# Carbohydrates
# Lecture 1

**Lecture : Biochemistry**

**Stage : 1st Stage, Second Semester**

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**Department: Chemistry and Biochemistry**

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# Learning Objective

- **Define** and classify carbohydrates.
- **Identify** monosaccharide structures.
- **Understand** sugar stereochemistry.
- **Explain** sugar cyclization (ring formation).
- **Recognize** carbohydrate derivatives and their uses.

# Introduction

- ✓Carbohydrates are the most abundant organic molecules in nature.
- ✓The primary role of carbohydrates is to supply energy to all cells in the body.
- Many cells use glucose as a source of energy.
- ✓The formula for many of the simpler carbohydrates is (CH2O)n, hence the name “hydrate of carbon.
- ✓They serve as the primary immediate energy source for the human body, particularly the brain.
- There are three major size classes of carbohydrates: **monosaccharides,** oligosaccharides, and polysaccharides (the word “saccharide” is derived from the Greek sakcharon, meaning “sugar”).
- Your body breaks down carbohydrates into glucose. Glucose, or blood sugar, is the main source of energy for your body's cells, tissues, and organs.
- **Glucose** can be used immediately or stored in the liver and muscles for later use.

# carbohydrates

- Some cells, such as red blood cells, are only able to produce cellular energy from glucose.
- The brain is also highly sensitive to low blood-glucose levels because it uses only glucose to produce energy and function.
- **Energy Storage:** If the body already has enough energy to support its functions, the excess glucose is stored as **glycogen** (the majority of which is stored in the muscles and liver).
- They are structural components of many organisms.

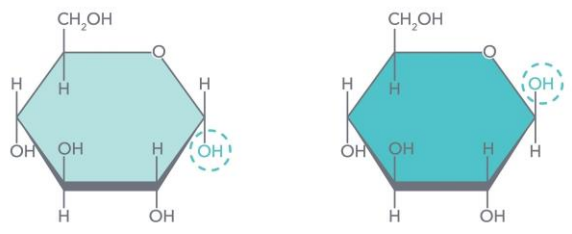
# CLASSIFICATION OF CARBOHYDRATE

## ❑Monosaccharide :

- Monosaccharides contain of a single polyhydroxy aldehyde or ketone unit.

- **Most Abundant**: The six-carbon sugar D-glucose (also known as dextrose) is the most abundant monosaccharide in nature.
- **Structural Rule**: Monosaccharides containing more than four carbons tend to exist in cyclic structures rather than open chains.

Alpha (α) vs. Beta (β) Glucose




Orientation of hydroxyl group (R-OH) is below the ring plane on the α-D-glucose compared to above the ring plane on the β-D-glucose

# ❑ Oligosaccharides and Disaccharides

- **Definition**: Oligosaccharides consist of short chains of monosaccharide units joined by characteristic **glycosidic bonds**.
- **Disaccharides**: These are the most abundant oligosaccharides, containing of exactly two monosaccharide units.
- **Example**: Sucrose (cane sugar) is a typical disaccharide made of D-glucose and D-fructose.
- **Nomenclature**: All common monosaccharides and disaccharides have names ending with the suffix "-ose“

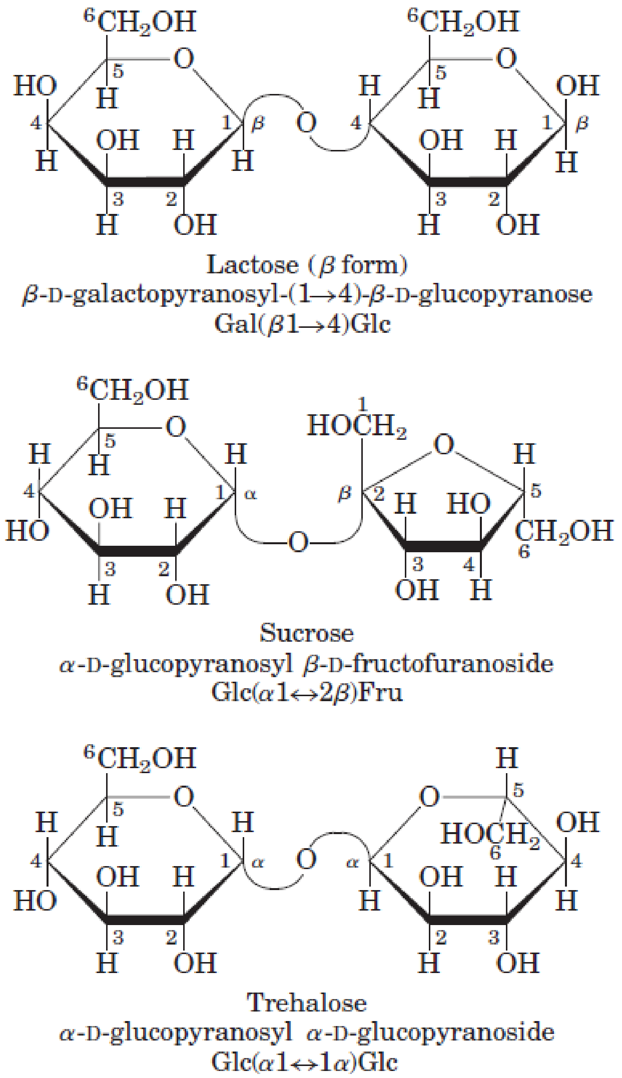



**FIGURE 7–12 Some common disaccharides.** Like maltose in Figure 7–11, these are shown as Haworth perspectives. The common name, full systematic name, and abbreviation are given for each disaccharide.

# Monosaccharides

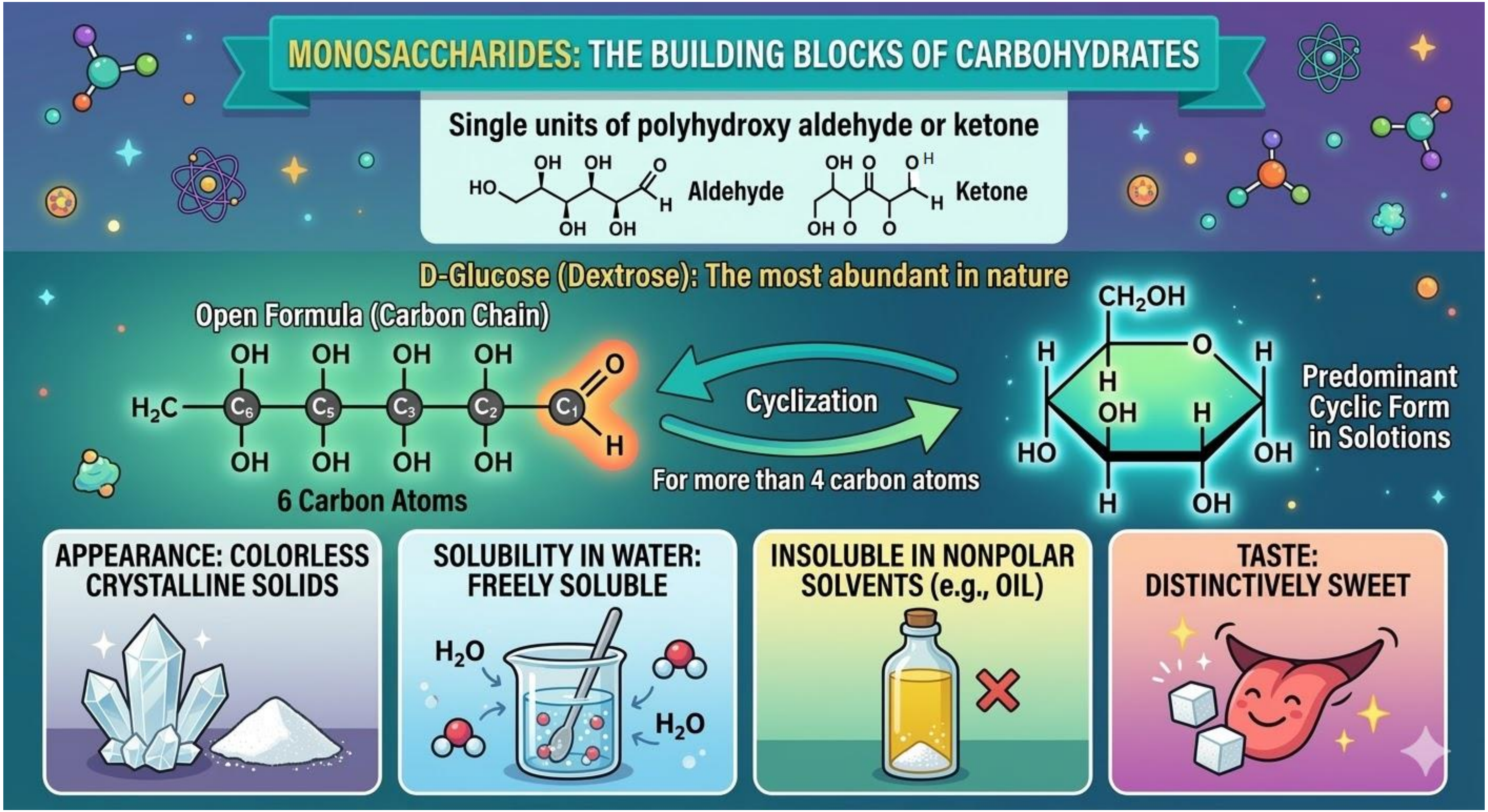
❖ **Monosaccharides are aldehyde or ketone derivatives of straight-chain polyhydroxy alcohols containing at least three carbon atoms.**

- They are classified according to the chemical nature of their **carbonyl group** and the **number of their C** atoms.

1. If the carbonyl group is an **aldehyde**, the sugar is an **aldose**.

- If the carbonyl group is a **ketone**, the sugar is a **ketose**.
- The smallest monosaccharides, those with three carbon atoms, are **trioses**.
- Those with **four**, five, six, seven, etc. C atoms are, respectively, **tetroses**, pentoses, hexoses, heptoses, etc.

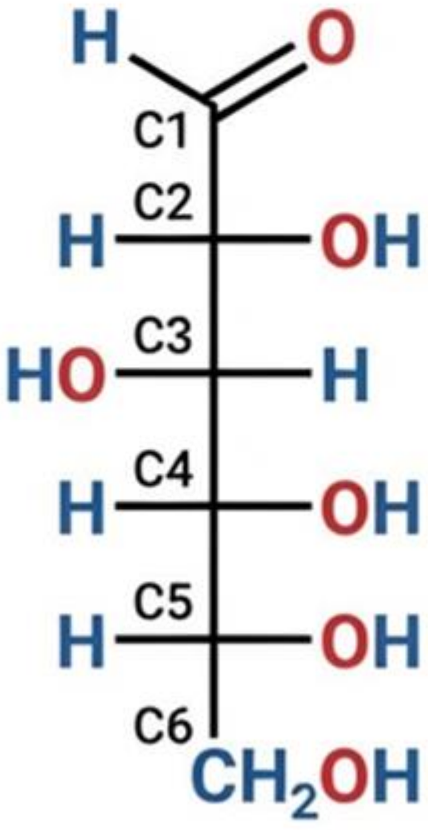
# Monosaccharides

- 

# Monosaccharides

## ❑The Structural Backbone

- The backbones of common monosaccharides consist of unbranched carbon chains where all carbon atoms are linked by single bonds.
- **Open-Chain Form:** One carbon atom is double-bonded to an oxygen atom, forming a **carbonyl group**.
  - Every other carbon atom in the chain has a **hydroxyl group** attached to it.
- **Size:** These carbon backbones typically range from three to seven carbons in length.



