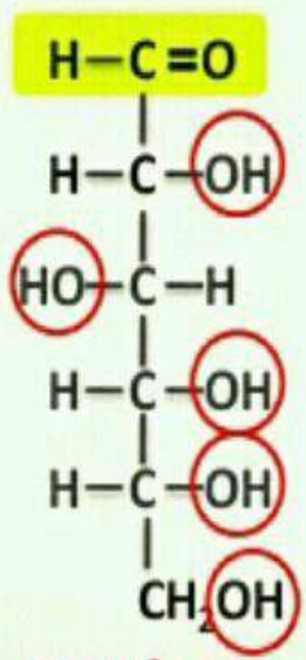
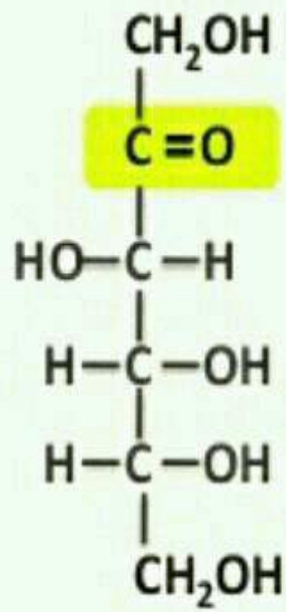
CARBOHYDRATE

Definition

Carbohydrates may be defined as **polyhydroxy aldehyde** or **polyhydroxy ketone** or compound that yield these derivatives on hydrolysis.



D - Glucose



D - Fructose

CLASSIFICATION OF CARBOHYDRATES

- **Simple Sugars**
  - Monosaccharides
  - Disaccharides
- **Complex Carbohydrates**
  - Starch
  - Glycogen
  - Cellulose (a form of fiber)

- Another type of classification scheme is based on the hydrolysis of certain carbohydrates to simpler carbohydrates i.e. classifications based on number of sugar units in total chain.
- Monosaccharides: single sugar unit
- Disaccharides: two sugar units
- Oligosaccharides: 3 to 10 sugar units
- Polysaccharides: more than 10 units

Monosaccharides

A. Structure and Nomenclature

- The 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.
- Monosaccharide containing an aldehyde group are classified as aldoses; 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.

Some Additional Terms

Aldose	A carbohydrate that contains an aldehyde group
Ketose	A carbohydrate that contains a ketone group
Triose	A carbohydrate having three carbons
Tetrose	A carbohydrate having four carbons
Aldopentose	A five-carbon carbohydrate that contains aldehyde group
Ketohexose	A six-carbon carbohydrate that contains a ketone group

Oligosaccharides

- Contains 2 to 10 monosaccharide units.
- Joined together by a specific bonds called glycosidic bond.
- On hydrolysis, they gives 2 to 10 molecules of simple sugar units.
- They are subdivide based on the number of monosaccharide units.
  - Disaccharides
  - Trisaccharide
  - Tetrasaccharide
  - Pentasaccharide

Classification of Oligosaccharides

	No "C"	Examples	Type of monosaccharide
Disaccharides	2	Maltose	Glucose + Glucose
		Lactose	Glucose + Galactose
		Sucrose	Glucose + Fructose
Trisaccharides	3	Raffinose	Glu + Fruc + Galactose
Tetra saccharides	4	Stachyose	2 Galactose + Glucose + Fructose
Penta saccharides	5	Verbascose	3 Galactose + Glucose + Fructose

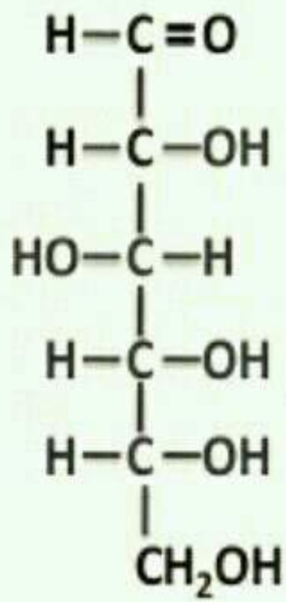
Polysaccharides

- Contains many (more than 10) sugar units.
- They have high molecular weight and are sparingly soluble in cold water.
- They are also called as Glycans.
- They may be either liner or branched in structure.
- They are not sweetish and do not exhibit any of the properties of aldehyde or ketone group.

POLYSACCHARIDES

- Homopolysaccharides
  - Starch
  - Glycogen
  - Dextrins
- Hetropolysaccharides
  - Agar
  - Pectins
  - Glycosaccharide

Structural functional relationship of Monosaccharide



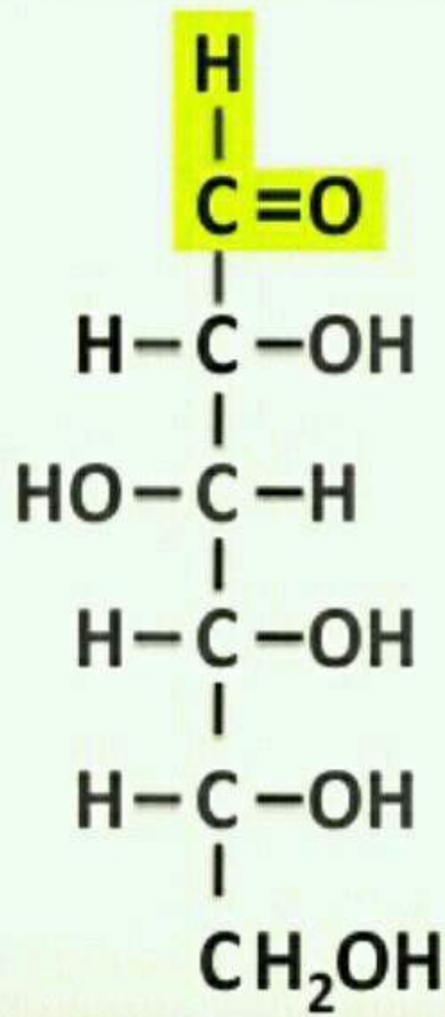
STRUCTURE OF MONOSACCHRIDES

PHYSICAL PROPERTIES

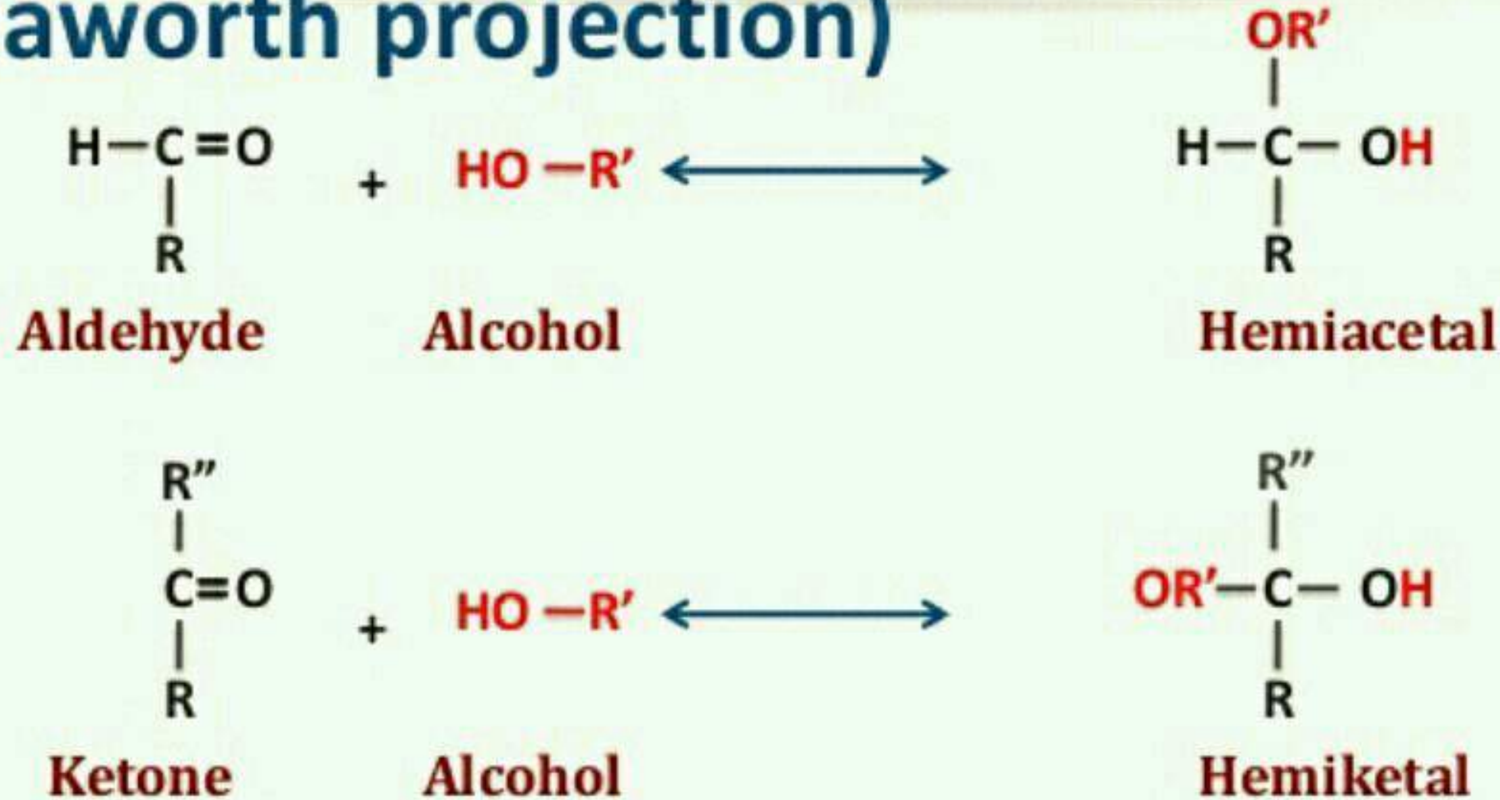
CHEMICAL PROPERTIES

- Glucose is the most important physiological and biomedical monosaccharide.
- It can be represented in...
  - The straight chain structure
  - Ring /cyclic structure
  - Boat and chair form.

