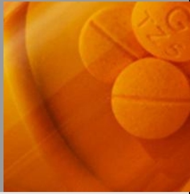
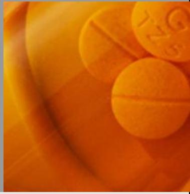
Carbohydrates



PPES ACS College

Dept of Chemistry

IMPORTANT FUNCTIONS OF **CARBOHYDRATES**



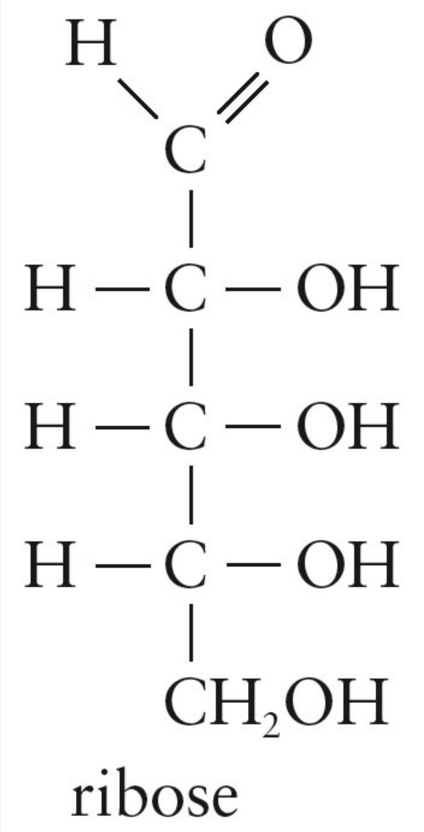
- To provide energy through their oxidation
- To supply carbon for the synthesis of cell components
- To serve as a stored form of chemical energy
- To form a part of the structural elements of some cells and tissues

- **Biomolecule** – a general term referring to organic compounds essential to life

- **Biochemistry** – a study of the compounds and processes associated with living organisms

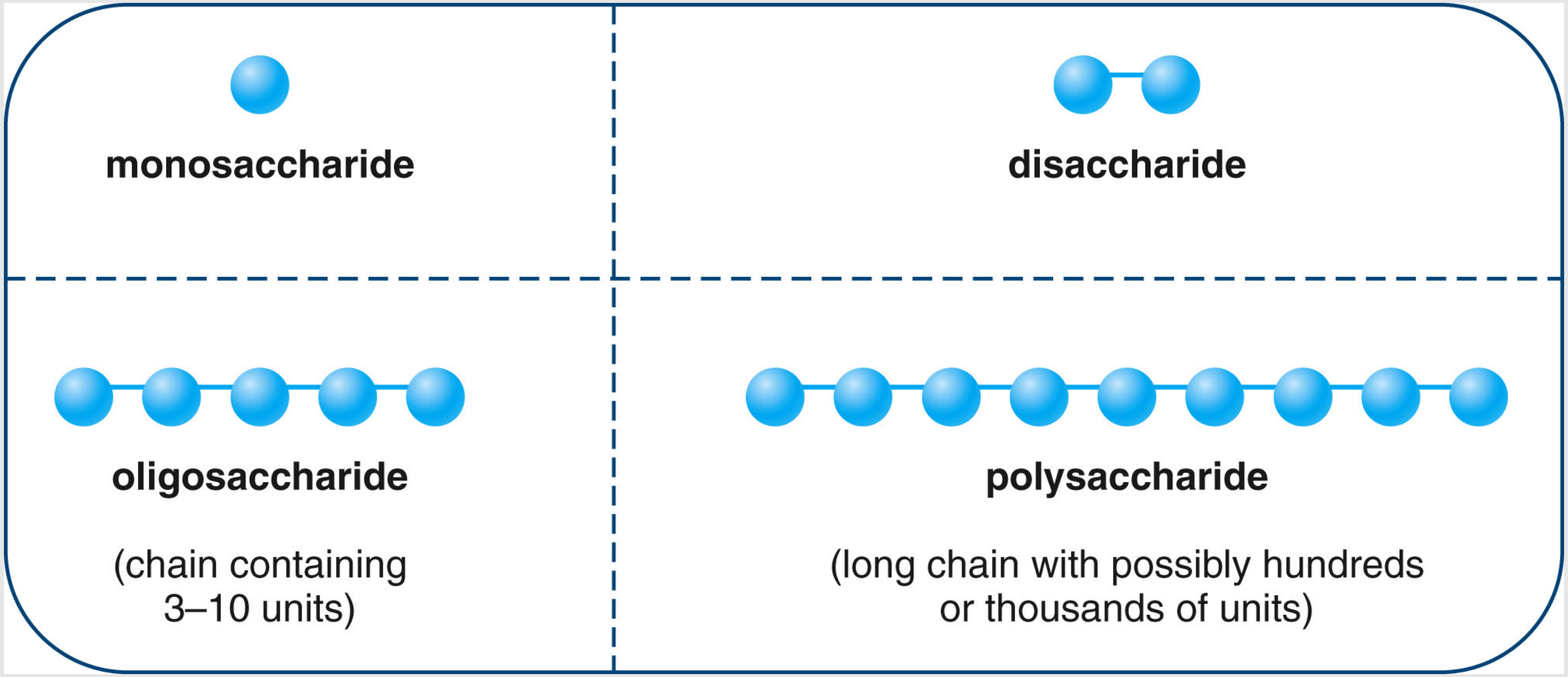
CARBOHYDRATES

- **Carbohydrates** are polyhydroxy aldehydes or ketones, or substances that yield such compounds upon hydrolysis.
- Example:



