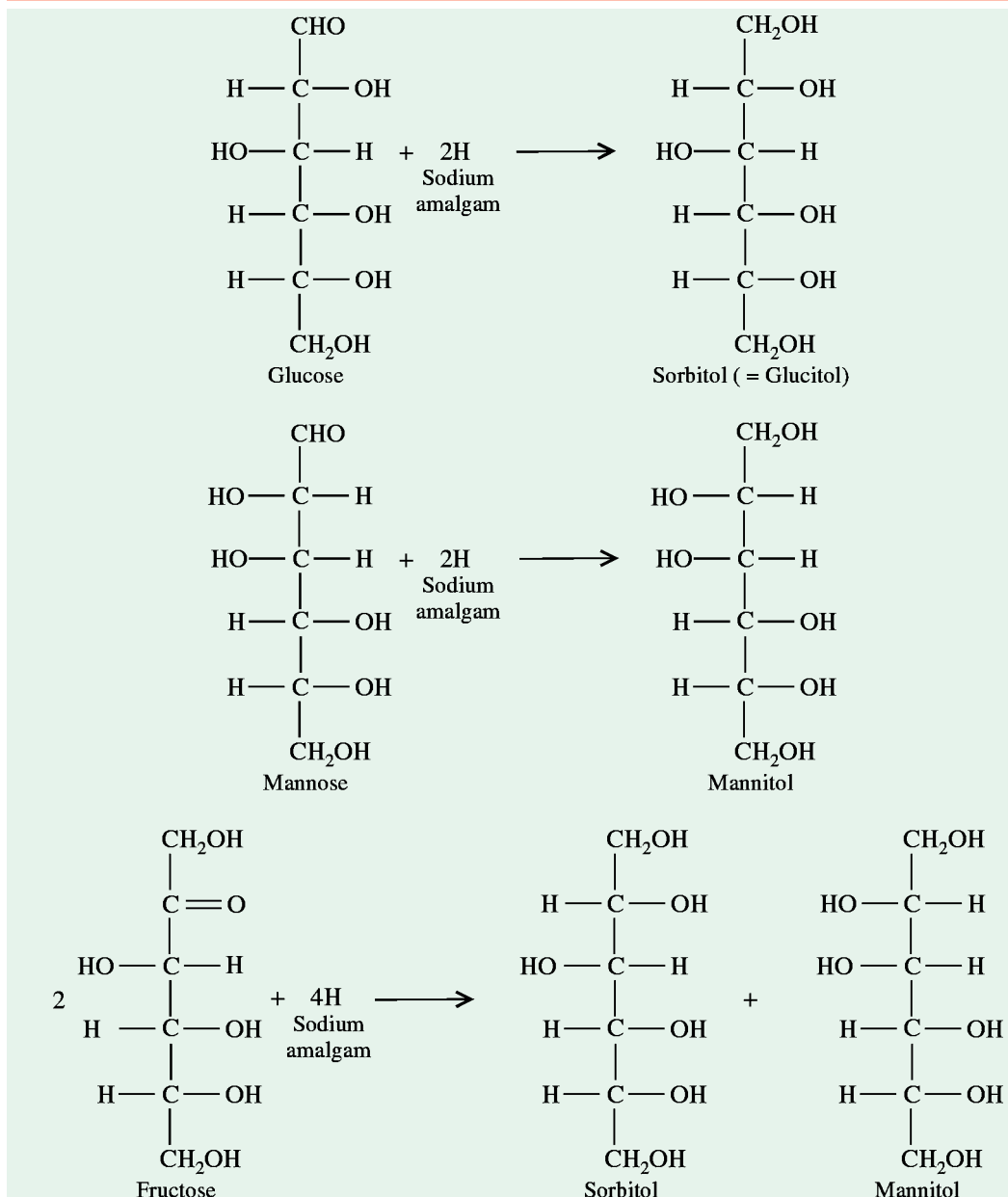
In clinical laboratories, however, a modification of Fehling's reagent is used for the qualitative determination of glucose in urine. This is known as **Benedict's reagent** and consists of a single solution containing CuSO_4 , Na_2CO_3 (in place of KOH) and sodium citrate (in place of sodium potassium tartarate). Sodium carbonate reduces alkalinity to such an extent that, unlike the Fehling's reagent, the two solutions (Cu.SO_4 and sodium citrate) here are kept mixed indefinitely as one solution.

