Carbohydrates

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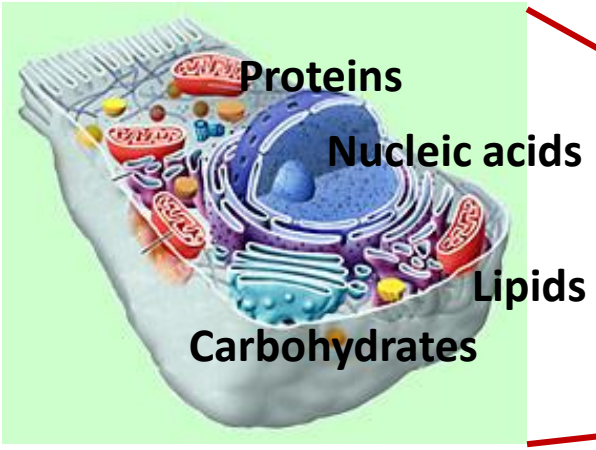
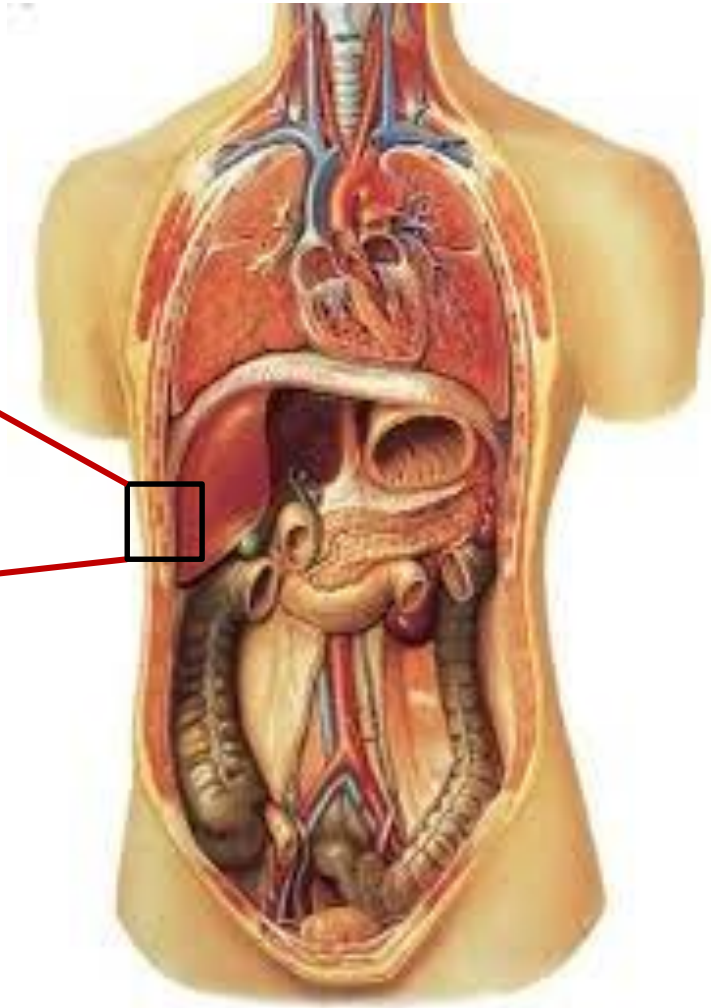
Major Types of Macromolecules





Classification of Carbohydrates

- Carbohydrates are "Sugars" or "Saccharides" consist of the empirical formula $(CH_2O)n$ where $n \geq 3$. → simplest sugar is $C_3H_6O_3$
- Empirical formula, Molecular formula, Structural formula

The simplest ratio between each type of atoms found in the molecule

Exact number of each type of atoms found in the molecule

Atomic conductivity
arrangement of the atoms
type of functional groups
Type of bonds

Carbohydrates

C

H2O

Classification of Carbohydrates

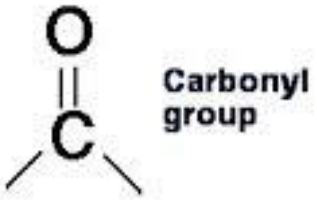
- Carbohydrates are "Sugars" or "Saccharides" consist of the empirical formula $(CH_2O)n$ where $n \geq 3$.
  - Monosaccharides: The basic units of CHO which cannot be hydrolyzed into smaller sugars like glucose, galactose and fructose
  - Disaccharides: contain two monosaccharides covalently linked by glycosidic bond like sucrose which consists of glucose and fructose

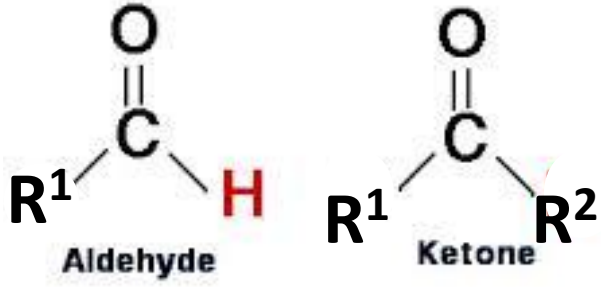
*linked by covalent bond

  - Polysaccharides: are polymeric molecules composed of long chains of monosaccharides linked together via glycosidic bonds like starch, cellulose and glycogen

Monosaccharides

- They are classified according to the number of carbon atoms: trioses, tetroses, pentoses, **hexoses** …..etc
- Also classified according to the chemical nature of the carbonyl group C=O either to Aldoses (the carbonyl group is an aldehyde) or Ketoses (the carbonyl group is a ketone)





Aldehyde: R^1 = H, alkyl or aryl

Ketone: R^1 and R^2 = alkyl or aryl

Monosaccharides

—the difference between the glucose and fructose is the functional group

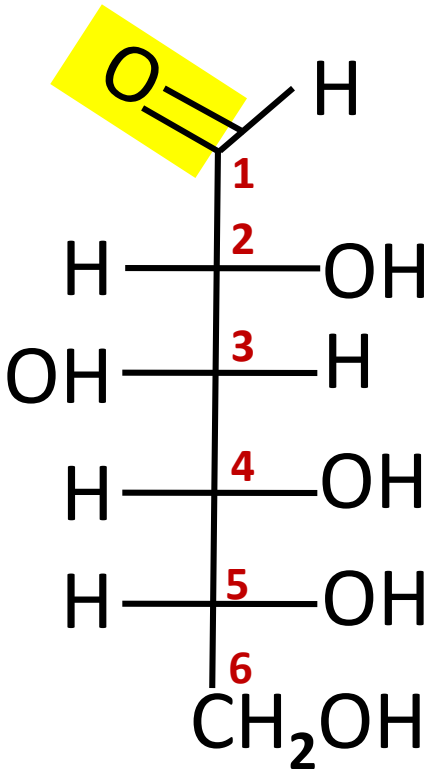
Aldehyde — Ketone

Hexose $C_6H_{12}O_6$

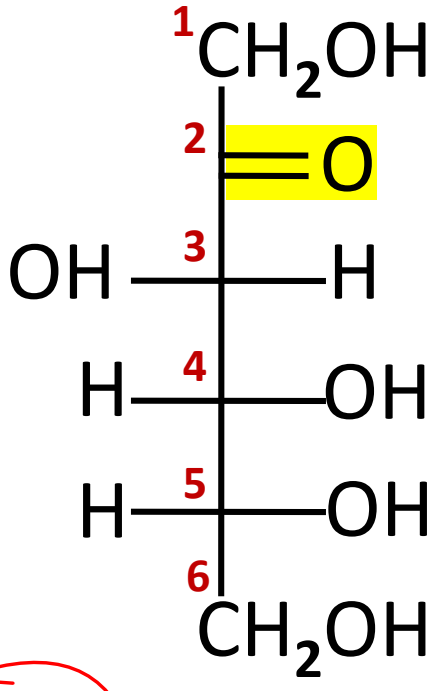
**If it's aldehyde we put the hydrogen Atom on carbon atom number 1

** If it is ketone we put the oxygen atom on carbon number 2

Hexoaldose\Aldohexose



Fischer projections



Hexoketose\Ketohexose

**Accumulation of the glucose leads to diabetus

D-glucose

"grape or blood sugar"