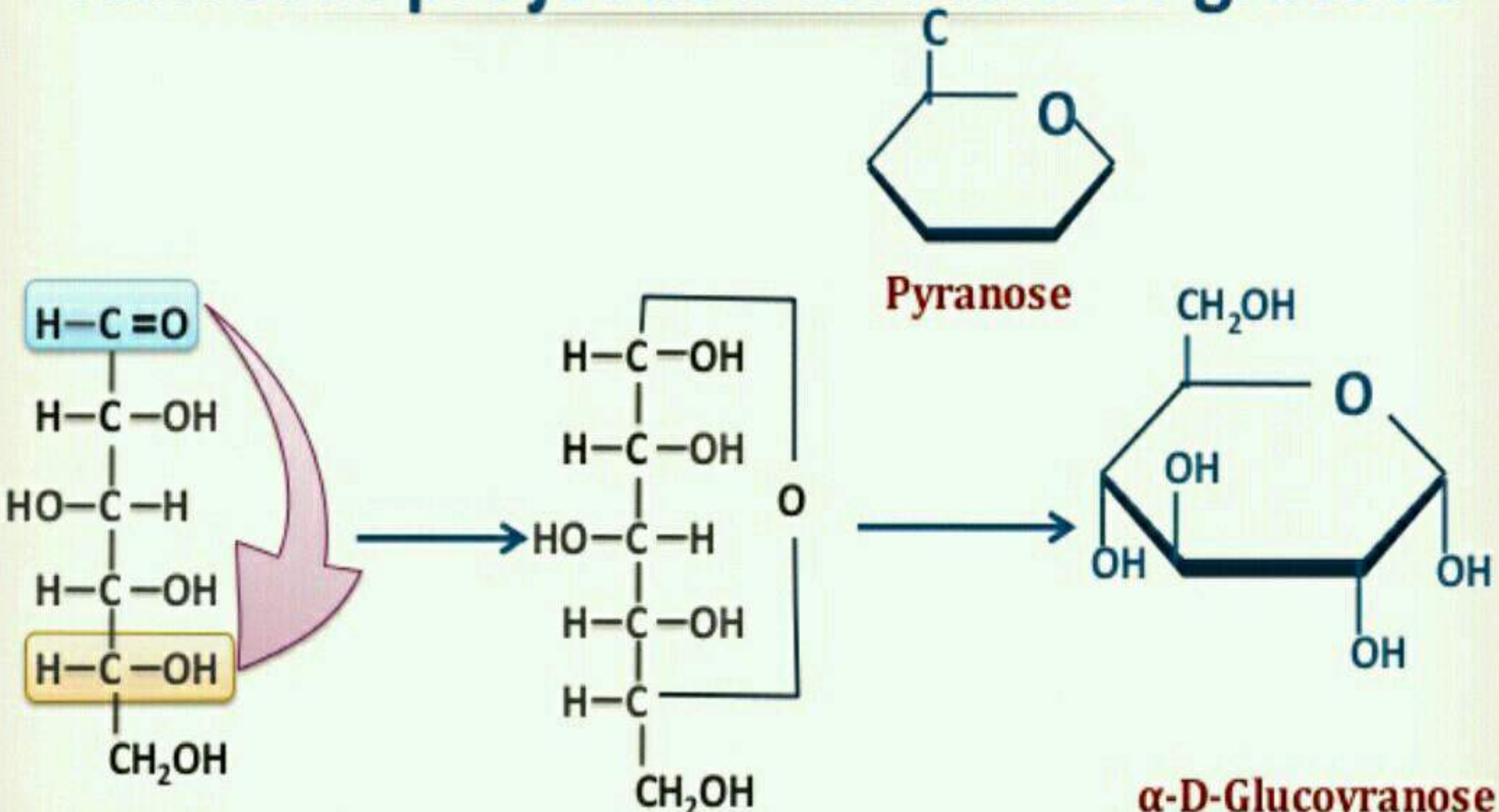
The straight chain structure



Ring /cyclic structure (Haworth projection)



Haworth projection formula of glucose

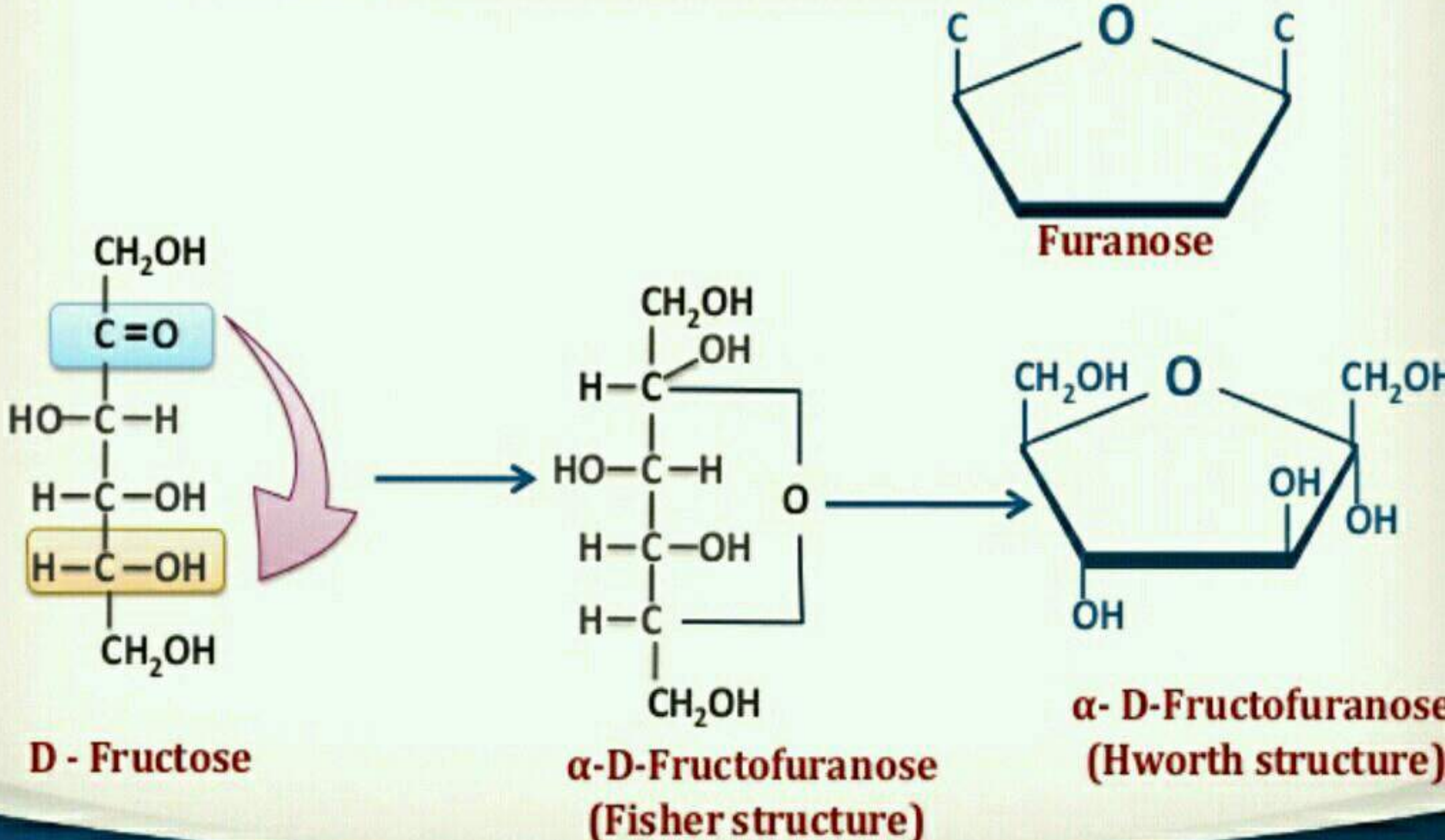


D - Glucose

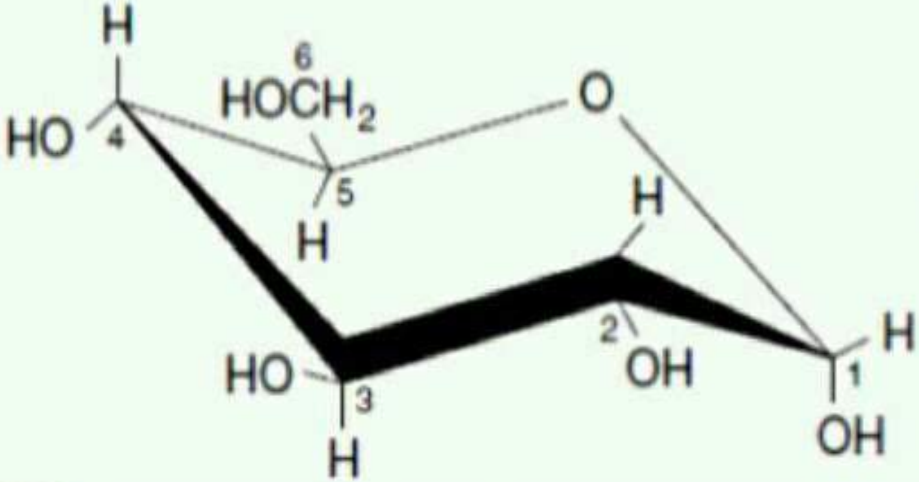
α-D-Glucoyranose
(Fisher structure)

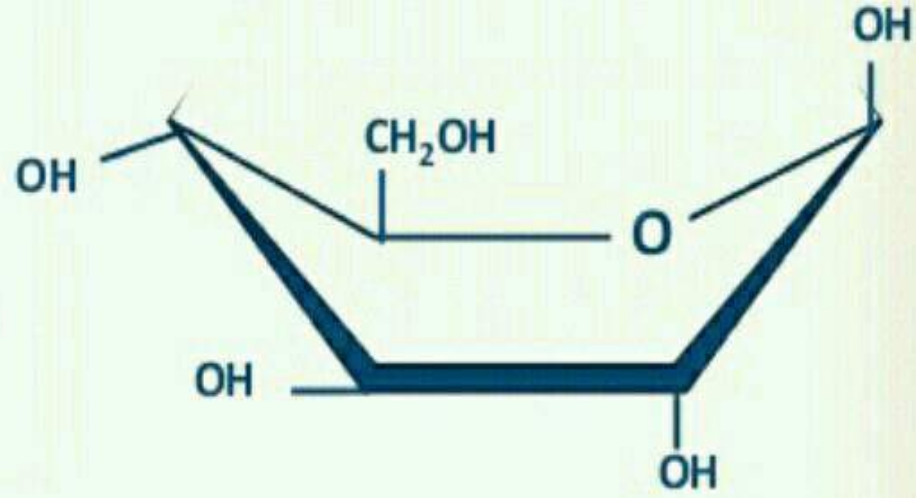
α-D-Glucoyranose
(Hworth structure)

Haworth projection formula of fructose



Chair and boat from of D- glucose





Properties of Monosaccharides

Isomerism

Chemical reactions

Isomerism

- The compounds possessing same molecular formula and different structures are referred as **Isomers**.

- The phenomenon of existence of isomer is called **Isomerism**.

