Carbohydrates

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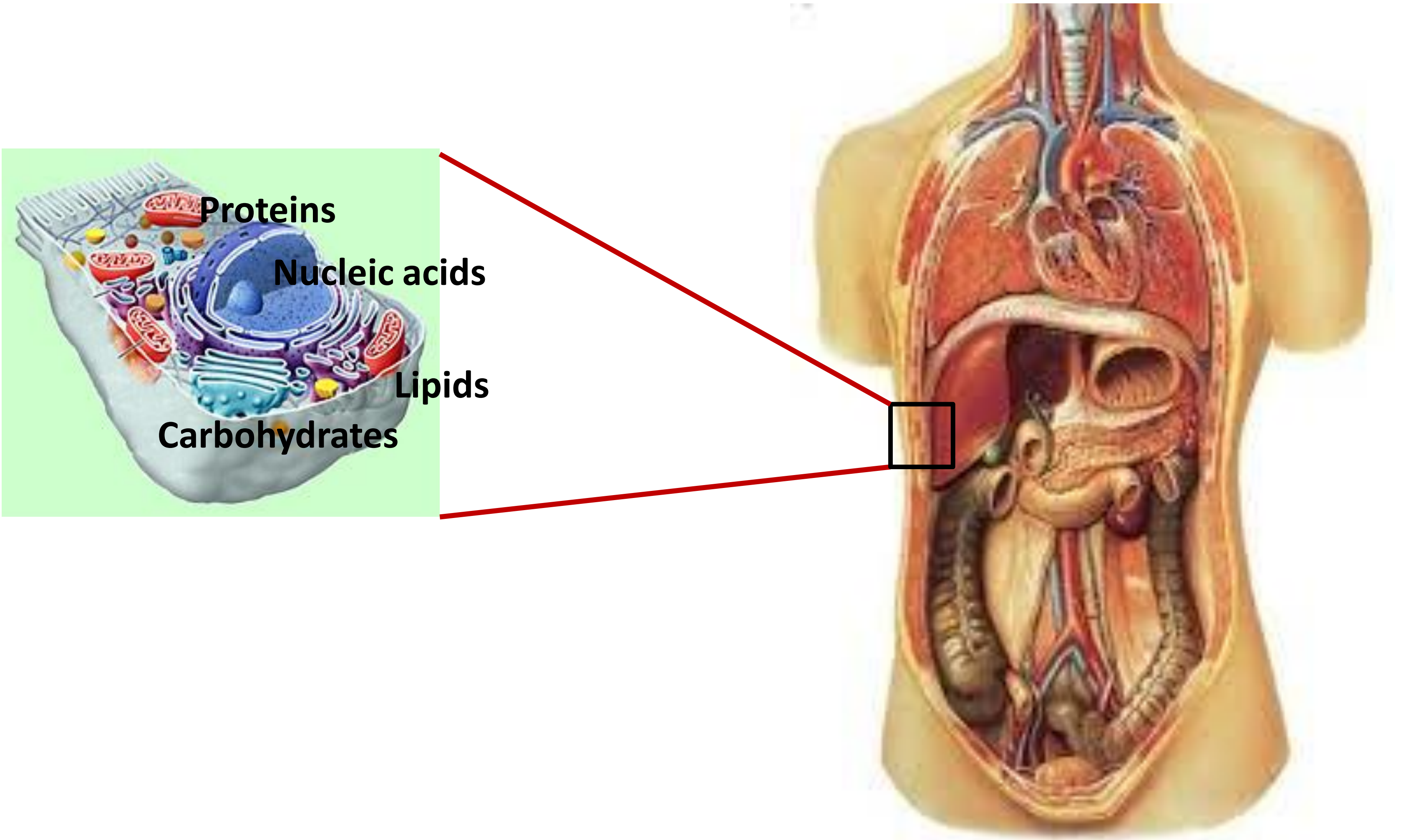
Major Types of Macromolecules



Classification of Carbohydrates

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

Carbohydrates

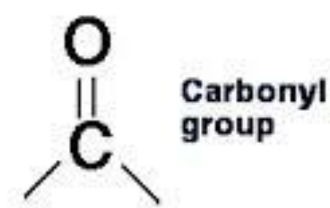
C → H2O

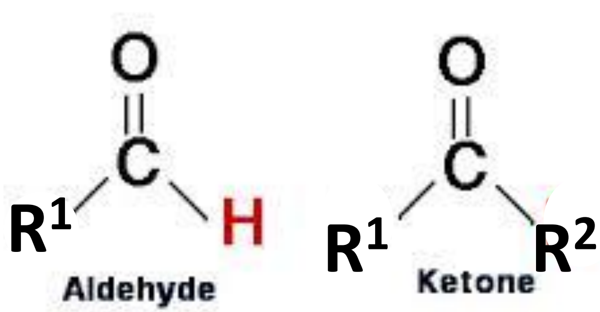
Classification of Carbohydrates

- 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
  - 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)





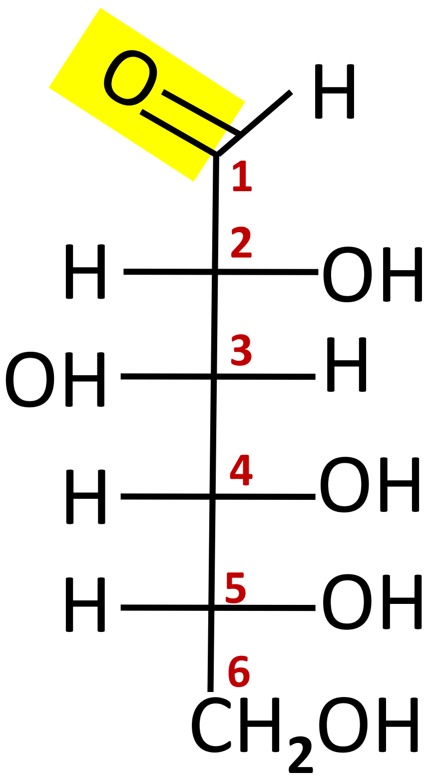
Aldehyde: R^1 **= H, alkyl or aryl**

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

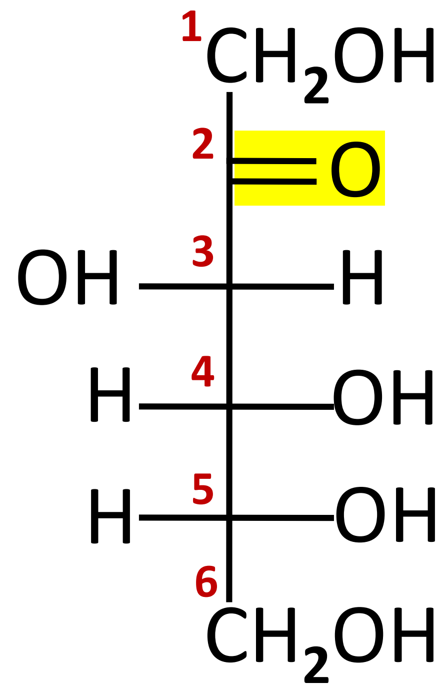
Monosaccharides

Hexose $C_6H_{12}O_6$

Hexoaldose\Aldohexose



Fischer projections



Hexoketose\Ketohexose

D-glucose

"grape or blood sugar"

D-fructose

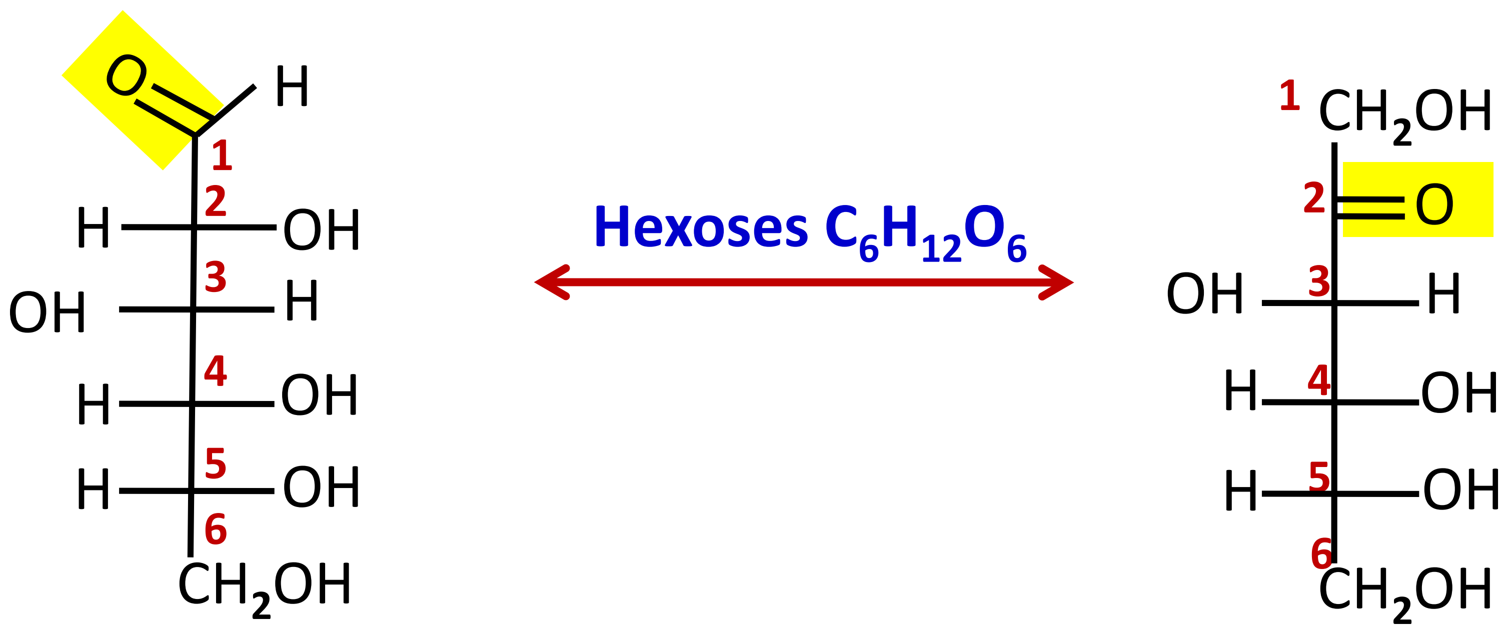
"fruit sugar"

