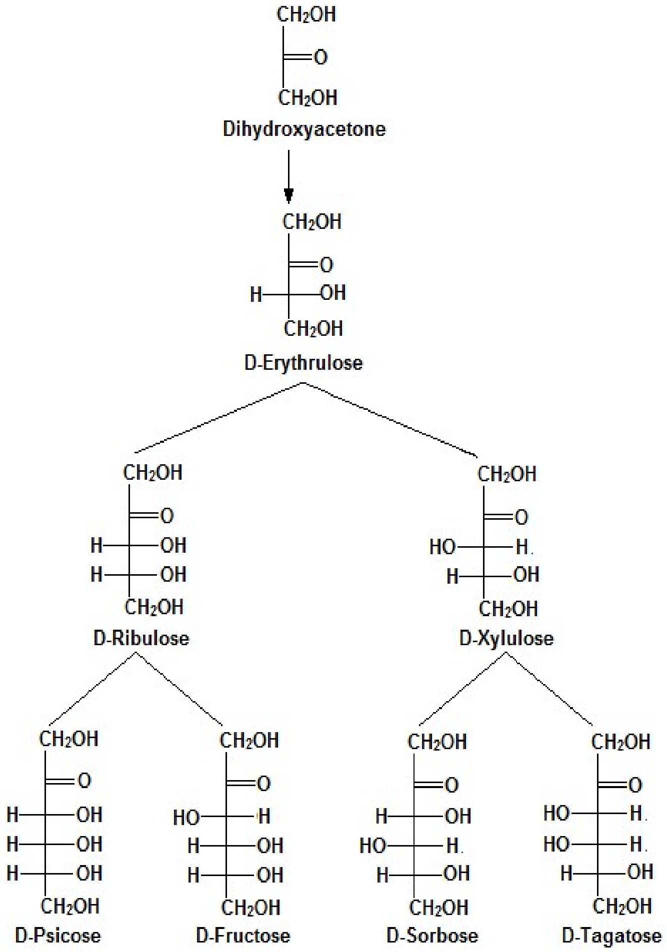


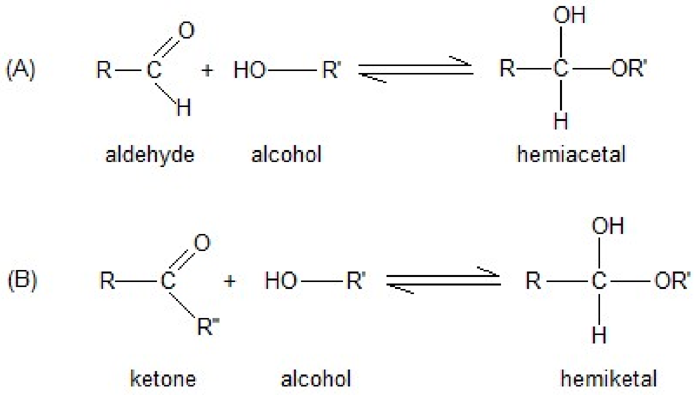
Figure (1.4): Fischer projection formulas and names of the D-ketoses. L-ketoses are the mirror images of them.

Note that some of these ketoses are named by the insertion of -ul- before the suffix -ose in the name of the corresponding aldose; thus D-xylulose is the ketose corresponding to the aldose D-xylose. Dihydroxyacetone, D-fructose, D-ribulose, and D-xylulose are the biologically most prominent ketoses.

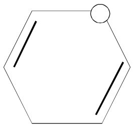
Pyranose and Furanose rings formation

For simplicity, we have -until now- represented the structures of aldoses and ketoses as straight-chain molecules. In fact, in aqueous solution, aldotetroses and all monosaccharides with five or more carbon atoms in the backbone occur predominantly as cyclic (ring) structures in which the carbonyl group has formed a covalent bond with the oxygen of a hydroxyl group along the chain.

Aldehyde groups and ketone groups can react with the hydroxyl groups of alcohols to form hemiacetals and hemiketals respectively as shown below:



A similar reaction can occur intramolecularly in monosaccharides where the aldehyde or the ketone groups react with one of the hydroxyl groups in the same molecule.



Pyran

In glucose, the aldehyde group (carbon number 1) reacts with the hydroxyl group at carbon number 5 to form a six-membered ring which is structurally similar to **pyran** (a simple heterocyclic compound) thus, it is called a **pyranose** ring. The cyclic form of glucose with a six-membered ring is therefore known as **glucopyranose**. Figure (1.5) shows the ring formation in glucose.