Structural Isomerism

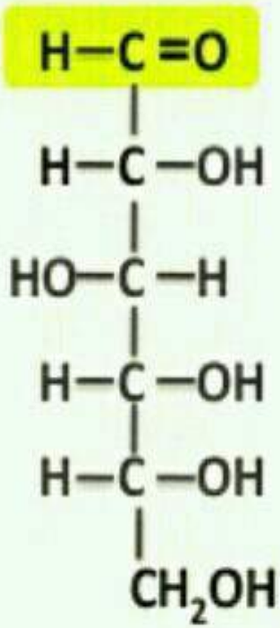
Stereoisomerism

Structural Isomerism

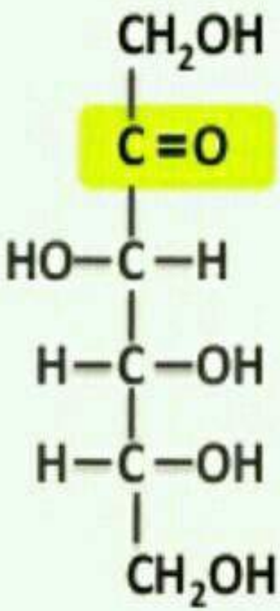
- same molecular formulae but differ in their structures.
- Aldose-Ketose Isomerism
- Glucose and fructose isomers of each other.
- They are having same molecular formula $C_6H_{12}O_6$
- But differ in their structural formula.

Aldose-Ketose Isomerism

$C_6H_{12}O_6$



D - Glucose



D - Fructose

Stereoisomerism

- same molecular formula, structures but differ in their configuration.
- Asymmetric (Chirl) carbon allow the formation of stereoisomerism.
  - Types of stereoisomerism of glucose are……

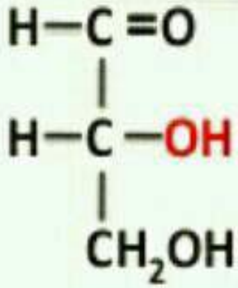
D and L isomerism

Optical isomerism

Epimerism

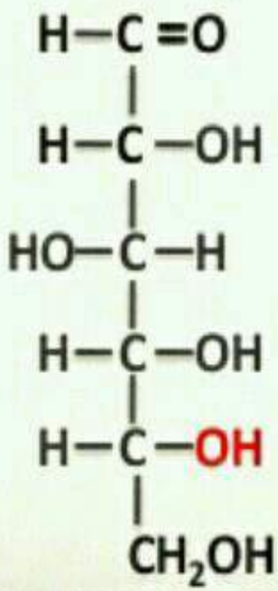
Anomerism

D and L isomerism (enantiomer)

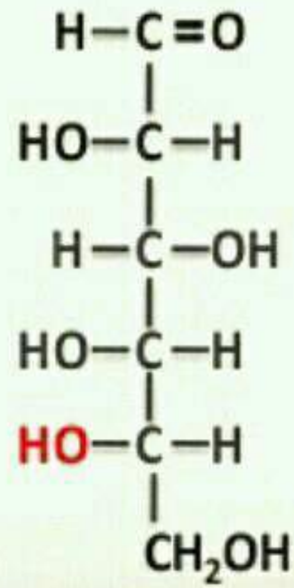


D - Glyceraldehyde

L - Glyceraldehyde



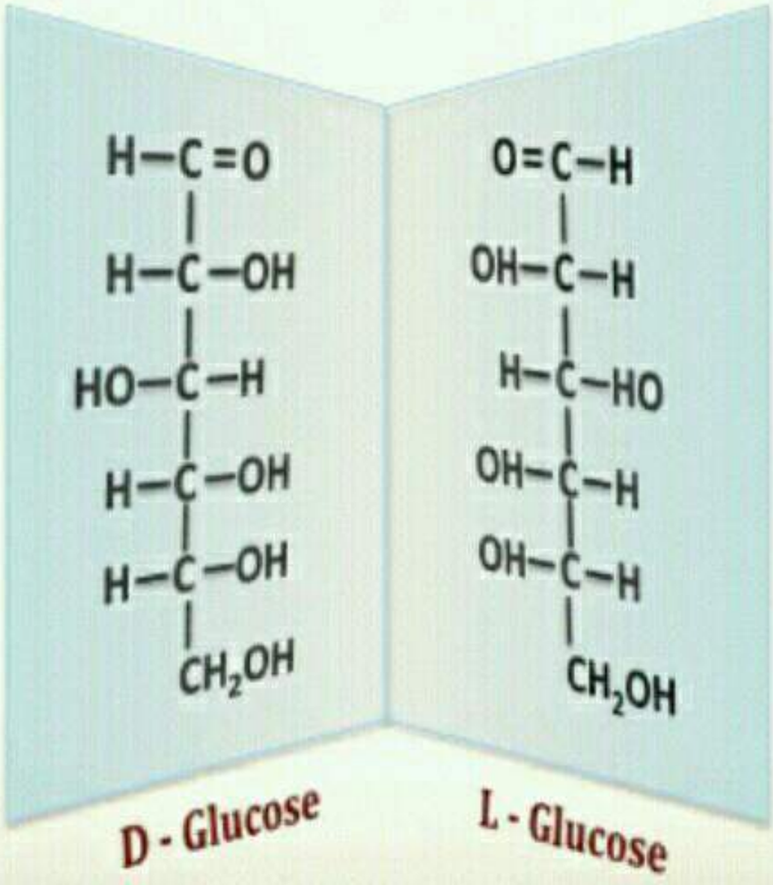
D - Glucose



L - Glucose

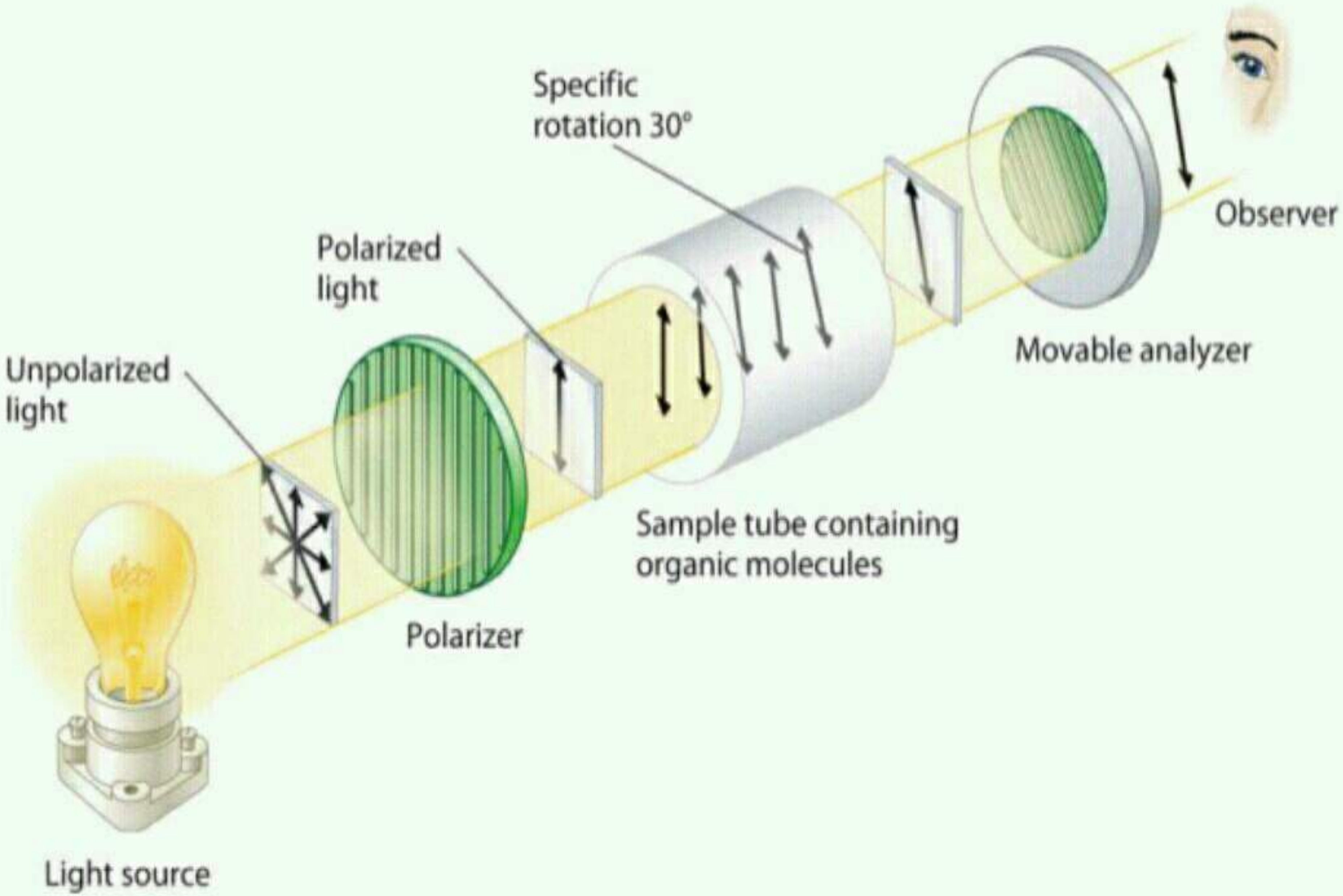
D and L isomerism (enantiomer)

- D and L isomers are mirror images of each other.
- These two forms are called Enantiomers.



Optical isomerism

- Optical activity is the capacity of a substance to rotate the plane polarized light passing through it.
- When light rotate to right (clockwise) direction, that substance is said to be **dextrorotatory** (d) (+).
- When light rotate to left (anticlockwise) direction, that substance is said to be **levorotatory** (l) (-).
- When equal amount of d and l isomers are present, that mixture is said to be recemic / dl mixture.

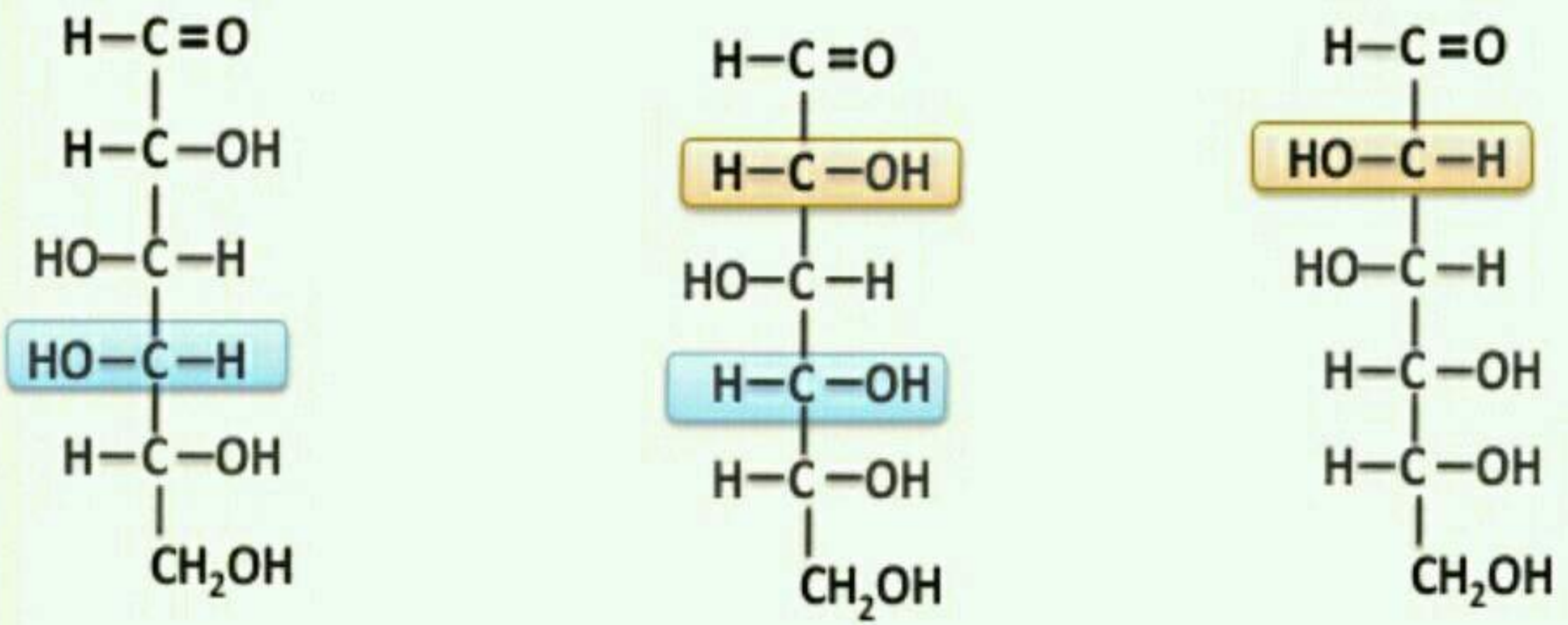


Specific rotation 30°
Observer
Polarized light
Movable analyzer
Unpolarized light
Sample tube containing organic molecules
Polarizer
Light source