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)

D-glucose



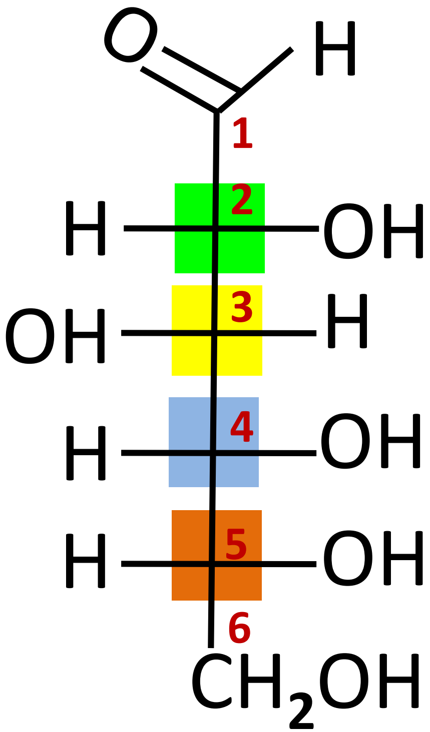
D-fructose

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 = $\mathbf{2^n}$ where n represents the number of chiral centers

Isomerization

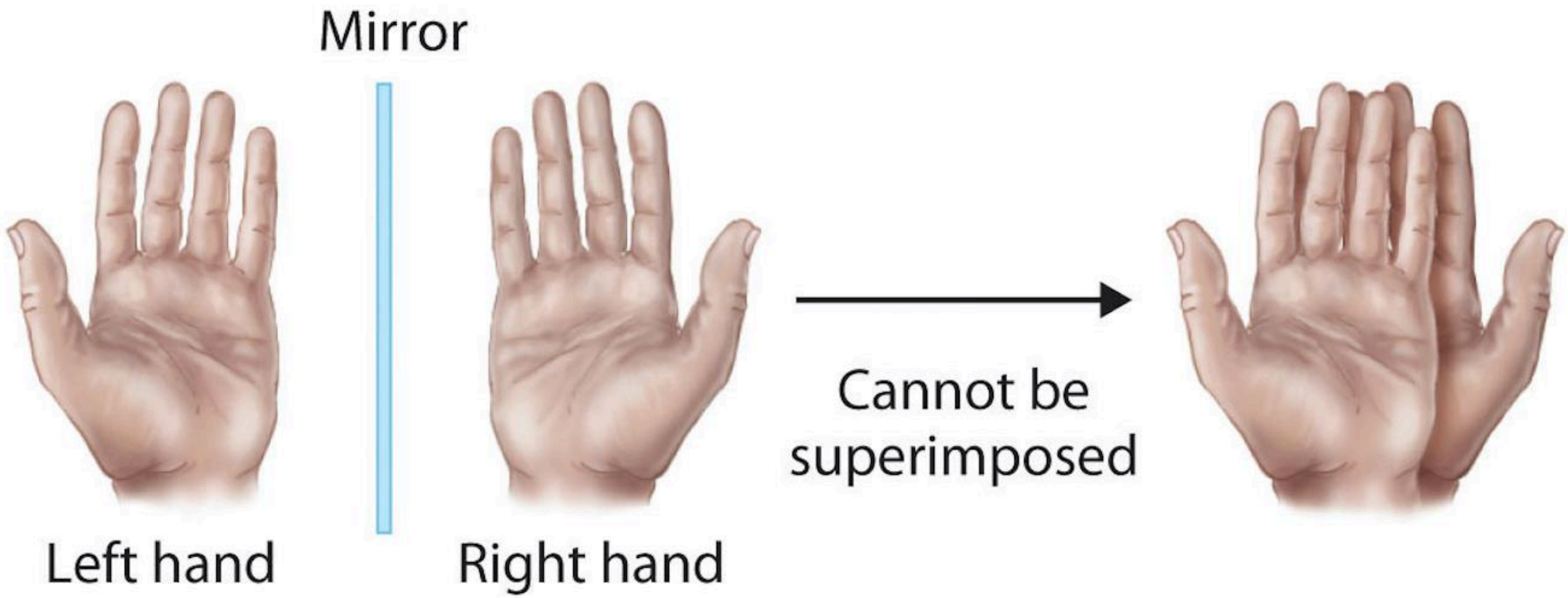


D-glucose

Number of stereoisomers = 2^4

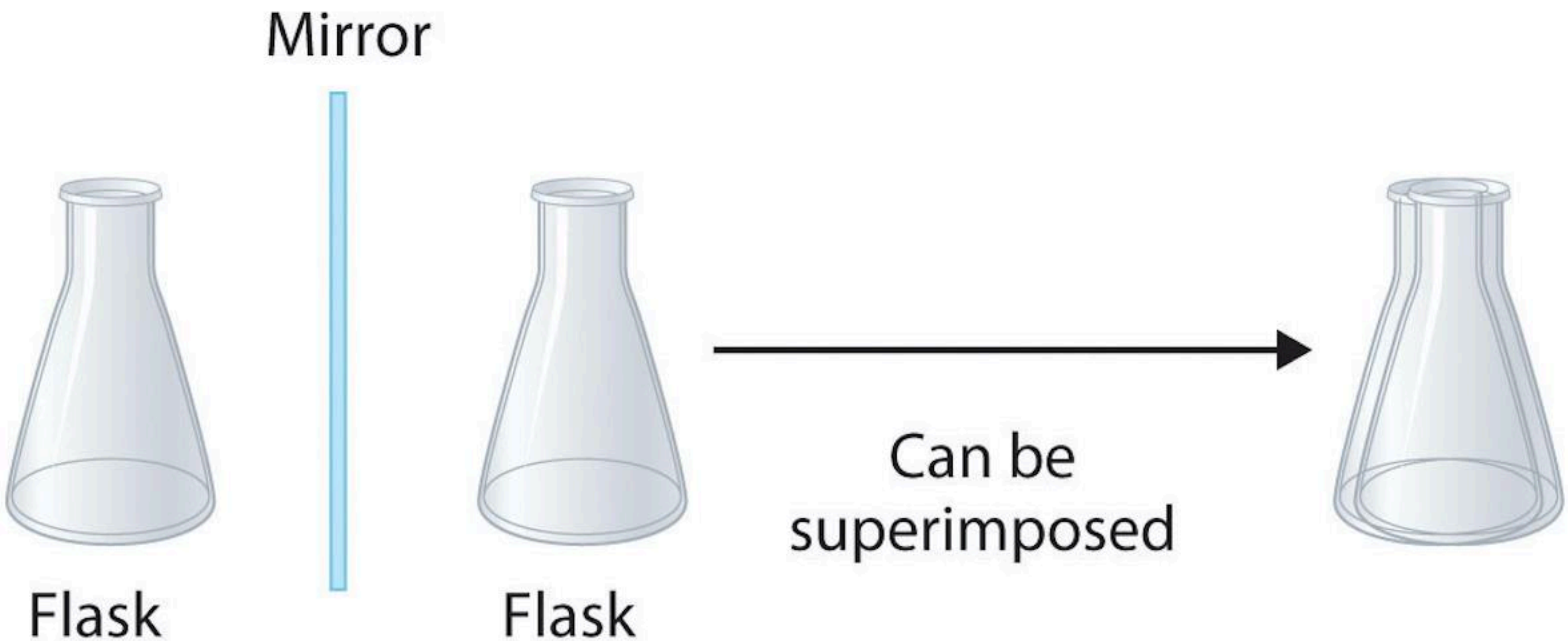
= 16

Chirality & Chiral Object



(a) Chiral objects

Chirality & Chiral Object



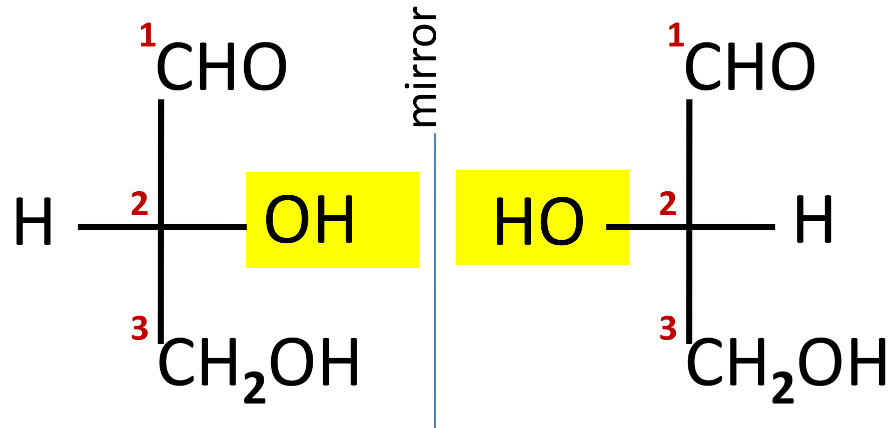
(b) Achiral objects

