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Unit: 4
(Carbohydrate)
(Lecture-Part 2)

For
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Terms and symbols used in stereochemistry: A Revision

- Before moving to the different ways of designation/notation, one thing must have been noticed that these carbohydrates contain chiral carbons so different stereoisomers will also be there.

- **Maximum number of possible stereoisomers in case of compound with n chiral carbons = 2^n**

- Therefore it is important to have a look at few terms and symbols which could be used while dealing with the stereochemistry of carbohydartes.

- Let us revise few terms and notations which could be used while dealing with stereochemistry of carbohydrate:

(a) Chiral centre/Stereogenic Centre: If a molecule contains one carbon atom carrying four different groups it will not have a plane of symmetry and must therefore be chiral. A carbon atom carrying four different groups is a stereogenic or chiral centre.

(b) A racemic mixture is a mixture of two enantiomers in equal proportions. This principle is very important. Never forget that, if the starting materials of a reaction are achiral, and the products are chiral, they will be formed as a racemic mixture of two enantiomers.

(c) (+) or (–) notations: Enantiomers can be described as depending on the their ability to rotate plane-polarized light in left or right direction. Enantiomer that rotates plane-polarized light to the right (gives a positive rotation) the **(+)-enantiomer** (or the **dextrorotatory enantiomer**) and the enantiomer that rotates plane-polarized light to the left (gives a negative rotation) the **(–)-enantiomer** (or the **laevorotatory enantiomer**).

Terms and symbols used in stereochemistry: A Revision

- ***Important points where confusion may occur*:**

The direction in which light is rotated is not dependent on whether a stereogenic centre is R or S. **An (R) compound is equally as likely to be (+) as (–)—of course, if it is (+) then its (S) enantiomer must be (–).** For example, is R-(–)-mandelic acid, because its specific rotation is negative, and (S)-alanine happens to be S-(+)-alanine.

- **D or L notations:** Enantiomers could also be described as D or L notations. As glyceraldehyde is one of the simplest Chiral compounds with two enantiomers (Figure 1).

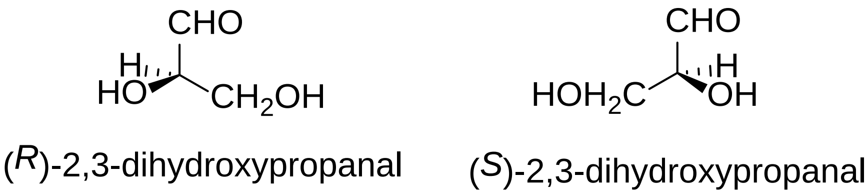


Figure 1: Two enantiomers of glyceraldehyde

- The two enantiomers of glyceraldehyde were given the labels **D (for dextro—because it was the (+)-enantiomer**) and **L (for laevo—because it was the (–)-enantiomer**). Any enantiomerically pure compound that could be related, by a series of chemical degradations and transformations, to D-(+)-glyceraldehyde was labelled D, and any compound that could be related to L-(–)-glyceraldehyde was labelled L. These labels, **D and L, are in *small capital letters***.

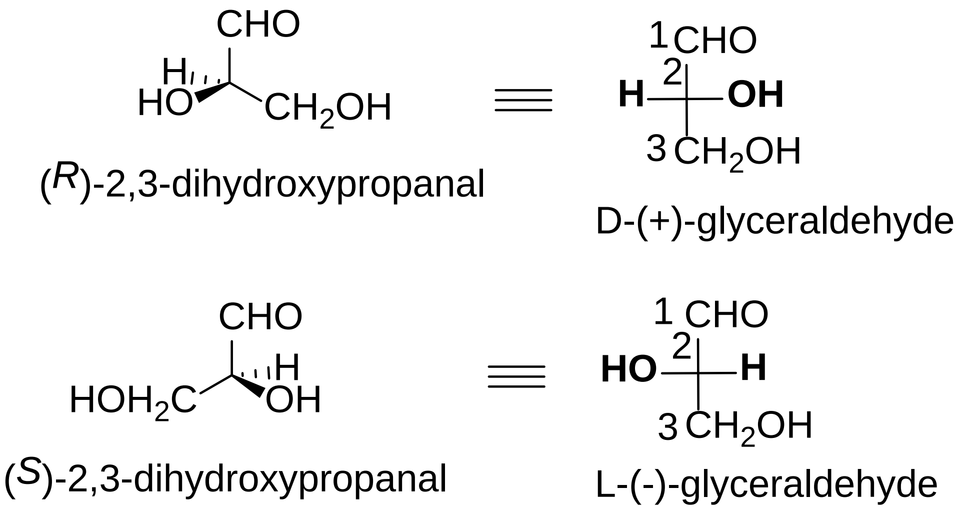
So overall remember that the R/S, +/–, and D/L nomenclatures all arise from different observations and the fact that a molecule has, say, the R configuration gives no clue as to whether it will have +or – optical activity or be labeled D or L. Never try and label a molecule as D/L, or +/–, simply by working it out from the structure. Likewise, never try and predict whether a molecule will have a +or – specific rotation by looking at the structure.