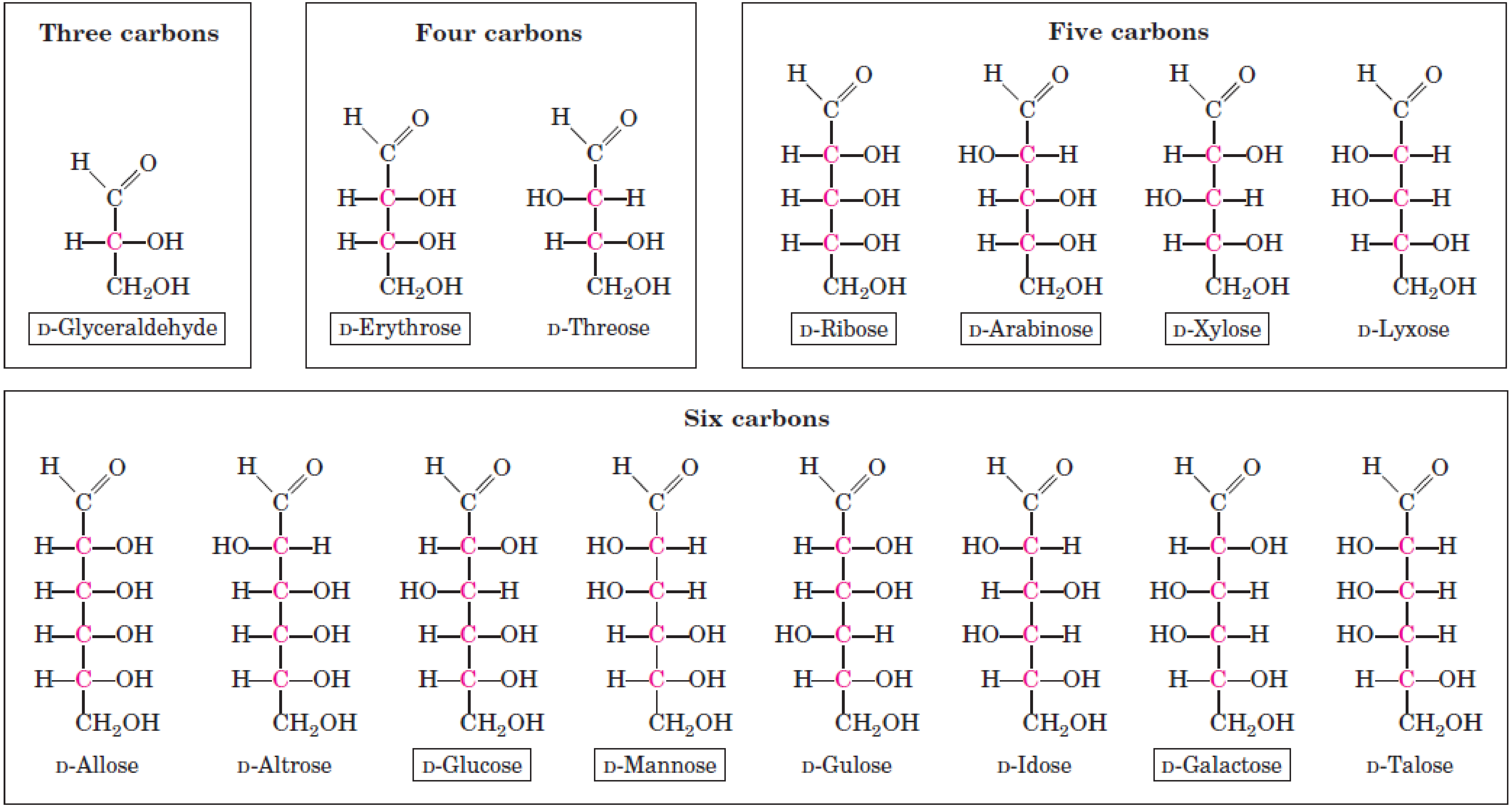

Open-Chain (Acyclic) Glucose

# Monosaccharides

- **Naming by Carbon Chain Length**
- Monosaccharides are classified and named according to the number of carbon atoms in their backbones:

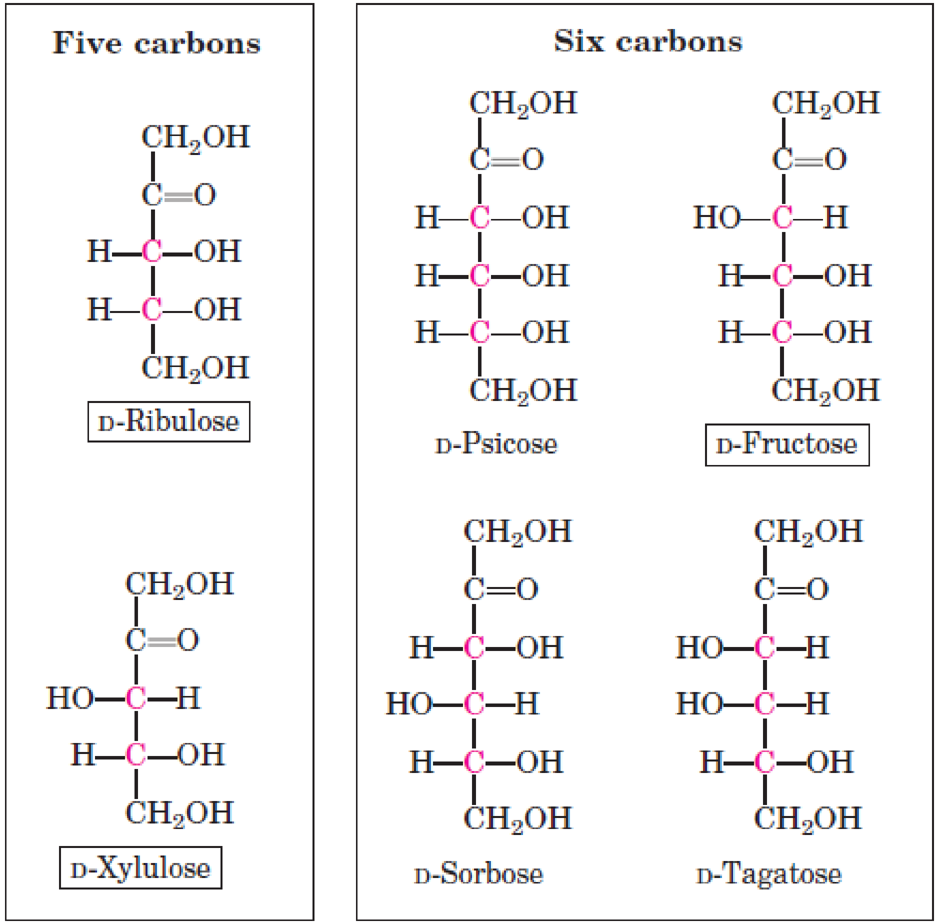
| GENERIC NAMES | | EXAMPLES |
|---|---|---|
| 3 Carbons: | trioses | Glyceraldehyde |
| 4 Carbons: | tetroses | Erythrose |
| 5 Carbons: | pentoses | Ribose |
| 6 Carbons: | hexoses | Glucose |
| 7 Carbons: | heptoses | Sedoheptulose |
| 9 Carbons: | nonoses | Neuraminic acid |

# Aldoses




**D-Aldoses**

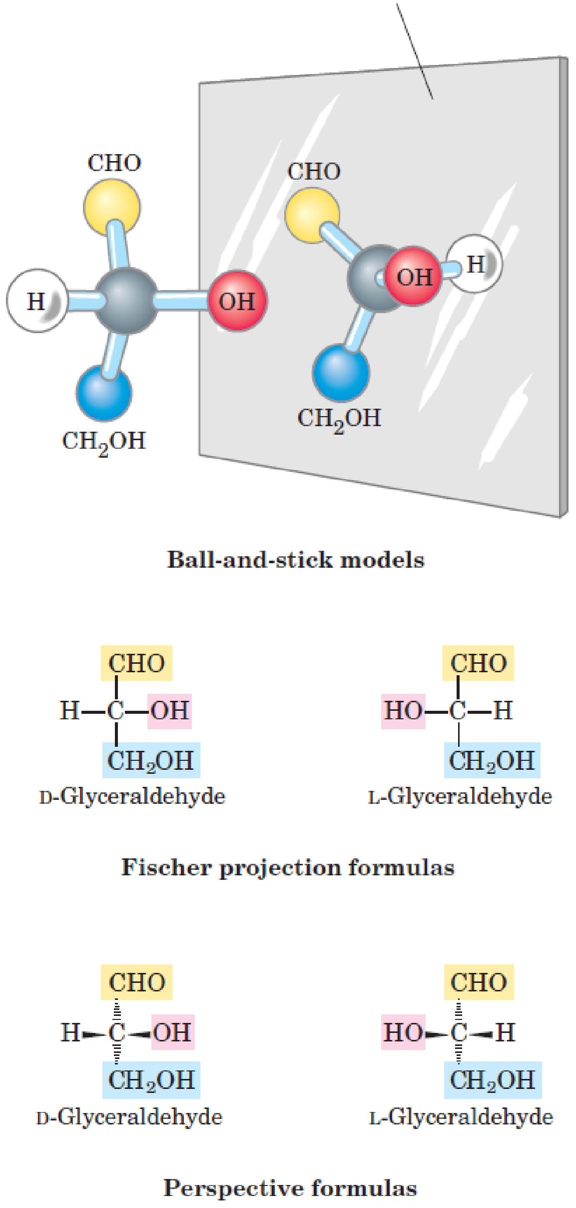
# Ketoses




**D-Ketoses**
**(b)**

# The stereochemistry of Monosaccharides

- <u>**Asymmetric (Chiral) Centers**</u>
- **Chirality Rule:** All monosaccharides, with the single exception of **dihydroxyacetone**, contain one or more asymmetric (chiral) carbon atoms.
- **Optical Activity:** Because of the presence of these chiral centers, these monosaccharides naturally occur in **optically active isomeric forms**.
- A molecule with n chiral centers can have a total of 2n possible stereoisomers.
- Glyceraldehyde: Has 1 chiral center. (2^1 = 2 stereoisomers).
- Aldohexoses: Have 4 chiral centers. (2^4 = 16 possible stereoisomers).