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

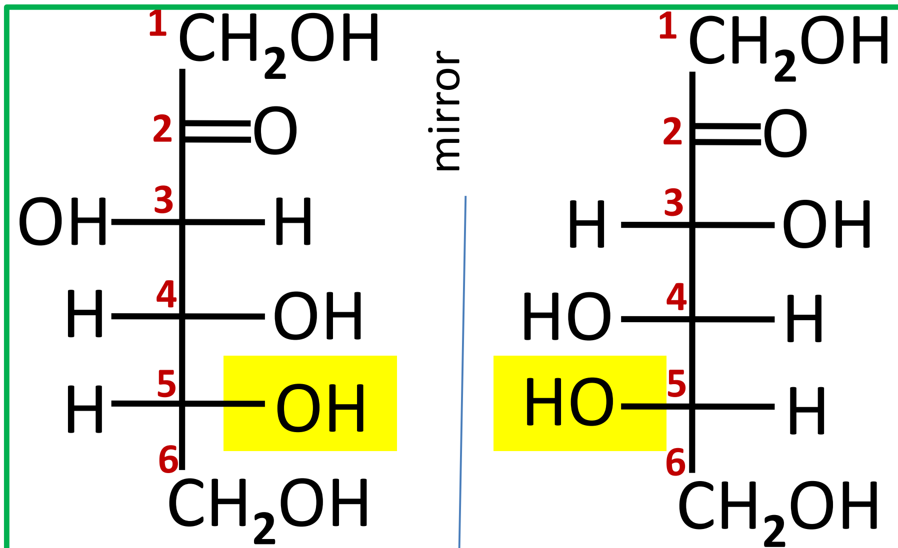
Stereoisomers

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

D/L Monosaccharides

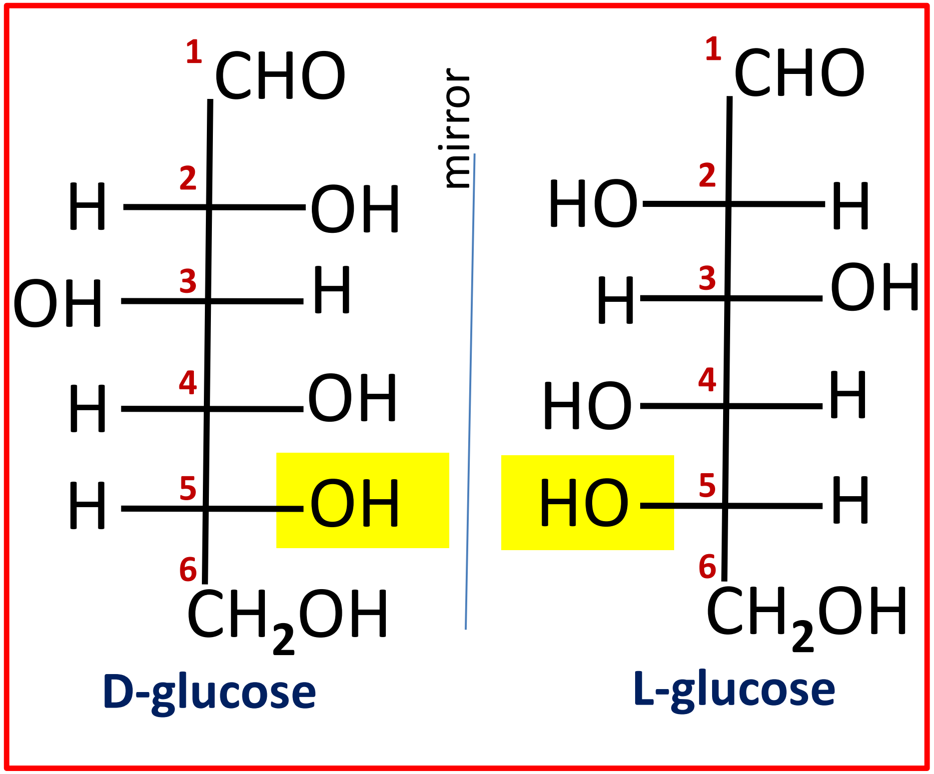


D-glyceraldehyde L-glyceraldehyde



D-fructose L-fructose

D/L Monosaccharides

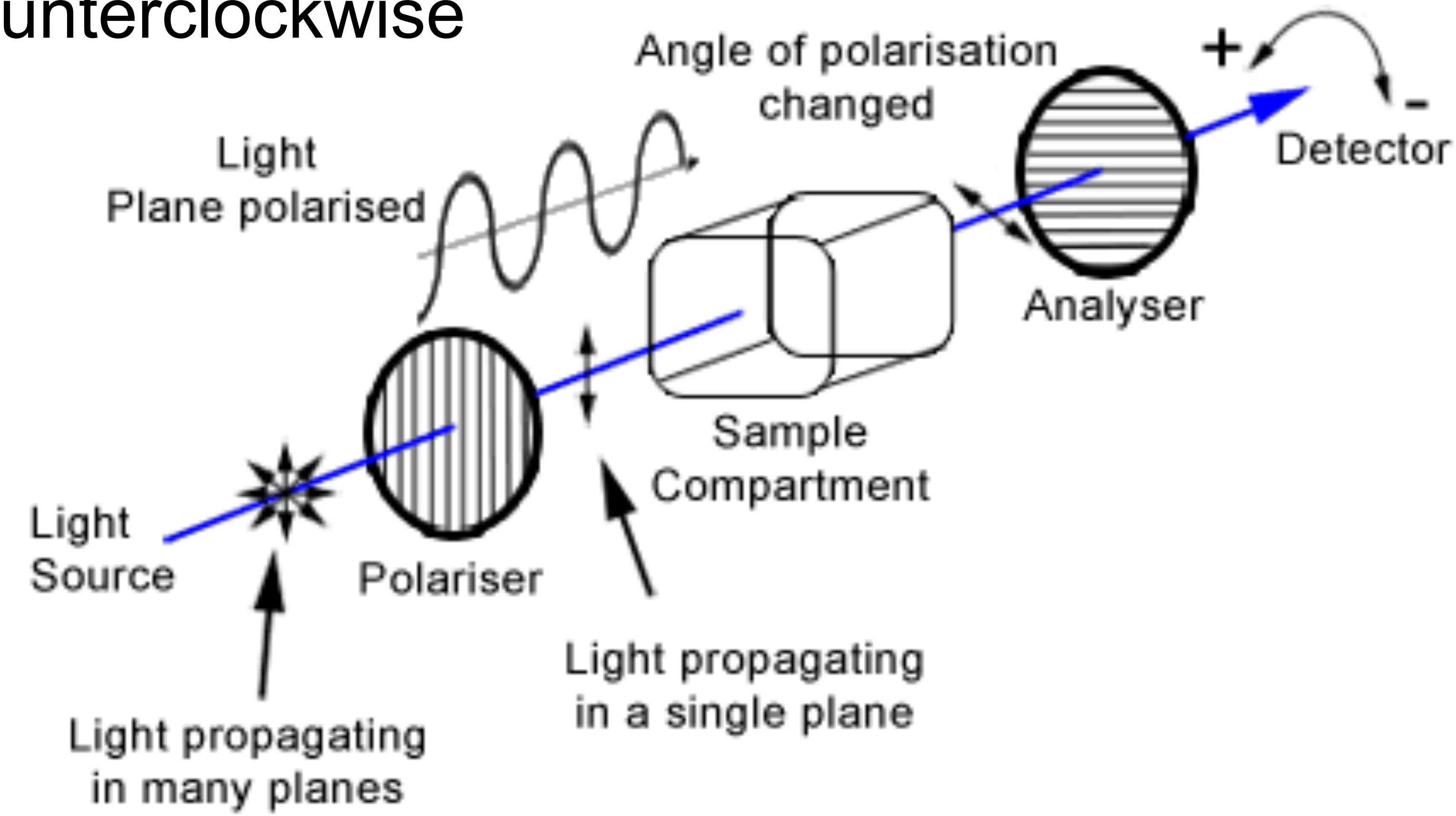


Isomerization

- 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

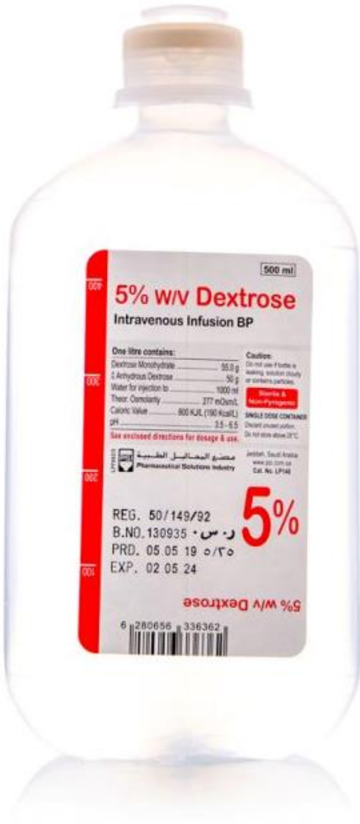
- Enantiomers are optically active and can rotate the polarized light plane either clockwise or counterclockwise