-Also it's found on original honey

- And it's the sweetest of all naturally occurring Sugar

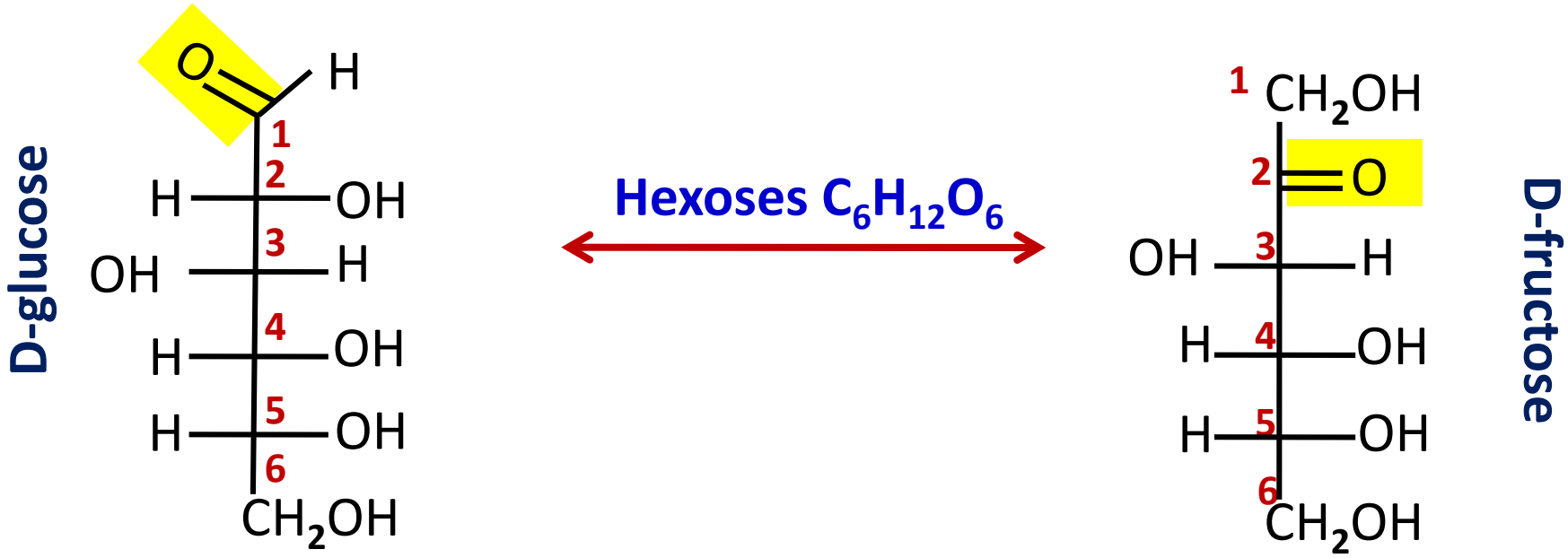
D-fructose

"fruit sugar"

Isomerization

- Isomers: are molecules with same molecular formula but different chemical structures

1. Constitutional (structural) isomers: atoms and functional groups bind together in different ways (e.g. glucose and fructose)



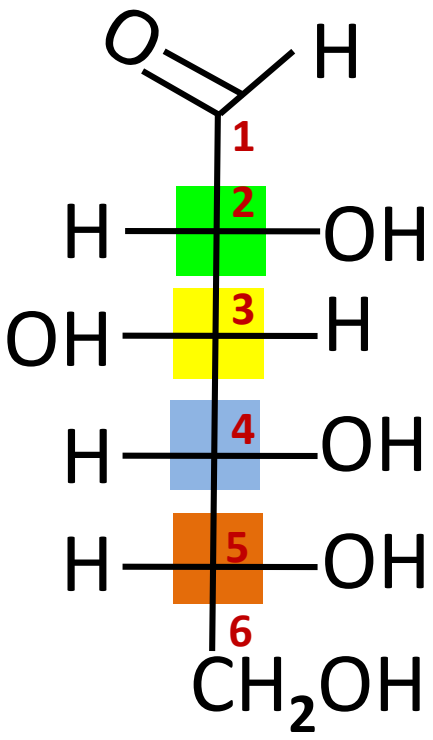
Isomerization

- **Isomers**: are molecules with same molecular formula but different chemical structures

1. **Constitutional** (structural) isomers: atoms and functional groups bind together in different ways (e.g. glucose and fructose)
2. **Stereroisomers** (spatial isomers): differ in the configuration of atoms in space rather than the order of atomic connectivity

   - **Chiral carbon**: asymmetric carbon atom attached to 4 different groups of atoms
   - The number of stereoisomers for any given molecules $= 2^n$ where n represents the number of chiral centers

Isomerization

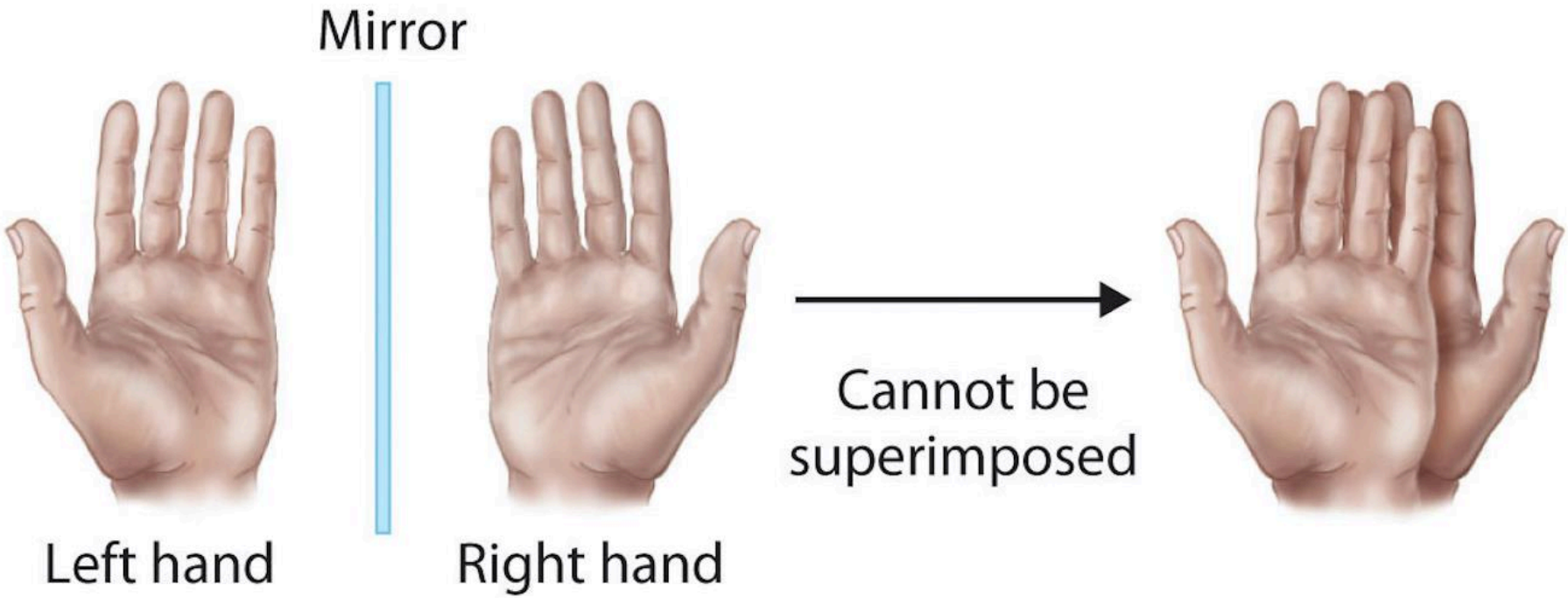


D-glucose

Number of stereoisomers = 2^4

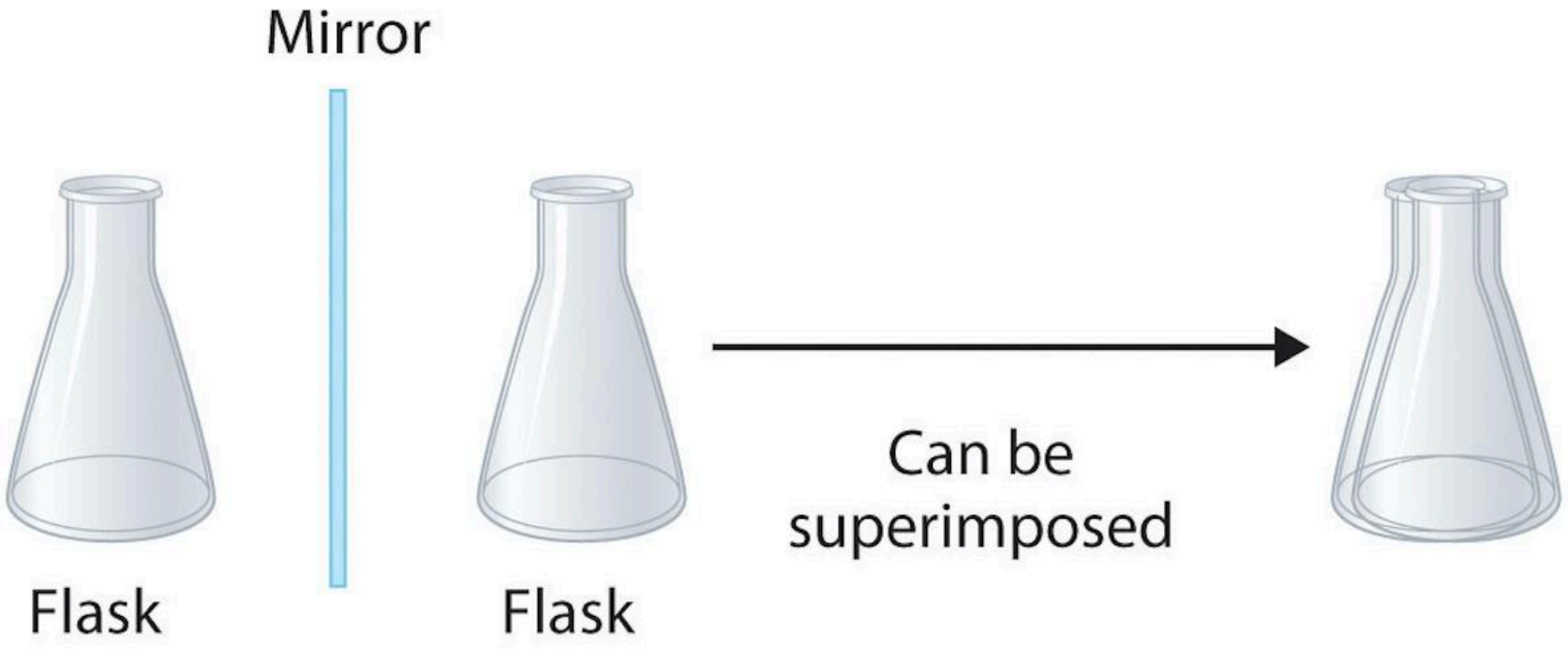
= 16

Chirality & Chiral Object



(a) Chiral objects

Chirality & Chiral Object



(b) Achiral objects

- Chiral molecules should contain at least one chiral center (**usually a carbon atom**)