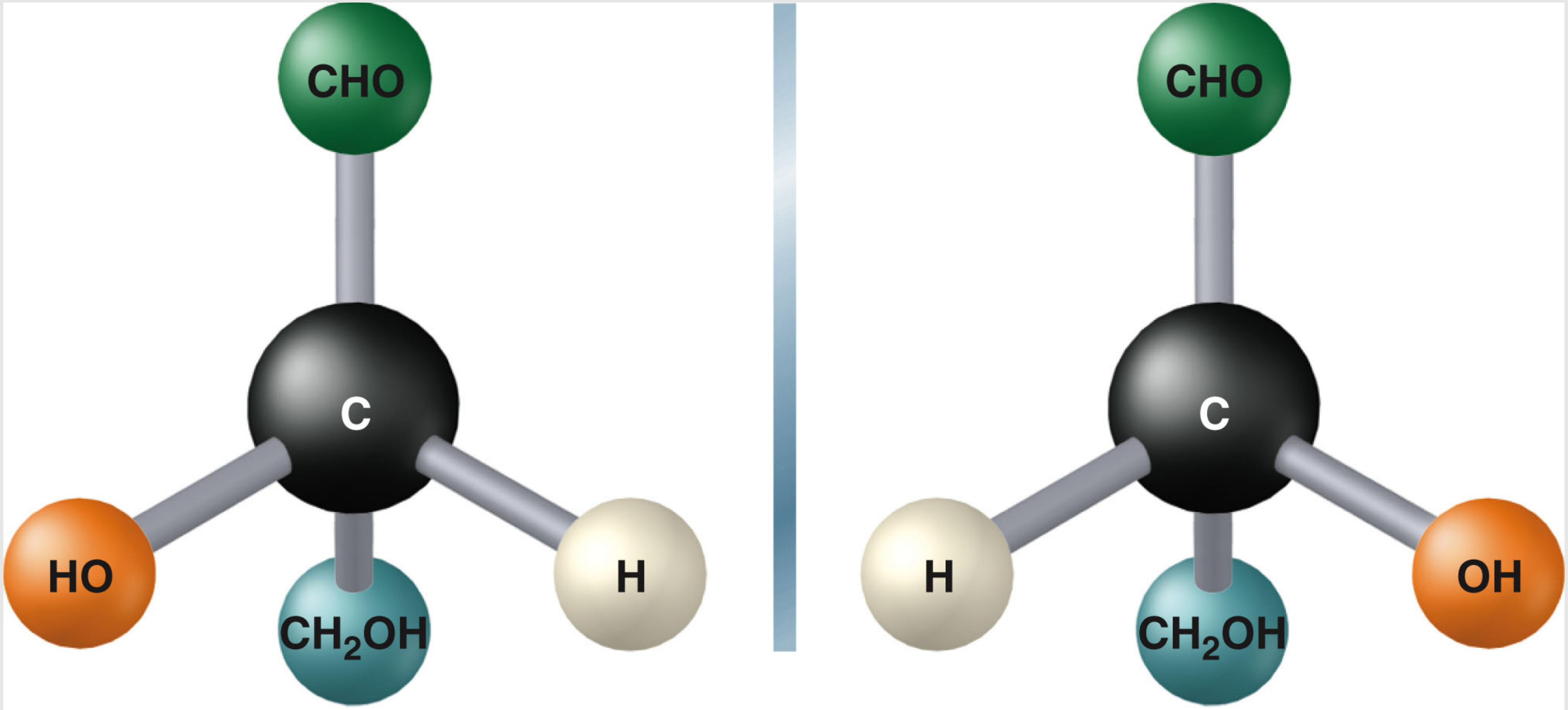
CLASSIFICATION OF CARBOHYDRATES

- **Carbohydrates** are classified according to size:
  - **Monosaccharide** – a single polyhydroxy aldehyde or ketone unit
  - **Disaccharide** – composed of two **monosaccharide** units
  - **Polysaccharide** – very long chains of linked **monosaccharide** units



STEREOCHEMISTRY

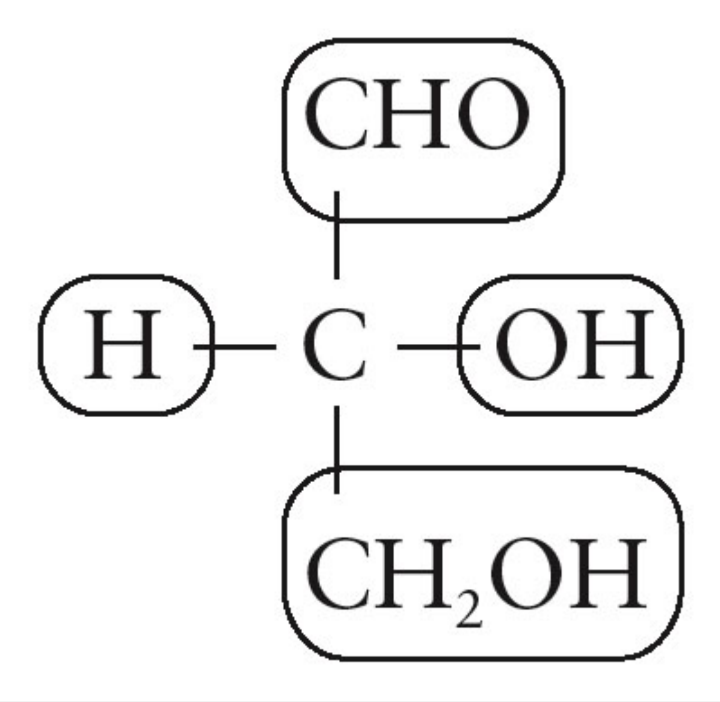
- Many **carbohydrates** exist as **enantiomers** (stereoisomers that are mirror images).



L-glyceraldehyde **Mirror** D-glyceraldehyde

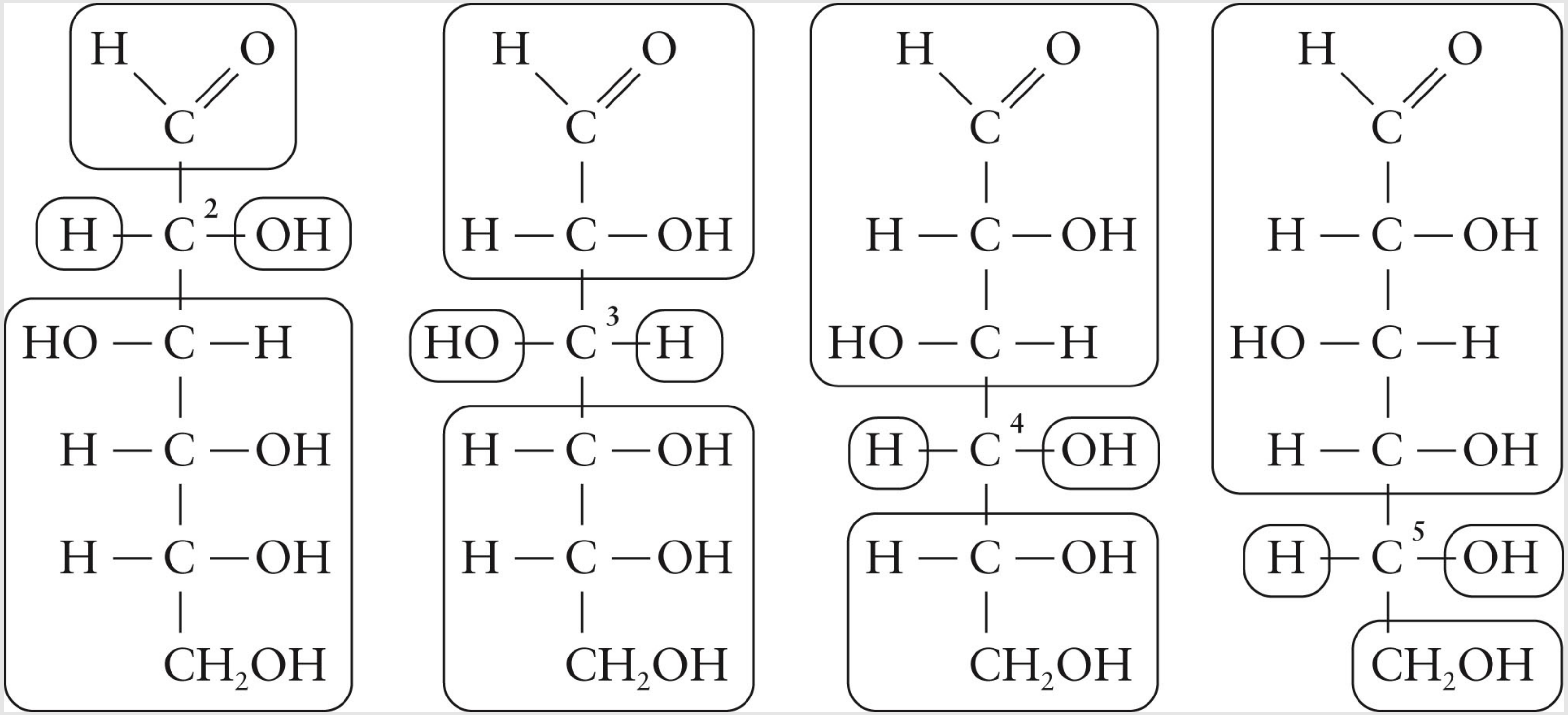
STEREOCHEMISTRY (continued)

- A **chiral** object cannot be superimposed on its mirror image.
- A **chiral carbon** is one that has four different groups attached to it.