Barfoed's reagent utilizes a weakly acid solution for oxidation. It contains 7% cupric acetate and 1% acetic acid. This reagent can be used to distinguish monosaccharides from disaccharides as the former give a cuprous oxide precipitate in dilute acid more quickly than the latter. *Monosaccharides are, thus, more active reducing agents than the disaccharides.*

Carbohydrates with free carbonyl groups or in hemiacetal form give positive tests to these reagents without having been hydrolyzed first and are referred to as '**reducing**' sugars ; others (*i.e.*, the acetal types) are then '**nonreducing**' sugars (Table 6-1).

Table 6-1. Differences between reducing and nonreducing sugars

<i>Reducing sugar</i>	<i>Nonreducing sugar</i>
<ol style="list-style-type: none"> 1. Carbohydrates with a free aldehyde (at C-1) or a free ketone (at C-2) group. 2. They are in hemiacetal or hemiketal form. 3. Do exhibit mutarotation. 4. Do form osazones with phenyl hydrazine. 5. Do form oximes with hydroxylamine. <p><i>Examples</i> – Glucose, Fructose, Lactose, Maltose, Cellobiose</p>	<ol style="list-style-type: none"> 1. Aldehyde or ketone group is not free but instead utilized in bond formation. 2. They are in acetal or ketal form. 3. Do not exhibit mutarotation. 4. Do not form osazones. 5. Do not form oximes. <p><i>Examples</i> – Sucrose, Glycogen, Inulin</p>



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The **Molisch test** employs sulfuric acid for dehydration and α -naphthol as the phenol. The acid also hydrolyzes acetal groups present and thus makes this test probably the most general of all the tests for carbohydrates.

Since the alkali present in some of the above tests causes fragmentation of the sugar molecule, a mixture of hydroxy acids of different chain length is obtained upon oxidation of carbohydrates. Hence, these tests, although widely employed in analytical methods for sugars, are of little value in preparative chemistry.

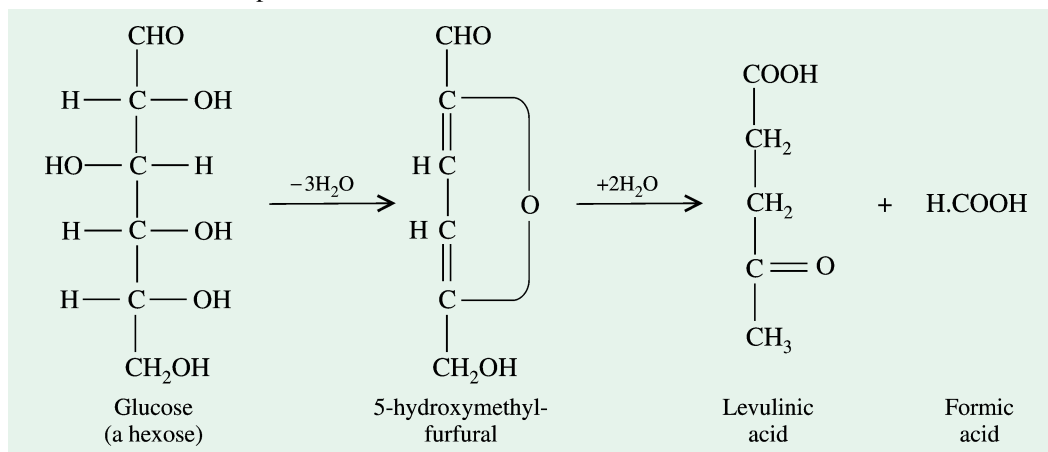
2. **Reduction.** The sugars may be reduced in various ways depending upon the type of reducing agent used.

(a) With sodium amalgam – The monosaccharides are reduced to their corresponding **alcohols** by treating them with reducing agents like Na-amalgam. Thus, glucose yields sorbitol (= glucitol), mannose yields mannitol, galactose yields dulcitol, fructose yields a mixture of sorbitol and mannitol, and glyceraldehyde yields glycerol.