Continued…..

D and L Designations of Monosaccharides

- In 1906, M. A. Rosanoff of New York University suggested that **(+)-glyceraldehyde is designated D-(+)-glyceraldehyde** and **(-)-glyceraldehyde is designated L-(-)-glyceraldehyde**.

- **A monosaccharide *whose highest numbered chirality center (the penultimate carbon) has the same configuration as D-(+)- glyceraldehyde is designated* as a D sugar; one whose highest numbered chirality center has the same configuration as L-glyceraldehyde is designated as an L sugar (Figure 2).** By convention, acyclic forms of monosaccharides are drawn vertically with the aldehyde or keto group at or nearest the top. When drawn in this way, D sugars have the OH on their penultimate carbon on the right.



(*R*)-2,3-dihydroxypropanal ≡ D-(+)-glyceraldehyde

(*S*)-2,3-dihydroxypropanal ≡ L-(-)-glyceraldehyde

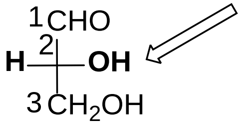
Figure 2: D and L-Configuration of glyceraldehyde (aldotriose)

- The D and L nomenclature designations are like *(R) and (S) designations in* ***that they are*** **not necessarily related to the optical rotations of the sugars to which they are applied.** Thus, one may encounter other sugars that are D-(+) or D-(-) and ones that are L-(+) or L-(-).

Continued…..

Examples of D-Aldoses

- **Aldotriose:** Monosaccharide with 3 Carbons and aldehyde functional group. As it contains only one chiral carbon so total number of stereoisomers (enantiomer) are 2 only with D (Figure 3) and L configurations.

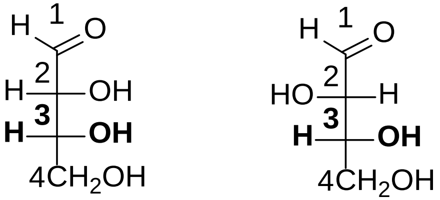


(This OH group present at the hightest number chirality centre is on the right side (In case of glyceraldehyde only one chiral C is there)

D-(+)-glyceraldehyde

Figure 3: Fischer Projection of D-glyceraldehyde (aldotriose)

- **Aldotetrose**: Monosaccharide with 4 Carbon atoms and aldehyde functional group. As it contains two chiral carbons so total number of stereoisomers are 4 only. Only D-forms of two examples of aldotetroses have been shown below (Figure 4).



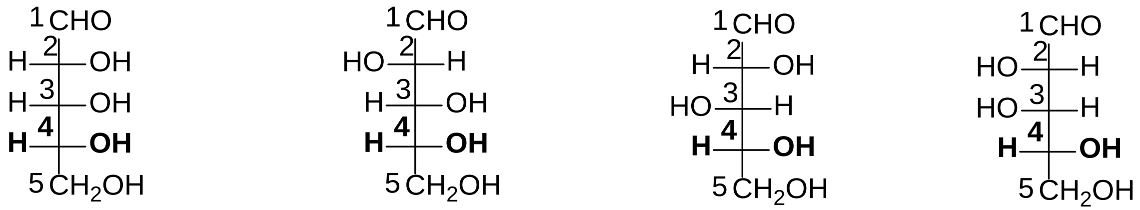
D(-)- erythrose **D(-)- threose**

Figure 4: Fischer Projection of two D-aldotetroses

Continued…..