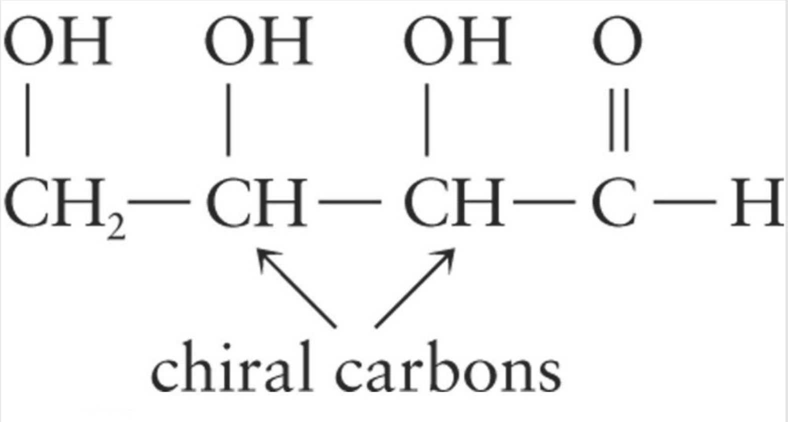
STEREOCHEMISTRY (continued)

- The presence of a single **chiral carbon** gives rise to stereoisomerism.
- If a carbon atom is attached to four different groups, it is **chiral**.
- If any two groups are identical, it is not **chiral**.



STEREOCHEMISTRY (continued)

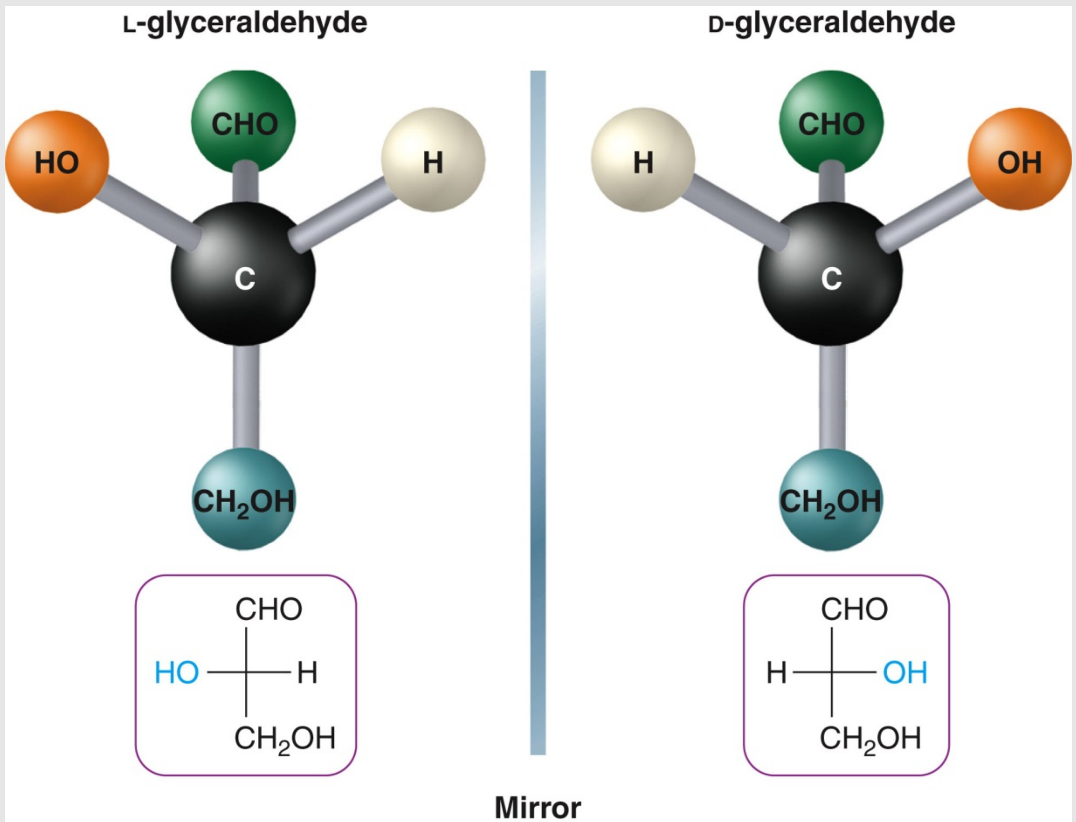
- Compounds can have more than one **chiral carbon**:



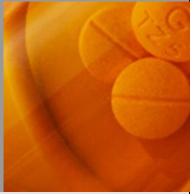
- The maximum number of stereoisomers is 2^n where n= number of **chiral carbon** atoms.
- Therefore, this compound with two **chiral carbon** atoms has 2^2 or 4 stereoisomers.
- The compound on the previous slide with four **chiral carbon** atoms has 2^4 or 16 stereoisomers.

FISCHER PROJECTIONS

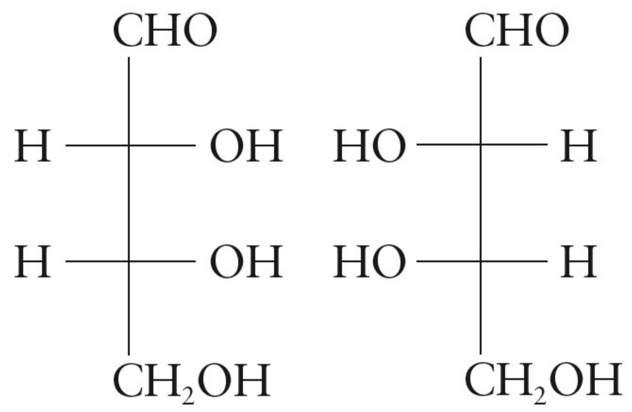
- **Fischer projections** depict three-dimensional shapes for **chiral** molecules, with the **chiral carbon** represented by the intersection of two lines.