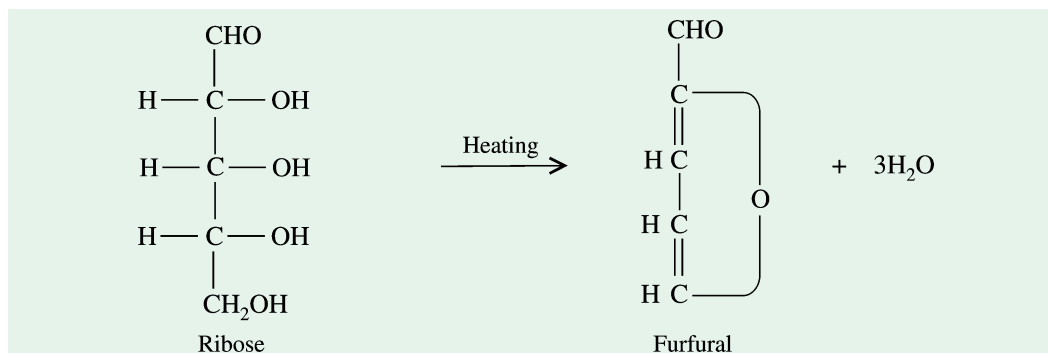
Sorbitol and mannitol both are important and are used in the manufacture of surface-active agents and explosives, respectively.

(b) With strong mineral acids – With *hexoses*, the reduction leads to the formation of 5-hydroxymethylfurfural, which on further heating is transformed to levulinic acid.

This reaction forms the basis of some colour tests (*e.g.*, Molisch test and Bial's orcinol test) for sugars as the aldehyde products of these reactions condense with certain organic phenols to give characteristic coloured products.



With *pentoses*, a product **furfural** is obtained on heating.



Tetroses and *trioses*, however, do not undergo this reaction as they do not possess the necessary minimum 5 carbon atoms for furfural formation.

(c) With dilute alkalies – Glucose, fructose and mannose are interconvertible in weak alkaline solutions such as $\text{Ca}(\text{OH})_2$ and $\text{Ba}(\text{OH})_2$ at low temperatures. This reaction is known as **Lobry de**

Bruyn-Alberda van Ekenstein transformation. This reaction, proposed in 1890, is of special significance as a similar reaction is supposed to take place in the human body. The mechanism of this reaction involves **enolization**, the migration of a proton from a carbon atom onto the oxygen of an adjacent carbonyl group, resulting in the formation of an unsaturated alcohol called **enol** (*ene* = unsaturation ; *ol* = alcohol). The interconversion between glucose, fructose and mannose may, in fact, be visualized as occurring through a common enediol form (Fig. 6-1).

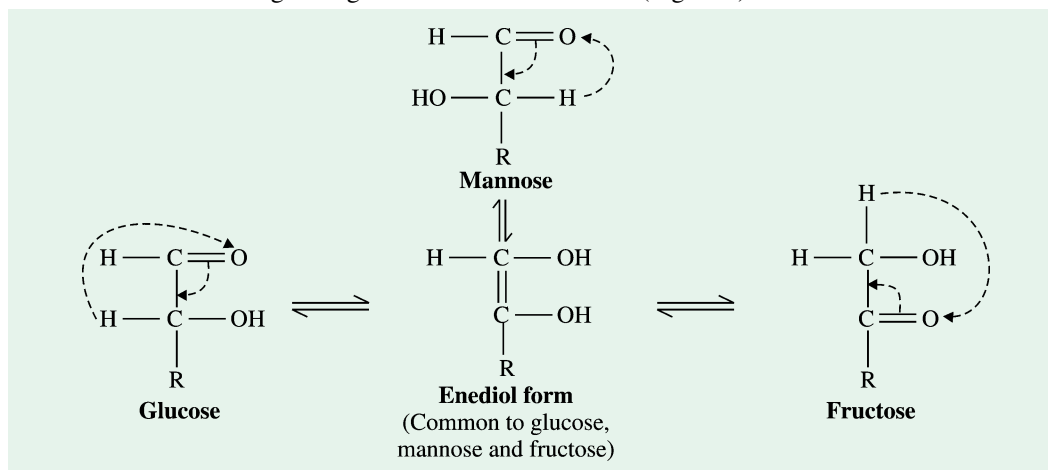
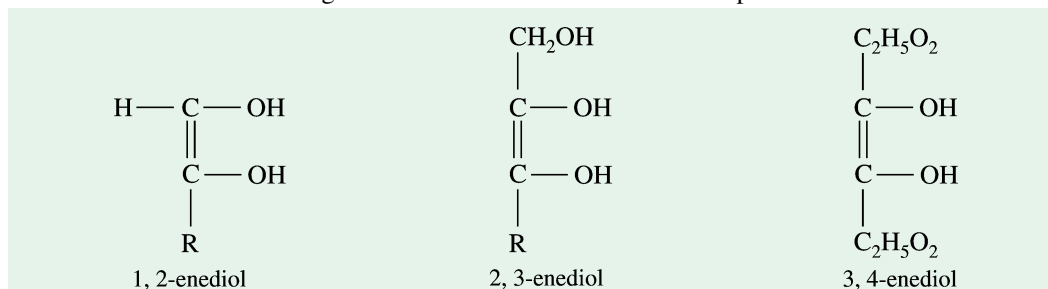