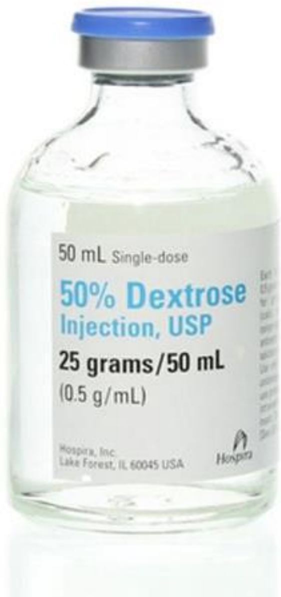


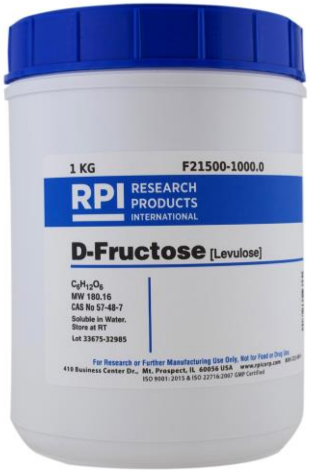
Monosaccharides

- 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



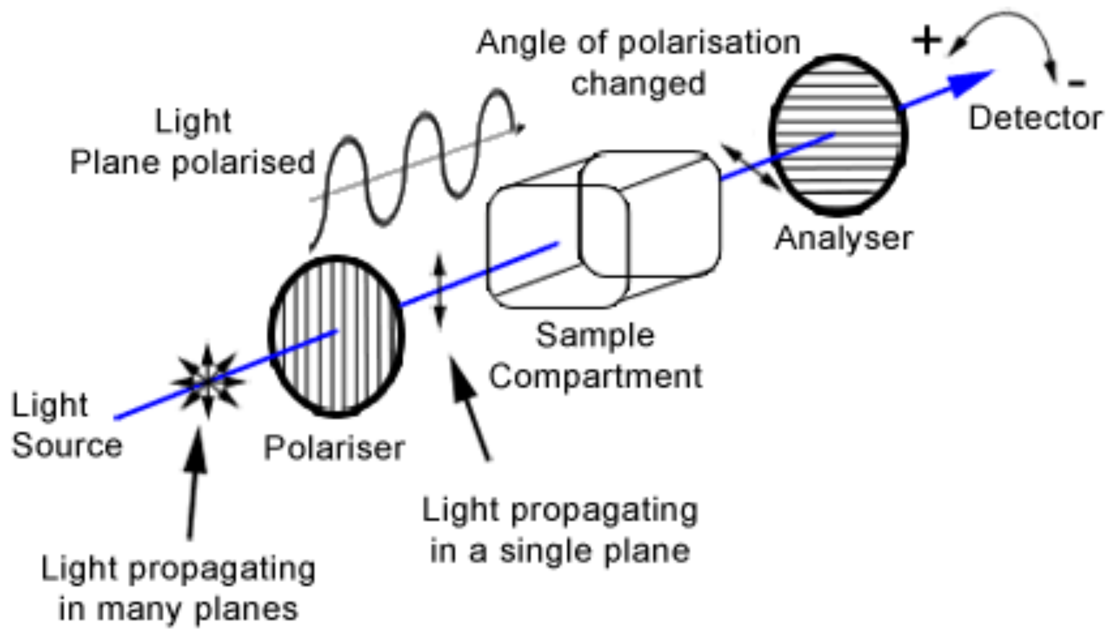




- **Dextrose** is the commercial/trade name of **D-glucose**
- **Laevulose** is the the commercial name of **D-fructose**

Monosaccharides

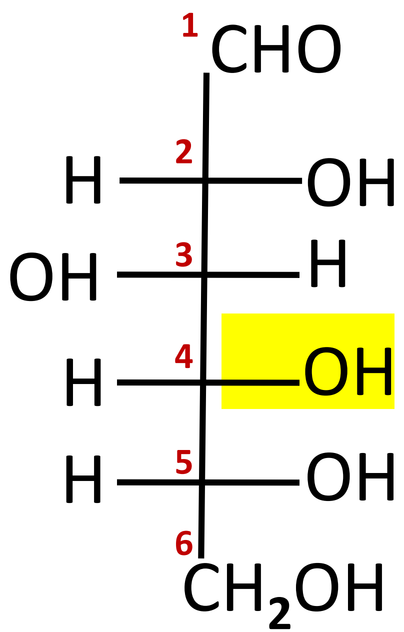
- Enantiomers are optically active and can rotate the polarized light plane either clockwise or counterclockwise



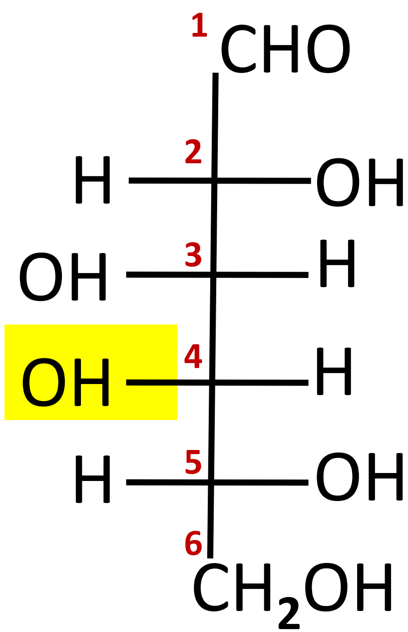
- **Racemic mixture** contains equal amounts of each enantiomer (net rotation is zero)

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.