Examples of D-Aldoses

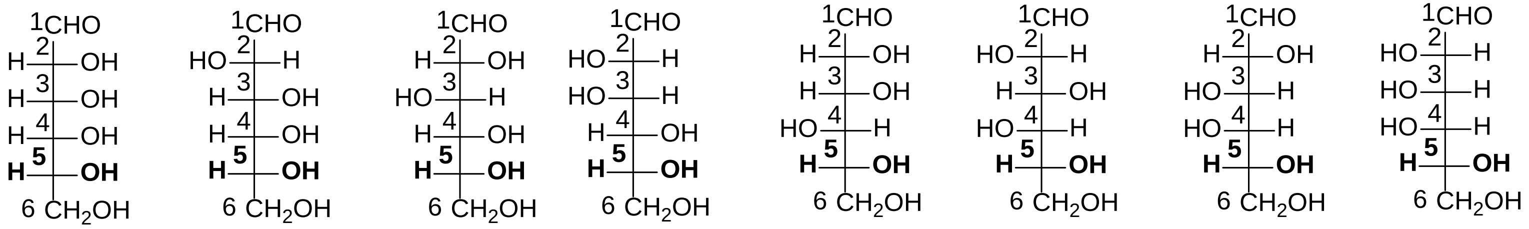
- **Aldopentose**: Monosaccharide with 5 Carbon atoms and aldehyde functional group. As it contains only 3 chiral carbons so total number of stereoisomers are 8 only. Four D-form have been shown below (Figure 5).



D(-)-ribose D(-)-arabinose D(+)-xylose D(-)-lyxose

Figure 5: Fischer Projection of four D-aldopentoses

- **Aldohexose**: Monosaccharide with 6 Carbon atoms and aldehyde functional group. As it contains only 4 chiral carbons so the total number of stereoisomers are 16. only eight D-forms have been shown below (Figure 6).



D(+)-allose D(+)-altrose D(+)-glucose D(+)-mannose D(-)-gulose D(-)-idose D(+)-galactose D(+)-talose

Figure 6: Fischer Projection of eight D-aldohexoses

- **L-Aldoses are exactly the mirror image. For example, L-Glucose has been shown in next slide.**

Example of L-Aldohexose

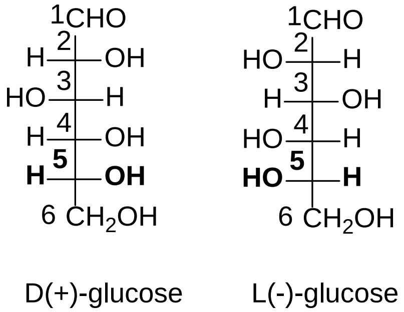

D(+)-glucose L(-)-glucose

Figure 7: Fischer Projection of both D and L-form of glucose

- As it can be seen that **D-Glucose and L-glucose (Figure 7) are exactly mirror image of each other i.e. both are enantiomers.**

Example of D-Ketohexose

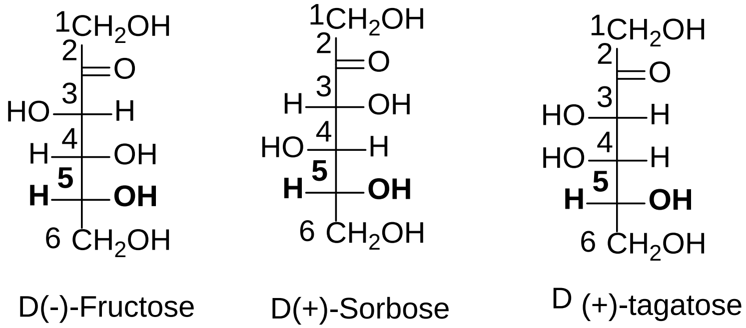

D(-)-Fructose D(+)-Sorbose D (+)-tagatose

Figure 8: Fischer Projection of few D-ketohexoses

- D(+)-Glucose (Figure 7) and D(-)-Fructose (Figure 8) are dextro and laevorotatory respectively. Once again remember that D doesn't always means dextro or leavo and vice-versa. D(-) Fructose is also known as fruit sugar.