Pyranose: A six-membered cyclic hemiacetal form of a monosaccharide.

Ring formation gives glucose molecule one additional chiral center. The new chiral center is simply the former carbonyl carbon. Remember that two isomeric forms can exist for each chiral atom, so the resulting pair of stereoisomers is known as anomers and the carbonyl carbon is referred to as anomeric carbon atom.

Haworth projection:
A way to view furanose and pyranose forms of monosaccharides. The ring is drawn flat with the anomeric carbon on the right and the oxygen atom to the rear.

The systematic names of the two anomers of D-glucose are α-D-glucopyranose (in which the hydroxyl group at the anomeric carbon is drawn below the ring) and β-D-glucopyranose (in which the hydroxyl group at the anomeric carbon is drawn above the ring). Note that the configurations of the substituents to each carbon atom of these sugar rings are usually represented by their **Haworth projection formulas**.

Anomers: pairs of monosaccharides that differ in configuration only at the anomeric carbon.

Anomeric carbon: The hemiacetal or the hemiketal carbon (the former carbonyl carbon) of the cyclic form of a monosaccharide.

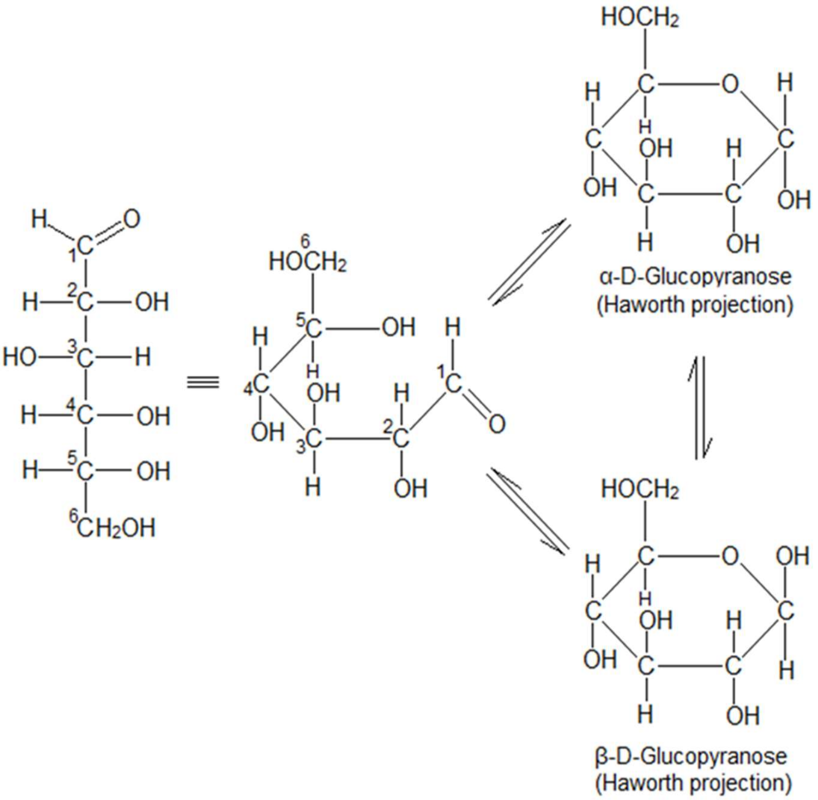


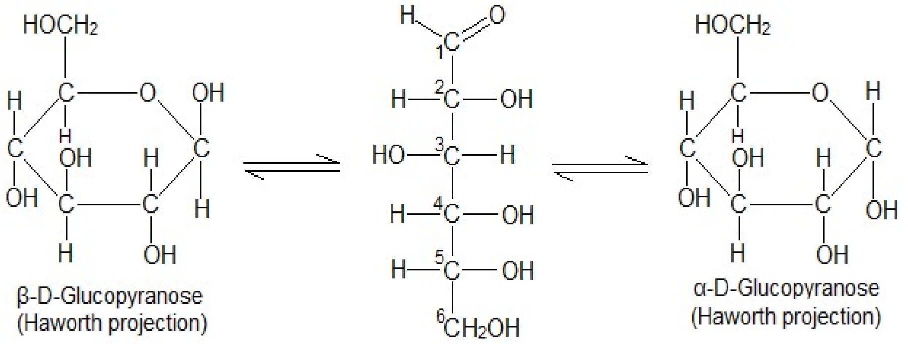
Figure (1.5): Ring formation in D-glucose occurs via the reaction of carbonyl group with OH group at C 5 atom.