FISCHER PROJECTIONS (continued)



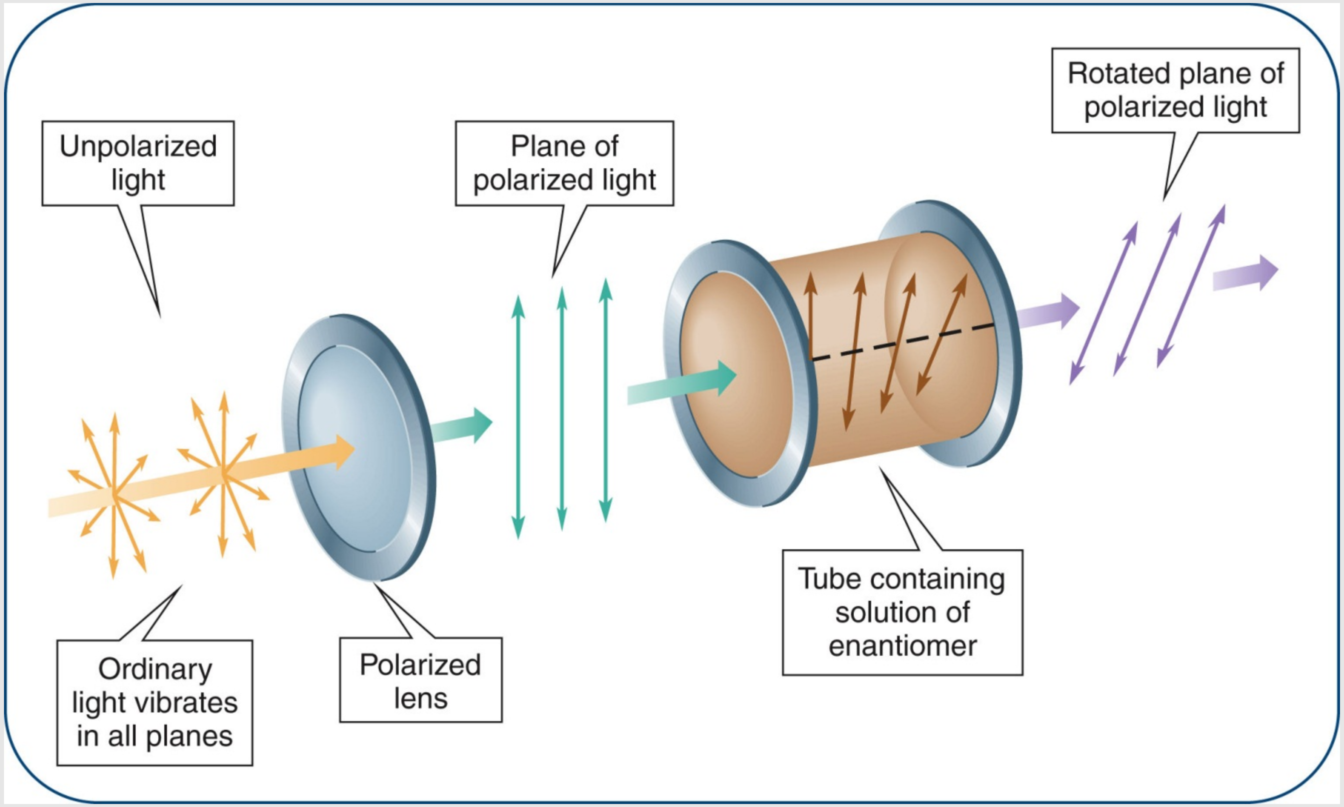
- **Fischer projections** of **carbohydrates** have the carbonyl (C=O) at the top. It is projecting away from the viewer behind the plane in which it is drawn as is the other vertical bond at the bottom of the image.
- The hydroxyl group on the **chiral carbon** farthest from the C=O group determines whether the **carbohydrate** is D (OH on right) or L (OH on left). The two horizontal bonds are coming toward the viewer out of the plane in which they are drawn.



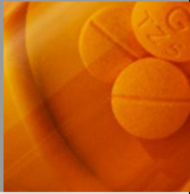
D-erythrose L-erythrose

ENANTIOMER PROPERTIES

- The physical properties of D and L **enantiomers** are generally the same.
- D and L **enantiomers** rotate polarized light in equal, but opposite directions.

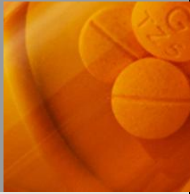


ENANTIOMER PROPERTIES (continued)



- The **enantiomer** that rotates polarized light to the left is the **levorotatory** or (-) **enantiomer**.
- The **enantiomer** that rotates it to the right is the **dextrorotatory** or (+) **enantiomer**.
- The D and L designations do not represent **dextrorotatory** and **levorotatory**.
- The property of rotating the plane of polarized light is called optical activity, and the molecules with this property are said to be **optically active**.
- Measurements of optical activity are useful for differentiating between **enantiomers**.

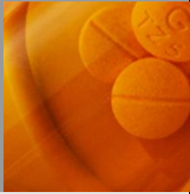
ENANTIOMER PROPERTIES (continued)



- In some instances, only the D or L **enantiomers** are found in nature.
- If both D and L forms are found in nature, they are rarely found together in the same biological system.

- For example:
  - **Carbohydrates** and amino acids are **chiral**.
  - Humans can only metabolize the D-isomers of **monosaccharides**.
  - Most animals are only able to utilize the L-isomers of amino acids to synthesize proteins.