Epimerism

- Epimers are sugars which are differ with each other with respect to single carbon, other than anomeric carbon.
- **Galactose** and **Mannose** are the epimers of the glucose.
- They differ from the glucose with the respect of the C-4 and C-2 respectively.

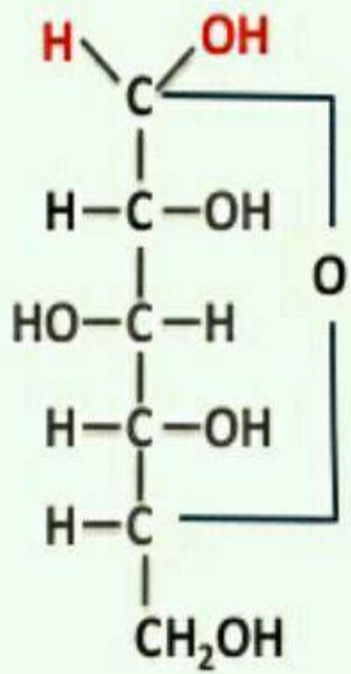
Epimers of glucose



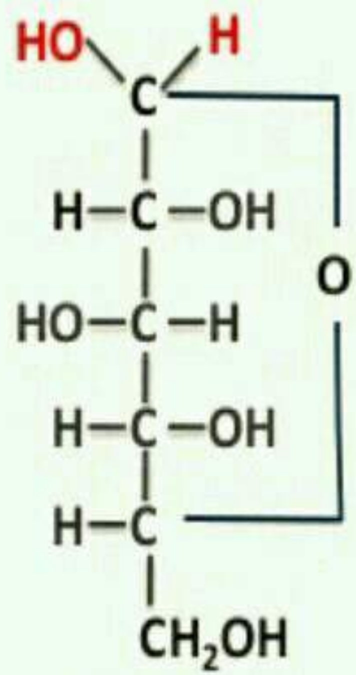
D - Galactose   D - Glucose   D - Mannose

Anomerism

- In solution glucose predominantly exist as closed chain structure.
- Because of cyclization of sugar, an additional asymmetric center is created at C-1 (anomeric carbon).
- This leads to formation of two isomers namely....
  - α- D-glucopyranose
  - β- D-glucopyranose



α- D - Glucose



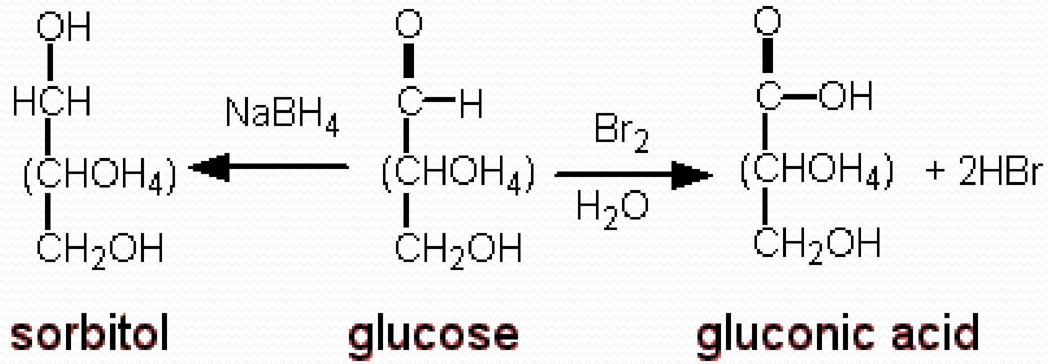
β - D - Glucose

ELUCIDATION OF GLUCOSE MOLECULE

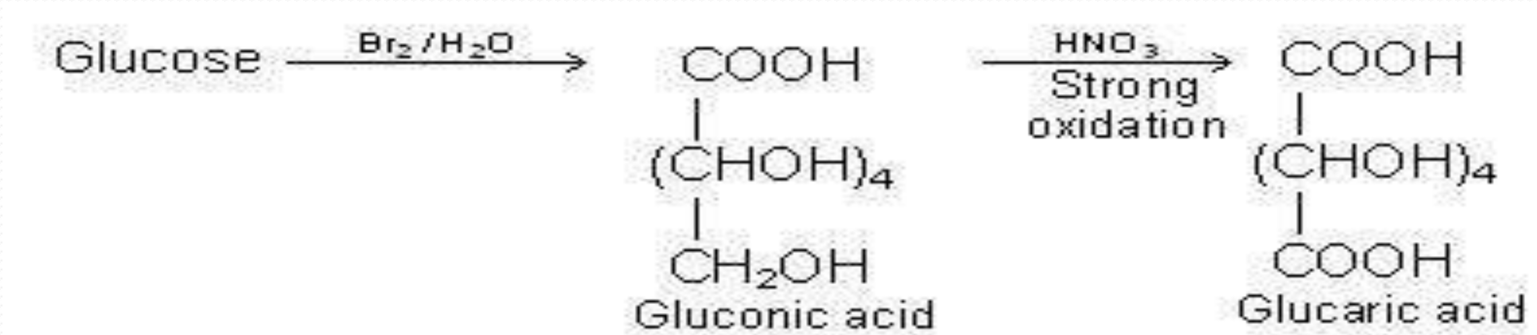
By analysis of the molecular formula of glucose is found to $C_6 H_{12} O_6$.

Glucose forms oxime with hydroxymine and cyanohydrin with HCN and with phenyl hydrazine yielding a phenyl hydrozone.
All these reaction indicates the presence of carbonyl (C=O) group. which may either aldehyde and ketones.

On mild oxidation with bromine water or tollens reagent glucose gives gluconic acid, a penta hydroxyl mono carboxylic acid containing six carbon atom. This indicates the presence of an aldehyde group because only one aldehyde can be oxidised so early to a carboxylic acid with some number of carbon atom.



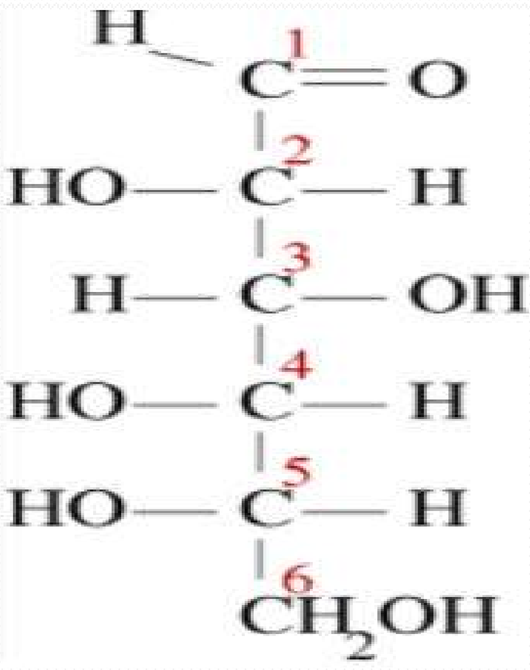
Further oxidation of gluconic acid yield a carboxylic acid . The same dicarboxylic acid is obtained o oxidation of glucose with dilHNO_3 while one of the COOH group must have come from the CHO group. The second group must have been generated by the oxidation of primary alcoholic group. (CH2OH). This indicates the presence of a primary alcoholic group.



On heating with concentrated hydroiodic acid and red phosphorous glucose forms n – hexane . this indicates the glucose has a straight chain of sixcorbon atom.

$$C_6H_{12}O_6 \xrightarrow{P/\ H_2I} CH_3-CH_2-CH_2-CH_2-CH_2-CH_3$$

On acetylation with acetic anhydride, glucose yields a penta acetate derivative consuming the 5 molar equivalent of acetic anhydride.
This show the presence of 5 hydroxy group in glucose, all of which must be attached to different corbon atom



Though the open chain structure of glucose account for most of its properties, it does not account for the following

Glucose does not give some typical reaction of normal aldehyde, neither does it restore the pink colour of Schiff reagent, nor does it form addition product with sodium bisulphate or ammonia.

Glucose pent acetate does not react with hydroxalamine this show the absence of free aldehyde group.

There are two stereoisomeric forms of glucose the first is obtained by recrystallization from methanol and has a melting point of 146^0 c. Second is obtained by recrystallization from water at temperature above 98^0 c and as a melting point of 150^o C. these two form are called the α and β form of glucose.