Mutarotation:
a phenomenon of the spontaneous change in specific rotation that accompanies the equilibration of α and β anomers in aqueous solution.

The two anomers of D-glucose have different physical and chemical properties. For example, the values of the specific optical rotation for α-D-glucose and β-D-glucose are, respectively, +112.2° and +18.7°.When either of these pure substances is dissolved in water, however, the specific optical rotation of the solution slowly changes until it reaches an equilibrium value of +52.7°. This phenomenon is known as **mutarotation**.

Interconversion: a process in which the α and β anomers convert into each other in aqueous solution via the linear structure.

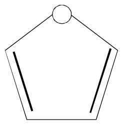
Mutarotation, in fact, occurs because the two anomers of D-glucose undergo **interconversion** in their aqueous solutions; in other words, when a pure sample of α anomer is dissolved in water it gradually converts into the β anomer via the linear form of glucose and vice versa. This interconversion leads to the formation of an equilibrium mixture consisting of 63.6% of the β anomer and 36.4% of the α anomer as shown in figure (1.6).



Figure(1.6): Interconversion between the two anomers of D-glucose occurs via the linear form.

Yet, since the linear forms of these monosaccharides are normally present in only small amounts, these carbohydrates are accurately described in amounts, these carbohydrates are accurately described as cyclic polyhydroxy hemiacetals or hemiketals (cyclic forms).

In D-fructose, the carbonyl group (ketone group) reacts with the hydroxyl group at carbon number 5 to form a five-membered ring that structurally resembles **furan** (a simple heterocyclic compound) so the ring is named **furanose** and D-fructose in its cyclic form is called **D-fructofuranose** as shown in figure (1.7).



Furan

Furanose: A five-membered cyclic hemiacetal form of a monosaccharide.

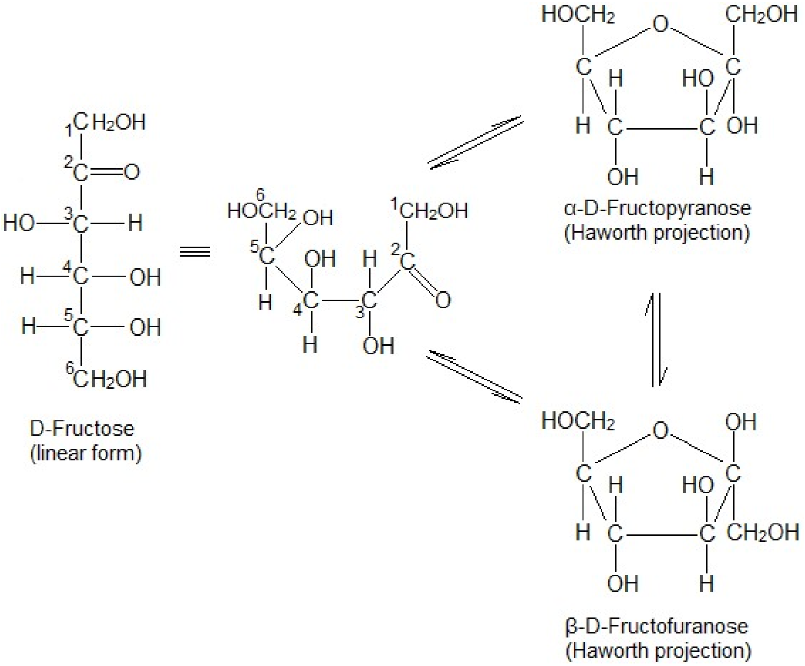


Figure (1.7): Ring formation in D-fructose occurs via the reaction of carbonyl group with OH group at C 5 atom.

The real conformations of monosaccharides

The use of Haworth formulas to represent monosaccharides may lead to the incorrect impression that furanose and pyranose rings are planar. This cannot be the case, however, because all of the atoms in these rings are tetrahedral (they are (*sp*3) hybridized).

Note:
Although, in principle, hexoses and larger sugars can form rings of seven or more atoms, such rings are rarely observed because of the greater stabilities of the five- and six-membered rings that these sugars can also form. The internal strain of three- and four-membered sugar rings makes them unstable with respect to linear forms.

The Pyranose ring, like the cyclohexane ring, may assume a **boat** or a **chair** conformation as shown below (fig.1.8).