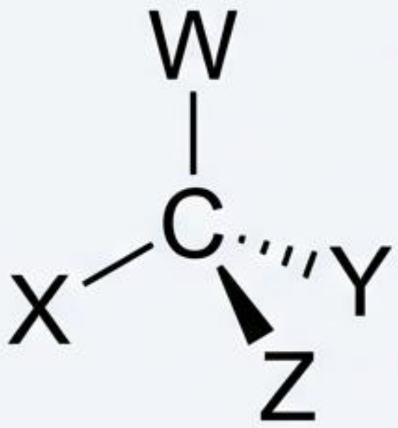


# Stereochemistry and the Chiral Carbon

3IW model

## Stereoisomerism

Compounds with the same structural formula but differing in how groups are arranged in 3D space.




## The Asymmetric (Chiral) Carbon

A carbon atom attached to four entirely different groups or atoms (e.g., the middle carbon of glyceraldehyde).

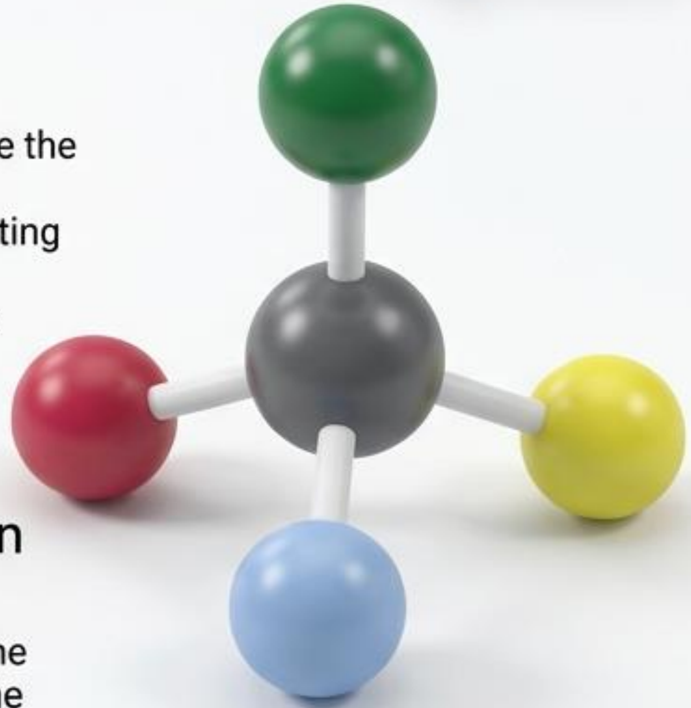
Clinical diagram

## Optical Activity

The presence of a chiral carbon gives the molecule the ability to rotate plane-polarized light (light vibrating in a single plane after passing through a Nicol's prism).

## Isomer Calculation

The number of possible optical isomers follows the formula $2^n$, where n is the number of asymmetric carbon atoms.



# Enantiomers and the Dominance of D-Sugars

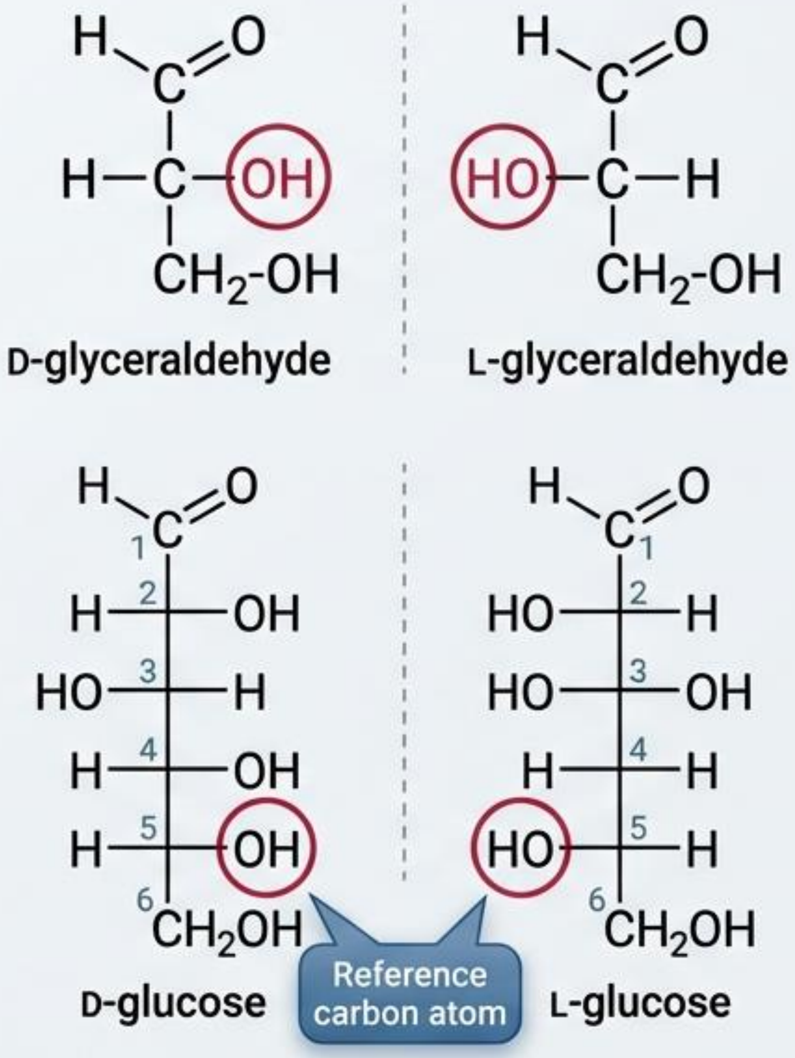
**Enantiomers** are stereoisomers that are perfect, non-superimposable mirror images of each other.

**The Reference Carbon:** Configuration is determined by the asymmetric carbon farthest from the carbonyl group (next to the terminal primary alcohol). In glucose, this is C5.

**D-Series:** The -OH group on the reference carbon is on the right side. The vast majority of sugars found in humans are D-sugars.

**L-Series:** The -OH group on the reference carbon is on the left side.

**Optical Rotation:** Compounds rotate light either right (Dextrorotatory, d or +) or left (Levorotatory, l or -).
Note: D-glucose is dextrorotatory, frequently called dextrose.

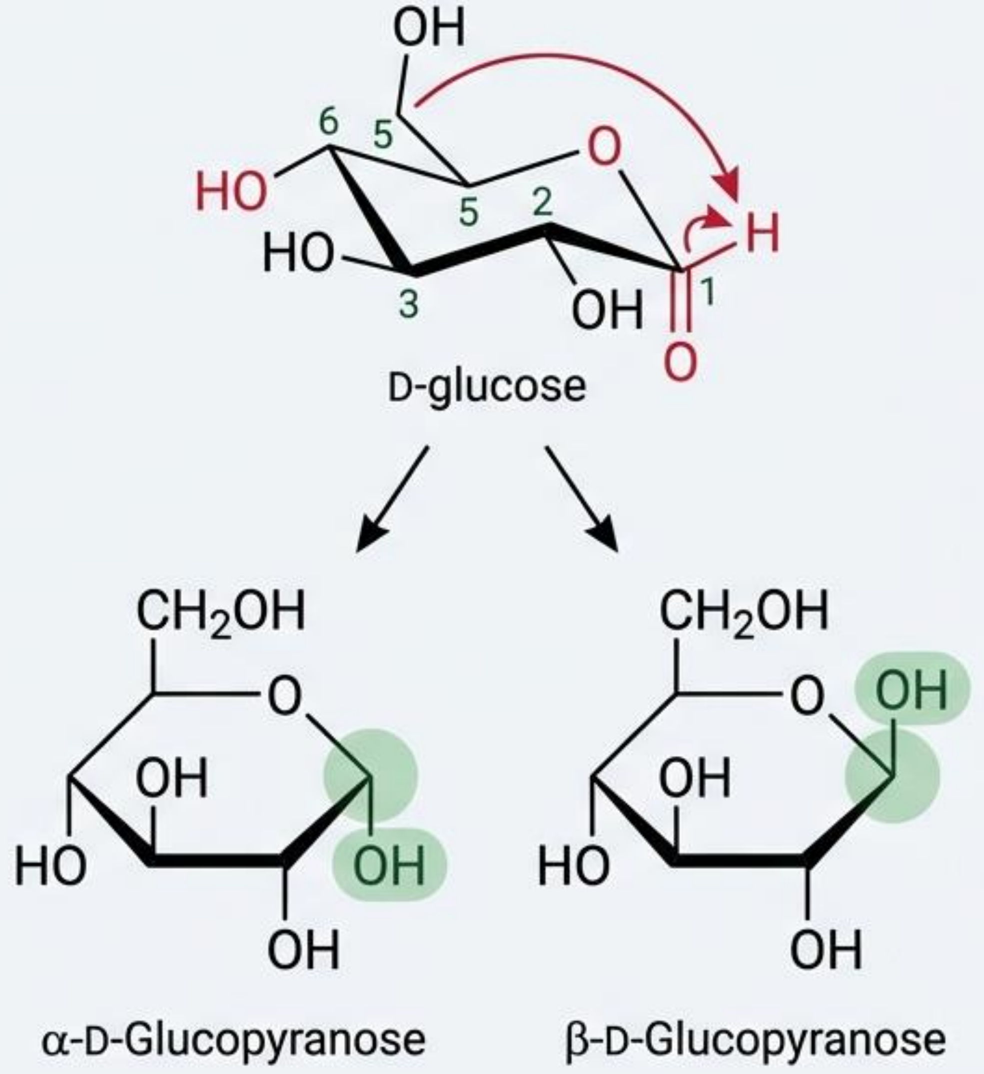


# Aqueous Environments Drive Cyclization

Roboto

Less than 1% of monosaccharides with five or more carbons exist in an open-chain (acyclic) form.

- **Hemiacetal Formation:** The linear carbohydrate reacts with an alcohol group on the same sugar. The nucleophilic alcohol attacks the electrophilic carbonyl carbon.
- **The Anomeric Carbon:** This cyclization converts the carbonyl carbon into a new asymmetric center, termed the anomeric carbon (C1 for aldoses, C2 for ketoses).
- **Ring Structures:** This process generates six-membered rings containing oxygen (Pyranose) or five-membered rings (Furanose).