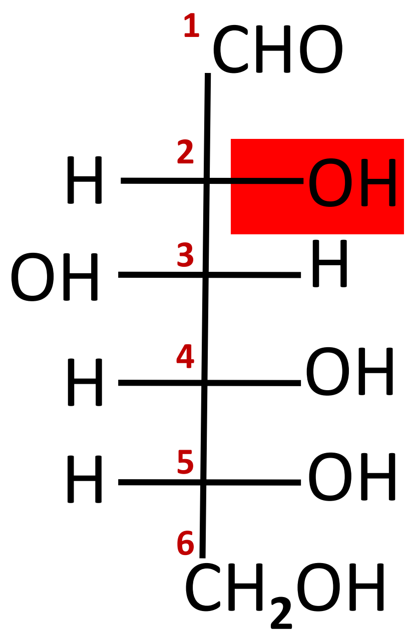


D-glucose

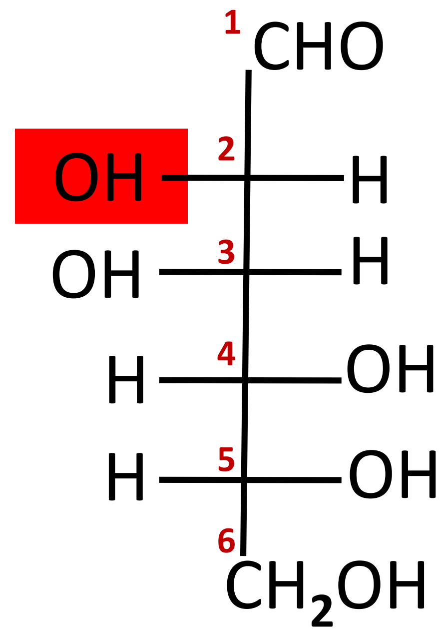


D-galactose

Monosaccharides



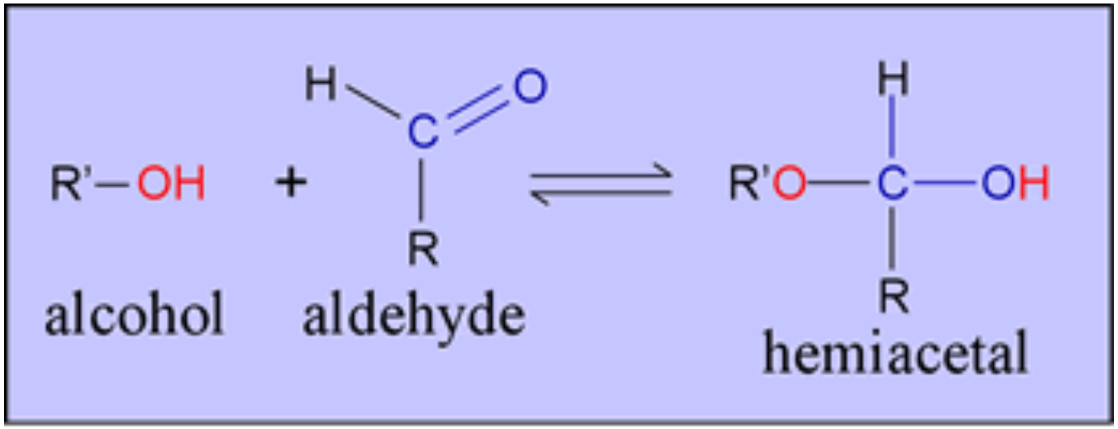
D-glucose

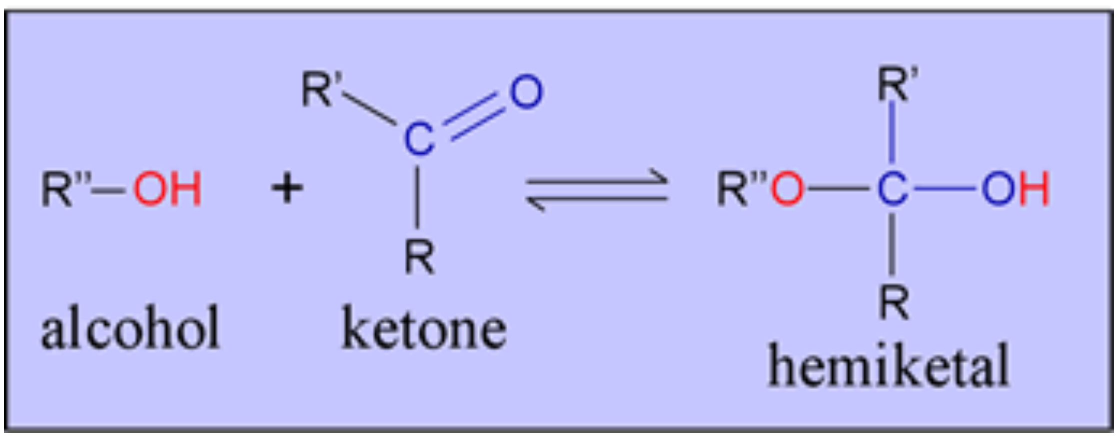


D-mannose

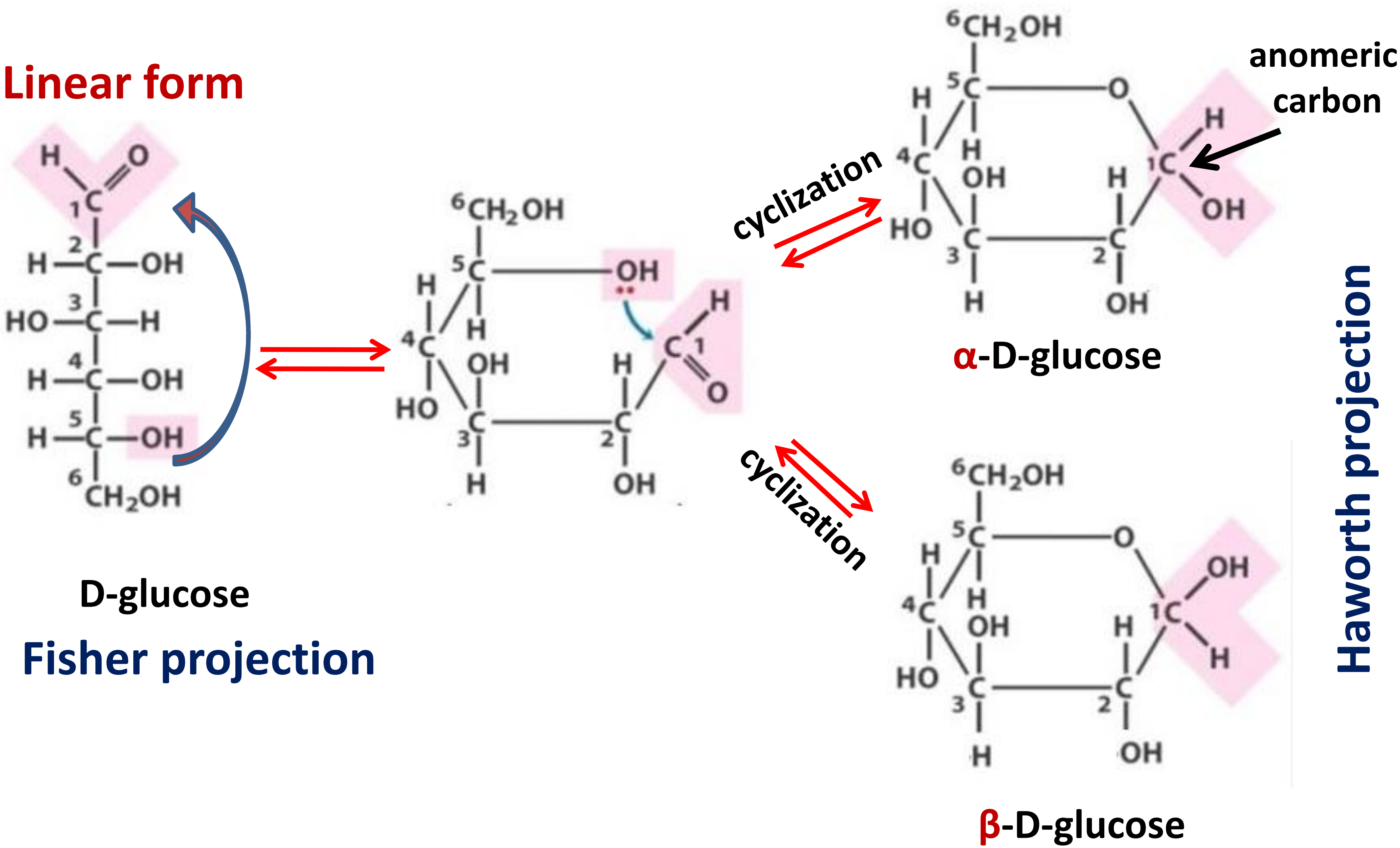
- Glucose and galactose are C4 epimers while glucose and mannose are C2 epimers