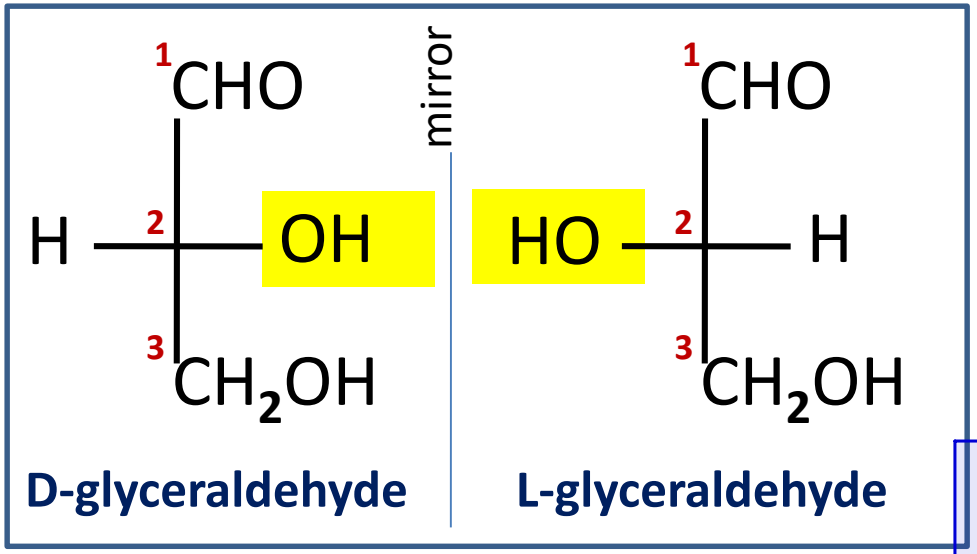
Stereoisomers

- Enantiomers: are two stereoisomers that are mirror images to each other but not superimposable

D/L Monosaccharides

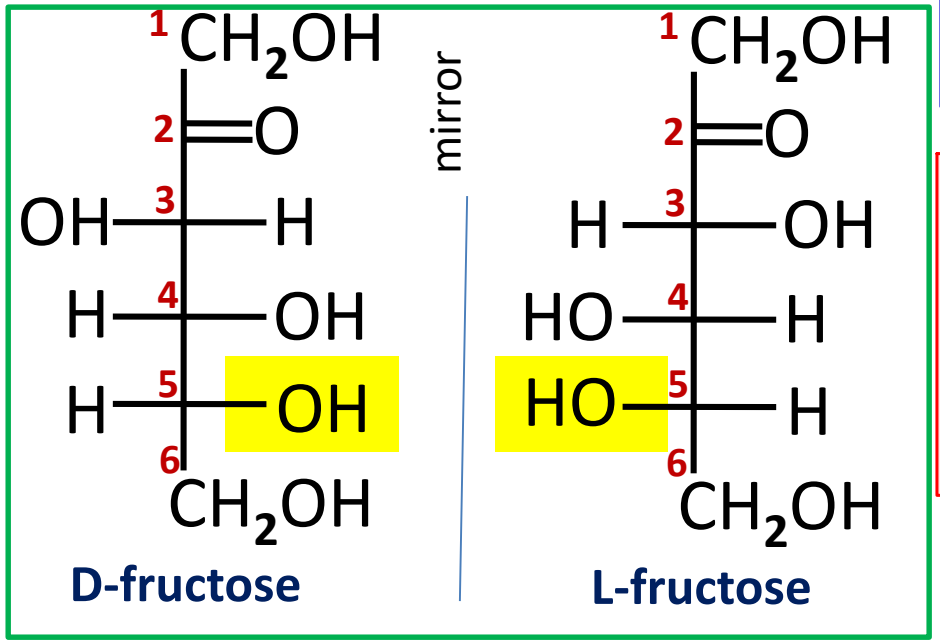
glyceraldehyde:- is the simplest sugar

*General rule:-
We chose D or L
According to the position of the hydroxyl group (OH) located on the chiral center, which is the farthest away from carbonyl carbon (Functional group)
It has the highest oxidation number



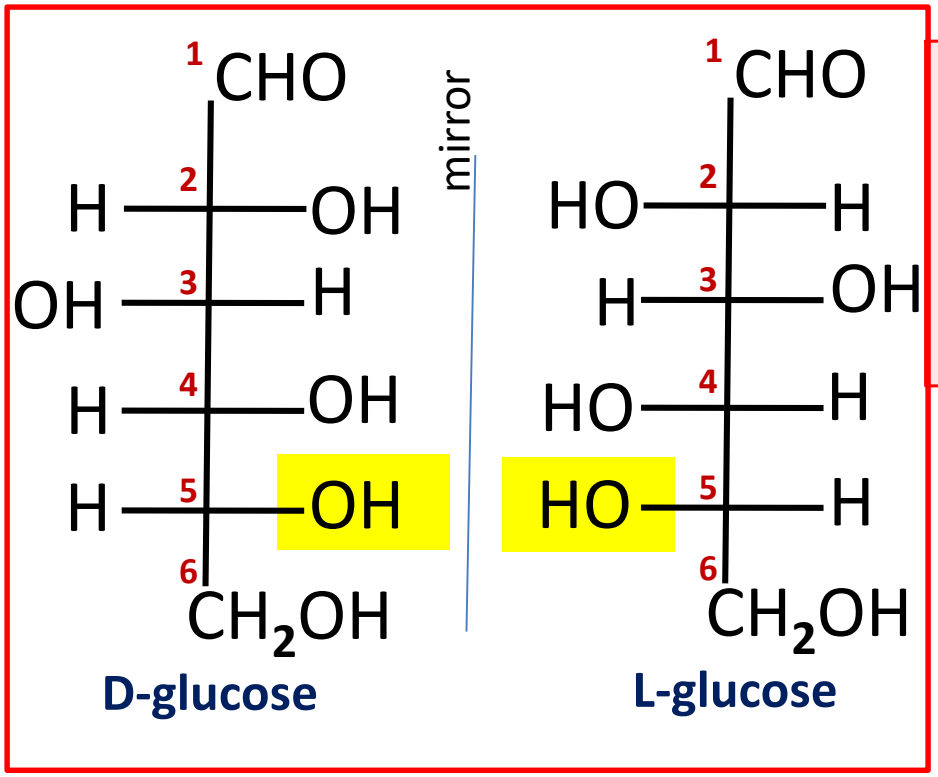
If the (OH) on the right it's D
If the (OH) on the lift it's L

-If we want to make a mirror images from enantiomers we have to change The position of ALL Chiral centers.



-Enantiomers is :- pairs of stereoisomers which are mirror to each other but not superimposable and they differ at the configuration Of the function of groups at ALL chiral centers

D/L Monosaccharides



Carbohydrates because it has **multiple hydroxyl group** and it's functional group is **aldehyde** or **ketone** we call it :-