# *Asymmetric carbon atom (chiral carbon)*

- Def: It is a carbon atom which is attached to 4 different group or atoms e.g. middle carbon of glyceraldhyde.
- Any substance having asymmetric carbon atom posses the following:

I. Show optical activity.

II. Show optical isomerism (stereoisomerism)

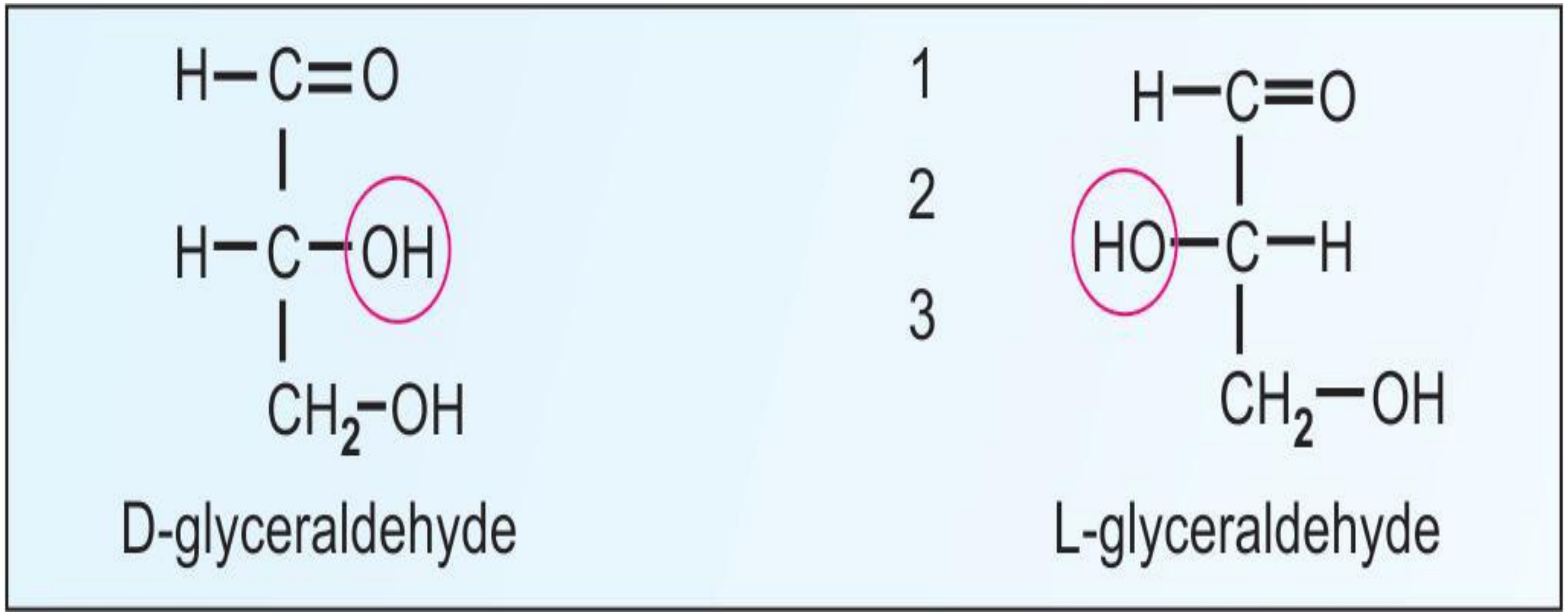
# Optical isomerism

- Def :Compounds having the same structural formulae (same chemical group) but differ in the way these groups are attached in space around only one of its asymmetric carbon atom.

- The number of optical isomers = $2^n$ where n = number of asymmetric carbon atoms in a molecule.

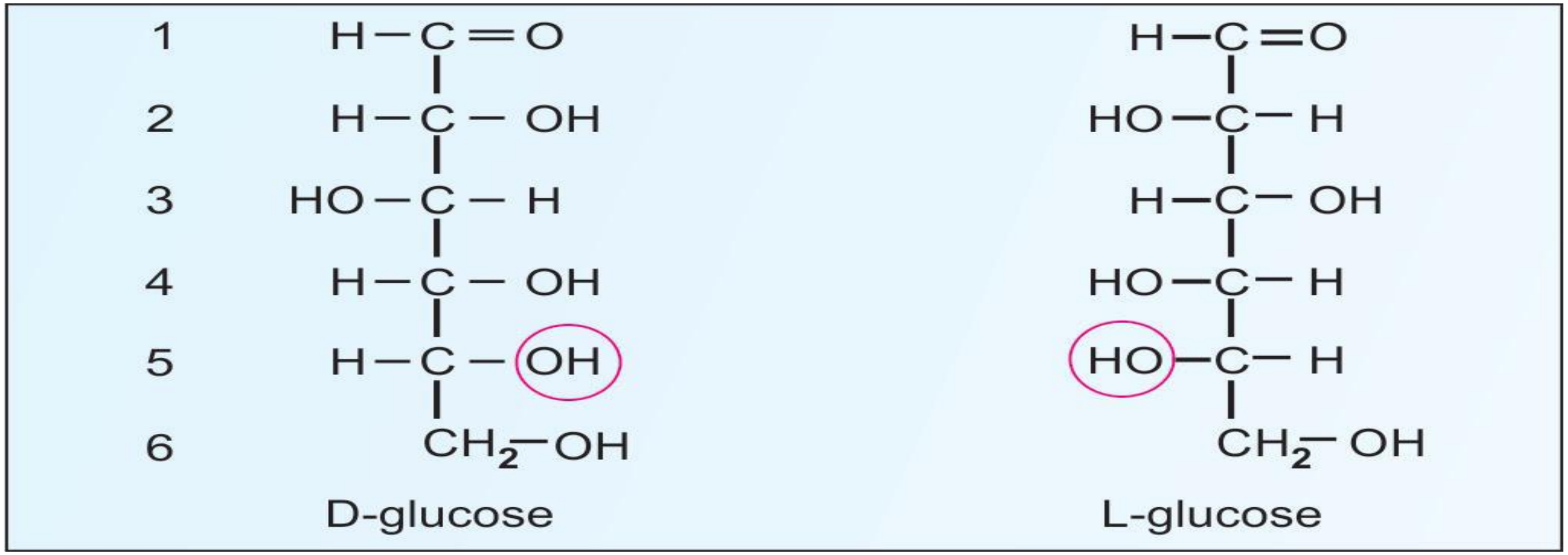
## Stereoisomer

Compounds with the same connectivity, Same chemical and structural formula, but differ arrangement in the space.



# Reference Carbon Atom of Sugars

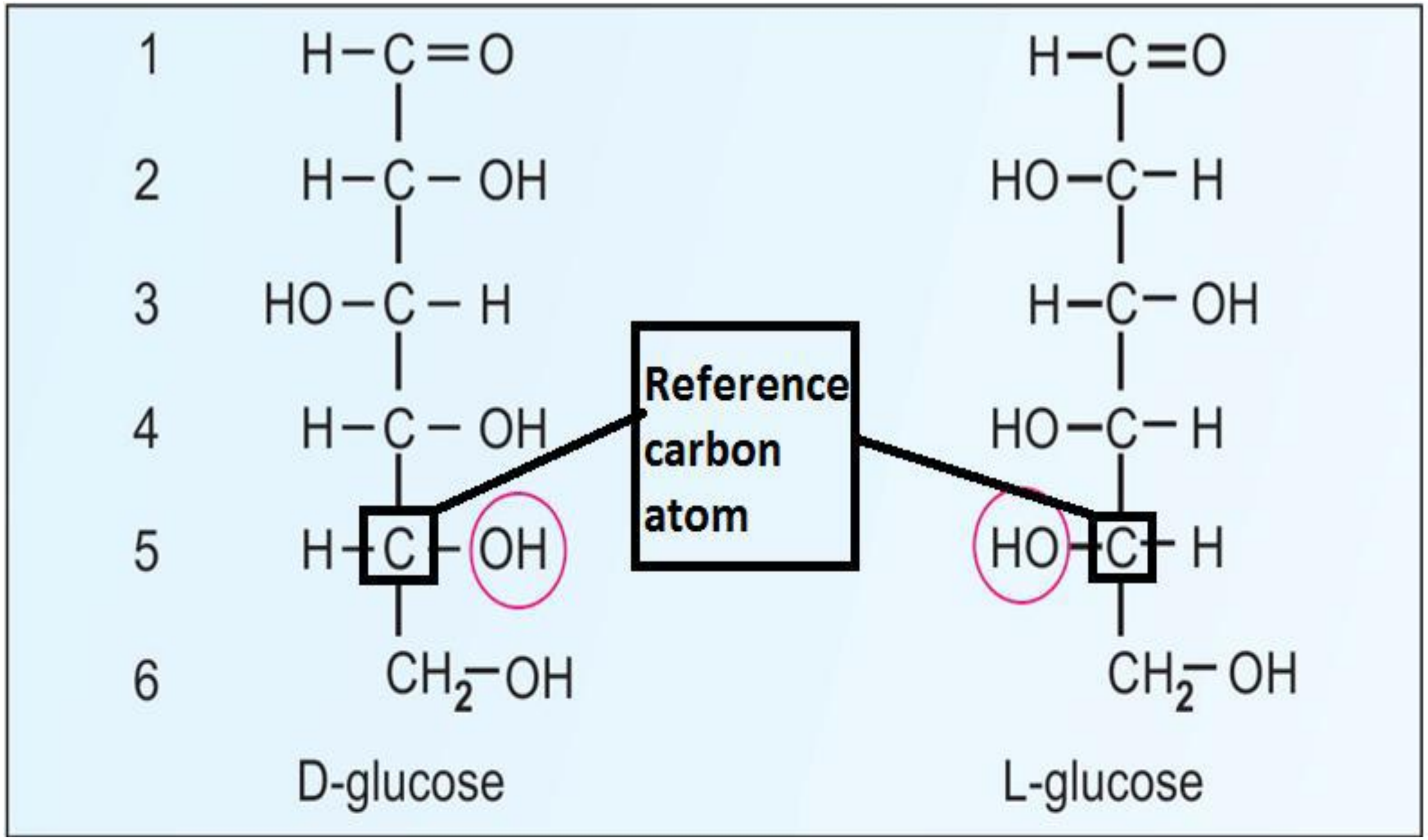
All monosaccharide can be considered as molecules derived from glyceraldehyde by successive addition of carbon atoms. Therefore, **next to last carbon atom is the reference carbon atom for naming the mirror images**



# Types of isomerism of monosacharides:

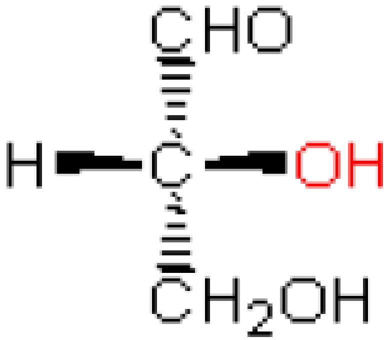
- 1-**Enantiomers: (D & L configuration).**
- **2-Anomers or α and β isomer.**
- **3-Epimers.**
- **4-Aldose and ketose isomers .**
- **5-Pyranose and furanose isomers**