MONOSACCHARIDE CLASSIFICATION

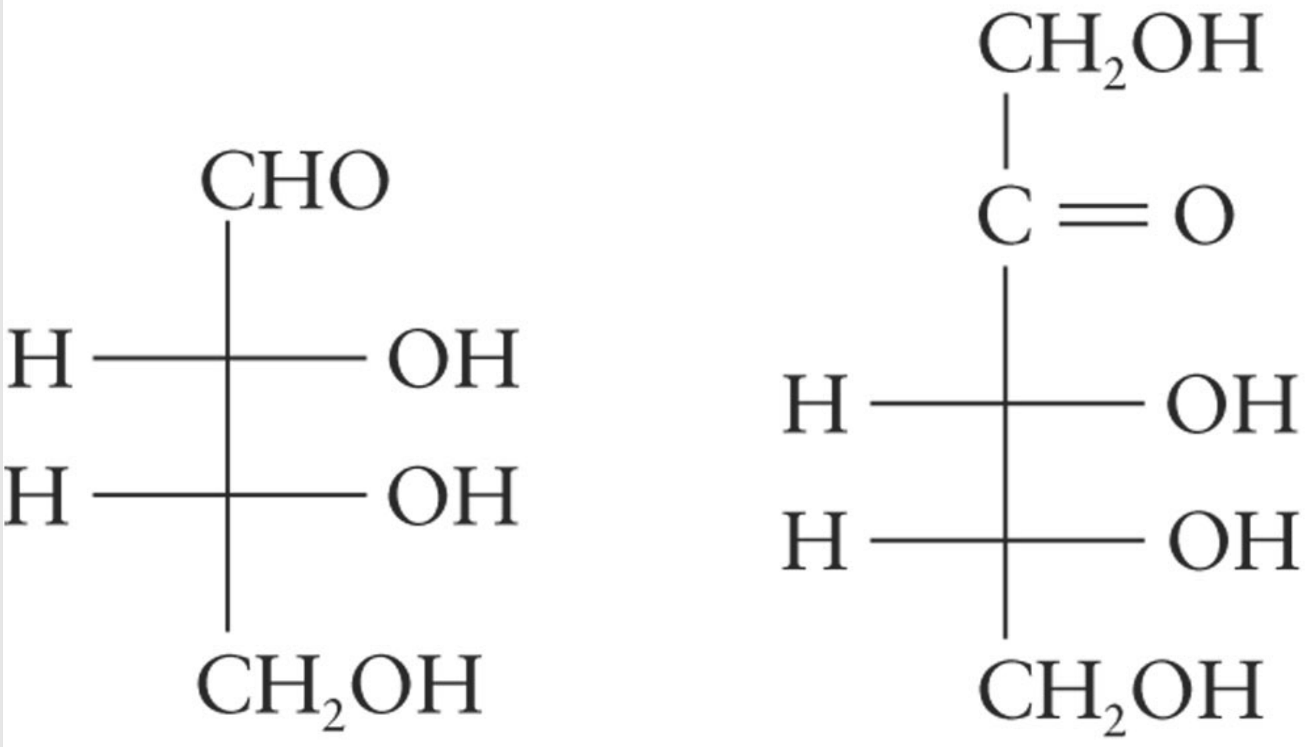


- Questions to ask when classifying a **monosaccharide**:
  - Is the **monosaccharide** an aldehyde (aldose) or ketone (ketose)?
  - How many carbon atoms are in the **monosaccharide**?

Table 17.1 Monosaccharide Classification Based on the Number of Carbons in Their Chains

Number of Carbon Atoms	Sugar Class
3	Triose
4	Tetrose
5	Pentose
6	Hexose

MONOSACCHARIDE CLASSIFICATION (continued)



an aldotetrose

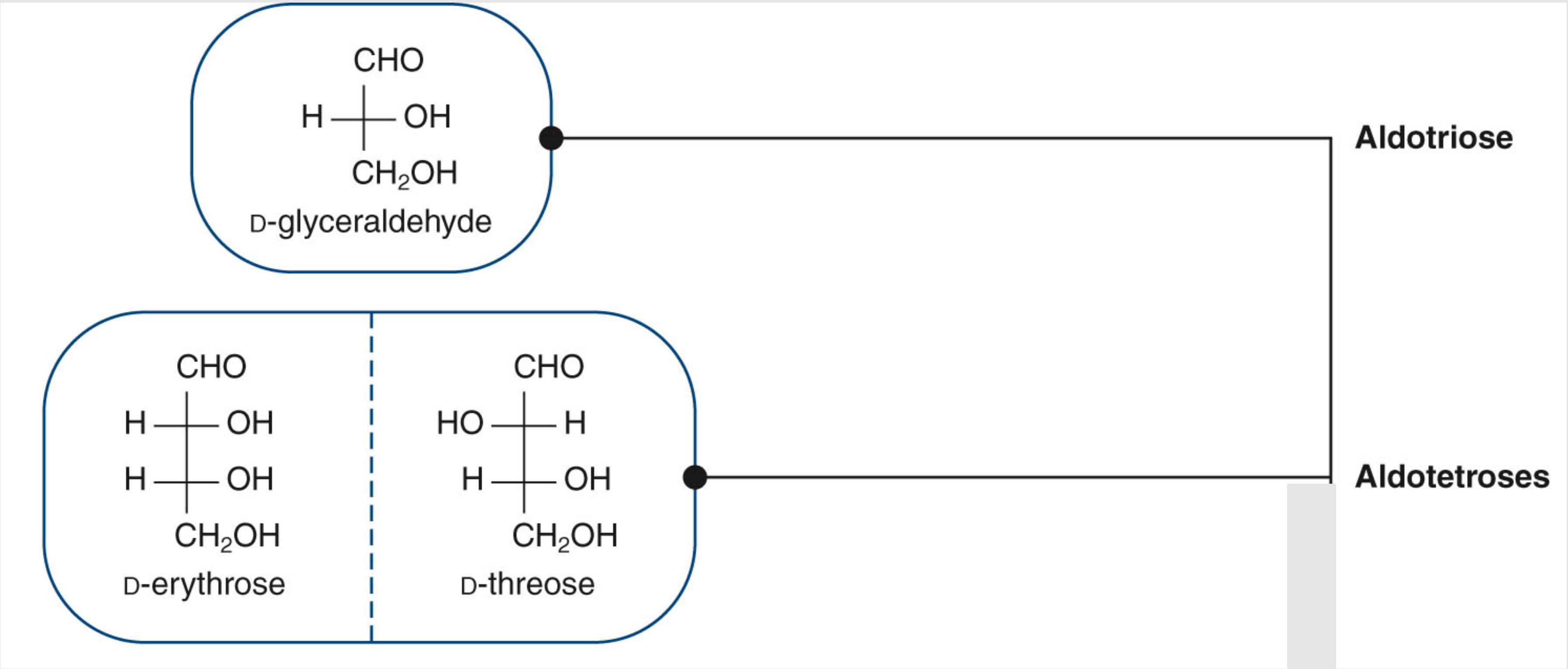
a ketopentose

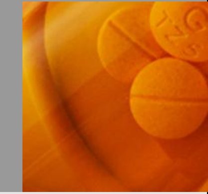
MONOSACCHARIDE CLASSIFICATION (continued)

- Most **monosaccharides** are aldoses.
- Almost all natural **monosaccharides** belong to the D series.
- The maximum number of possible stereoisomers is 2^n, where n = number of **chiral** carbon atoms.
- Half of stereoisomers are D and the other other half are L.

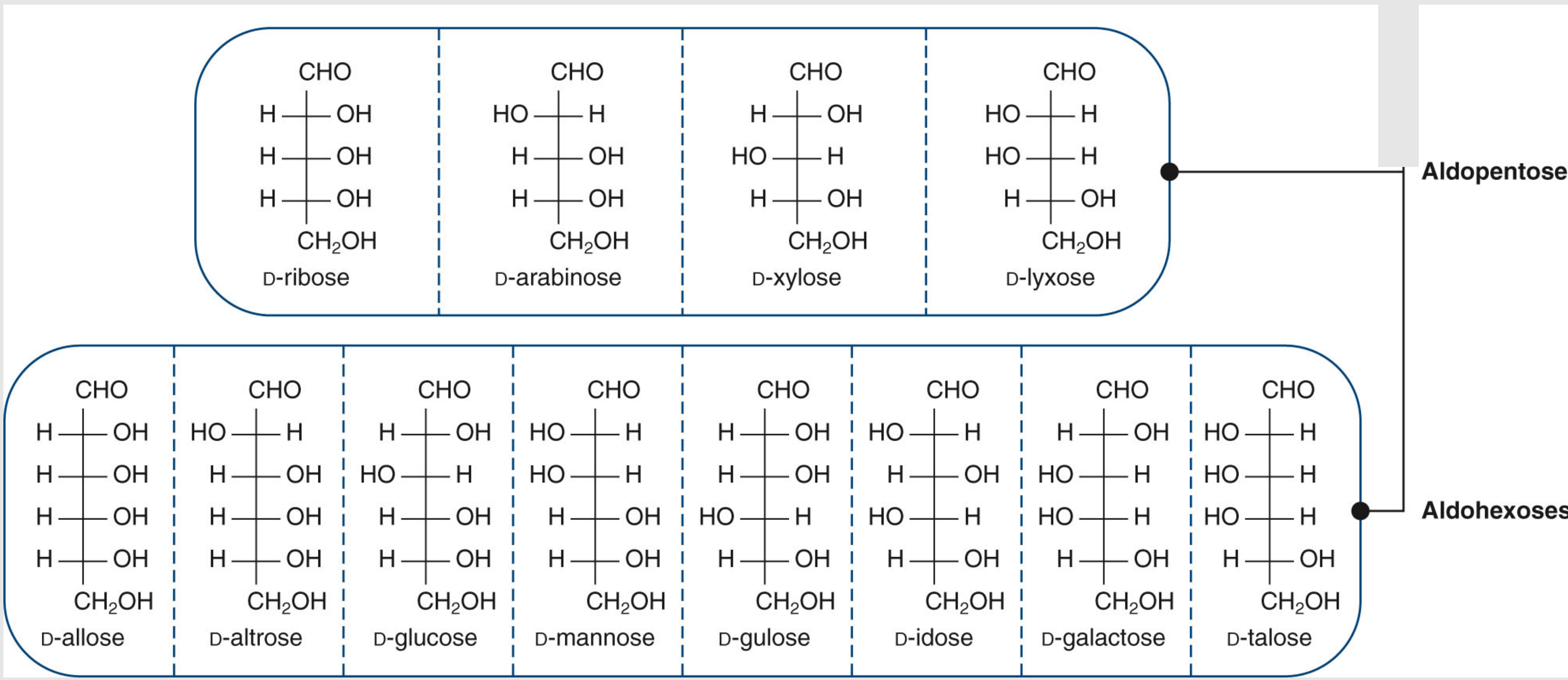
# of Carbon Atoms	Name of Sugar Class	# of Chiral Carbon Atoms (n)	# of Stereoisomers (2^n)	# of D Stereoisomers	# of L Stereoisomers
3	triose	1	2	1	1
4	tetrose	2	4	2	2
5	pentose	3	8	4	4
6	hexose	4	16	8	8