Fig. 6-1. Interconversion of glucose, mannose and fructose (Enolization)

The above mechanism emphasizes that the same mixture (of glucose, fructose and mannose) is obtained even if, instead of D(+)-glucose, the starting material is D(-)-fructose or D(+)-mannose. Using deuterium oxide, Topper et al, in 1951, have supported this enolization mechanism but have concluded that fructose and mannose cannot arise from the same enediol and that there are two geometric isomeric enediol intermediates, both forms capable of changing into fructose.

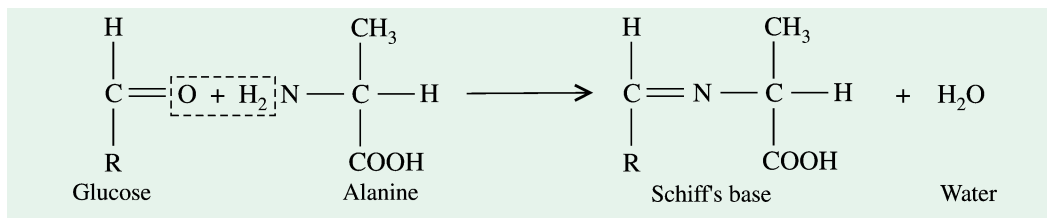
If the mixture is, however, heated to 37°C, the acidity increases and a series of enols are produced in which the double bonds migrate from O—C link to various C—C positions.



In concentrated alkali, sugar caramelizes and many decomposition products are formed. Certain coloured pigments develop and salts may also be formed.

3. **Reaction with hydrogen cyanide (Kiliani synthesis).** As already discussed (see page 73), the addition of HCN to mutarotating sugars creates a new asymmetric carbon atom, producing two new compounds namely, cyanohydrin A and cyanohydrin B. These are, then hydrolyzed with dilute mineral acids to form hydroxy acids which are later converted to γ -lactones and finally reduced to two new sugars containing one more carbon atom than the parent sugar.

4. **Reaction with alanine.** The aldehyde group of carbohydrates condenses with the amino group of alanine to form Schiff's base.



The browning reaction (Maillard's reaction) occurring during the baking of bread and other mixtures of carbohydrates and proteins is believed to be due to the formation of Schiff's base between the amino groups of proteins and the aldehyde groups of carbohydrates (Mertz, 1960).

5. Reaction with phenyl hydrazine. Reaction with phenyl hydrazine involves only 2 carbon atoms viz., the carbonyl (i.e., the aldehyde or ketone group) and the adjacent one. One mole of phenyl hydrazine reacts with one mole of aldose (or ketose) to form a mole of hydrazone. With a second mole of phenyl hydrazine, the hydrazone is oxidized to **aldohydrazone** and the phenyl hydrazine itself is reduced to aniline and ammonia. Finally, a third mole of phenyl hydrazine reacts with the aldohydrazone to produce **osazone**. The hydrazone may, in fact, be regarded as a special type of Schiff's base and the osazone as a double Schiff's base (Fig. 6-2).