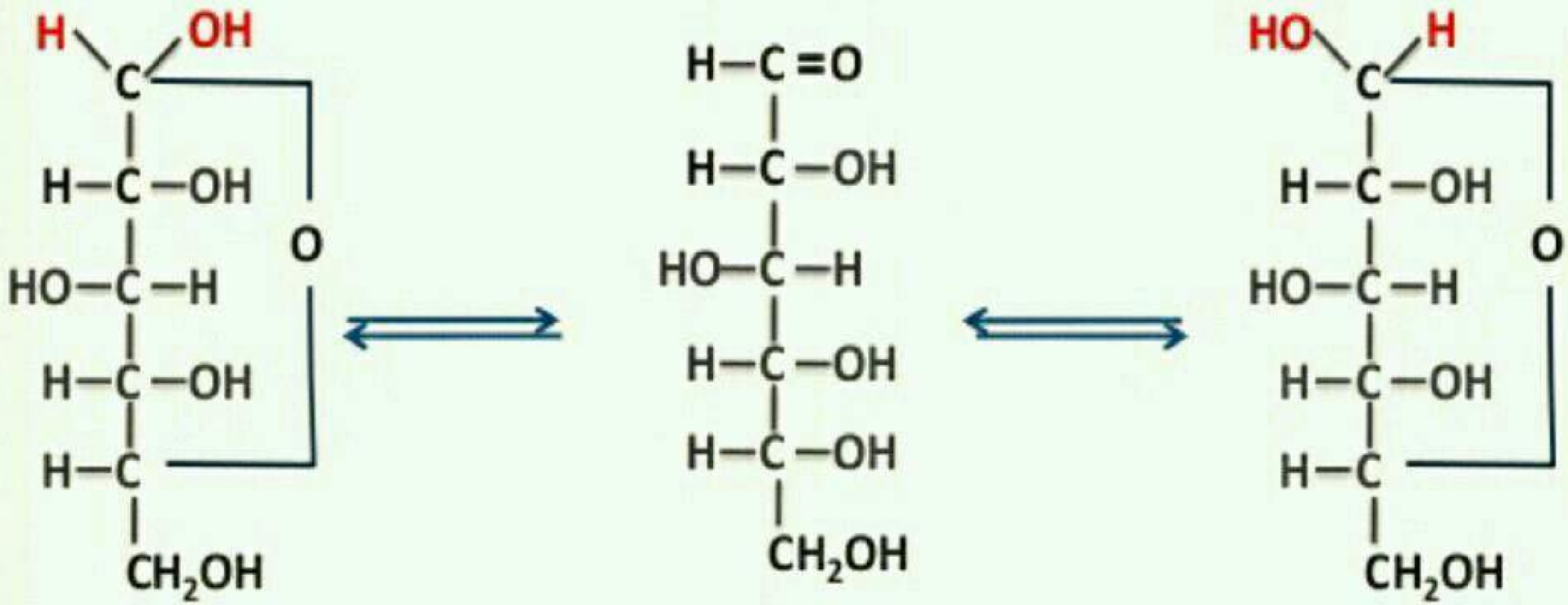
Both the α and β form of glucose undergo the mutarotation . the initial specific rotation of the α form ios +112 . 2 while that of the β form is + 18. 7 The solution of the forms gradually attain are equilibrium specific rotation of+ 52.7.

Glucose reacts with methanol in the presence of anhydrous HCl to form the two isomeric methyle glucosides.
These suggest that the CHO Group in glucose is not free but tied up in combination with one of the (OH) group.
In order to explain the above the facts , the cyclic or ring structure is assigned to glucose, the ring structure of glucose involves an intra molecular hemiacetal. By interation between the CHO group and OH group at $C_{5.}$

Mutarotation

- It is defined as "**the change in the specific optical rotation representing interconversion of α and β forms of D-glucose to an equilibrium mixture.**"

α- D - Glucose	$\longrightarrow$	Equi. mixture	$\longleftarrow$	β - D - Glucose
Specific rotation $[\alpha]_D = +112.2^\circ$		Specific rotation $[\alpha]_D = +52.7^\circ$		Specific rotation $[\alpha]_D = +18.7^\circ$



α- D - Glucose	D - Glucose	β - D - Glucose
+112.2°	+52.7°	+18.7°

Chemical Properties of monosaccharides

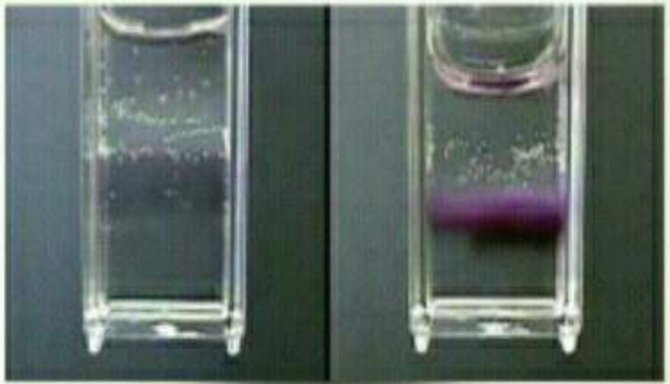
- Some of the important chemical properties of monosaccharides are…

- Furfural formation
- Enolization
- Oxidation
- Reduction
- Osazone formation

Furfural formation

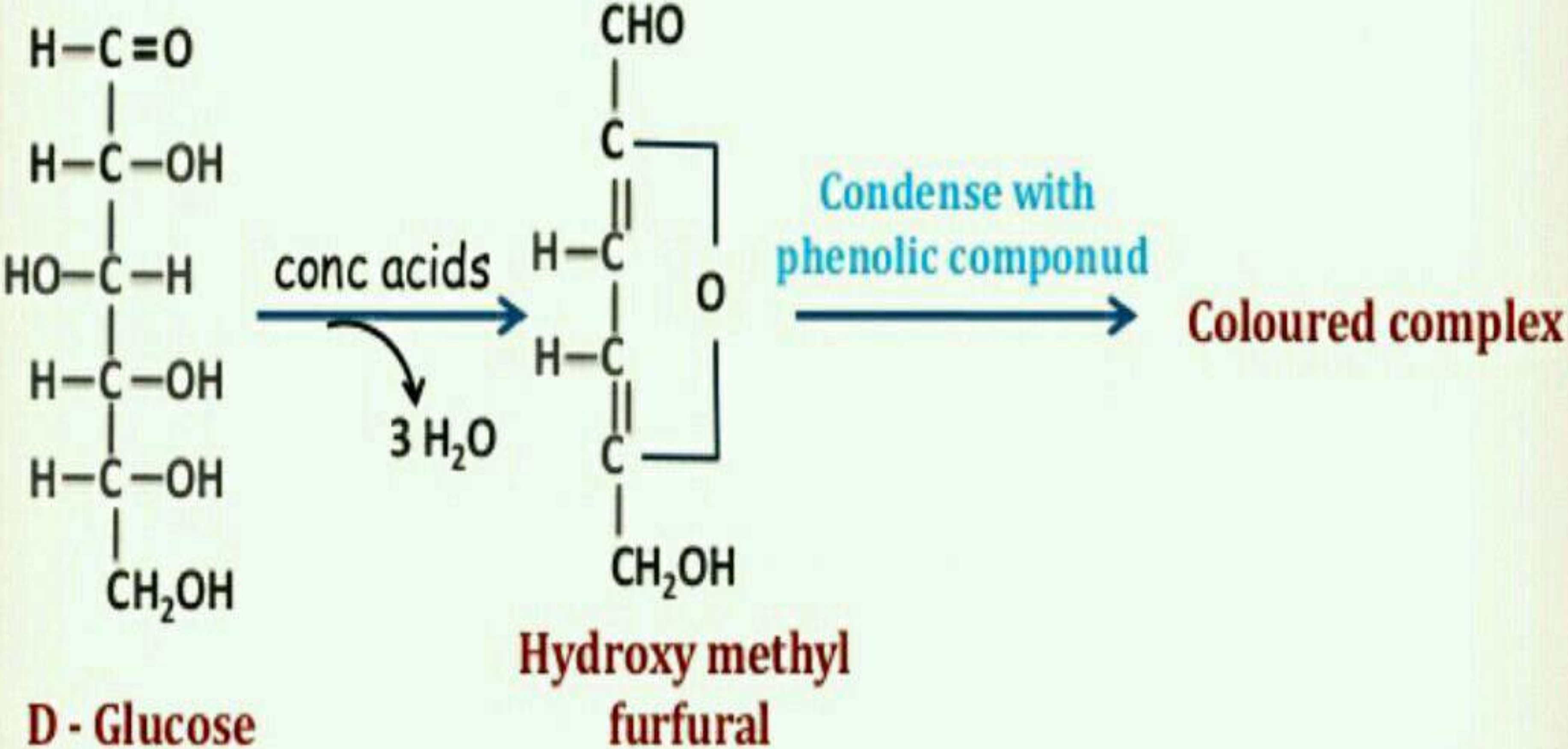
Action of strong acids

- Sugar when treated with strong mineral acids like...
  - Conc. Sulfuric acid (H_2SO_4)
  - Conc. Hydrochloric acid (HCL)
  - Conc. Nitric acid (HNO_3)



They undergoes **dehydration** loses 3 water molecules to form furfural derivatives.

- This is the basis for following reactions...
  - Molisch's test
  - Seliwanoff's test

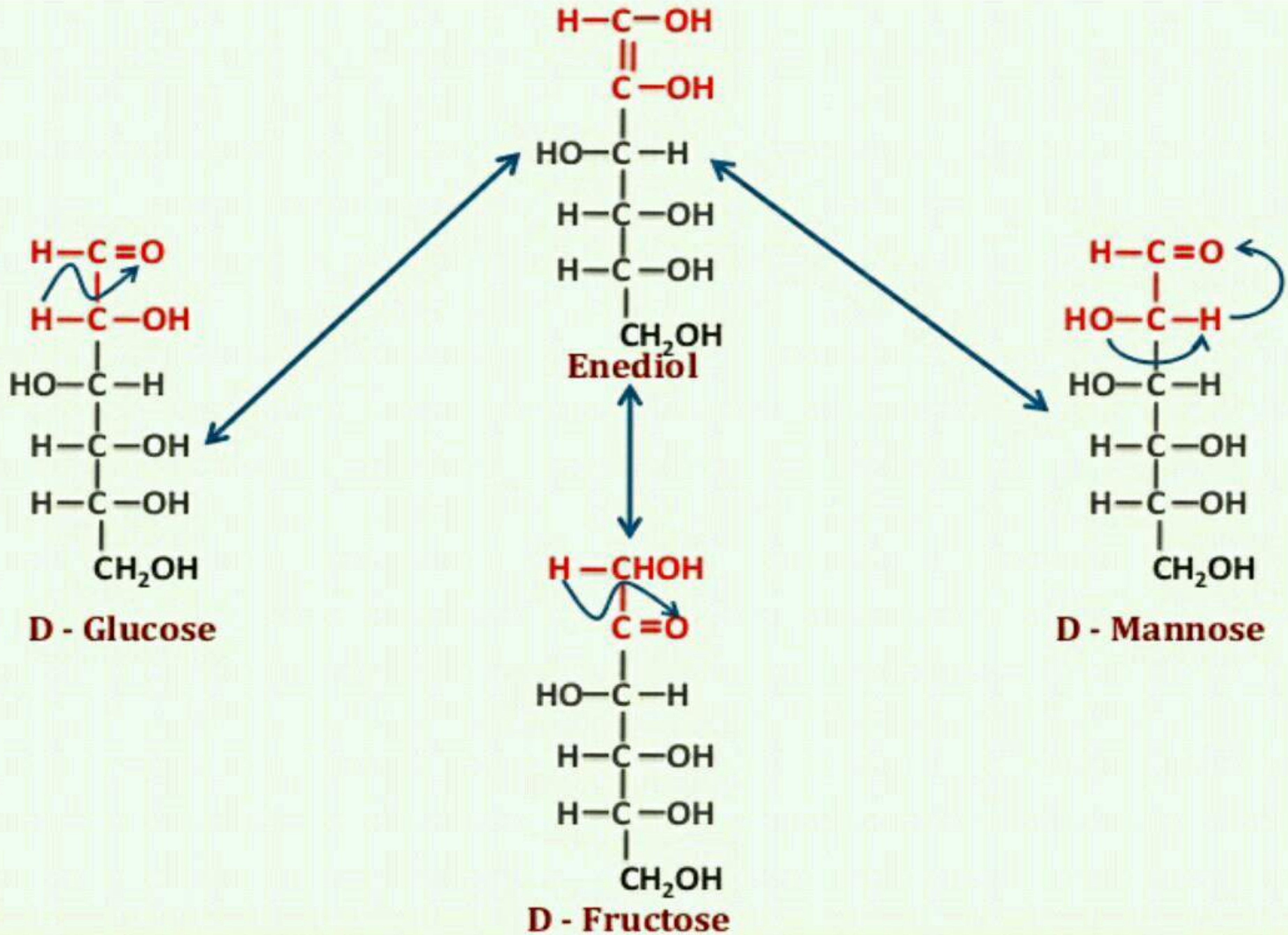


conc acids
$3\,H_2O$
D - Glucose
Hydroxy methyl furfural
Condense with phenolic componud
Coloured complex