MONOSACCHARIDE CLASSIFICATION (continued)

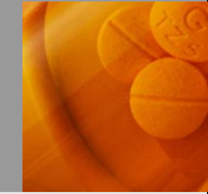




MONOSACCHARIDE CLASSIFICATION (continued)



PHYSICAL PROPERTIES OF **MONOSACCHARIDES**



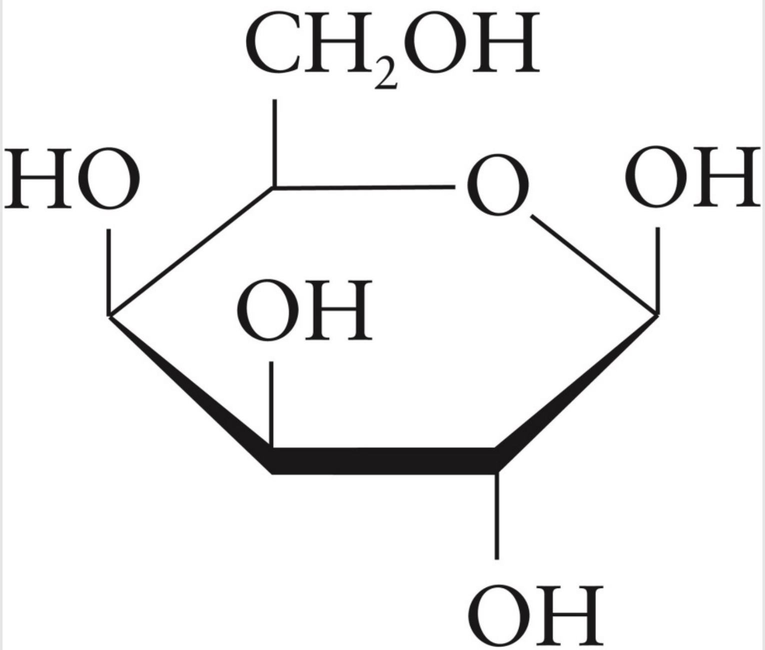
- Most are called sugars because they taste sweet.
- All **carbohydrates** are solids at room temperature.
- Because of the many –OH groups, they form hydrogen bonds with water molecules and are extremely water soluble.

Table 17.2 The Relative Sweetness of Sugars (Sucrose = 1.00)

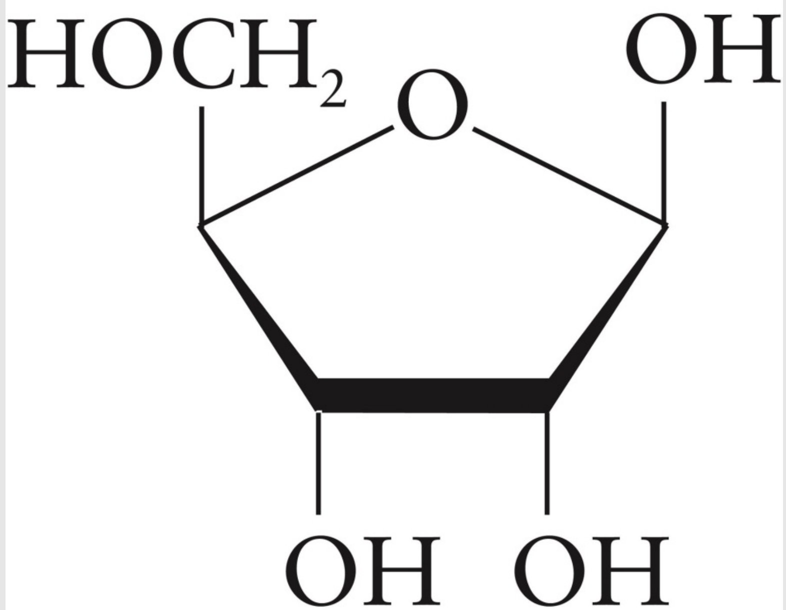
Sugar	Relative Sweetness	Type
Lactose	0.16	Disaccharide
Galactose	0.22	Monosaccharide
Maltose	0.32	Disaccharide
Xylose	0.40	Monosaccharide
Glucose	0.74	Monosaccharide
Sucrose	1.00	Disaccharide
Invert sugar	1.30	Mixture of glucose and fructose
Fructose	1.73	Monosaccharide

MONOSACCHARIDE REACTIONS

- All **monosaccharides** with at least five carbon atoms exist predominantly as cyclic hemiacetals and hemiketals.
- A **Haworth structure** can be used to depict the three-dimensional cyclic **carbohydrate** structures.