Stereochemical Relationships Among The D-aldoses With Three To Six Carbon Atoms

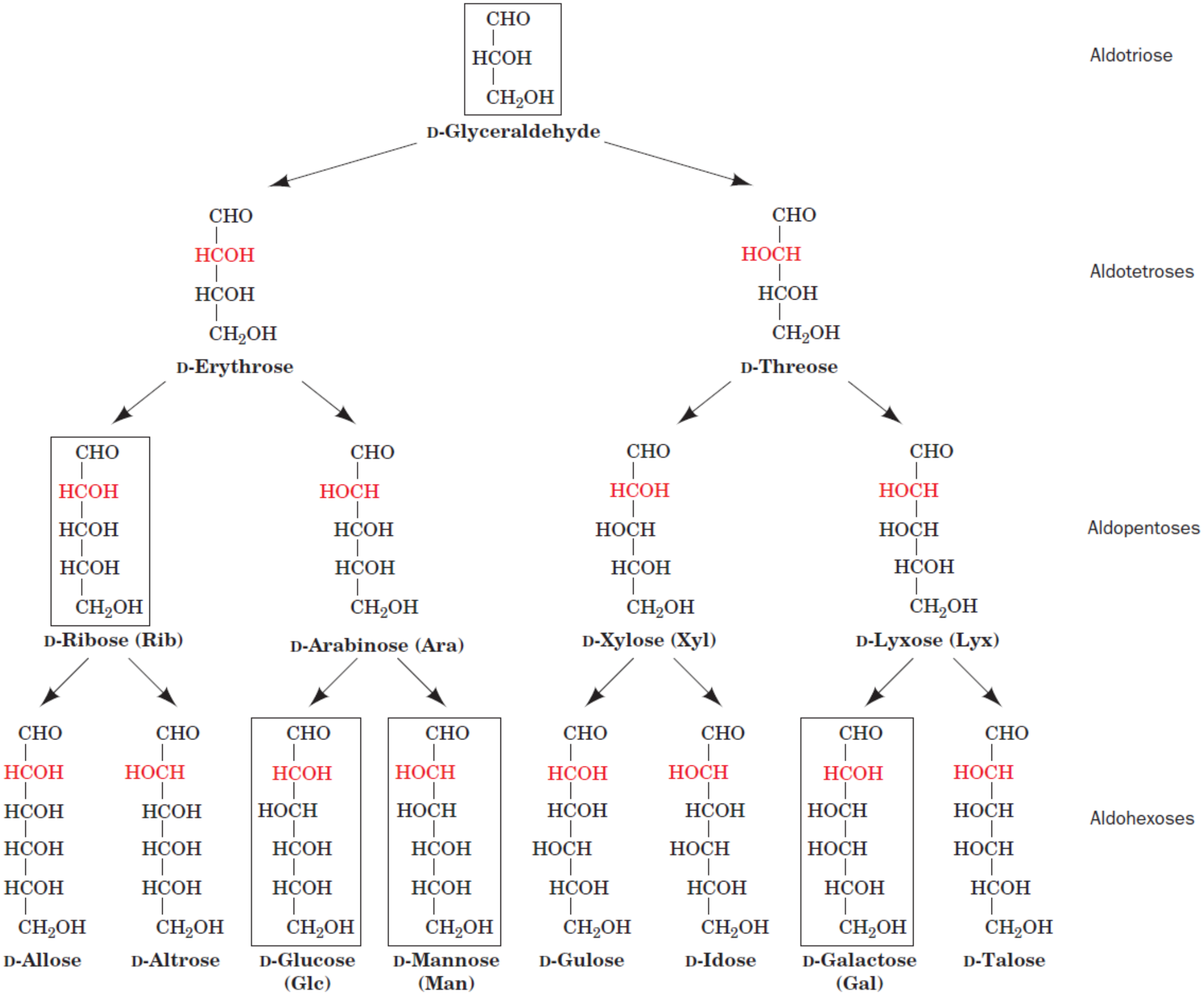


Figure 11-1 **The stereochemical relationships, shown in Fischer projection, among the D-aldoses with three to six carbon atoms.** The arrows indicate stereochemical relationships (not biosynthetic reactions). The configuration about C2 (*red*) distinguishes the members of each pair. The L- counterparts of these 15 sugars are their mirror images. The biologically most common aldoses are boxed.