# D and L isomerism(Enantiomers)

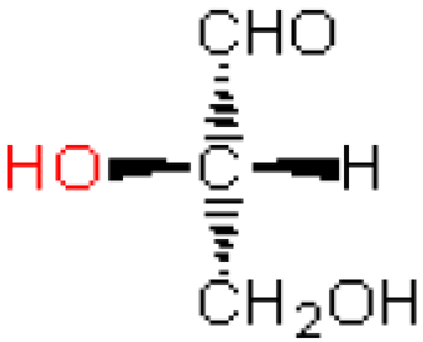


# Optical isomerism (D and L)

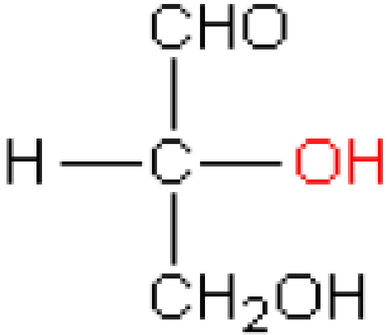
- The presence of asymmetrical carbon atom causes optical activity.
- When a beam of plane-polarized light is passed through a solution of carbohydrates, it will rotate the light either to right or to left.
- **Right** = Dextrorotatory (+) (D)
- **Left** = Levorotatory (-) (L)



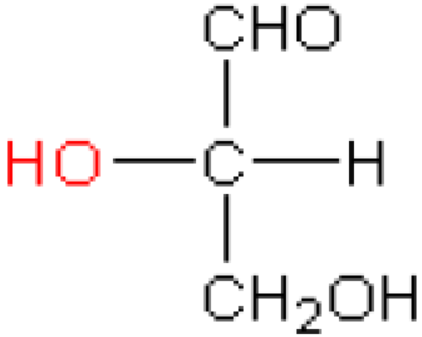
D-glyceraldehyde



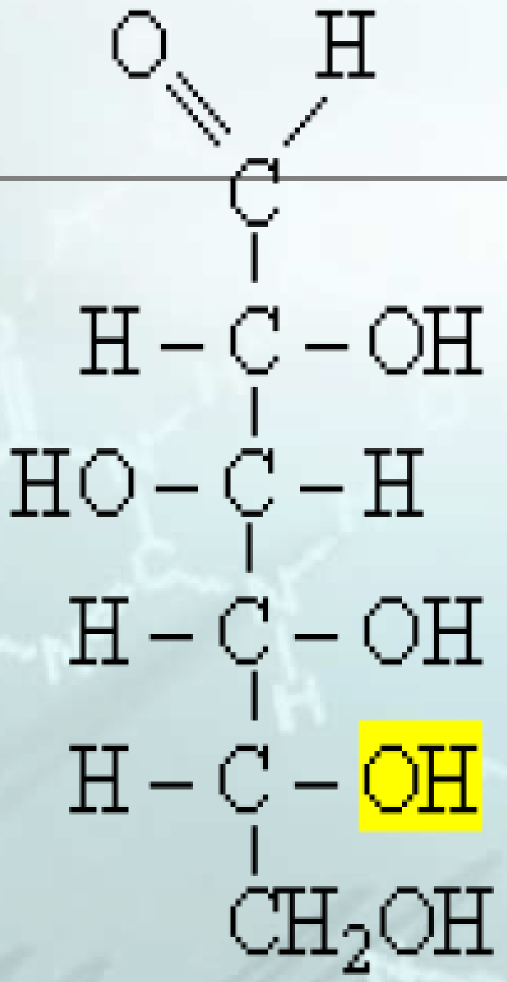
L-glyceraldehyde



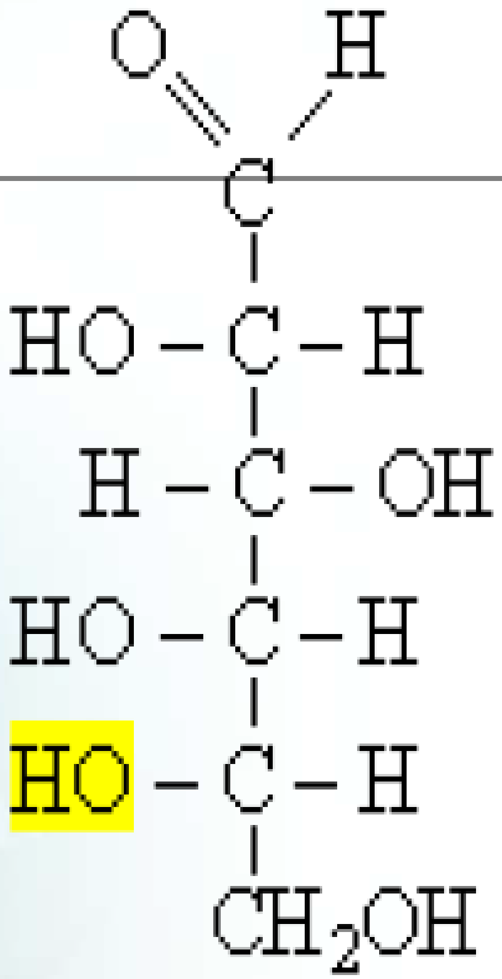
D-glyceraldehyde



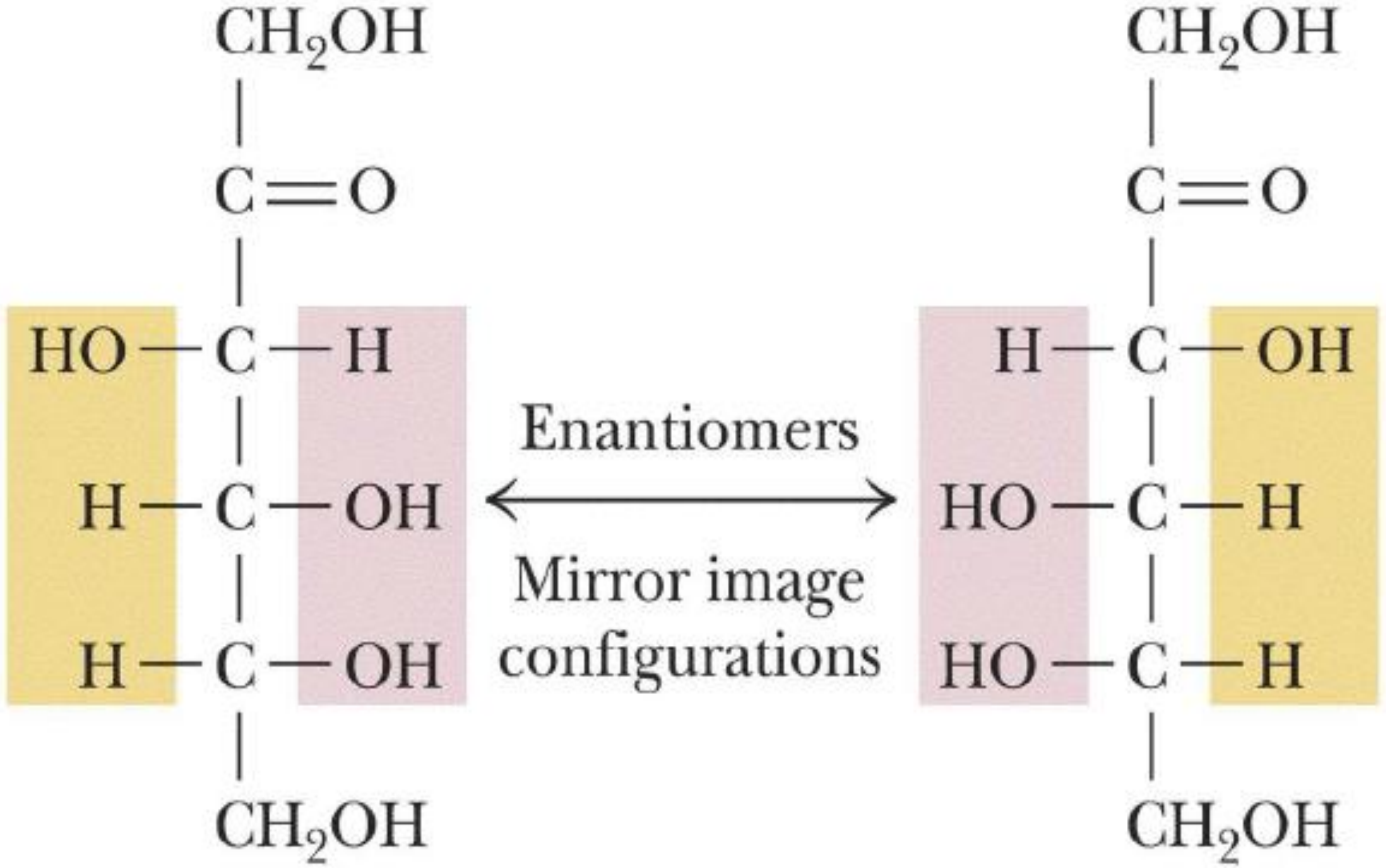
L-glyceraldehyde



D-glucose



L-glucose




**D-Fructose** **L-Fructose**

# Anomers :α and β isomer

- Concept: These are isomers that differ in position of OH group at the **anomeric carbon** atom.
- Reffered to: anomeric C atom
- Def of annomeric C atom: is the asymmetric carbon atom obtained from active sugar group in the **cyclic** structure .
- Position of anomeric C:C1 in aldose and C2 of ketose).
- **Types of anomers** :
- 1- **α sugar :** OH group attached to the anomeric carbon is on the right side.
- 2- **β sugar**. OH group attached to the anomeric carbon is on the left side.