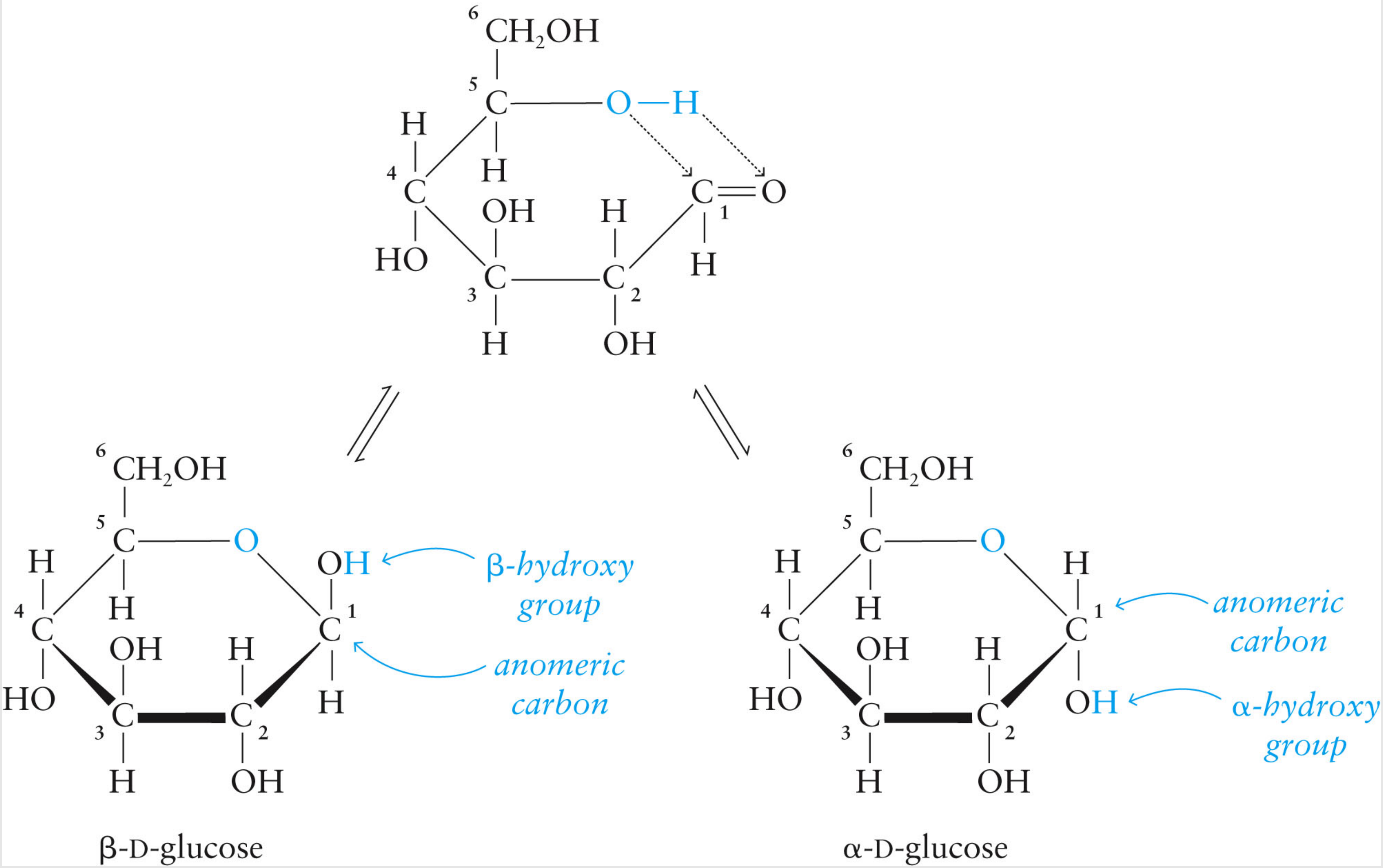


β-D-galactose



D-ribose

CYCLIZATION OF GLUCOSE



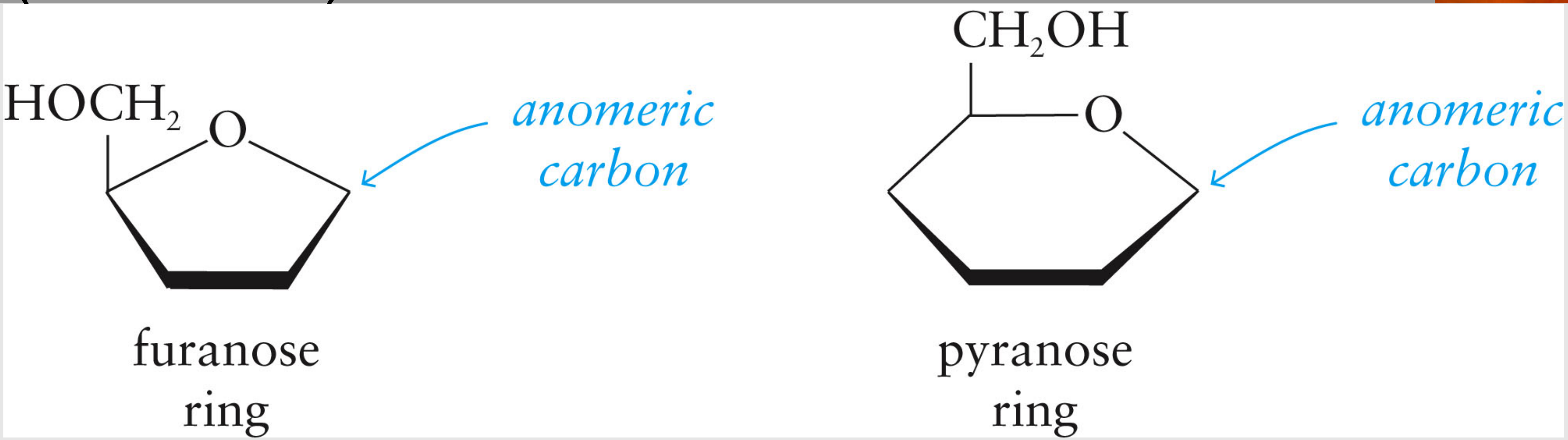
CYCLIZATION OF **MONOSACCHARIDES**

- The open-chain structure is numbered starting at the end closest to the carbonyl carbon atom.
- The alcohol group on the next to the last carbon atom adds to the carbonyl group.

- In the case of glucose, the alcohol group on carbon 5 adds to the aldehyde group on carbon 1 and a **pyranose** (six-membered ring containing an oxygen atom) forms.
- In the case of fructose, the alcohol group on carbon 5 adds to the ketone group on carbon 2 and a **furanose** (five-membered ring containing an oxygen atom) forms.