Hemiacetal & Hemiketal

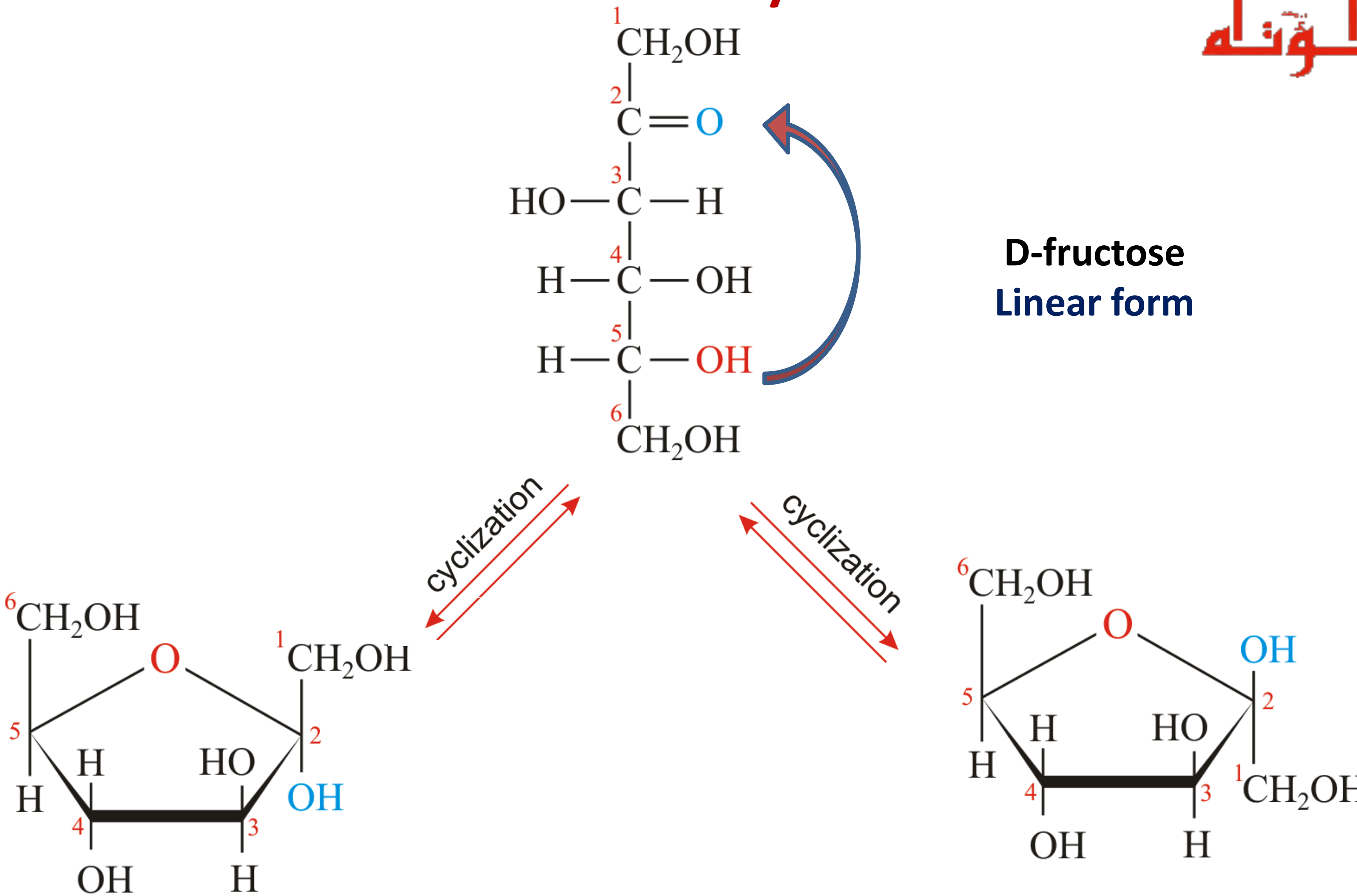




Monosaccharide cyclization



Monosaccharide cyclization



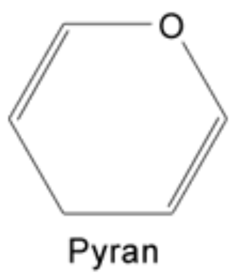
D-fructose
Linear form

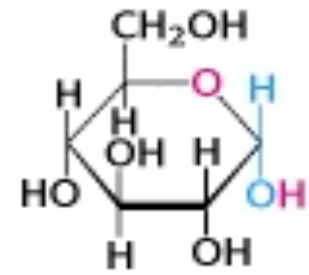
α-D-fructose

β-D-fructose

Pyranoses & Furanoses

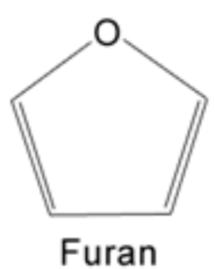
- Sugars with six-membered rings are known as pyranoses (e.g. glucopyranose) as they resemble the heterocyclic compound pyran.

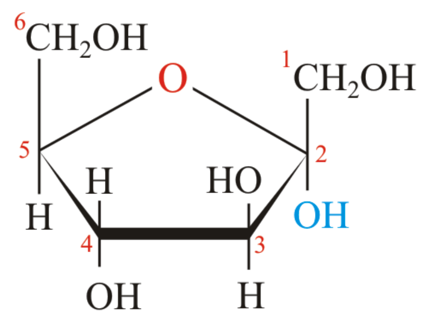




α-D-glucopyranose

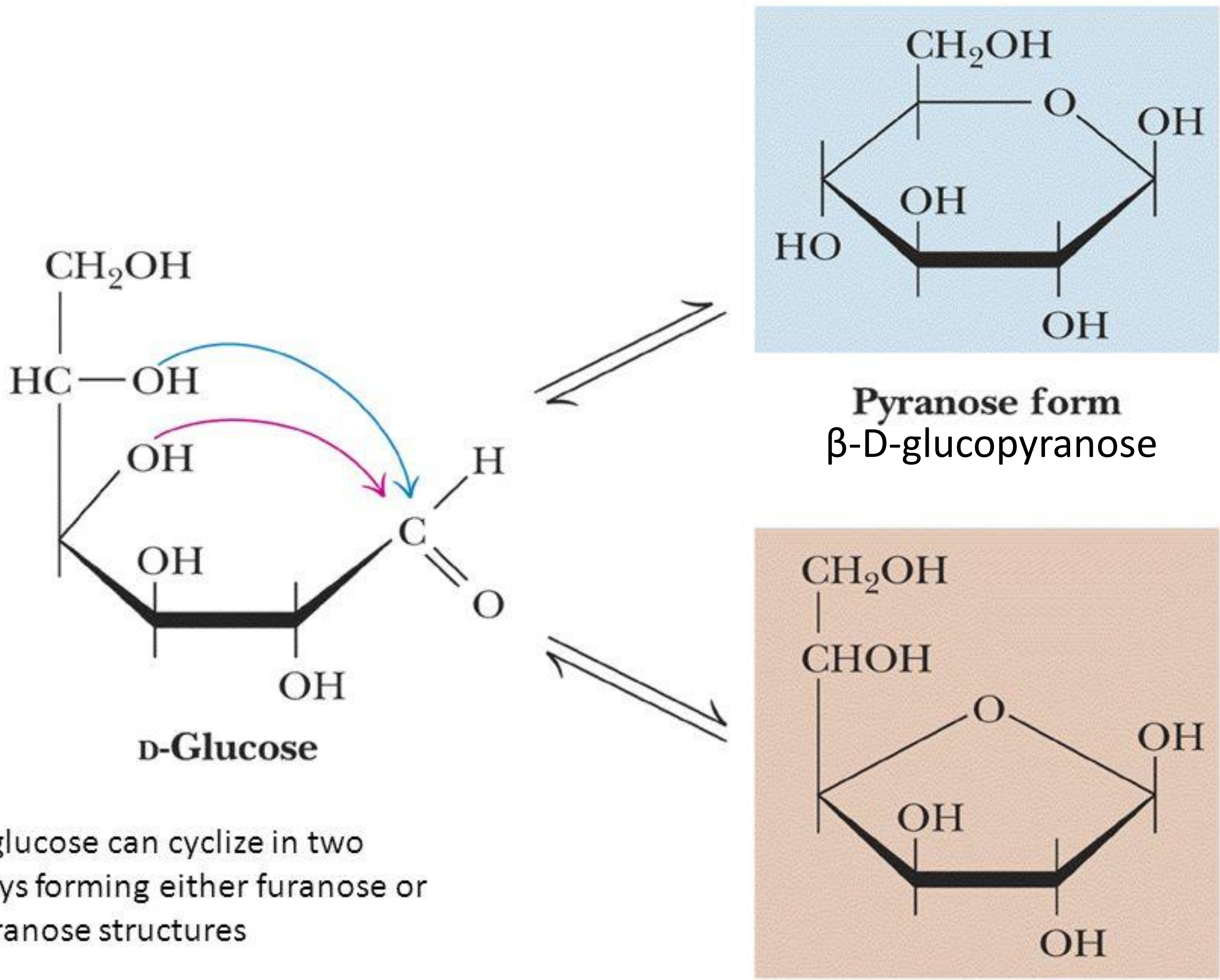
- Sugars with five -membered rings are known as furanoses (e.g. fructofuranose) as they resemble the heterocyclic compound furan.