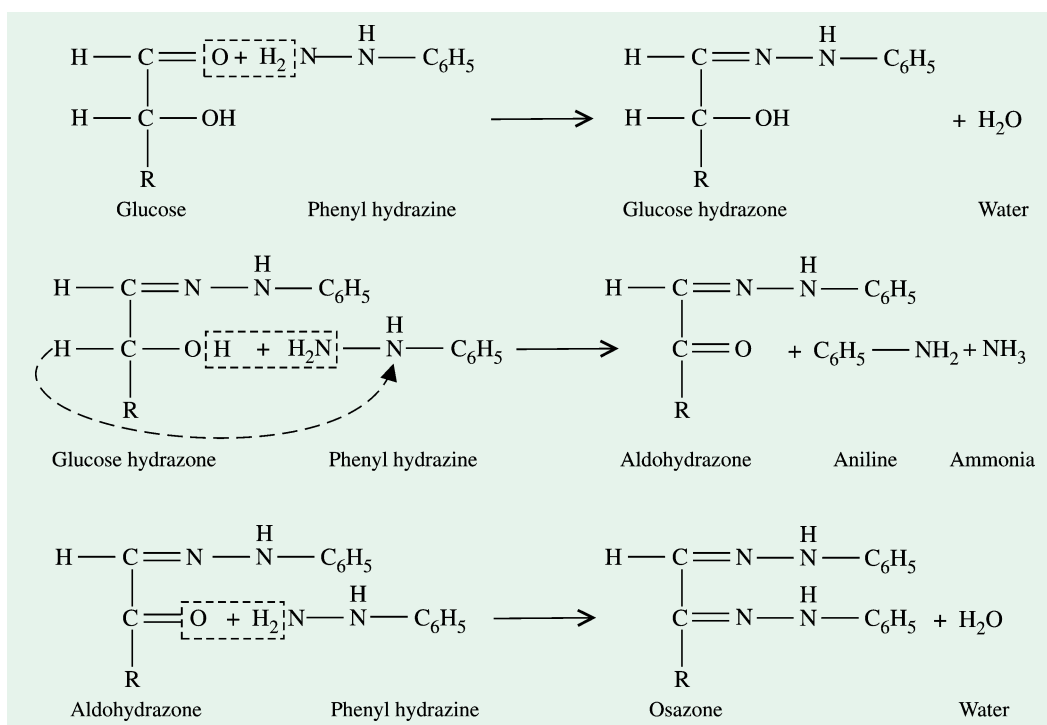


Fig. 6-2. Osazone formation

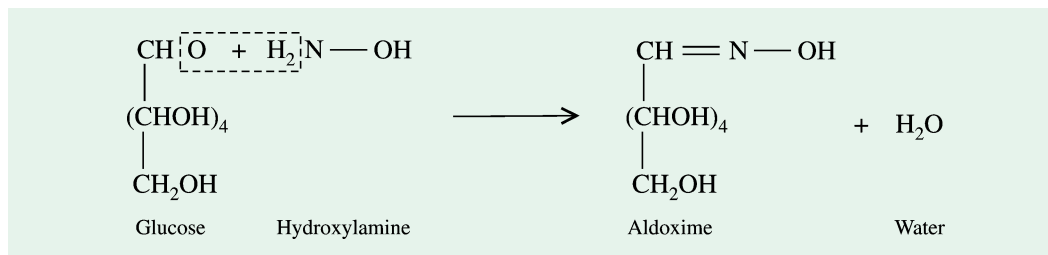
The reaction with ketose will also take place in a likewise manner.

The osazones of reducing (mutarotating) sugars are crystalline, yellow and usually insoluble compounds and hence may also be recovered. These have characteristic crystal structure and melting points and are, therefore, frequently used in the identification of sugars. It may, however, be noted that glucose, fructose, and mannose would yield the same osazone owing to their similar structure in the unaffected part of the molecule (from C₃ to C₆). Moreover, the asymmetry at C₂ is destroyed during the reaction. Obviously, galactose would, then, form a different osazone as it has a different configuration below C₂.

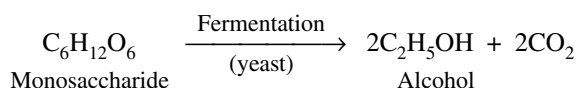
PROPERTIES OF MONOSACCHARIDES 99

Osazone formation is not restricted to monosaccharides but is also shown by most disaccharides. Lactosazone crystals have a typical hedgehog shape and are readily identifiable. Maltosazone crystals have a characteristic petal-like appearance and a cluster of them looks like the sunflower. Sucrose, however, does not form osazone since it does not contain a functional carbonyl group.

6. Reaction with hydroxylamine. Simple sugars react with hydroxylamine to yield **oximes**.



7. Fermentation. Monosaccharides such as glucose, fructose and mannose are readily fermented by yeast. The process of yeast fermentation is very complex. During this process, sugar phosphate and sugar acid phosphate are formed. Ordinarily, this process results in the formation of alcohol and carbon dioxide.



REFERENCES

See list following Chapter 8.

PROBLEMS

- Sucrose is commonly used to preserve fruits. Why is glucose not well suited for preserving fruits?
- Which of the following carbohydrates is most rapidly fermented by brewer's yeast (*Saccharomyces cerevisiae*):
 - glycogen
 - maltose
 - lactose
 - glucose
 - starch