(*Picture adapted from Chapter No. 11, 'Biochemistry' (4th edition) by D. Voet and J. G. Voet*)

Stereochemical Relationships Among The D-ketoses With Three To Six Carbon Atoms

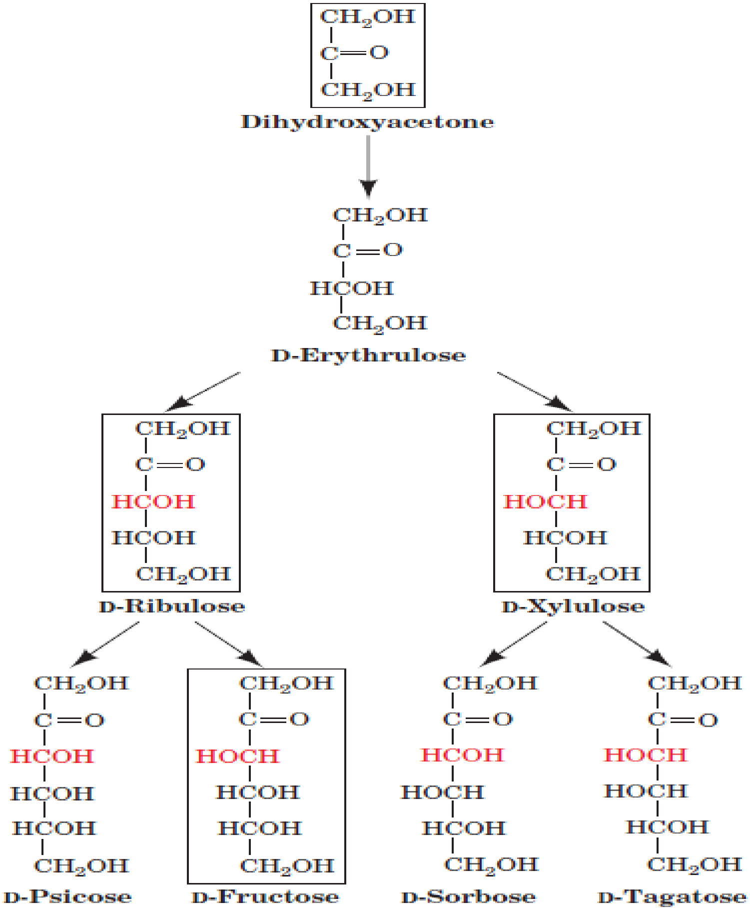
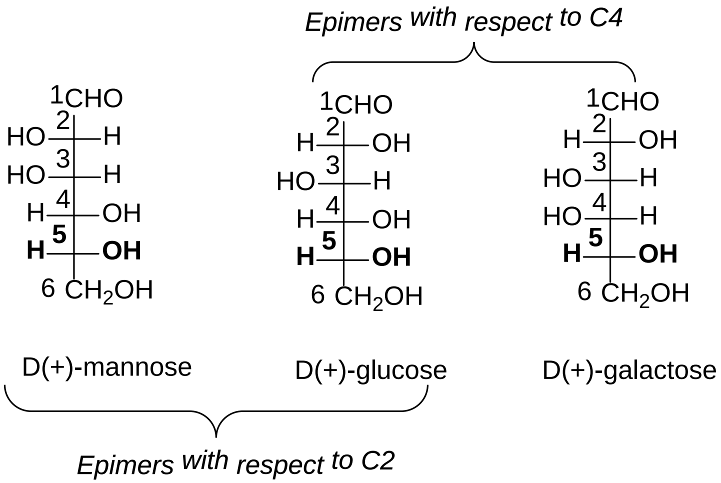


Figure 11-2 The stereochemical relationships among the D-ketoses with three to six carbon atoms. The configuration about C3 (*red*) distinguishes the members of each pair. The biologically most common ketoses are boxed.

(*Picture adapted from Chapter No. 11, 'Biochemistry' (4th edition) by D. Voet and J. G. Voet*)

Epimer

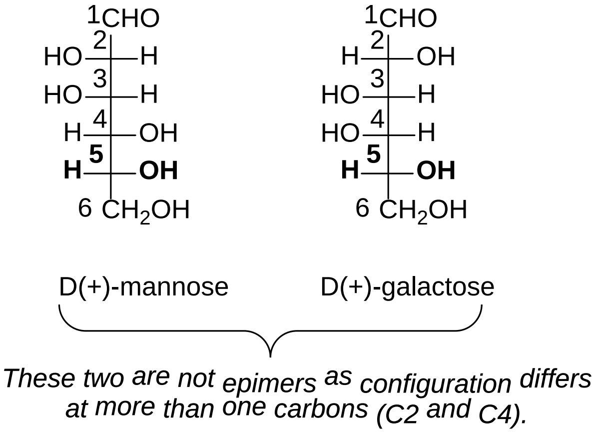
- Any pair of diastereomers that differ in configuration at only a single tetrahedral chirality center can be called **epimers.**
- Thus D-glucose and D-mannose are **epimers with respect to C2**, whereas D-glucose and D-galactose are **epimers with respect to C4** However, D-mannose and D-galactose are not epimers of each other because they differ in configuration about two of their C atoms