1-**Polyhydroxy Aldehyde**

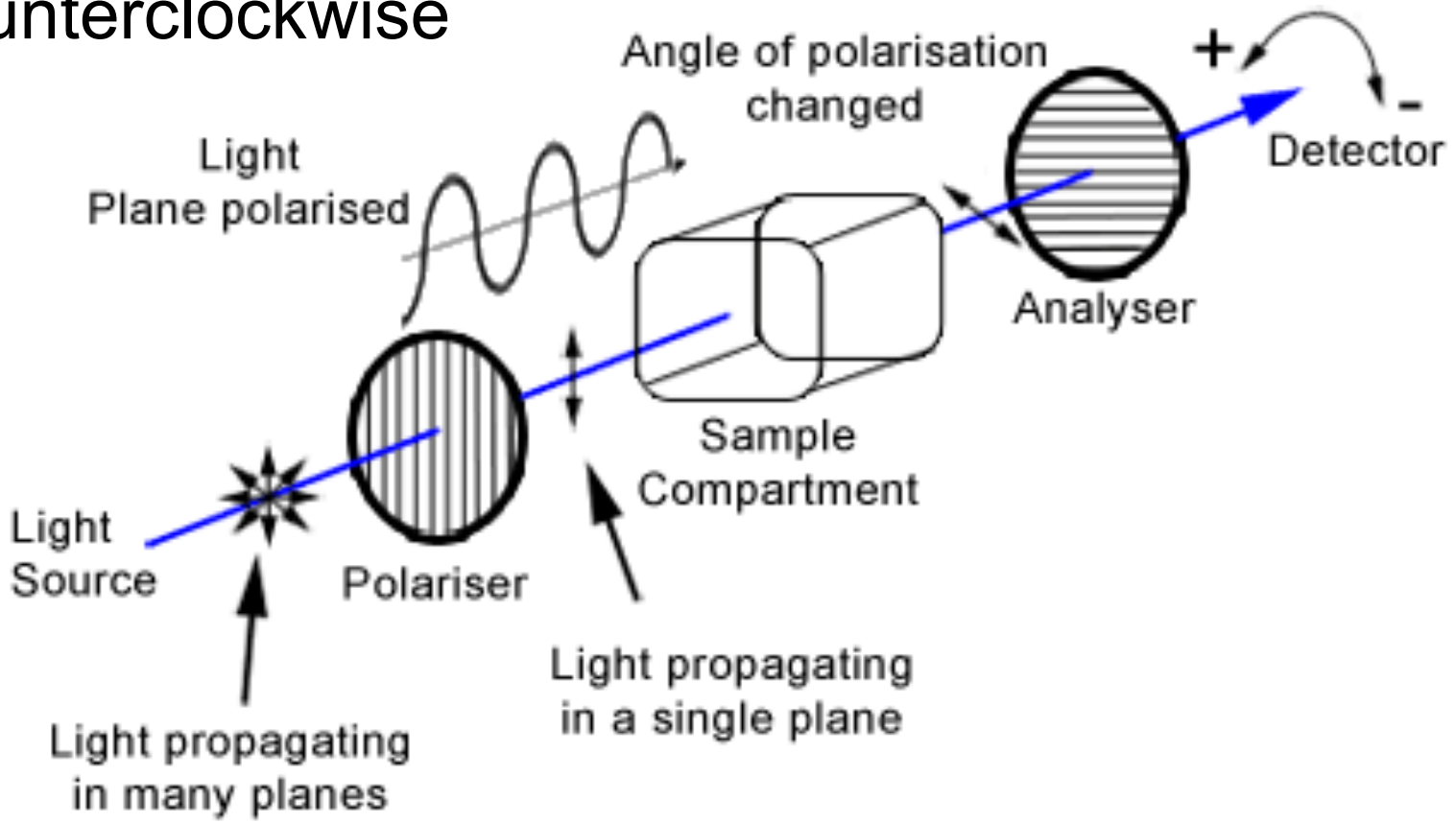
2-**polyhydroxy ketone**

Isomerization

- Enantiomers: are two stereoisomers that are mirror images to each other but not superimposable
- **D-** (dexter)/**L-** (laevus) Nomenclature system: commonly used to assign the configurations in sugars and amino acids
  - As a rule of thumb: if the farthest chiral atom from the highest oxidized carbon (i.e. carbonyl group) has –OH group on the right-hand side, the configuration is assigned as **D** but If it is on the left-hand side, the sugar is designated as **L**
- Most naturally occurring sugars are D-isomers (biologically active form)

Monosaccharides

- Enantiomers are optically active and can rotate the polarized light plane either clockwise or counterclockwise

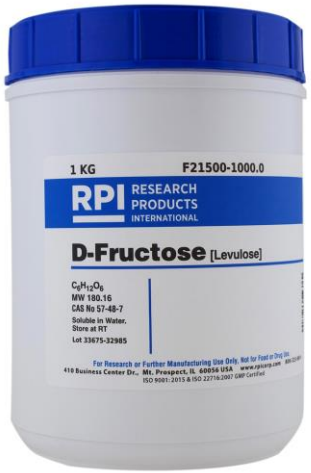


Monosaccharides

- Enantiomers are optically active and can rotate the polarized light plane either clockwise or counterclockwise
  - (+)/(-) nomenclature system: if one enantiomer rotates the light clockwise, it is labeled (+) or (*d*) (dextrorotatory). The second mirror image enantiomer is labeled (-) or (*l*) laevorotatory [(+)D-glucose, (*d*)D-glucose]
  - by chance, it was found that D-glyceraldehyde is in fact the dextrorotatory isomer.
  - D/L system should not be confused with +/- or *d*/l system. For example, D-fructose (laevulose) is levorotatory whereas D-glucose (dextrose) is dextrorotatory.

Monosaccharides

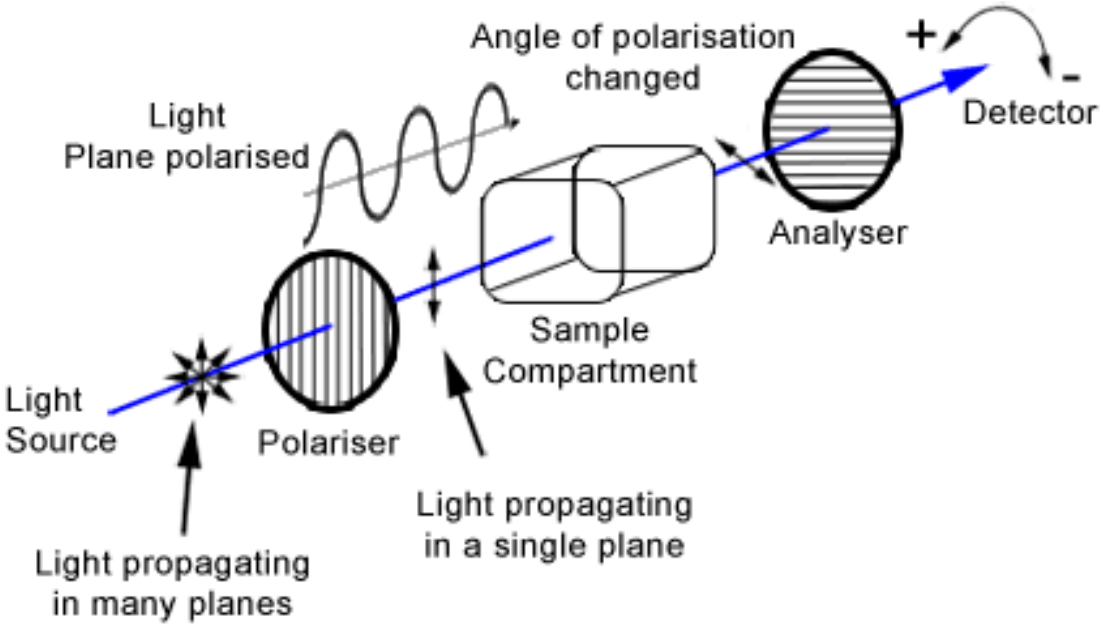
**The reason why GLUCOSE it's commercial name is DEXTROSE is when we put it in the polarimeter it rotates to the right while the FRUCTOSE it's commercial name is LAEVULOSE because it Rotates to the left when we put it in the polarimeter.



- **Dextrose** is the commercial/trade name of **D-glucose**
- **Laevulose** is the the commercial name of **D-fructose**

Monosaccharides

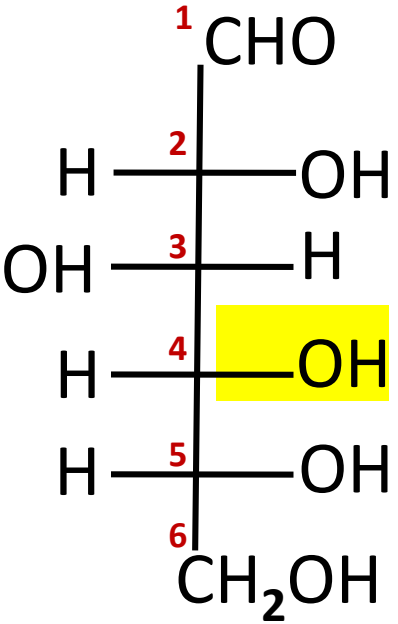
- Enantiomers are optically active and can rotate the polarized light plane either clockwise or counterclockwise



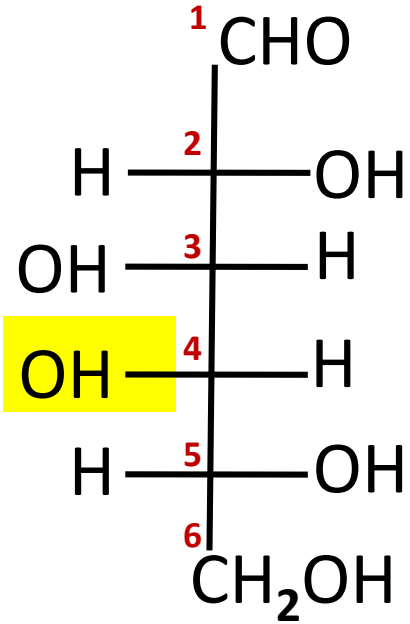
- **Racemic mixture** contains equal amounts of each enantiomer (net rotation is zero)

Monosaccharides

- Epimers: are stereoisomers that differ in the configurations of atoms at **only** one chiral center (i.e. chiral carbon in CHO). They are not mirror image isomers.