α-D-fructofuranose

Pyranoses & Furanoses

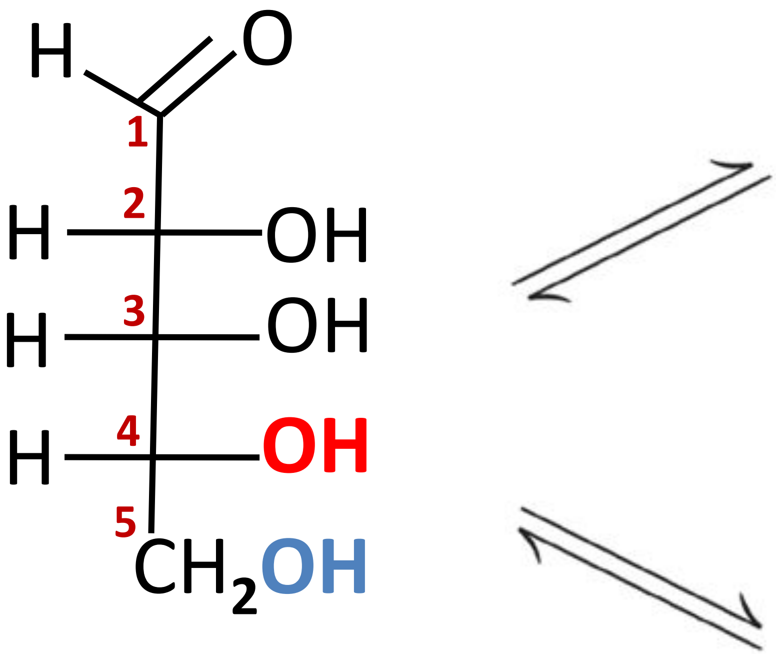


Pyranose form
β-D-glucopyranose

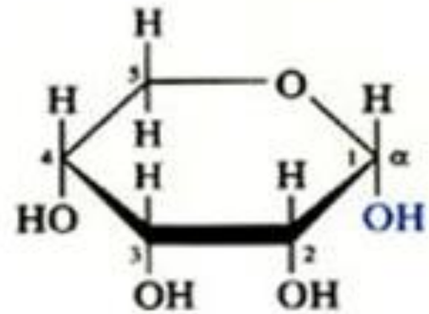
Furanose form
β-D-glucofuranose

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

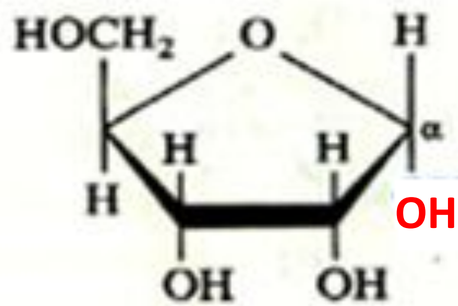
Pyranoses & Furanoses



D-ribose
Fisher projection

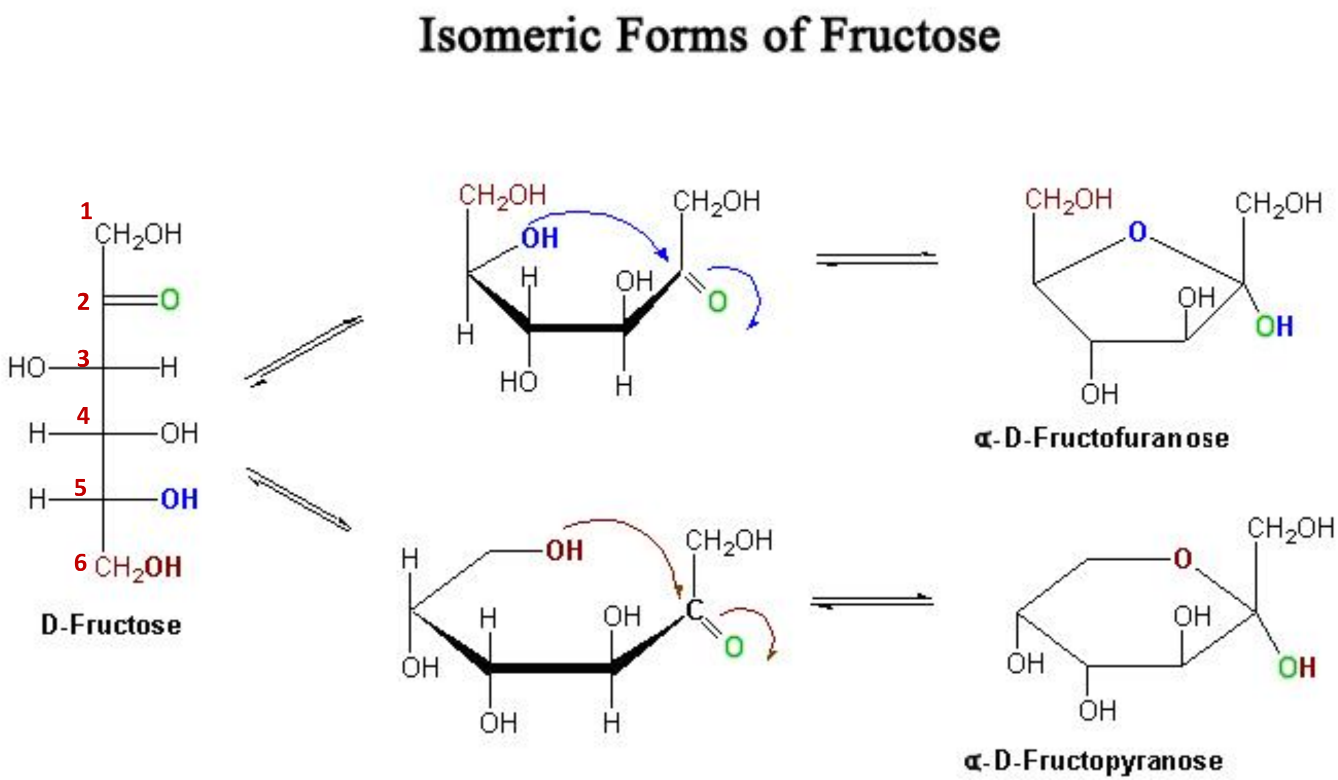


α-D-Ribopyranose
(Haworth projection)



α-D-Ribofuranose
(Haworth projection)

Pyranoses & Furanoses



- 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

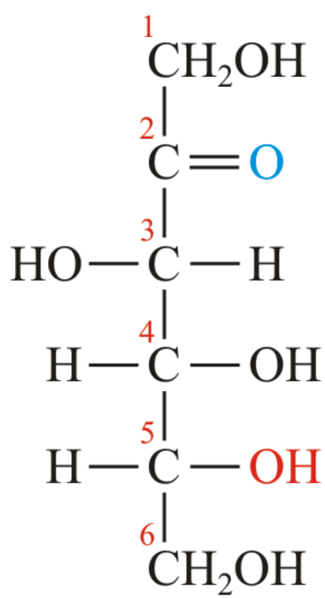
Anomers

- 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.

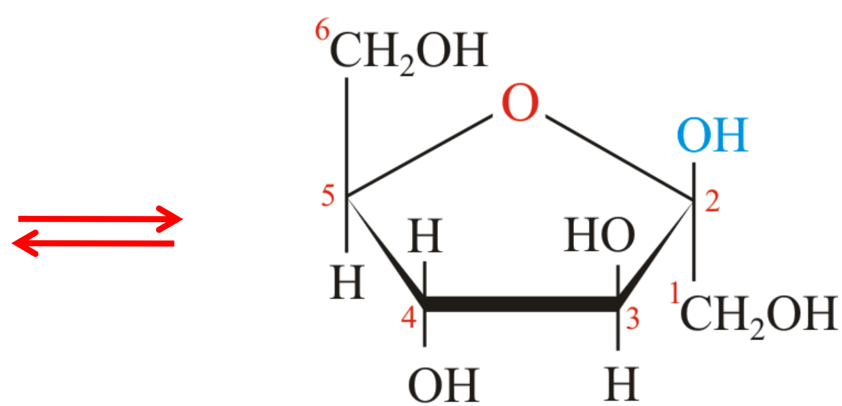
Haworth Projection

- 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



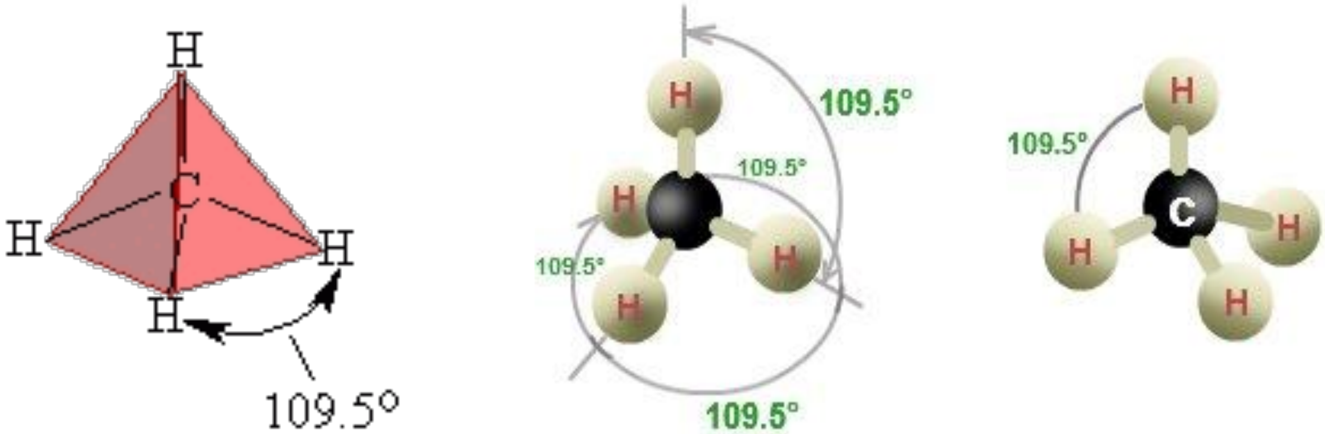
β-D-fructose

Haworth projection

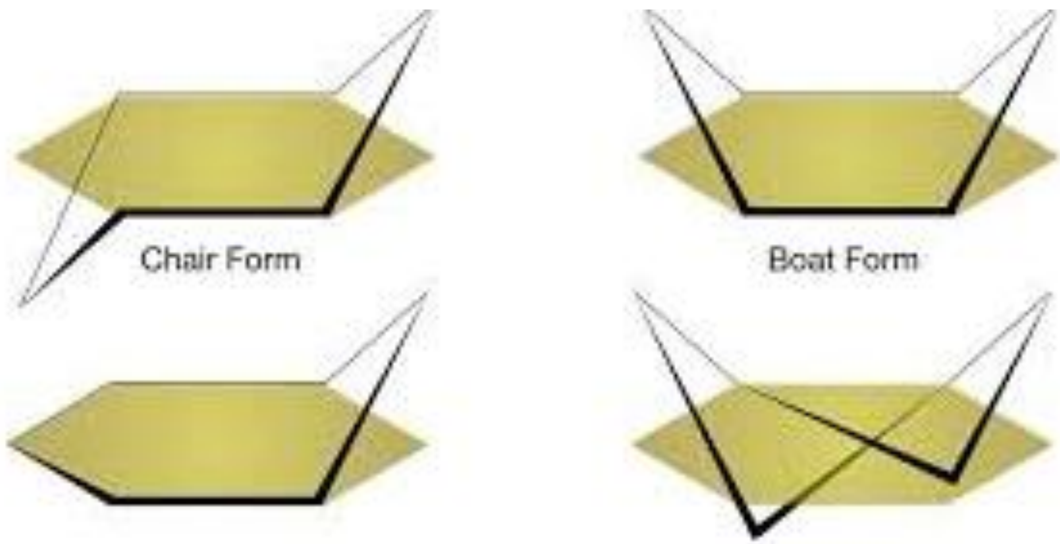
Conformers

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

Conformers



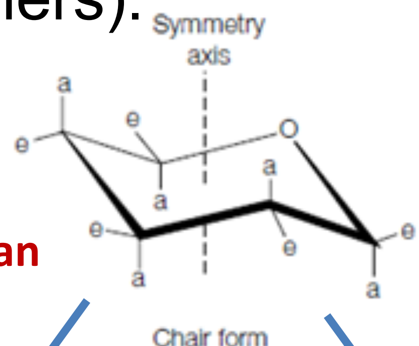
Carbon atoms are tetrahedral



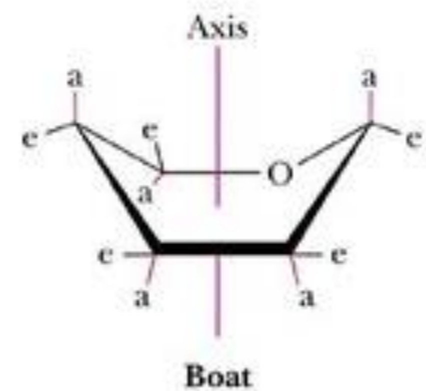
Conformers are stereoisomers with different rotations about single bonds