Epimers with respect to C4

D(+)-mannose D(+)-glucose D(+)-galactose

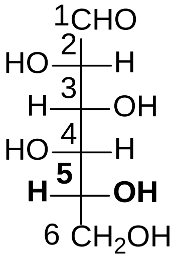
Epimers with respect to C2



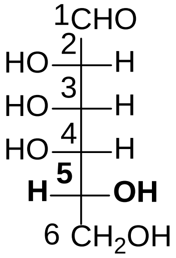
D(+)-mannose D(+)-galactose

These two are not epimers as configuration differs at more than one carbons (C2 and C4).

- **C3-Epimer**: D-idose and D-talose are example of epimers with respect to C3.



D(-)-idose



D(+)-talose

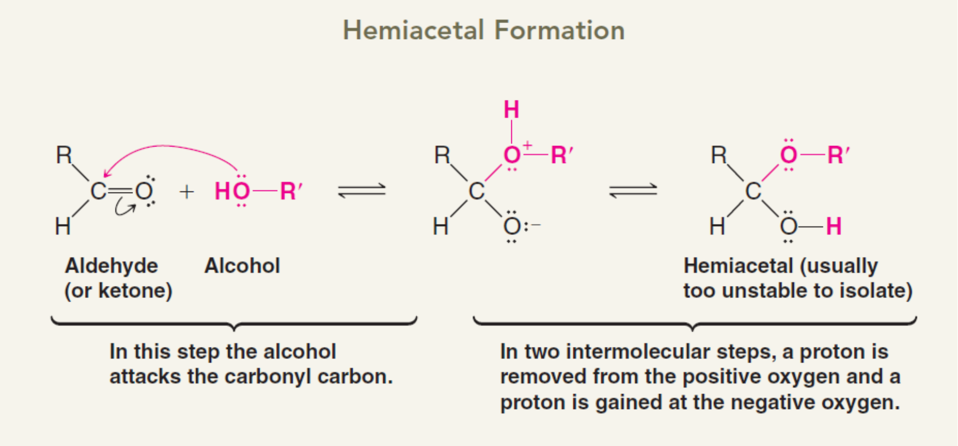
Cyclic structure of Monosaccharide

- So far we considered that monosaccharides are having open-chain structure and used Fischer projections to represent them. But experimentally it has been found that they exist in equilibrium with two cyclic forms.

- Now it will be observed in later part of discussion that cyclisation would only occur through the reaction between OH group with (-CHO) or (C=O) groups. Therefore the moment cyclisation occurs, the aldehyde or keto group which were free in open-chain will not be found in the cyclic form which is **hemiacetal**.

- So before moving to the cyclic form of glucose and related monosaccharides let us have a look at hemiacetal formation.

- The hemiacetal results by nucleophilic addition of an alcohol oxygen to the carbonyl carbon of an aldehyde or ketone. The essential structural features of a **hemiacetal are an OH and an OR group** attached to the same carbon atom.



(Picture adapted from *Chapter No. 16, 'Organic Chemistry' (10th edition) by T. W. G. Solomons and C. B. Fryhle.)*