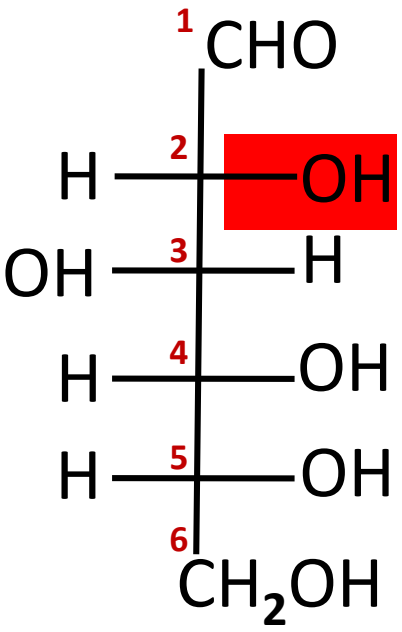


D-glucose

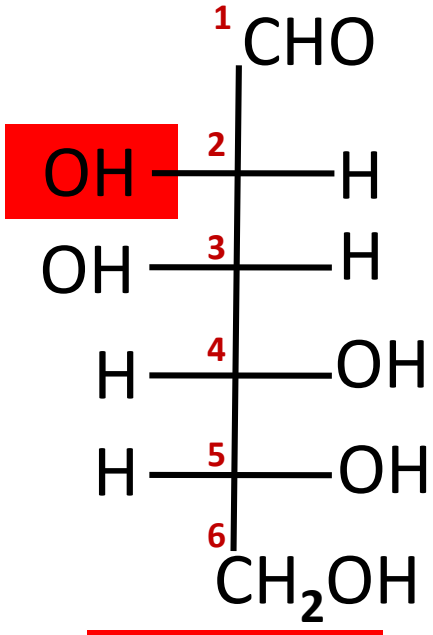


D-galactose

Monosaccharides



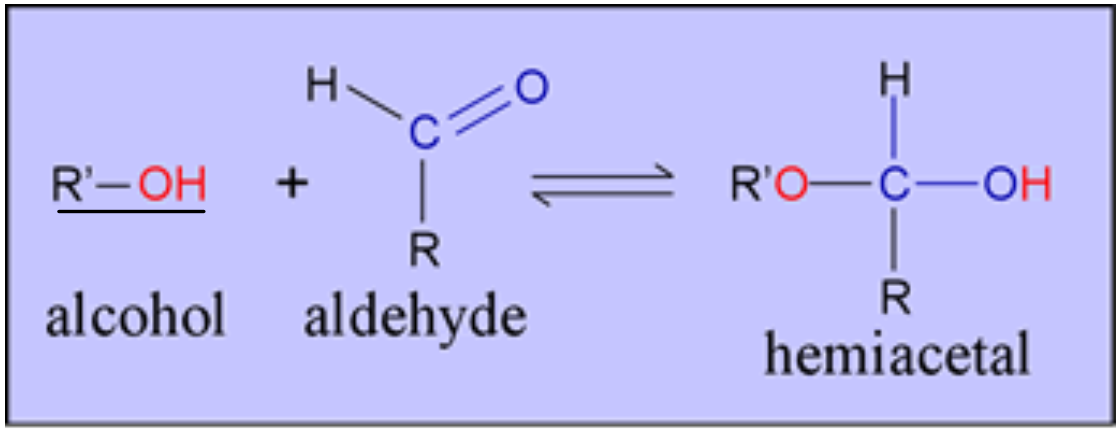
D-glucose

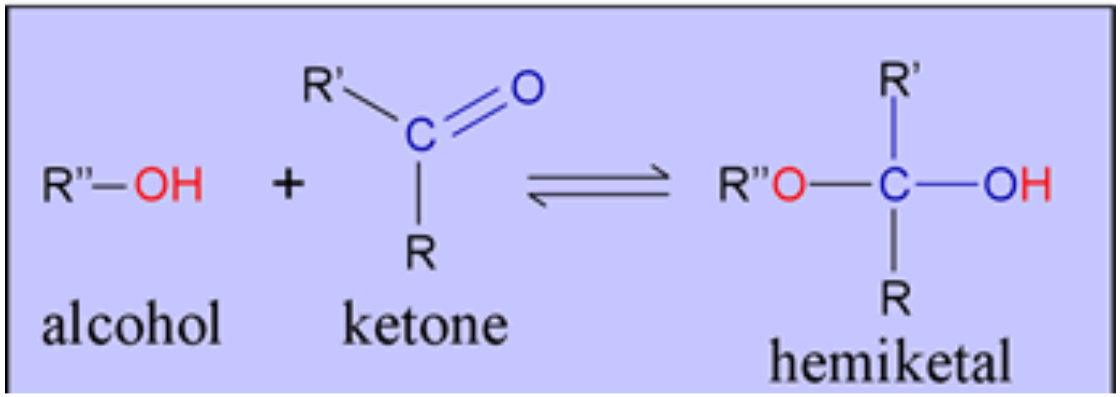


D-mannose

- Glucose and galactose are C4 epimers while glucose and mannose are C2 epimers

Hemiacetal & Hemiketal



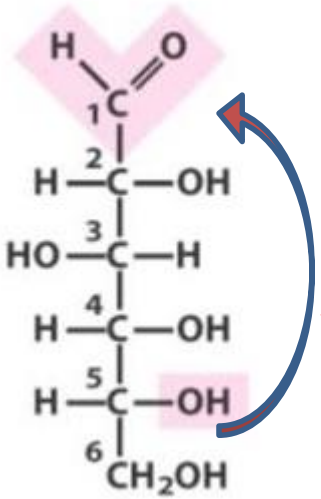


**The mechanism of this reaction :- in the alcohol the bond between the Oxygen and hydrogen in the hydroxyl bond Will be broken in the another hand The double bond on the aldehyde will also be broken to provide space for the coming visitors which are the hydrogen and oxygen with R So it will from something we call :- HEMIACETAL & HEMIKETAL

Monosaccharide cyclization

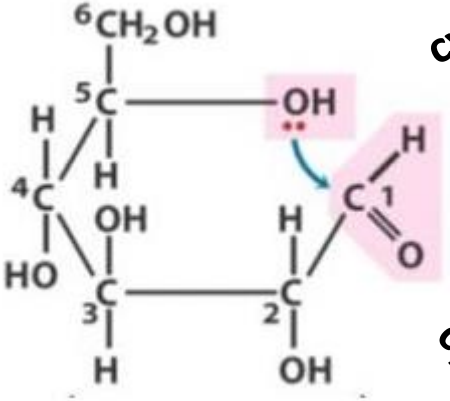
—We look at the configuration of the OH group that is linked with the Anomeric carbon:
if it points down with The opposite direction with the C6 it's :- ALPHA (α)
If it points up with the same direction with the C6 it's :- BETA (β)

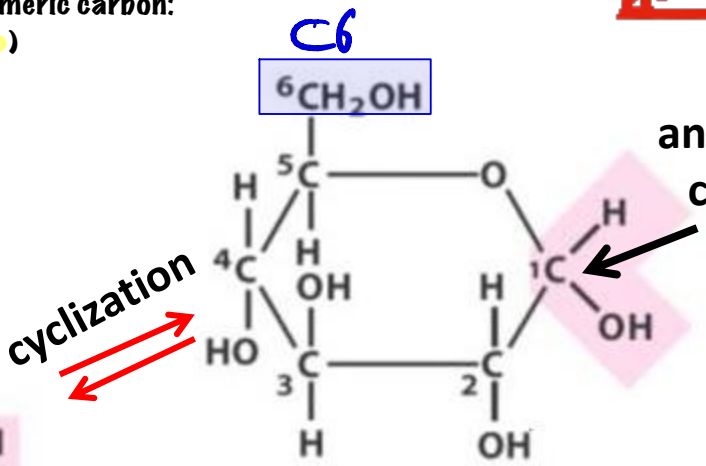
Linear form



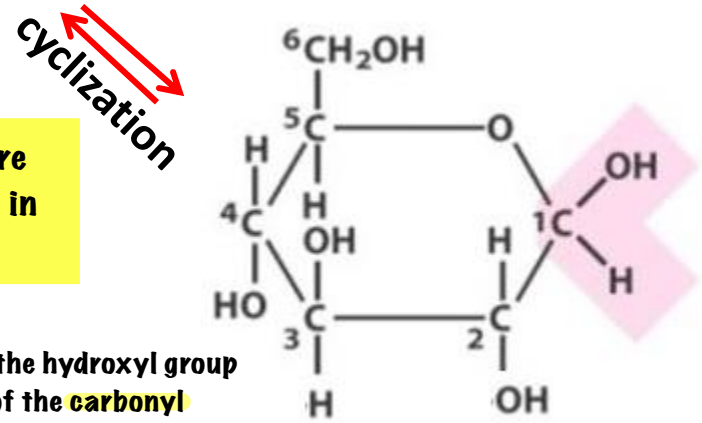
D-glucose

Fisher projection





α-D-glucose



β-D-glucose

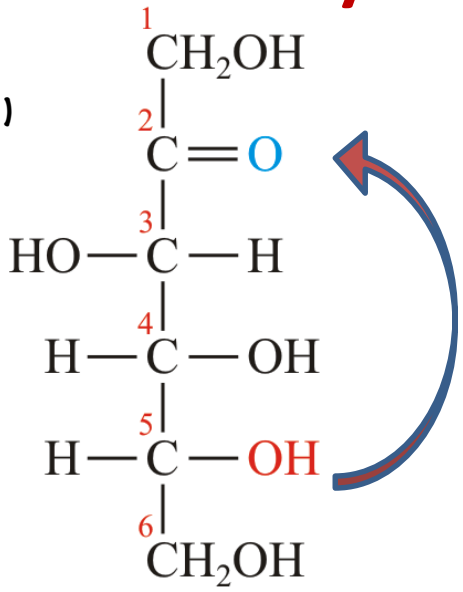
Haworth projection

* sugars in our bodies are found in cyclic form not in the linear form

The mechanism of cyclization: The bond between hydrogen and oxygen in the hydroxyl group with carbon number five is broken then the hydroxyl oxygen Will attack of the carbonyl carbon and provide space for the new coming hydroxyl oxygen, the double bond will be broken (providing space) then the bond will form between C1 with the oxygen and the hydrogen formed Hydroxyl group with the oxygen that was already connected to the C1

Monosaccharide cyclization

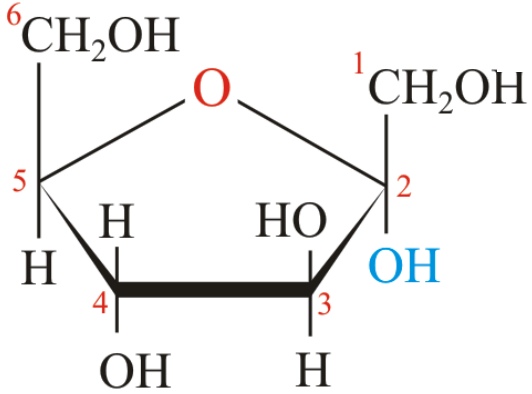
—What is fate of the carbonyl carbon?
It will become anomeric carbon (chiral center)
****
— what is the fate of hydroxyl oxygen?
It will become ether
****
— what is the fate of the carbonyl oxygen?
It will become hydroxyl group (OH) alcohol