Enolization / Tautomerization

Action of alkalies

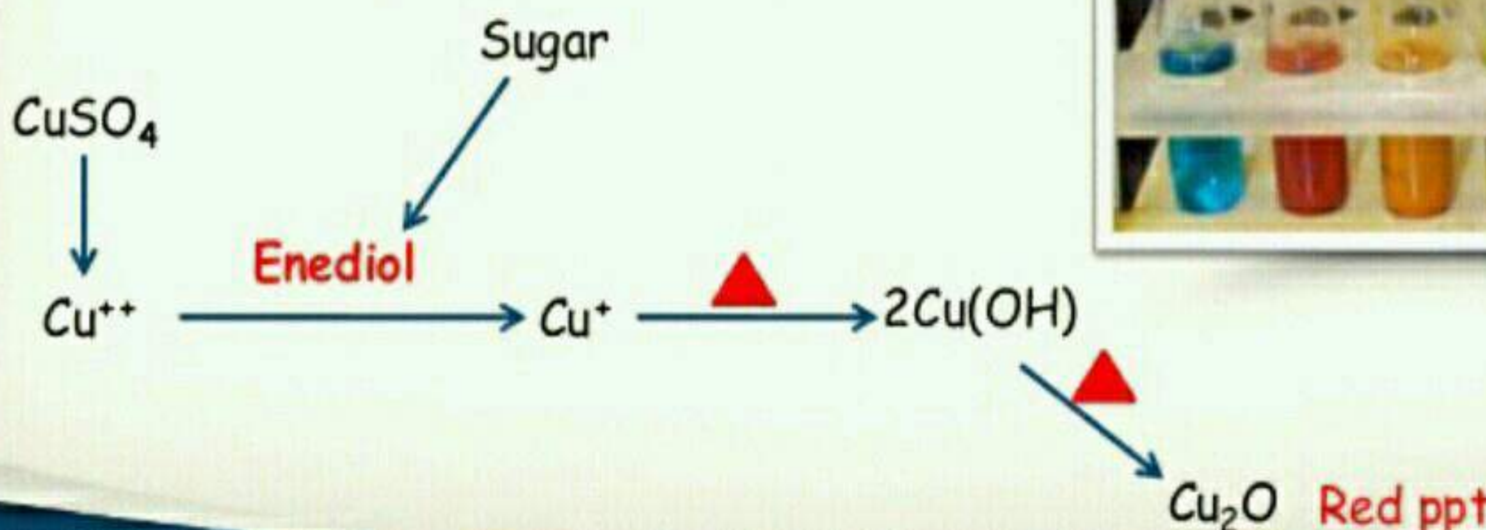
- When glucose is kept in alkaline solution for several hours, it undergoes isomerization to form D-fructose and D- mannose.
- This results in formation of a common intermediate - **enediol.**
- The process of shifting of hydrogen atom from one carbon atom to another to produce **enediols** is known as **tautomerization.**


Enediol
D - Glucose
D - Mannose
D - Fructose

Enolization / Tautomerization

Action of alkalies

- Enediols are good reducing agents.
- And forms basis of reducing property of sugars.
  - Benedict's test and
  - Fehling's test.



Oxidation

Sugar acid formation

- When glucose oxidizes under proper conditions the sugars may form:
  - **Monobasic Aldonic Acid**: oxidation with Hydrobromous acid.
  - **Dibasic saccharic acids or Alderic acid:** oxidation with nitric acid (HNO3).
  - **Monobasic Uronic acid**: oxidised by specific enzymes.

Formation of Aldonic acid

D - glucose

Gluconic acid

Medical Importance

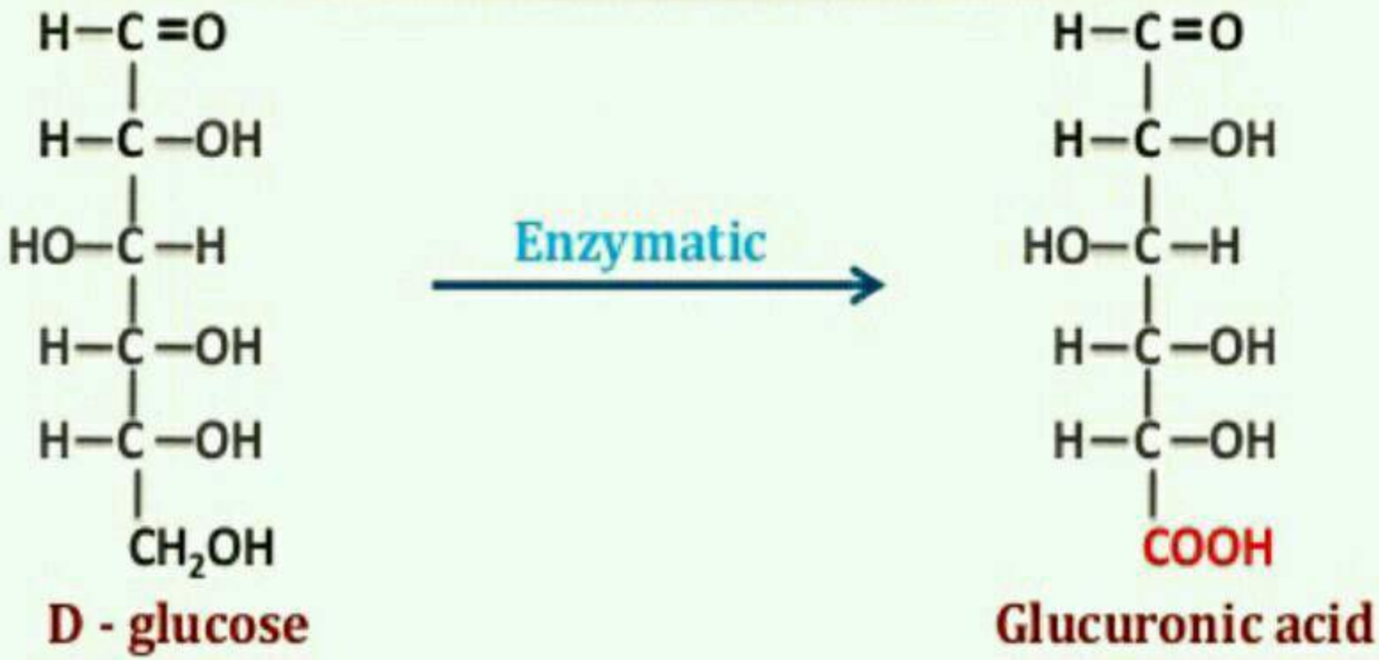
- Calcium gluconate (gluconic acid) used as source of calcium. These are given I.V. fluids rise the calcium levels.

Formation of Saccharic acid

D - glucose

Glucosaccharic acid

Formation of Aldonic acid



Medical Importance

- These are present in the heteropolysaccharides and glycoproteins.
- Involved in detoxification of benzoic acid, bilirubin & certain drugs

Osazone formation

Action of Phenylhydrazine

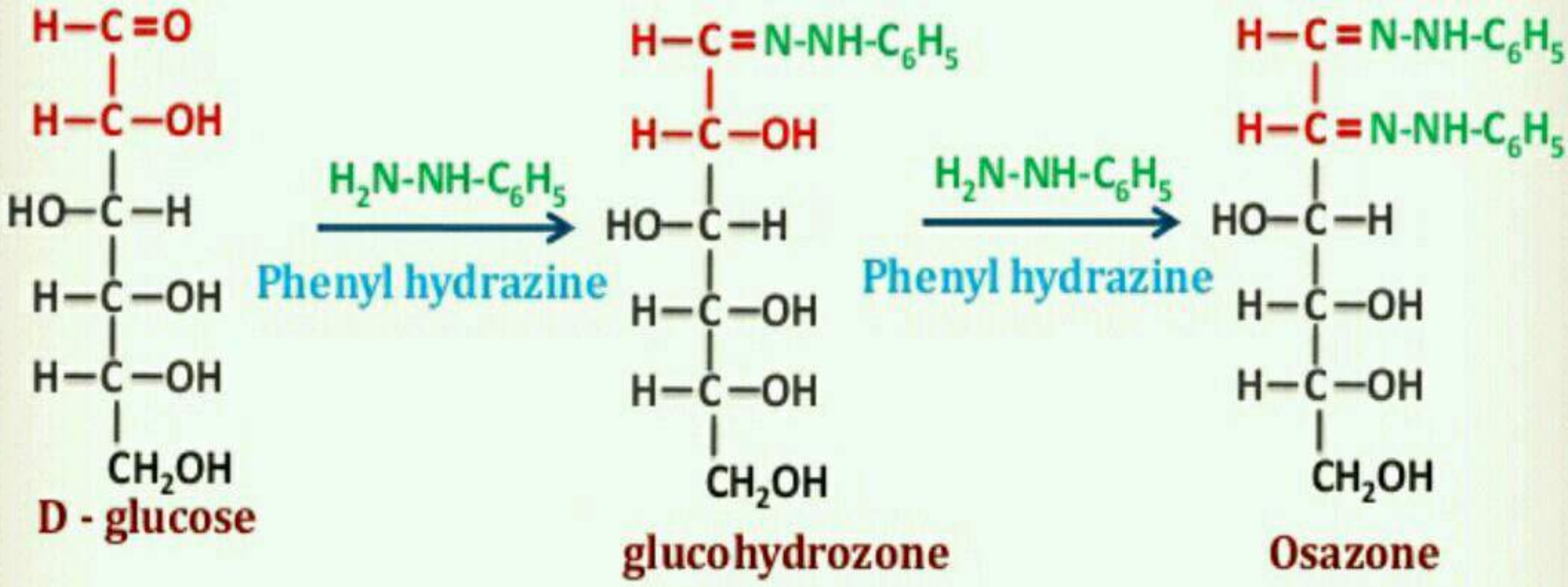
- Only reducing sugars gives this test positive.
- The presence of free carbonyl (aldehyde or ketone) group in the molecule is essential for the osazone formation.
- Osazones are yellow crystalline derivatives of reducing sugars with phenylhydrazine and have a characteristic crystal structure which can be used for identification and characterization of different sugars having closely similar properties.