# Cyclization of Monosaccharides

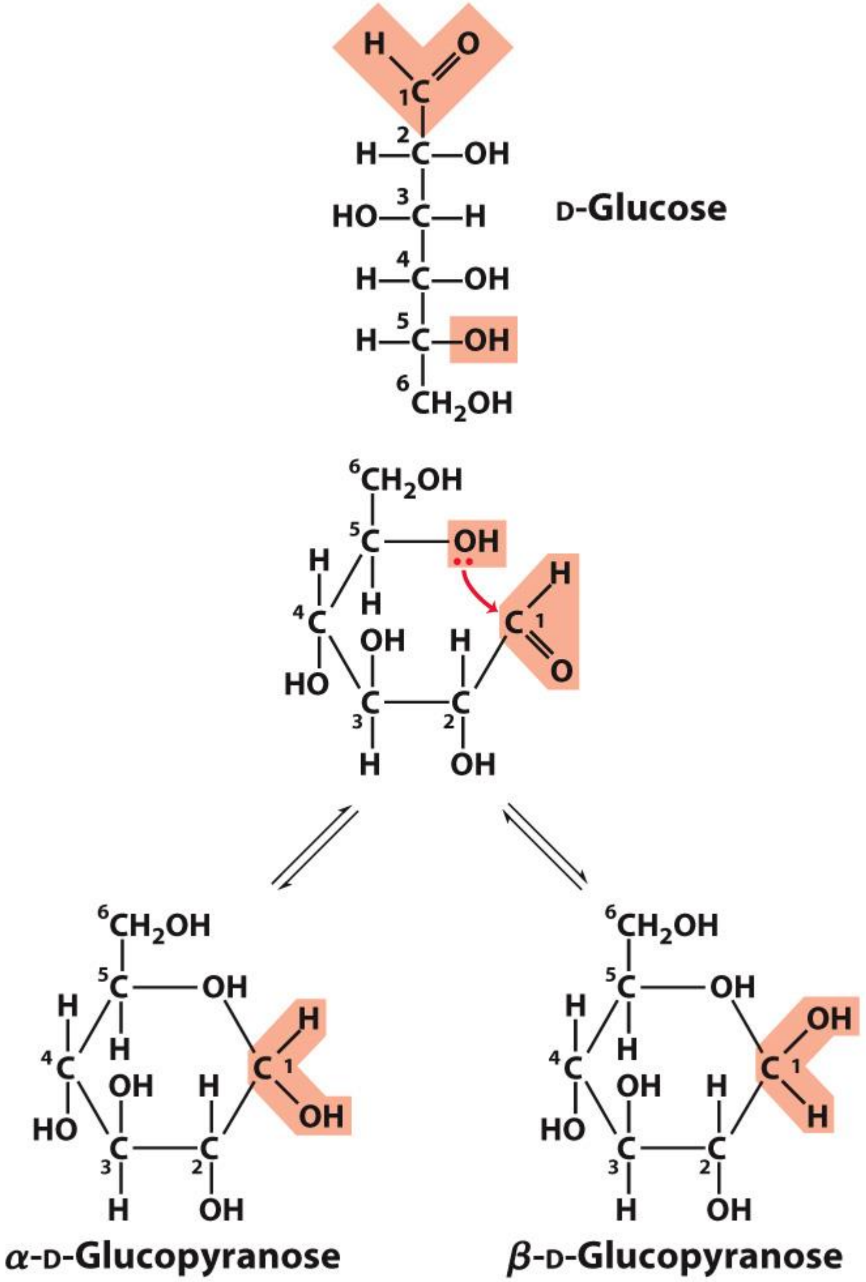
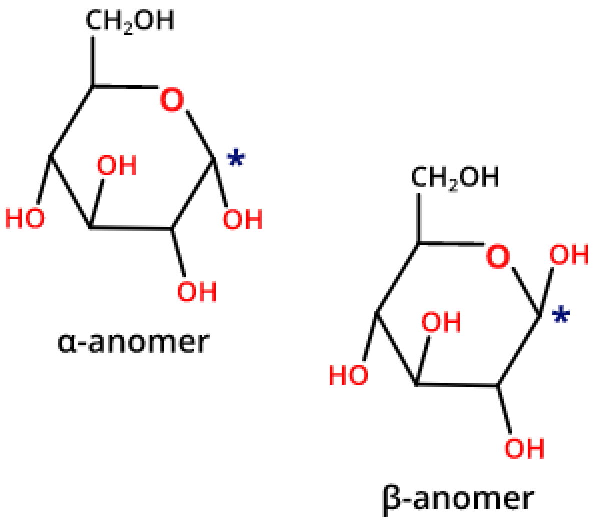


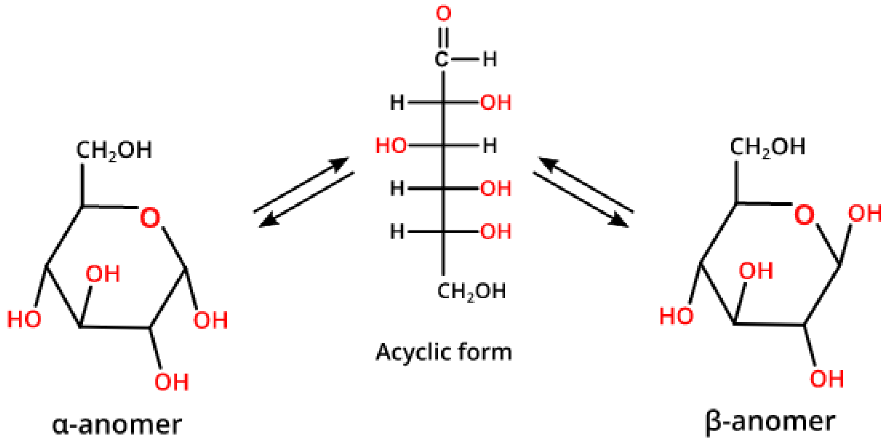

**Figure 7-6**
*Lehninger Principles of Biochemistry*, Seventh Edition


- The nucleophilic alcohol attacks the electrophilic carbonyl carbon, allowing formation of a **hemiacetal**.
- As a result, the linear carbohydrate forms a ring structure.
- At the completion of this structure, the **carbonyl** carbon **is** reduced to an **alcohol**

# α (Alpha) and β (beta) isomers




The Anomeric Carbon




**Mutarotation in α and β-D Glucose**

# Epimers

- Concept :If two monosaccharides differ in configuration around only one asymtetric carbon atom other than anomeric C& the prelist C atom ,((the epimeric carbon))>>>> they are defined as epimers of each other.
- Referred to: epimeric carbon .
- Def of epimeric carbon : asymtetric carbon atom other than anoneric& the prelist C atoms.
- Examples : usually erpimers are described in pairs :
  . Glucose & galactose are C4 epimer. .
- Glucose & mannose are C2 epimer

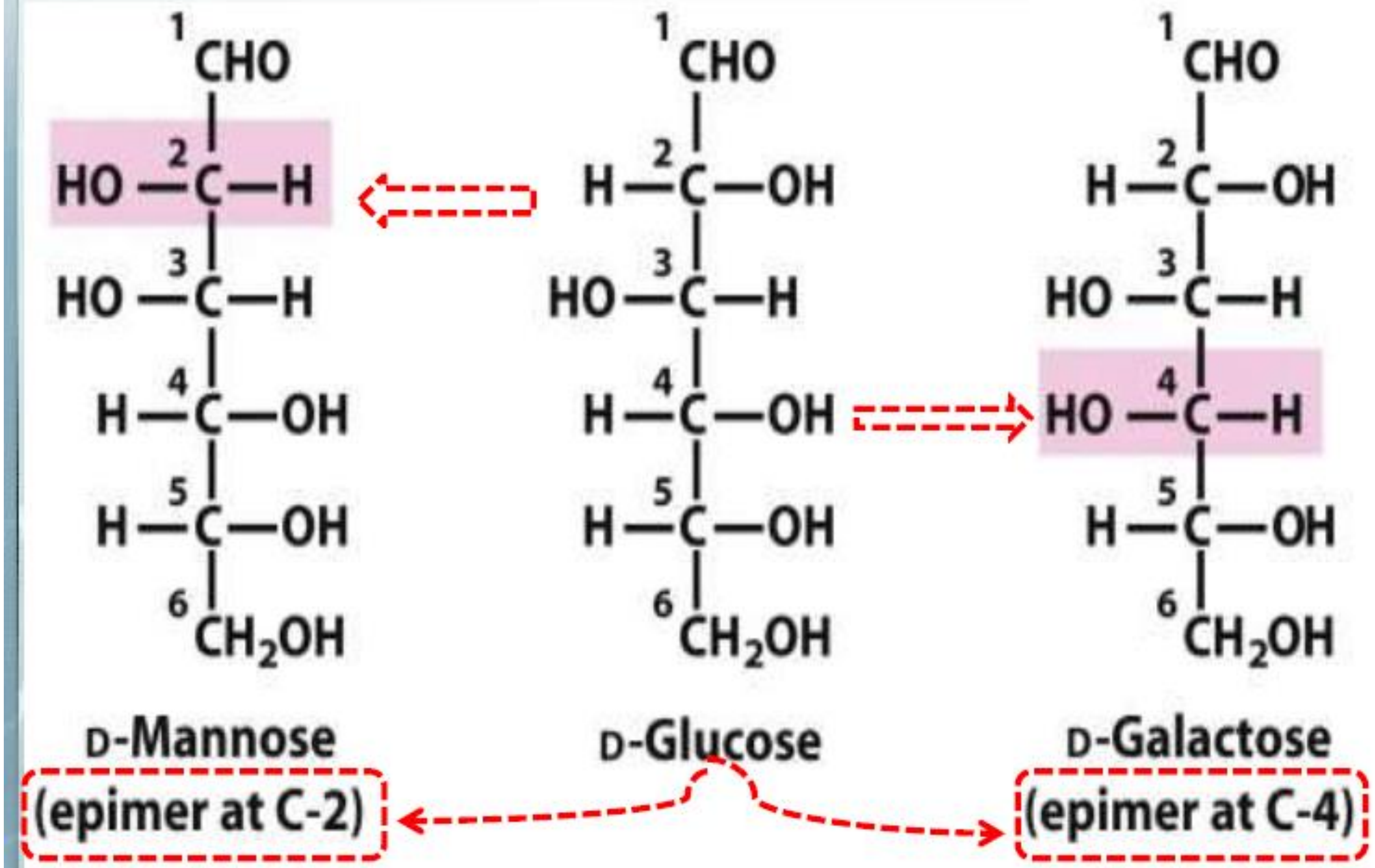


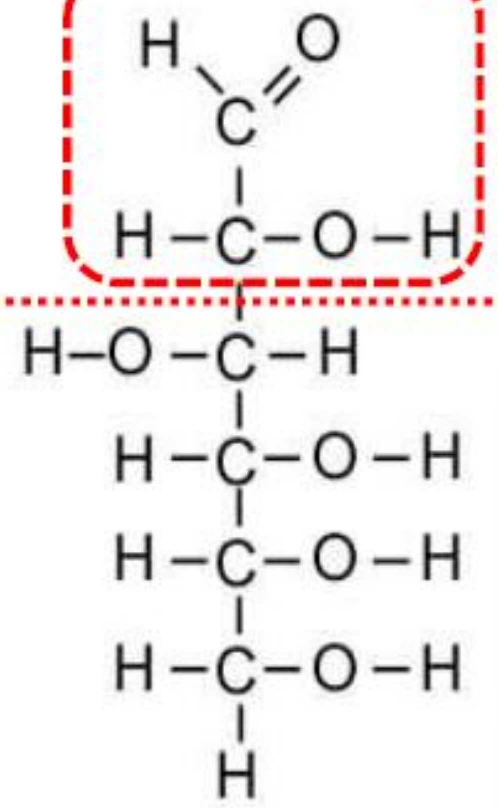

**Figure 7-4**

*Lehninger Principles of Biochemistry, Fifth Edition*

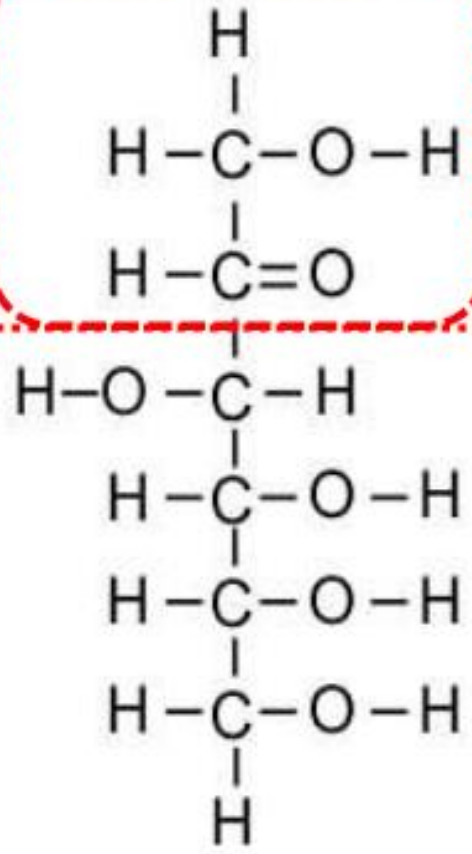
# Aldose and ketose isomers

- Concept :Two isomers have the same molecular formula but differ in aldhyde group or ketone group
- Example :. glucose --- fructose
- ribose --- ribulose.