Conformers

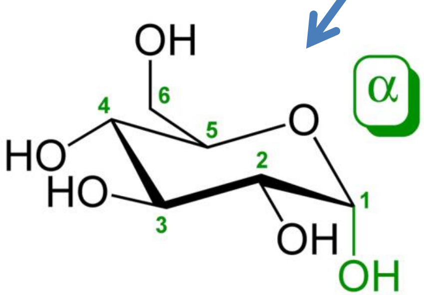
- The geometry of the carbon atoms of monosaccharide ring is tetrahedral (bond angles are close to 109.5º), so sugar rings are not actually planar. For example, pyranoses take on either **Chair** or **Boat** conformations (conformational isomers or conformers).



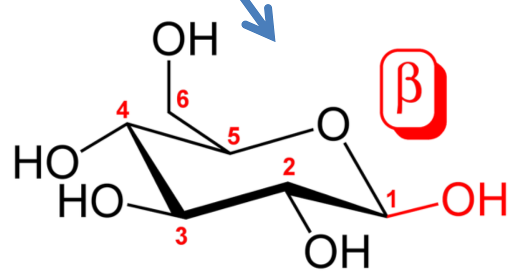
a: axial
e: equatorial



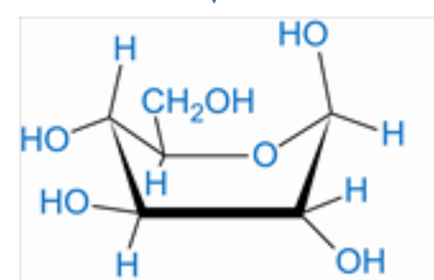
α is Less stable than β due to steric repulsion



Chair form of α-D-glucose



Chair form of β-D-glucose

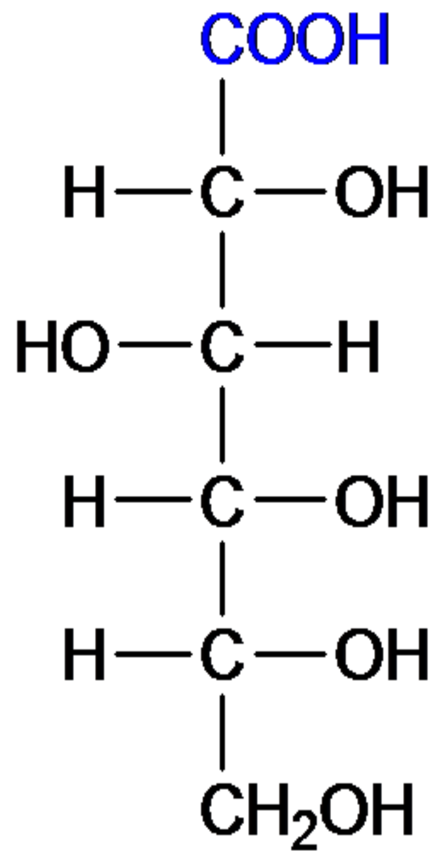


Boat form of β-D-glucose

Sugar Modification

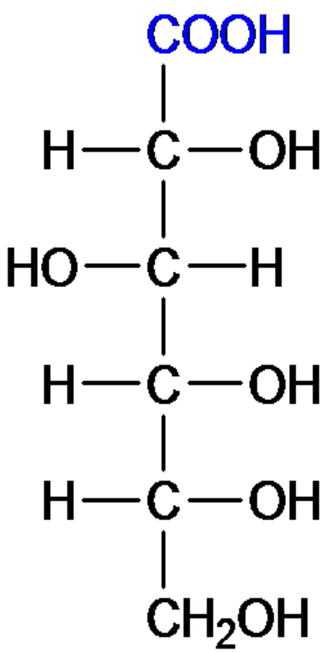
1. **Aldonic acids :** oxidation of aldehyde (C1) to carboxylic acid; e.g. D-gluconic acid

- **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^+

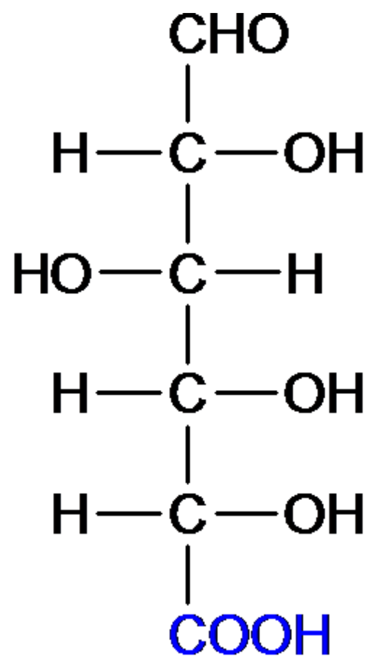


Sugar Modification

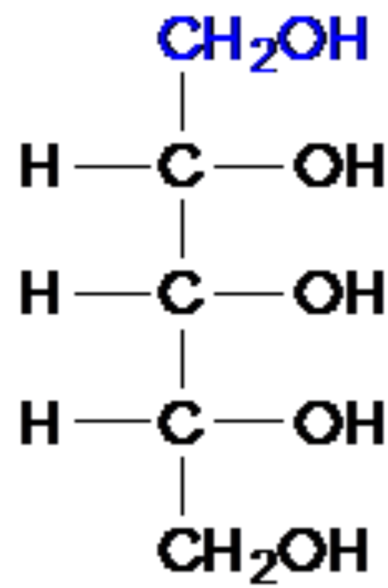
1. Aldonic acids : oxidation of aldehyde (C1) to carboxylic acid; e.g. D-gluconic acid



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



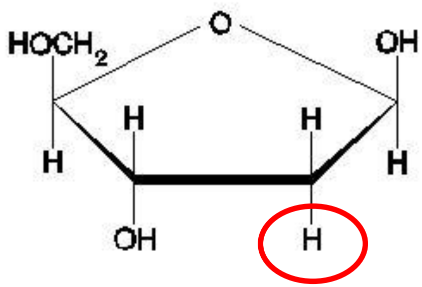
3. Alditols : reduction of carbonyl group to alcohol; e.g. D-ribitol, D-glycerol and D-sorbitol (sweetener)



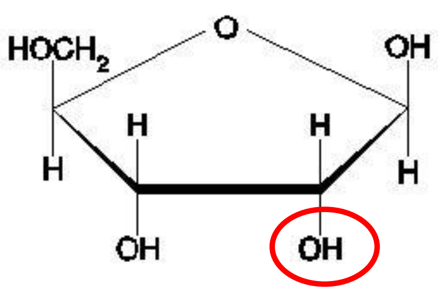
D-ribitol

Sugar Modification

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

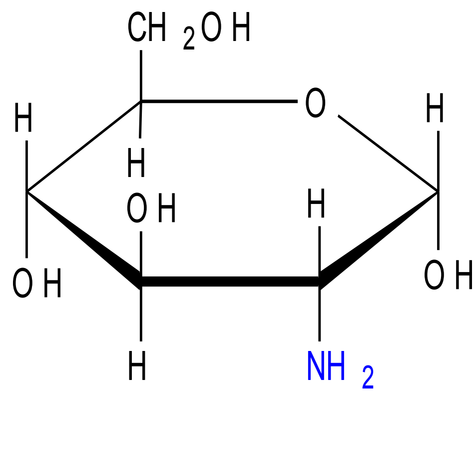


Deoxyribose

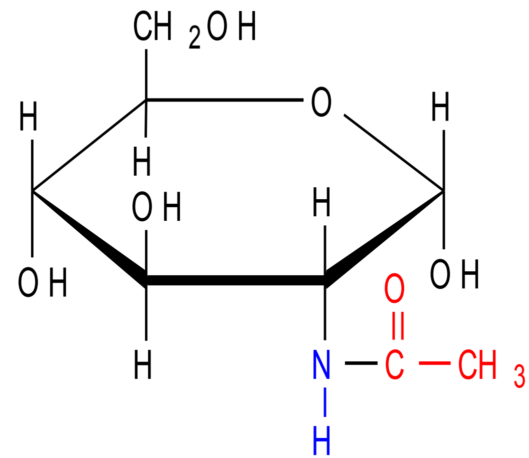


Ribose

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