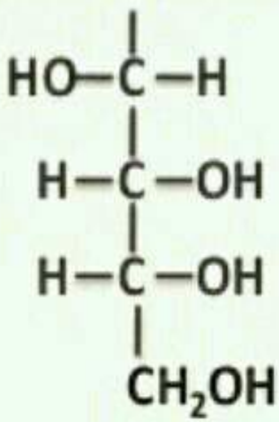
- Osazone formed from Glucose, Fructose and Mannose are identical because these are identical in their lower four carbon atoms.

- Non-reducing sugars like sucrose cannot form osazone due to the absence of a free carbonyl group.

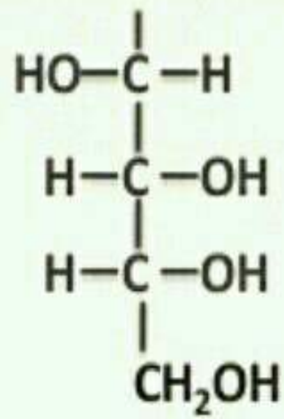
- The Osazone crystals of some sugars are:
  - Glucosazone - Needle shaped
  - Maltosazone - Sunflower petals shaped
  - Lactosazone - Powder puff of tennis ball shaped

Why glucose, fructose, and mannose give same type of osazones

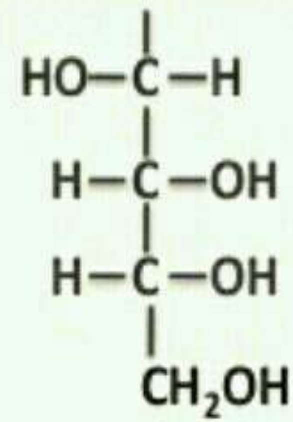




D - glucose



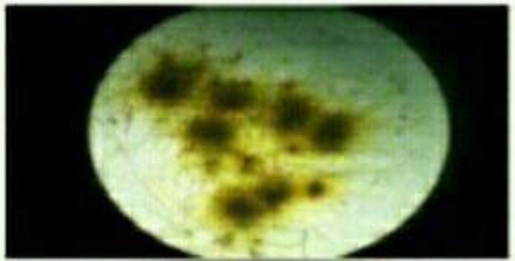
D - Fructose



D - Mannose

Needle shaped crystals

- Glucosazone ,
- Fructosazone
- Mannosazone



Powder puff or tennis ball shaped

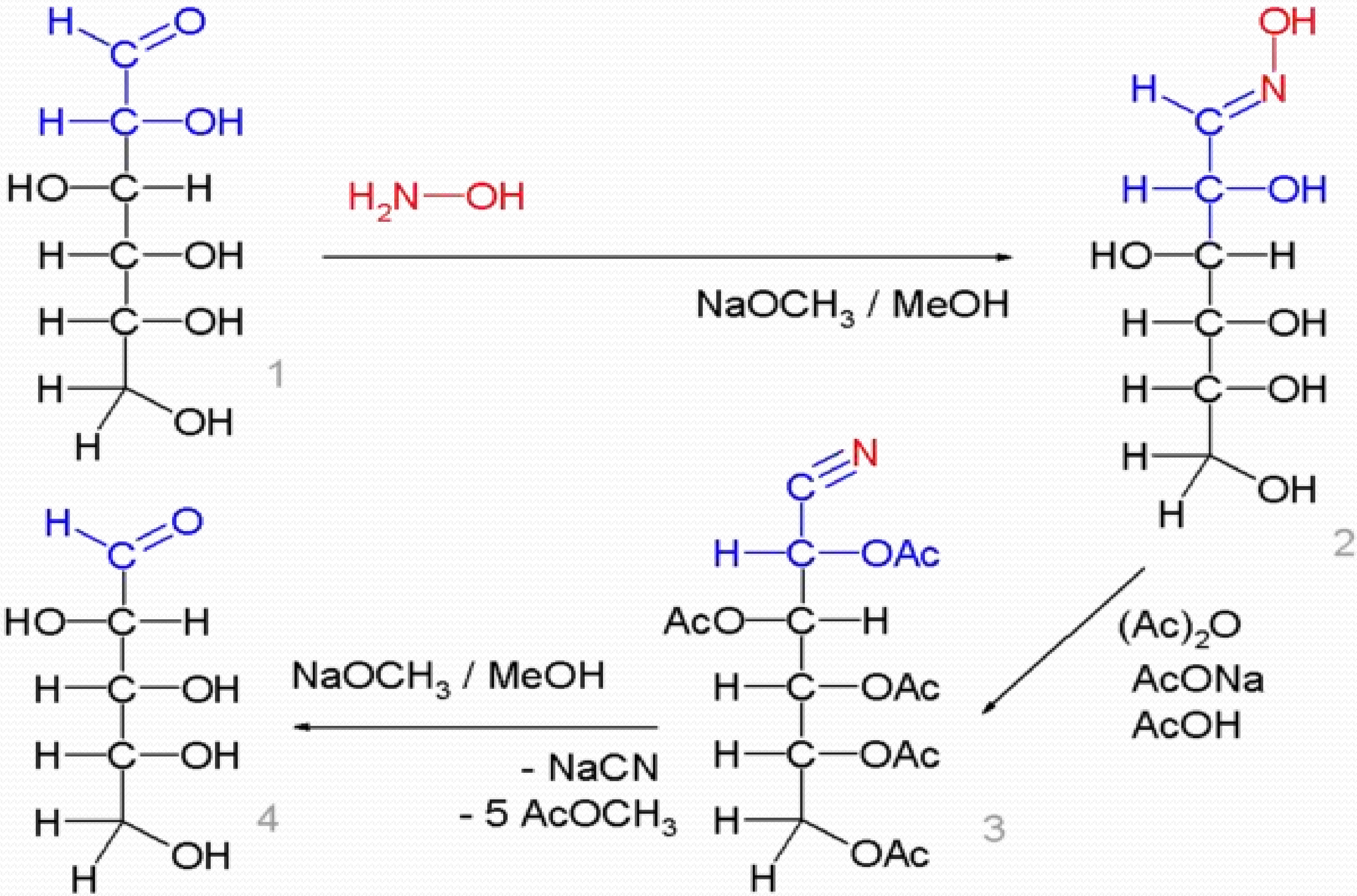
- Lactosazone

Sunflower petals shaped

- Maltosazone

CONVERSION OF GLUCOSE INTO FRUCTOSE:

Glucose is first converted into its osazone using exess phenylhydrazine .then osazone is hydrolysed with HCl to yield the osone which contain both an aldehyde and a keto group. The reduction with zinc and acetic acid the aldehyde group of osone is reduced to primary alcohol (CH_2O H) Group while the keto group is left unaffected, fructose is obtained.


H₂N—OH
NaOCH₃ / MeOH
1
2
(Ac)₂O
AcONa
AcOH
3
NaOCH₃ / MeOH
- NaCN
- 5 AcOCH₃
4

FRUCTOSE

CONVERSION OF FRUCTOSE TO GLUCOSE:

Fructose is reduced with hydrogen in the presence of nickel, glucitol formed. Glucitol is oxidized with dil HNO_3 to a monocarboxylic acid .this on heating gives a δ lactone, which on reduction with sodium bromo hydride or sodium amalgam in slightly acidic medium yields glucose.

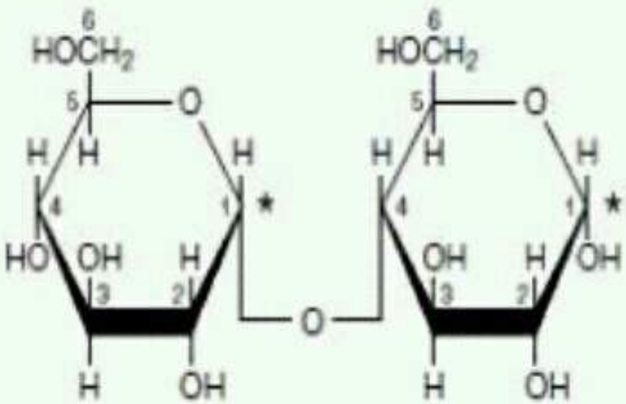
Glycoside Formation

- When hydroxyl group on the anomeric carbon of a monosaccharides reacts with an OH group of another carbohydrate or non-carbohydrate leads to glycosides formation.

- The bonds joining the monosaccharides are called glycosidic or glycosyl bonds.

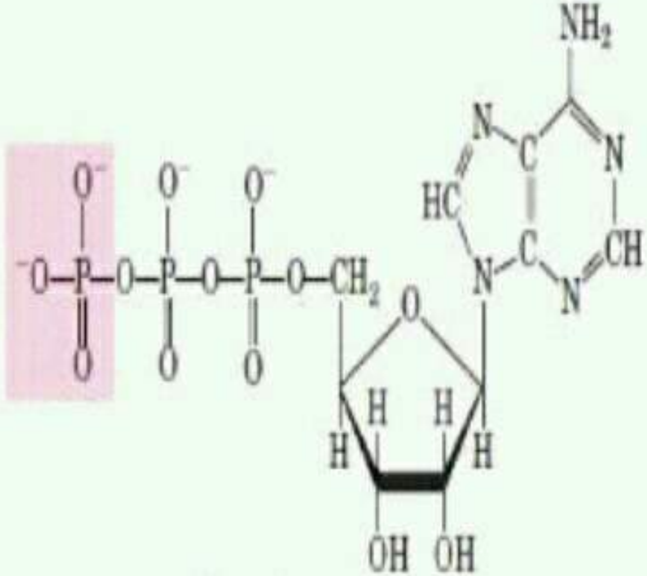
- There are two types of glycoside bonds:
  - O-glycosidic bonds
  - N-glycosidic bonds