**Glucose**

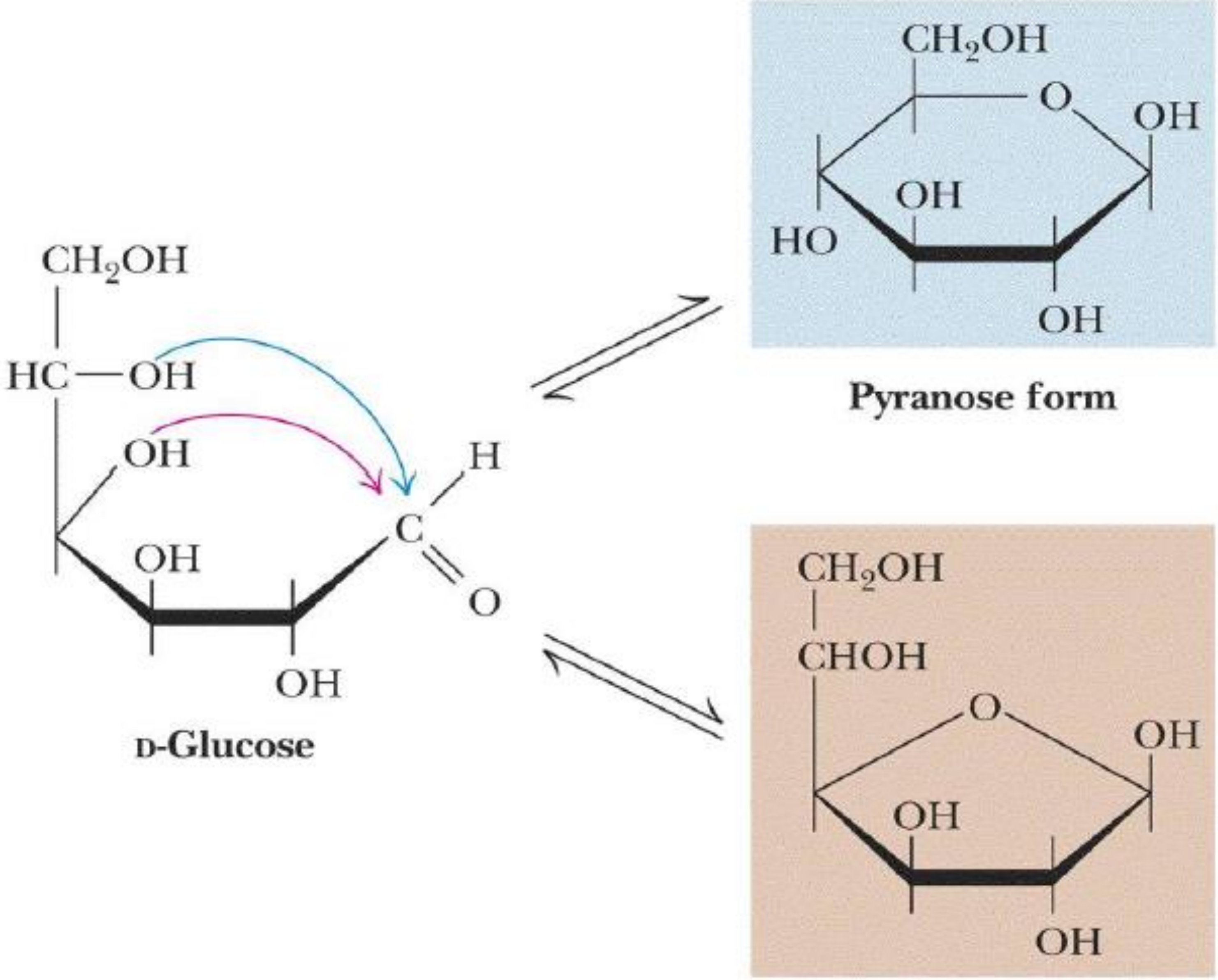


**Fructose**



# Pyranose and furanose isomers

- Glucose can be present in glucopyranose and as glucofuranose both are isomers.

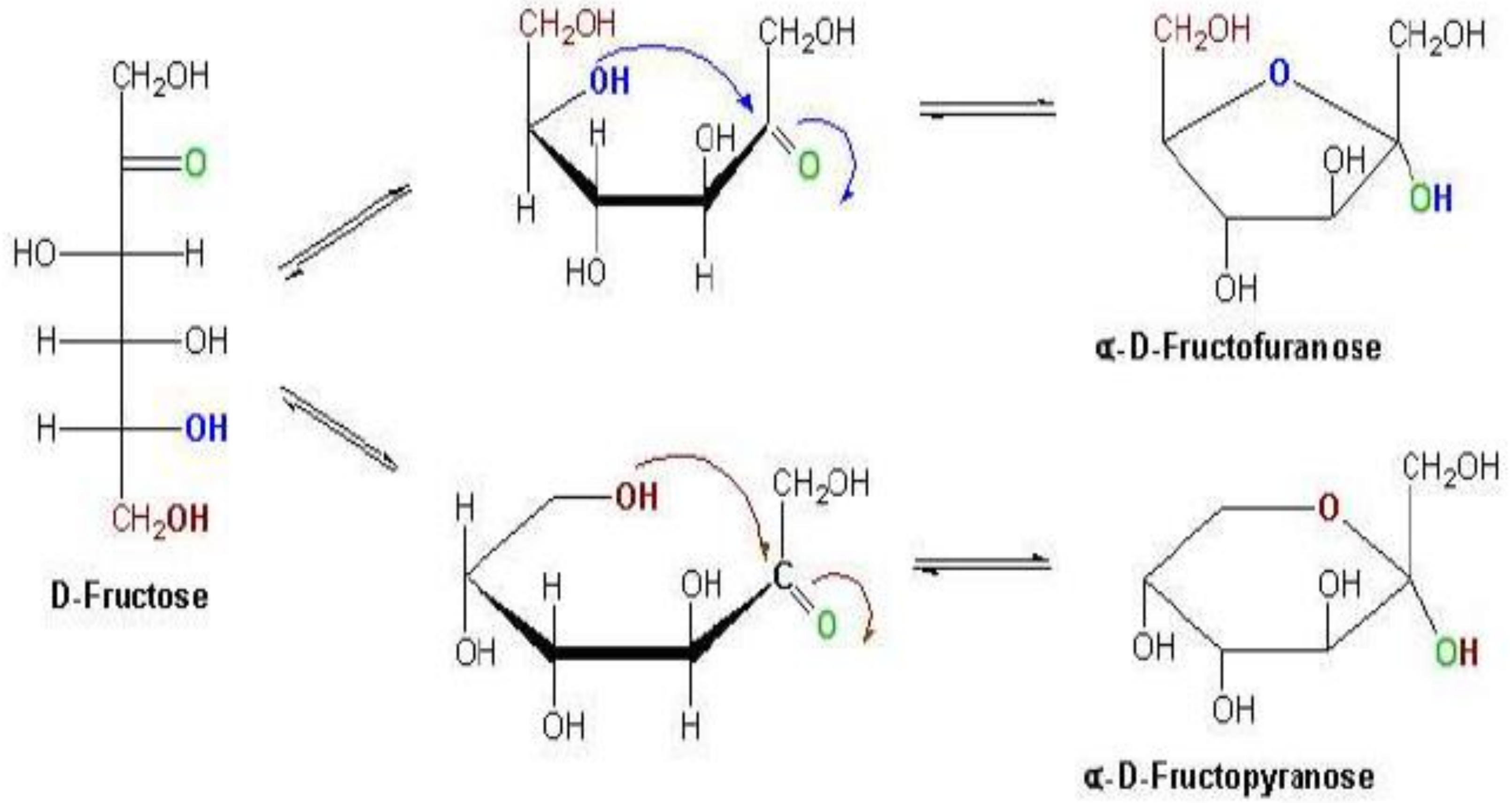



D-Glucose

Pyranose form

Furanose form

# Isomeric Forms of Fructose



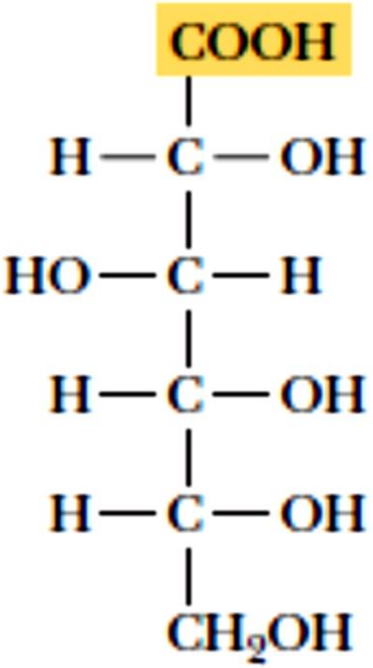
# Sugar Derivatives

- **They include:**

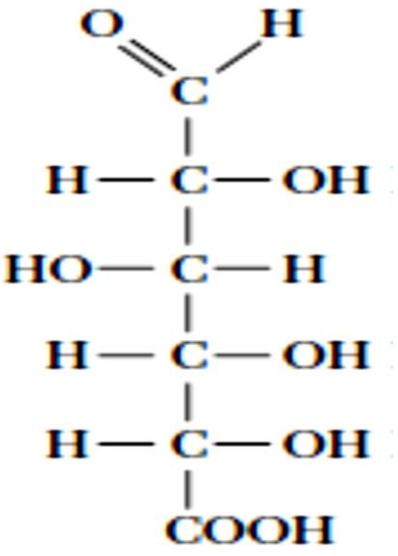
I. Sugar Acids.
II. Sugar Alcohols.
III. Deoxysugars.
IV. Amino Sugars.
V. Amino sugar acids.