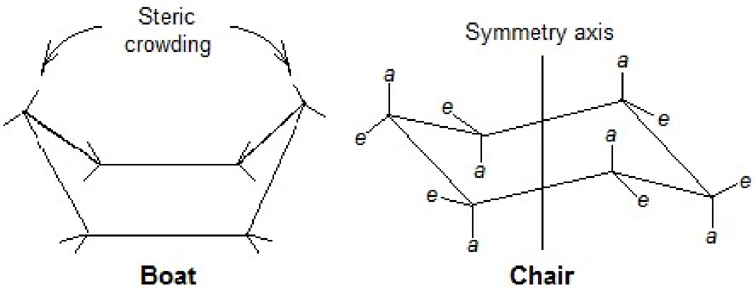


Figure (1.8): Conformations of the six-membered ring. Axial position (a) where the substituents extend parallel to the symmetry axis. Equatorial position (e) the substituents extend nearly perpendicular to the axis.

Note:
A five-membered furanose ring is so close to being planar and, in fact, it may assume two possible conformations: the envelope that has four atoms in a plane and the twist that has only three in a plane.

The relative stabilities of the two conformations depend on the stereochemical interactions between the substituents on the ring. The boat conformation is less stable due to crowding of the substituents (resulting in steric hindrance among them).

The ring substituents on the chair conformation (fig. 1.8) fall into two geometrical orientations: they may be either axial (ax), projecting parallel to the vertical axis through the ring, or equatorial (eq), projecting nearly perpendicular to this axis.

Since the axial and equatorial groups on a cyclohexane ring are conformationally interconvertible, pyranose ring has two alternative chair forms (fig. 1.9); the one that predominates usually has the lesser crowding among its axial substituents.

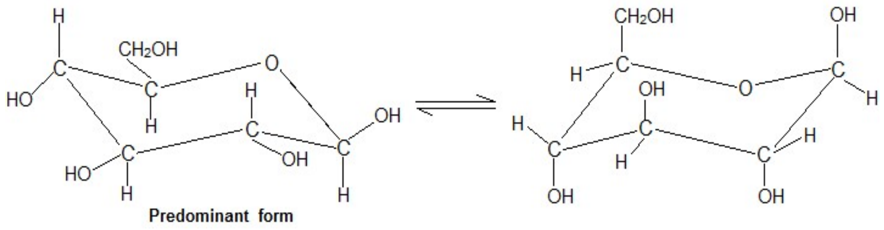


Figure (1.9): The two alternative chair conformations of β-D-glucopyranose. In the conformation on the left, which predominates, the relatively bulky OH and CH_2OH substituents all occupy equatorial positions, whereas in that on the right they occupy the more crowded axial positions.

The majority, about 64% of D-glucose exist in β form because when the molecule is in chair conformation, all the bulky hydroxyl groups will be placed in equatorial position which have lesser steric hindrance between the bulky groups. Thus, β-D-glucose is more stable than α-D-glucose that occupied typically 35% of D-glucose molecules, whereas the remaining 1% is in the open-chain form.

Monosaccharides as reducing agents:

A reducing sugar is any sugar that either has an aldehyde group or is capable of forming one in solution through isomerism. The aldehyde functional group allows the sugar to act as a reducing agent, for example in the Tollens' test or Benedict's reagent.

Reducing sugars can be oxidized by relatively mild oxidizing agents such as cupric ion (Cu^{2+}) (Fig. 1-10). The carbonyl carbon (aldehyde group) is oxidized to a carboxylic acid, at the same time; cupric ion (Cu^{2+}) is reduced to cuprous ion (Cu^{1+}).

Reducing sugar: A carbohydrate that reacts with a mild oxidizing agent under basic conditions to give an aldonic acid; the carbohydrate reduces the oxidizing agent.

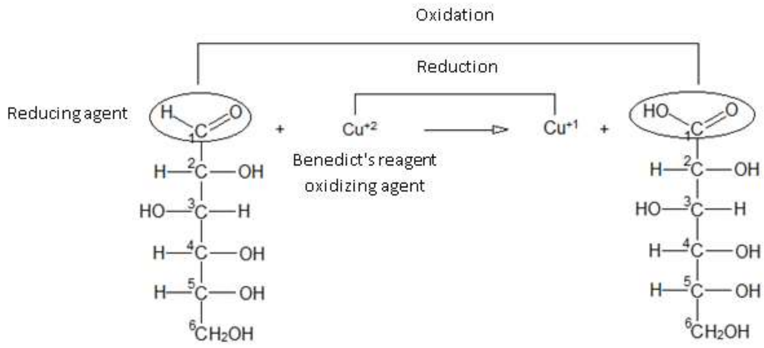


Figure (1.10): Oxidation process by reducing sugar.