D-fructose
Linear form

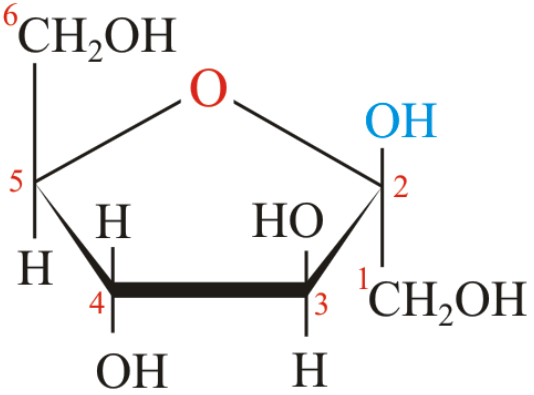
cyclization

cyclization



α-D-fructose

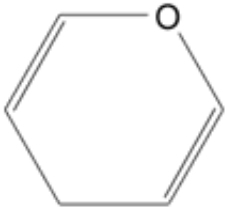
#cyclization of the Faructose will Form 5 member rings while glucose will Form 6 member rings



β-D-fructose

Pyranoses & Furanoses

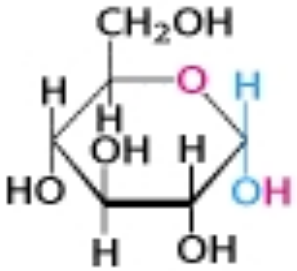
- Sugars with six-membered rings are known as pyranoses (e.g. glucopyranose) as they resemble the heterocyclic compound pyran.



Pyran

**We named it HETERO
Because it's mixture between carbon and oxygen

**The most common type of carbohydrates in the human body is Six-membered rings and five-membered rings

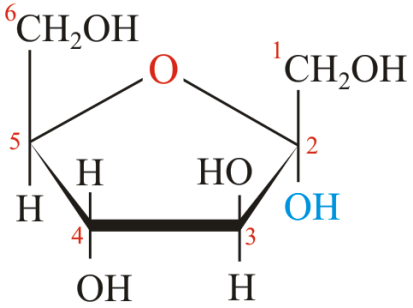


α-D-glucopyranose

- Sugars with five -membered rings are known as furanoses (e.g. fructofuranose) as they resemble the heterocyclic compound furan.

Furan

anomeric carbon

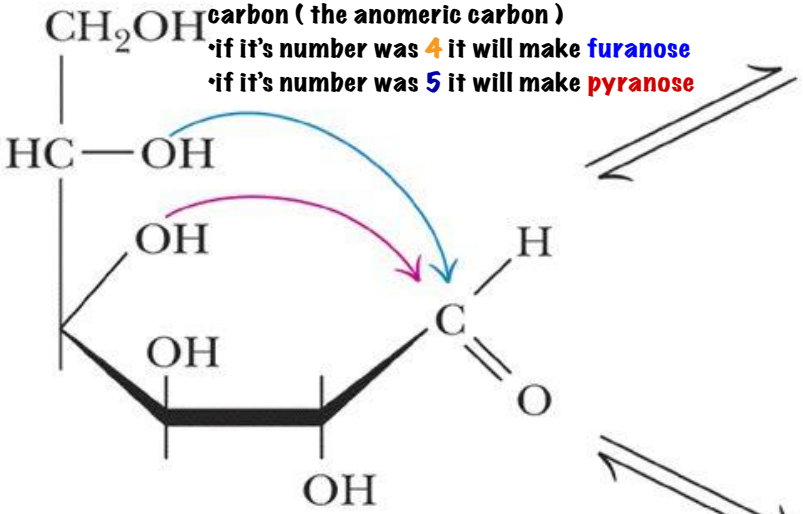


α-D-fructofuranose

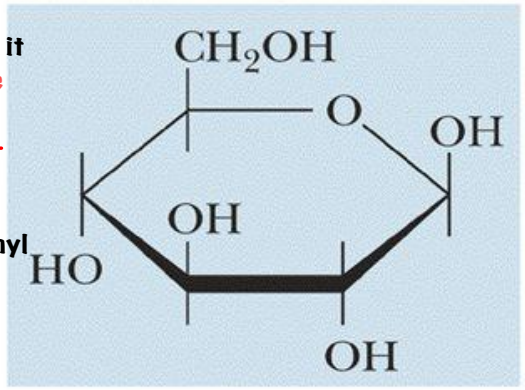
Pyranoses & Furanoses

**you can recognize the carbohydrate if it's glucose or fructose and that's done by:
• in glucose the anomeric carbon number is 1 and it has hydrogen and hydroxyl group on it
•while in fructose the anomeric carbon number is 2 and it has side chain looks like R-side chain but with hydroxyl group on it

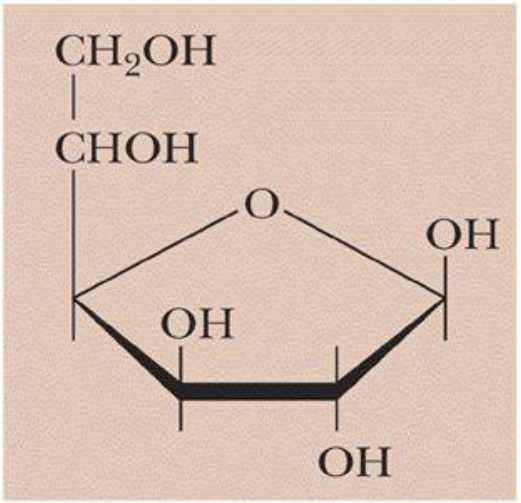
•Sugars can form both pyranose and furanose that depends on the number of the carbon atom ,that is linked with hydroxyl group, which attacks the carbonyl carbon (the anomeric carbon)
•if it's number was 4 it will make furanose
•if it's number was 5 it will make pyranose



D-Glucose



Pyranose form
β-D-glucopyranose



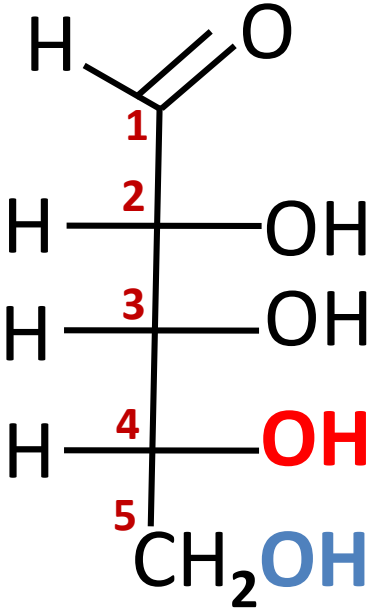
Furanose form
β-D-glucofuranose

D-glucose can cyclize in two ways forming either furanose or pyranose structures

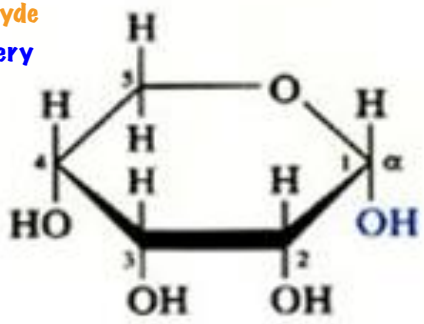
Pyranoses & Furanoses

- **Ribose**:-

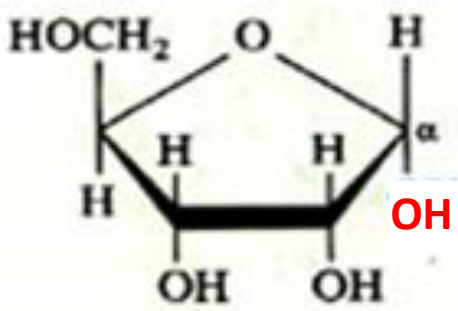
is an example of aldoese sugar because it has aldehyde group and it's also pentoses (5 carbon atoms) every hydroxyl group is on the right side