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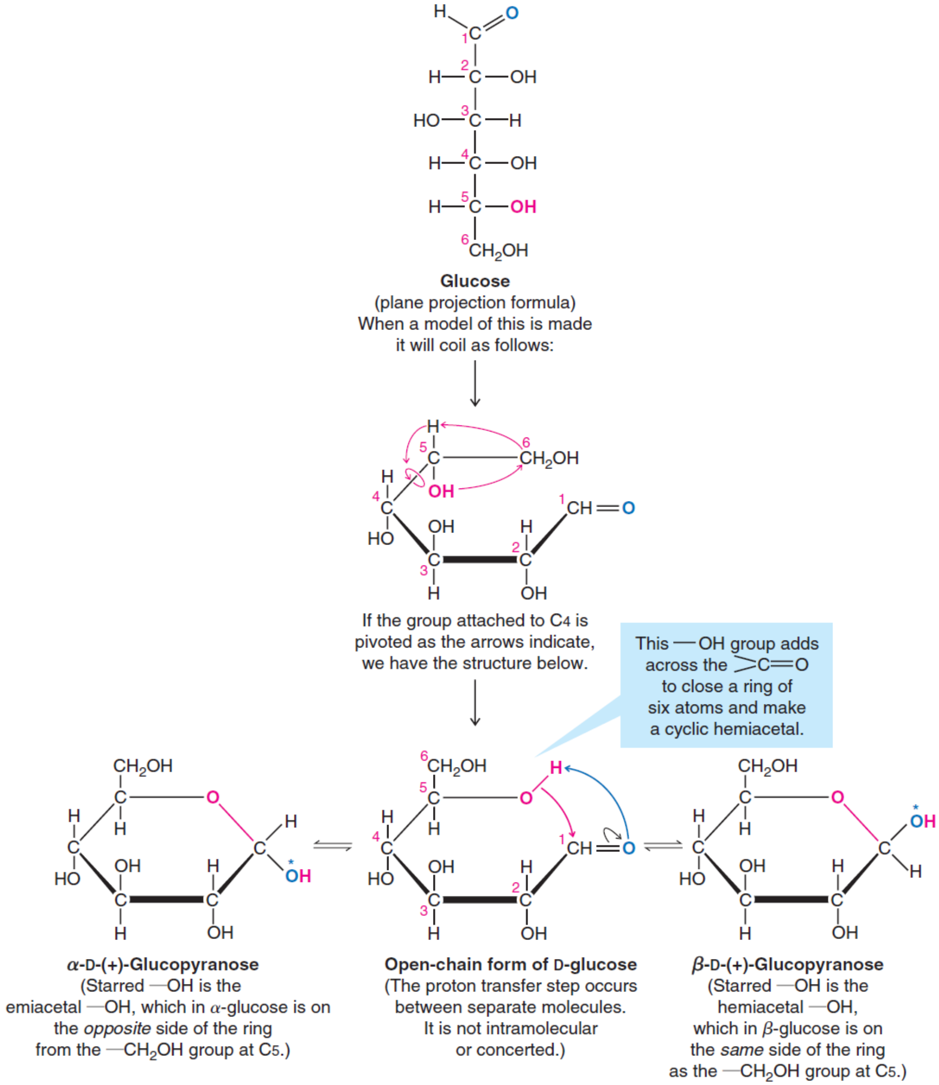
Conversion of Open-Chain to Cyclic structure of Monosaccharide

- *Similarly the cyclization also occurs in case of monosaccharide. Example of cyclization of glucose has been shown below.*



Glucose
(plane projection formula)
When a model of this is made
it will coil as follows:

If the group attached to C4 is
pivoted as the arrows indicate,
we have the structure below.

This —OH group adds
across the >C=O
to close a ring of
six atoms and make
a cyclic hemiacetal.

α-D-(+)-Glucopyranose
(Starred —OH is the
emiacetal —OH, which in α-glucose is on
the *opposite* side of the ring
from the —CH_2OH group at C5.)

Open-chain form of D-glucose
(The proton transfer step occurs
between separate molecules.
It is not intramolecular
or concerted.)

β-D-(+)-Glucopyranose
(Starred —OH is the
hemiacetal —OH,
which in β-glucose is on
the *same* side of the ring
as the —CH_2OH group at C5.)

(Picture adapted from *Chapter No. 22, 'Organic Chemistry' (10th edition) by T. W. G. Solomons and C. B. Fryhle.)*

References

- *Student may also consult following study materials and books:*

1. *Chapter 22, Organic Chemistry (10th edition); Publisher: John Wiley & Sons, Inc. Authors: T. W. G. Solomons and C. B. Fryhle.*

2. *Chapter No. 11, 'Biochemistry' ; Publisher: John Wiley & Sons, Inc.; 4th edition; Authors: D. Voet and J. G. Voet.*

3. *Chapter 16, 'Organic Chemistry'; Publisher: Oxford University Press; 2nd edition; Authors: Jonathan Clayden , Nick Greeves , Stuart Warren.*

4. *Chapter No. 7, 'Organic Chemistry; Volume 2: Stereochemistry and the chemistry of Natural Products'; Publisher: Pearson Education India; 5 edition; Author: I .L . Finar*

Rest of the topics of this unit will be discussed in next part of the lecture.

Stay Happy, Healthy and Safe!