# Monosaccharides Derivatives

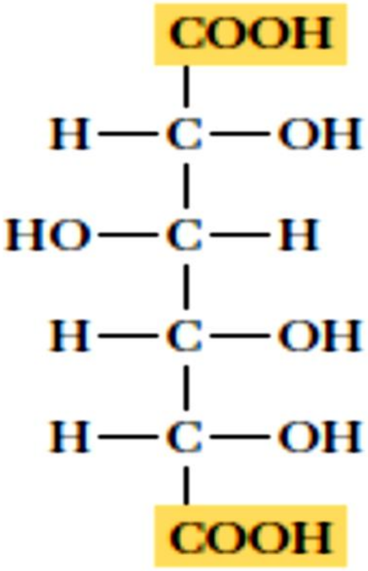
1. **Sugar Acids:** Sugars with free anomeric carbon atoms are reasonably good reducing agents, an **aldose** is converted to an **aldonic acid**, such as gluconic acid




D-Gluconic acid



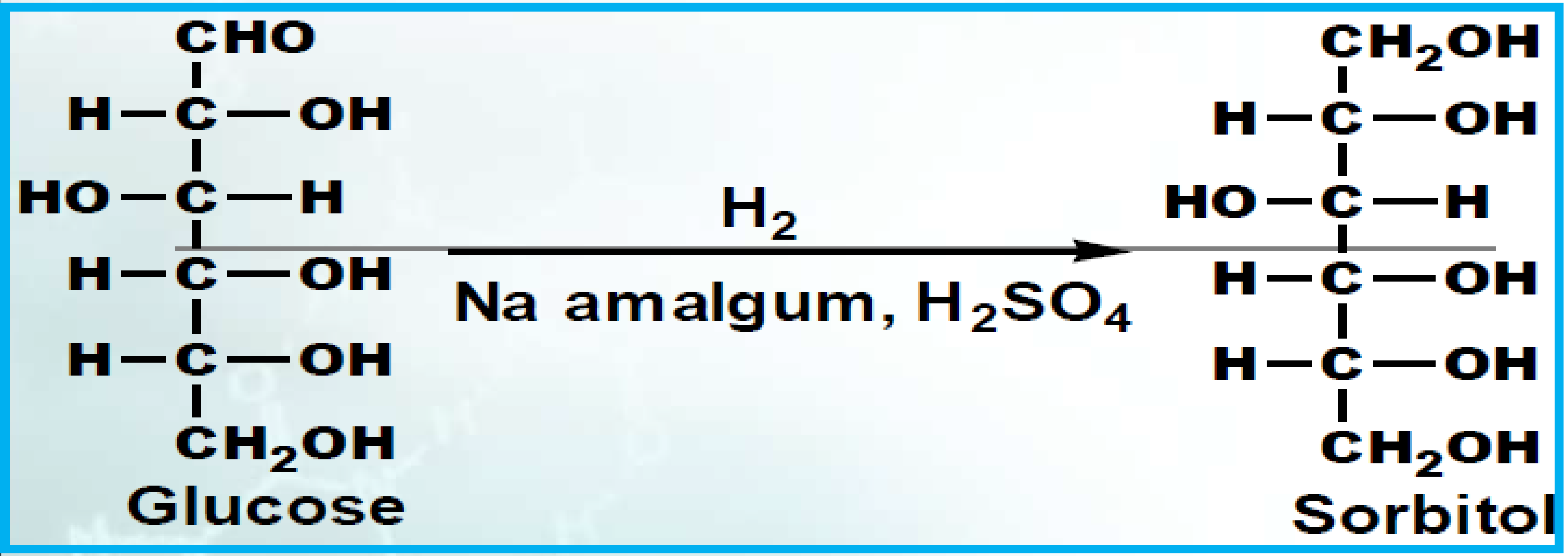

D-Glucuronic acid (GlcUA)

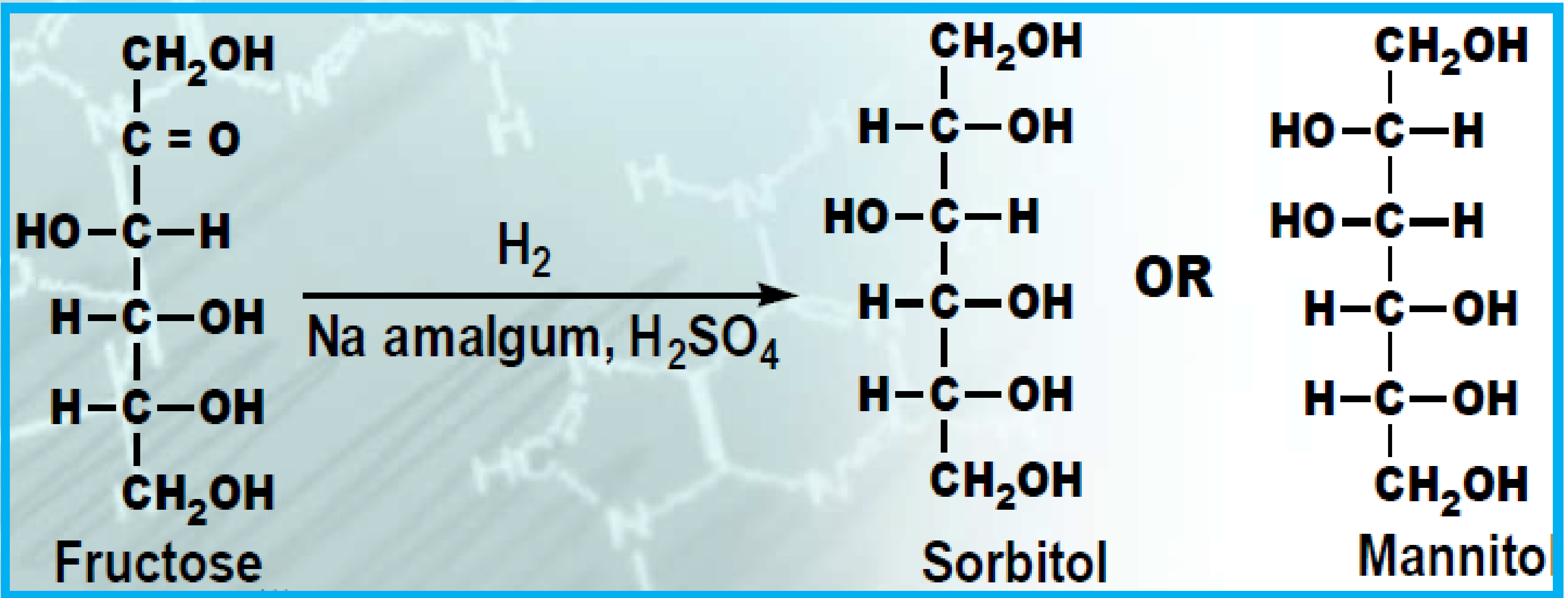



D-Glucaric acid

# 2-Sugar alcohols (Alditols)

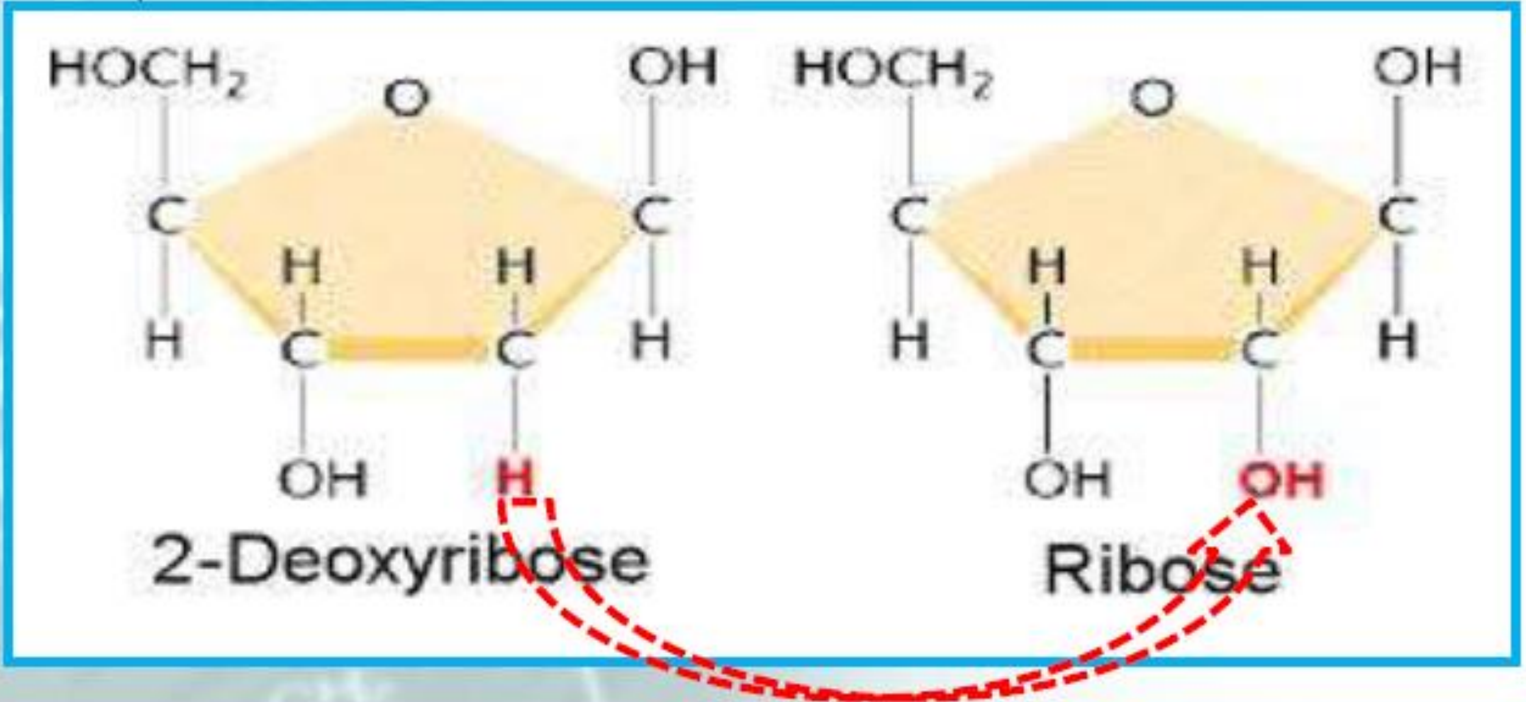
- **Diff:** It is the product of reduction of the active carbonyl group .
- **Concept:** Aldoses and Ketoses may be reduced at the carbonyl carbon to the corresponding polyhydroxy alcohols (sugar alcohols).
- **Examples** :
- D-glucose D-sorbitol.
- D-mannose D-mannitol.
- D-fructose D-sorbitol and D-mannitol.
- D-galactose D-galacticol.
- D-ribose D-ribitol


CHO
H—C—OH
HO—C—H
H—C—OH
H—C—OH
CH2OH
Glucose
H2
Na amalgum, H2SO4
CH2OH
H—C—OH
HO—C—H
H—C—OH
H—C—OH
CH2OH
Sorbitol


CH2OH
C = O
HO—C—H
H—C—OH
H—C—OH
CH2OH
Fructose
H2
Na amalgum, H2SO4
CH2OH
H—C—OH
HO—C—H
H—C—OH
H—C—OH
CH2OH
Sorbitol
OR
CH2OH
HO—C—H
HO—C—H
H—C—OH
H—C—OH
CH2OH
Mannitol

# 3- Deoxysugars

- **Def:** They are monosaccharides with only one of its hydroxyl groups is replaced by hydrogens i.e. there is only one oxygen missed.
- Examples :
- 2-Deoxy-D-ribose is a constituent of DNA.



# Homework

- What is the glycogen? Explain in detail.


Thank You
for your attention