D-ribose
Fisher projection



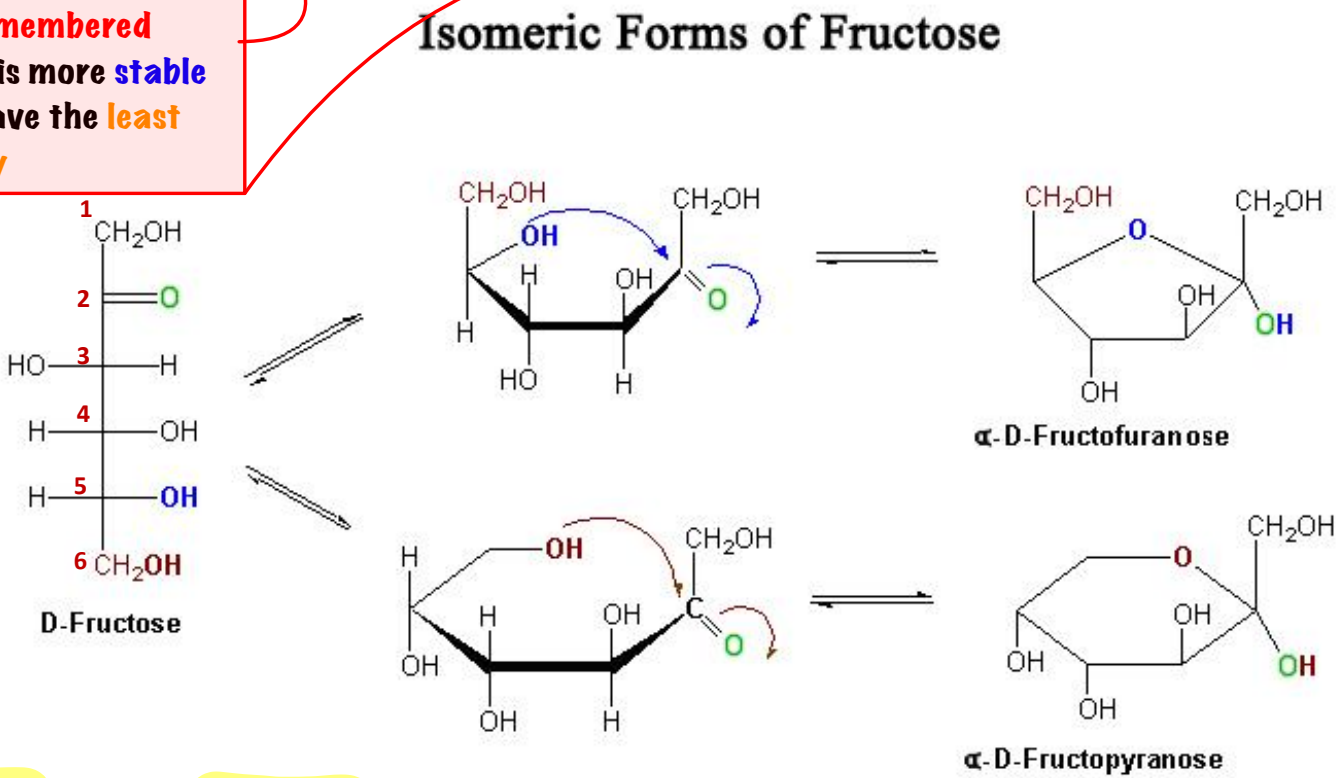
α-D-Ribopyranose
(Haworth projection)



α-D-Ribofuranose
(Haworth projection)

Pyranoses & Furanoses

- 5&6 membered rings: is more stable and have the least energy



6 carbon Atoms

5 carbon Atoms

- Hexose or pentose can exist in pyranose and furanose forms (the most stable rings).
- e.g in solution, glucose and fructose are mostly pyranoses whereas ribose is mostly furanose

Anomers

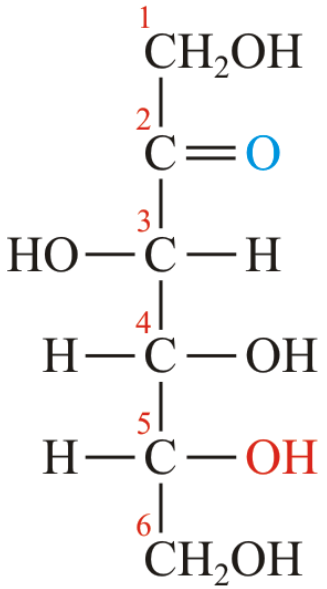
- In cyclic sugars, the carbonyl carbon becomes a chiral center (asymmetric carbon) with two possible configurations: α and β. This new carbon is called anomeric carbon.
- Anomers are pair of stereoisomers that differ in spatial arrangement of atoms at the anomeric carbon. In α-anomer, the OH group of the anomeric carbon is projecting down the plane of the ring and on the opposite side of the terminal CH_2OH group (in Fisher projection) and vise versa in β-anomer.
- The anomers freely interconvert in aqueous solution, e.g. at equilibrium D-glucose is a mixture of β-anomer (63.6%), α-anomer (36.4%) and extremely tiny amounts of the straight chain.

Deleted

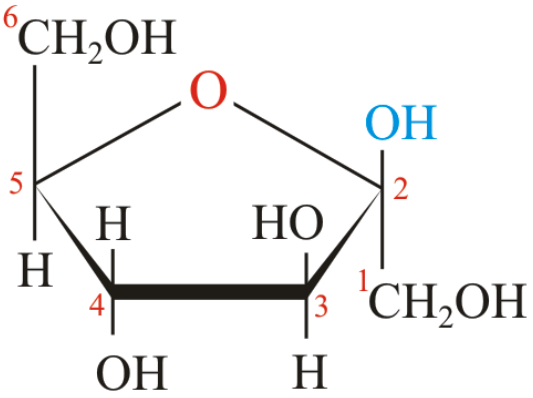
Haworth Projection

- Haworth projection is a simple 3D way to represent the cyclic monosaccharides. The OH groups on the right-hand side of Fisher projection are down in Haworth projection and vise versa. The dark line indicates atoms that are closer to the observer.

Fisher projection



D-fructose



β-D-fructose

Haworth projection

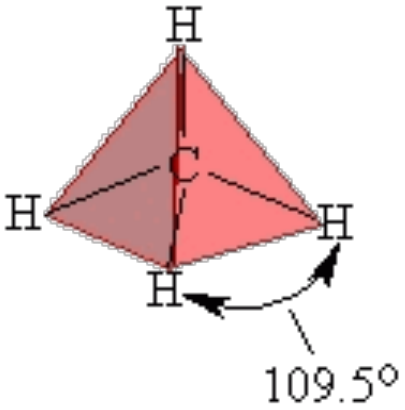
Cyclic form of sugar

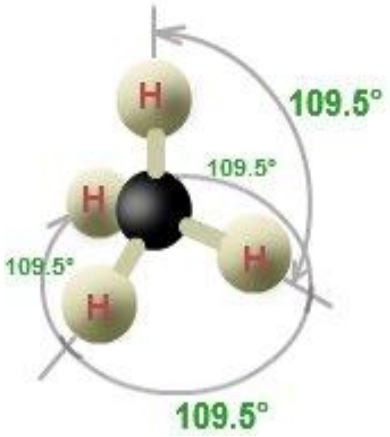
Conformers

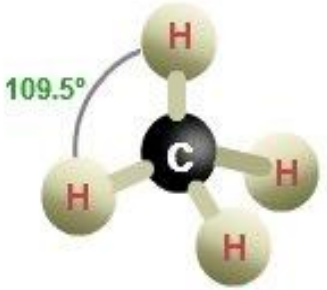
- The geometry of the carbon atoms of monosaccharide ring is tetrahedral (bond angles are close to 109.5º), so sugar rings are not actually planar. For example, pyranoses take on either **Chair** or **Boat** conformations (conformational isomers or conformers).

**what causes the stereoisomers on conformes? It's caused by the rotation around single bonds either boat or chair

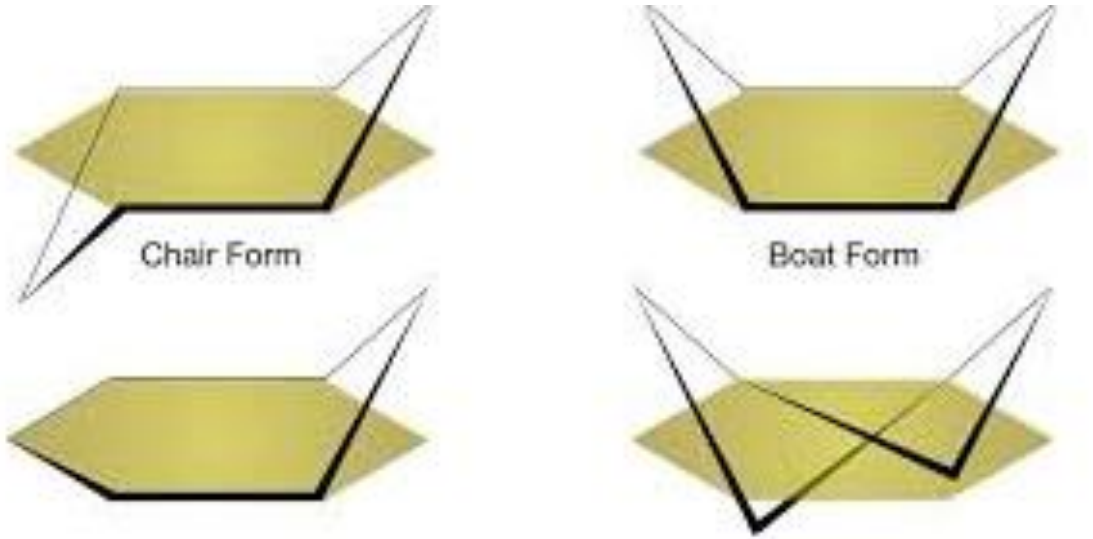
Conformers







Carbon atoms are tetrahedral



Conformers are stereoisomers with different rotations about single bonds

Chair is more stable than the boat
The reason why is the rotation

Conformers

Steric repulsion: is repulsion between electrons that are found on atom which are very closer to each other

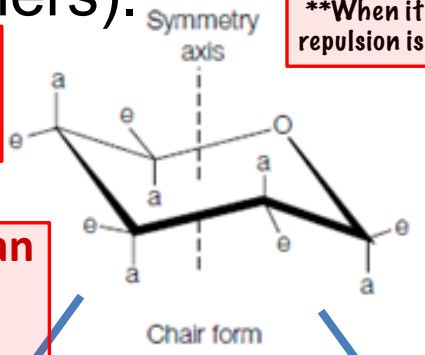
Bulk group is the atoms or functional groups or both that links with the carbon atom

-Axial: means it points up or down the plan of the ring outer
-equatorial : means this bond goes with the same plan of the ring