O- and -N type of Glycoside Bonds



O-α-D-Glucopyranosyl-(1 → 4)-α-D-glucopyranose

O-type Glycoside Bond



P—P—P—Ribose—Adenine

N-Type Glycoside Bond

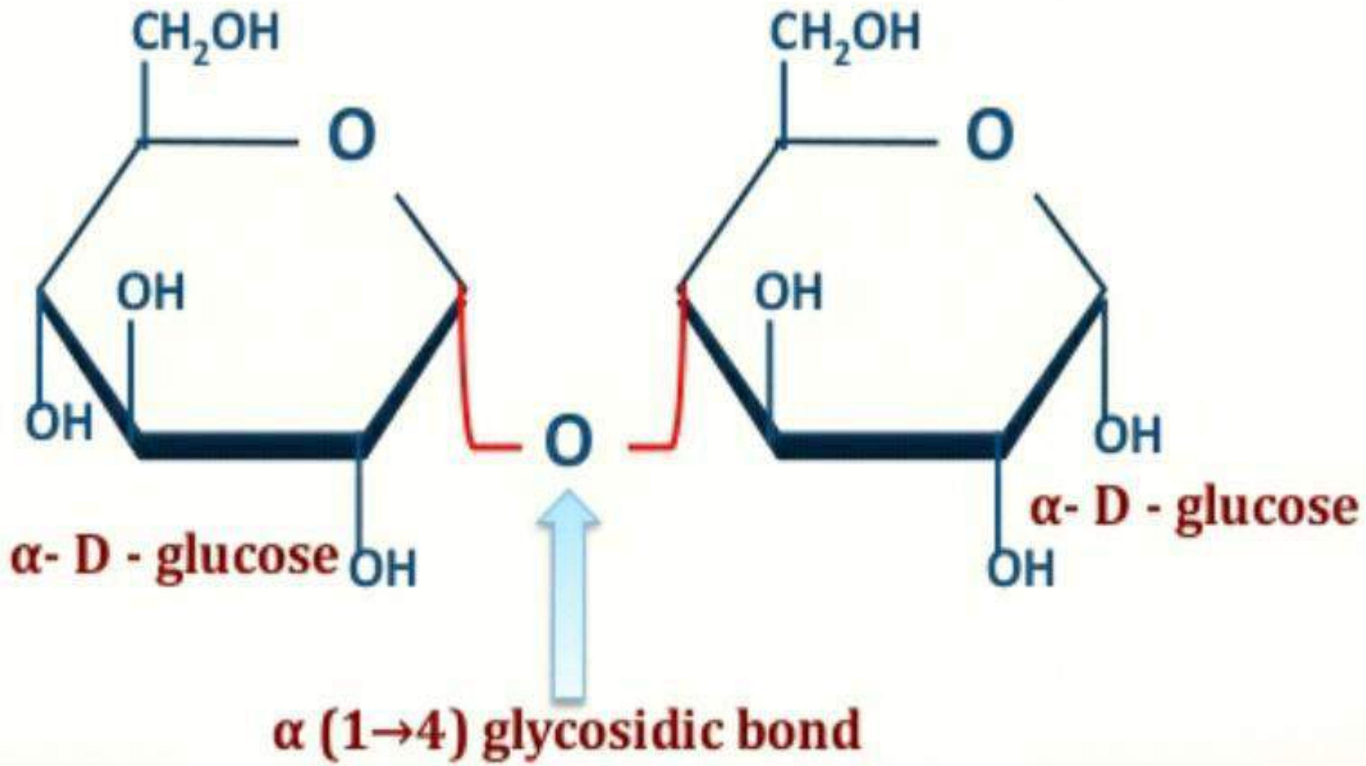
Disaccharide

- Consists of two monosaccharide units held by glycosidic bond.
- They are crystalline, water soluble, and sweet taste.
- They subdivide based on presence or absence of free reducing group into…
  - **Reducing disaccharides** with free aldehyde or keto gr
    - Example - Maltose and Lactose
  - **Non reducing disaccharide** without free aldehyde or keto gr
    - Example - Sucrose

Maltose

- It contains two moles of glucose units.
- They linked by α-(1-4) glycosidic linkage.
- It is a one of the reducing disaccharide, which has free functional group.

Maltose

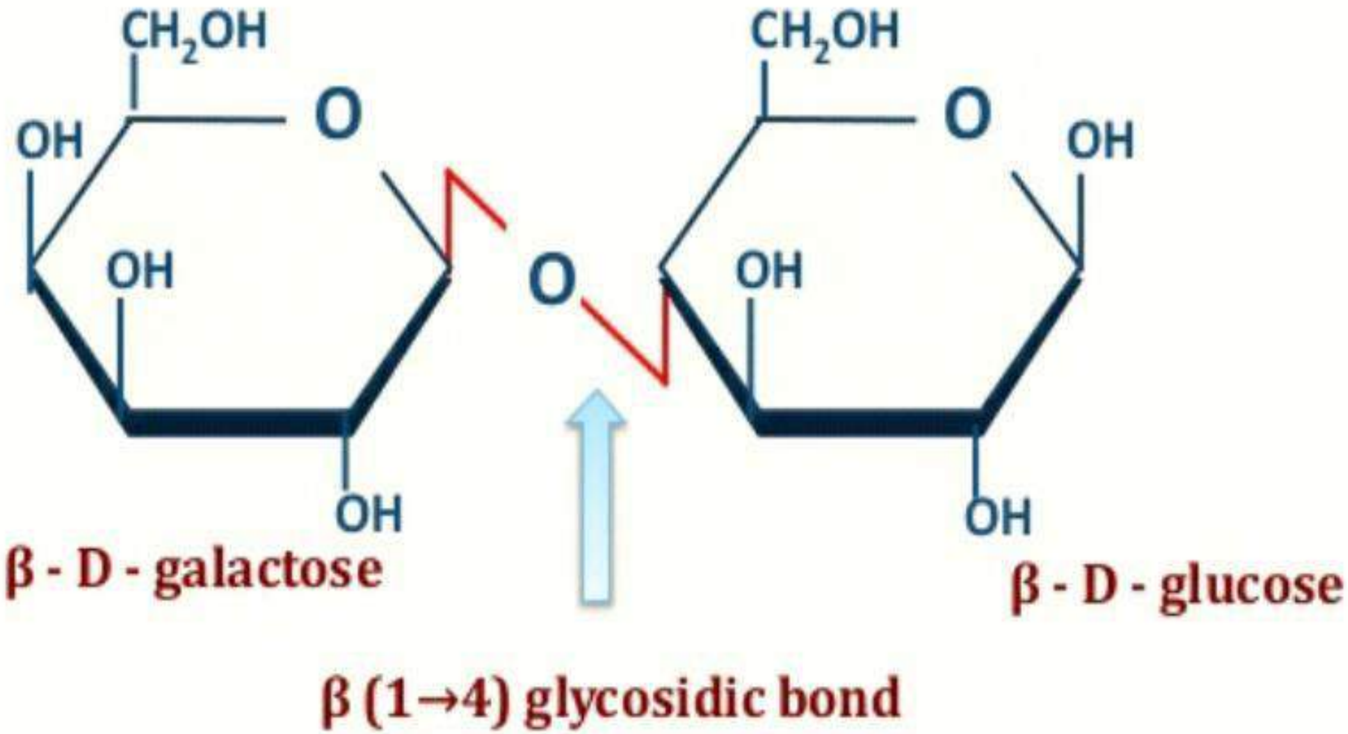


CH_2OH
O
OH
OH
α- D - glucose
OH
O
CH_2OH
O
OH
OH
α- D - glucose
OH
α (1→4) glycosidic bond

Lactose

- It is present in the milk sugar.
- It contains one mole of galactose and one mole of glucose that are linked by β-(1-4) glycosidic linkage.
- It is also a reducing disaccharide.
- It hydrolyzed into galactose and glucose by the enzyme lactase in human and by β-D-galactosidase in bacteria.
- It is the source of carbohydrates in breast fed infants.

Lactose

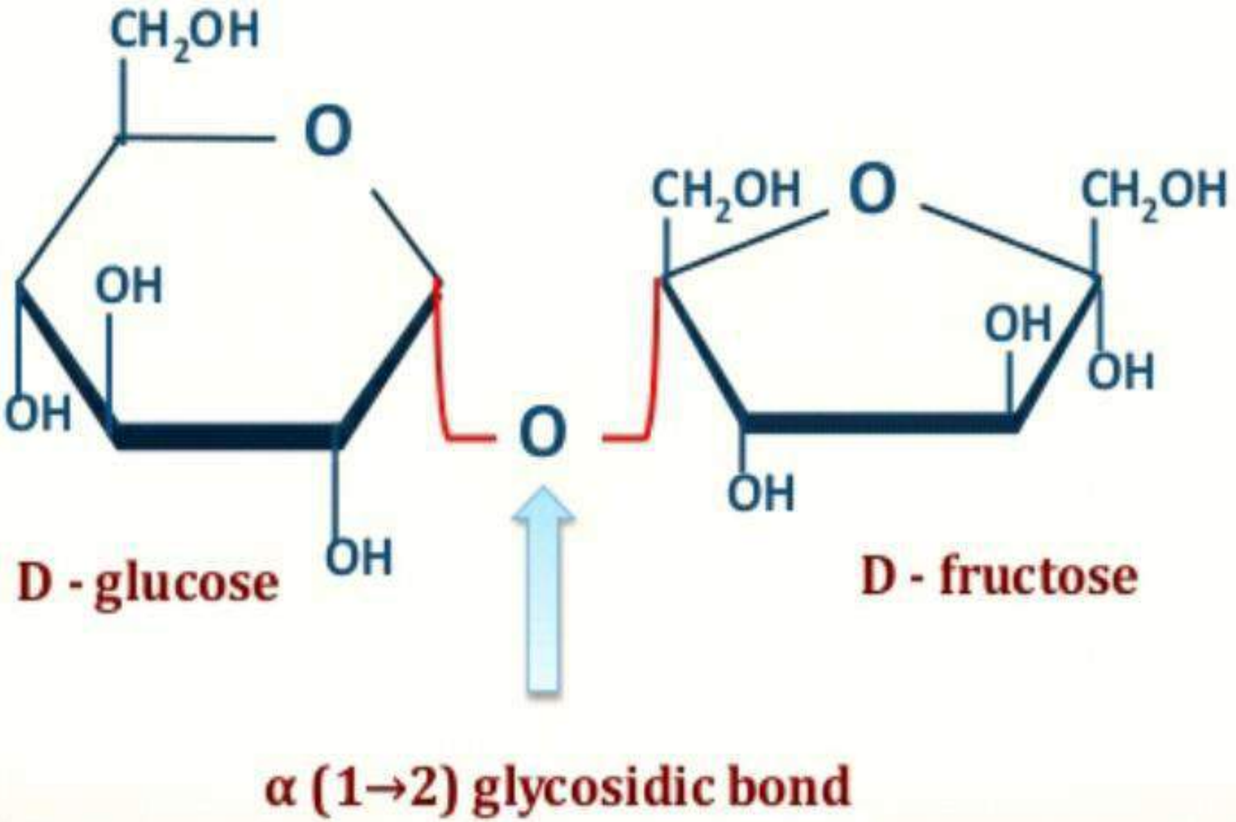


CH₂OH
O
OH
OH
OH
O
CH₂OH
O
OH
OH
OH
β - D - galactose
β - D - glucose
β (1→4) glycosidic bond

Sucrose

- It is commonly used table sugar and contributes some calories in the diet.
- It contains one mole of glucose and one mole of fructose that are linked by α-(1-2) glycosidic linkage.
- It is a non reducing disaccharide.
- It hydrolyzed into glucose and fructose by the enzyme Sucrase is also called as Invertase.

Sucrose


CH2OH
O
OH
OH
OH
D - glucose
O
CH2OH
O
CH2OH
OH
OH
OH
D - fructose
α (1→2) glycosidic bond