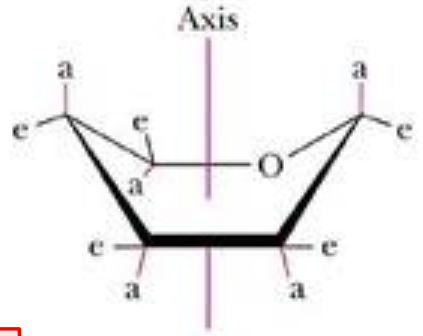
- The geometry of the carbon atoms of monosaccharide ring is tetrahedral (bond angles are close to 109.5º), so sugar rings are not actually planar. For example, pyranoses take on either **Chair** or **Boat** conformations (conformational isomers or conformers).

more stable means Less energy

**When it's equatorial the steric repulsion is less than when it's axial



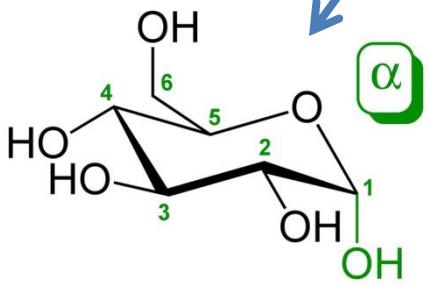
a: axial
e: equatorial



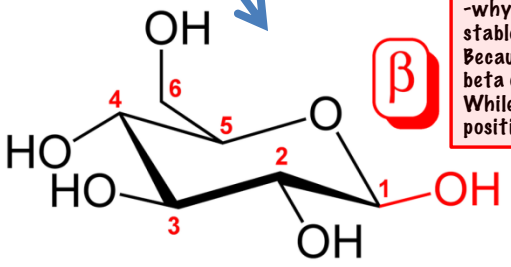
α is Less stable than β due to steric repulsion

*when the steric repulsion is high the energy between the molecules also will be high and that causes Instability

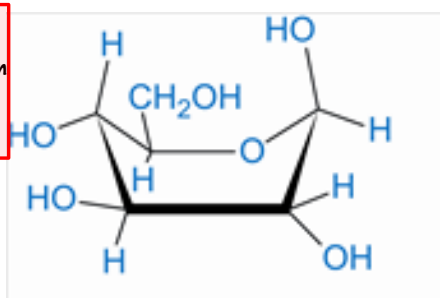
-why the β-D-glucose is more stable than α-D-glucose? Because the hydroxyl group on beta on equatorial position While In alpha it's on axial position



Chair form of α-D-glucose



Chair form of β-D-glucose



Boat form of β-D-glucose

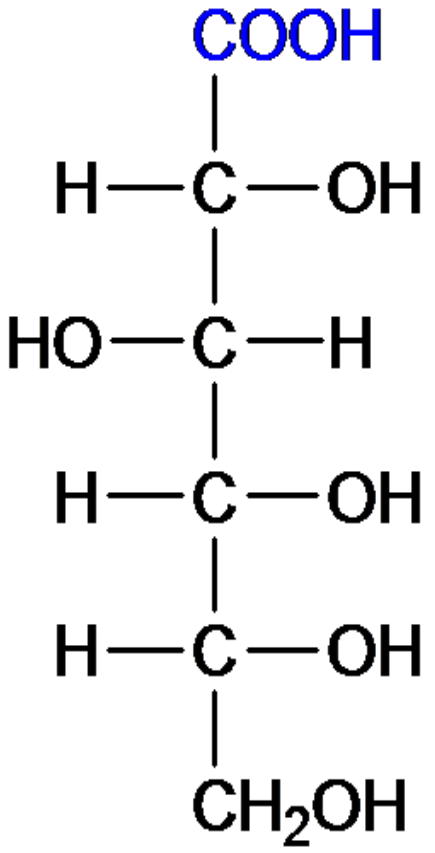
Sugar Modification

From aldehyde to carboxylic acid

1. **Aldonic acids** : oxidation of aldehyde (C1) to carboxylic acid; e.g. D-gluconic acid

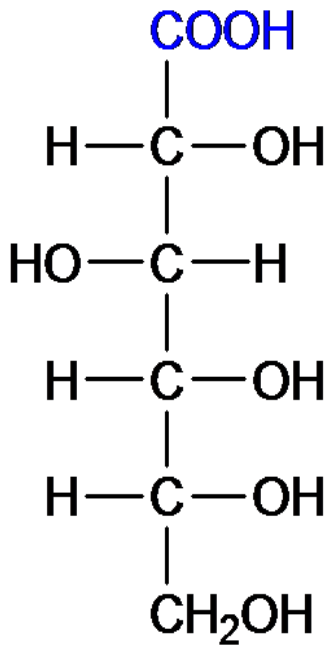
- **Uses:**
  - Some drugs are injected in the form Of **gluconate** (the salt of gluconic acid)
  - **Calcium gluconate solution (I.V)** as cardioprotective agent in patients with high blood level of K^+

** For people who had kidney failure we use calcium gluconate solution to reduce the high blood level of K^+

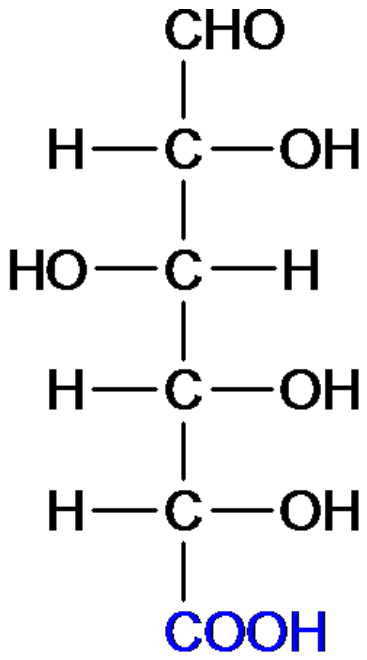


Sugar Modification

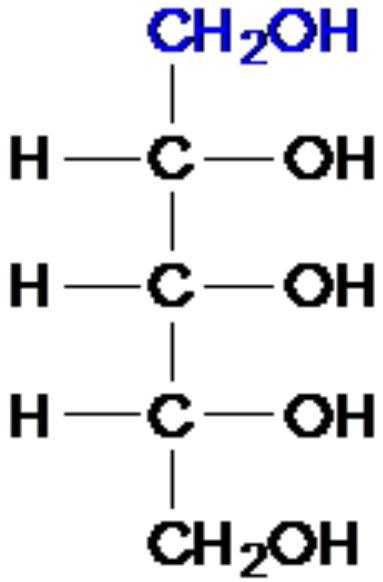
1. **Aldonic acids**: **oxidation** of aldehyde (C1) to carboxylic acid; e.g. D-gluconic acid



2. **Uronic acids**: **oxidation** of OH at (C6) to carboxylic acid; e.g. D-glucuronic acid



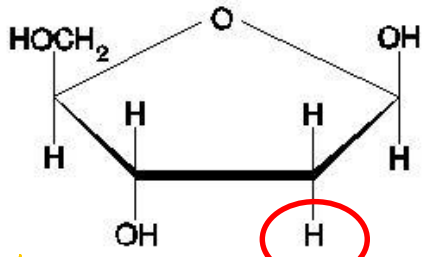
3. **Alditols**: **reduction** of carbonyl group to alcohol; e.g. D-ribitol, D-glycerol and D-sorbitol (sweetener)



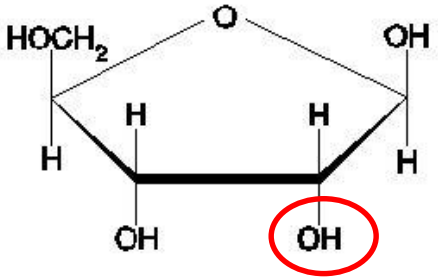
D-ribitol

Sugar Modification

4. **Deoxy sugars : OH group is replaced by H; e.g. β-D-2-deoxyribose**

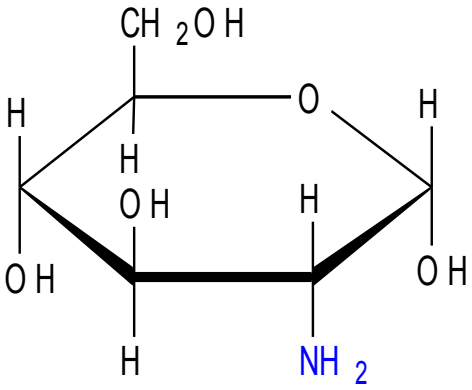


DNA ← **Deoxyribose**

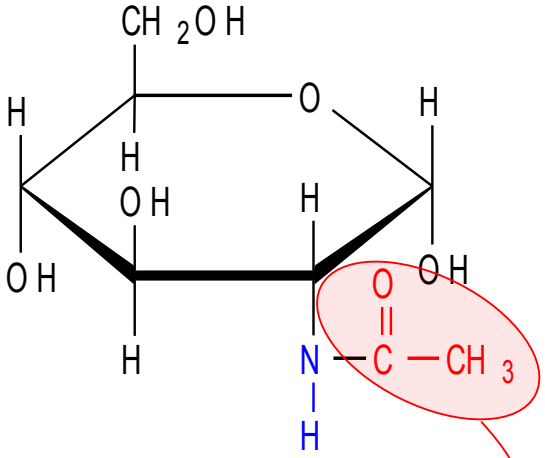


RNA ← **Ribose**

4. **Amino sugars : one or more OH groups are replaced by amino group which is often acetylated; e.g. α-D-glucosamine (rebuild cartilage in osteoarthritis & osteoporosis) and α-D-N-acetylglucosamine (both are derivatives of of α-D-glucose)**



α-D-glucosamine



α-D-*N*-acetylglucosamine

acetylated