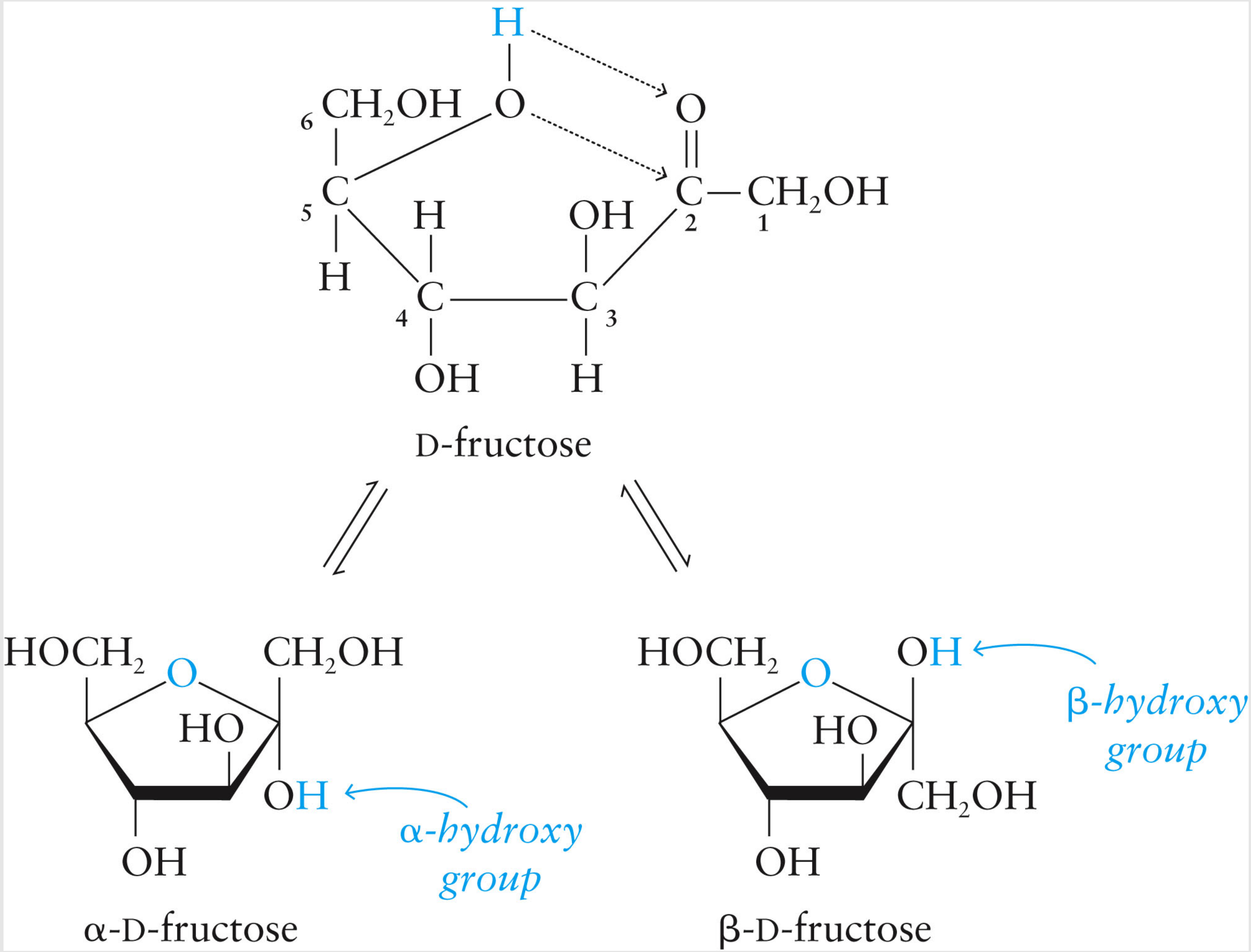
- The former carbonyl carbon atom is now **chiral** and called the **anomeric carbon** atom.

CYCLIZATION OF **MONOSACCHARIDES** (continued)



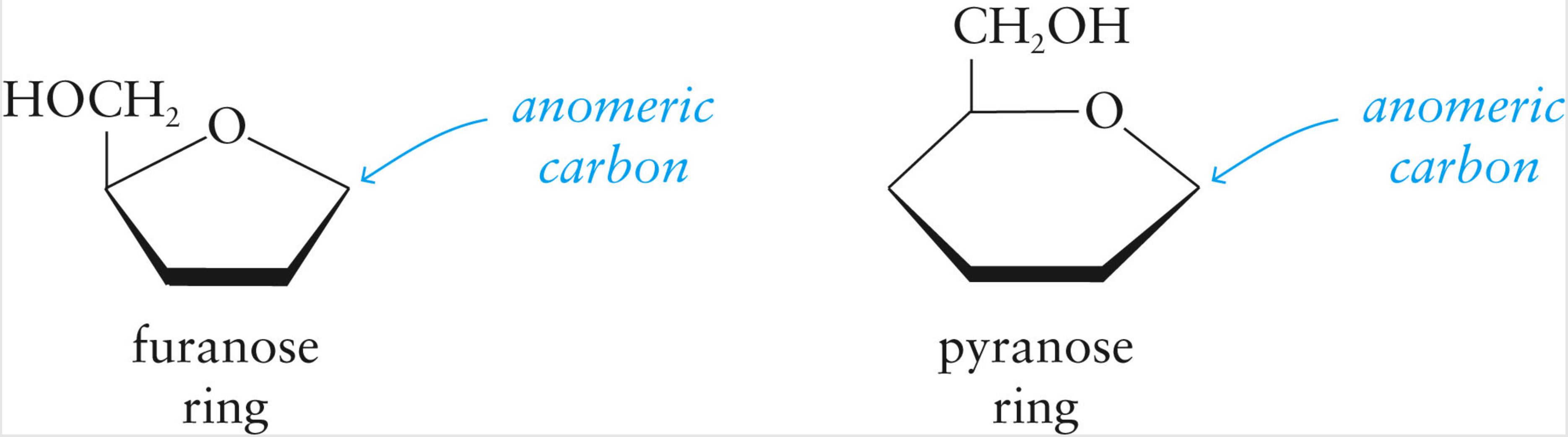
- Because the **anomeric carbon** atom is **chiral**, two possible stereoisomers can be formed during cyclization.
  - An α **anomer** (-OH on the **anomeric carbon** pointing down)
  - A β **anomer** (-OH on the **anomeric carbon** pointing up)
- **Anomers** are stereoisomers that differ in the 3-D arrangement of groups at the **anomeric carbon** of an acetal, ketal, hemiacetal, or hemiketal group.

CYCLIZATION OF FRUCTOSE



HAWORTH STRUCTURE RULES

- Draw the ring with its oxygen to the back.
- Put the **anomeric carbon** on the right side of the ring.
- Envision the ring as planar with groups pointing up or down.
- The terminal –CH_2OH group (position 6) is always shown above the ring for D-**monosaccharides**.



MONOSACCHARIDE REACTIONS (continued)

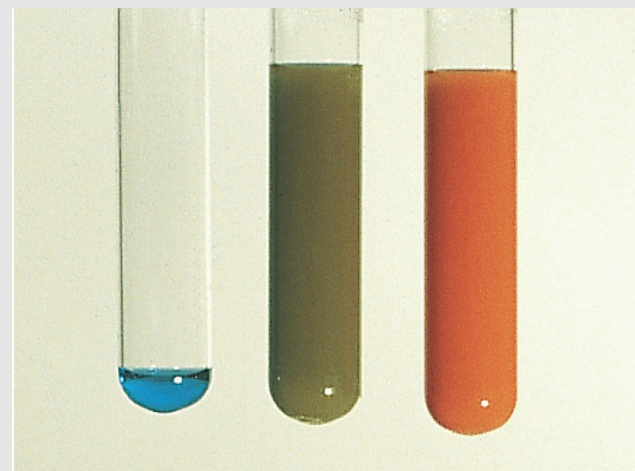
- A **reducing sugar** can be easily oxidized.
- All **monosaccharides** are **reducing sugars**.
- Benedict's reagent tests for **reducing sugars**:

$$\text{Reducing sugar} + Cu^{2+} \rightarrow \text{oxidized compound} + Cu_2O$$

blue

From left to right, three test tubes containing Benedict's reagent, 0.5% glucose solution, and 2.0% glucose solution

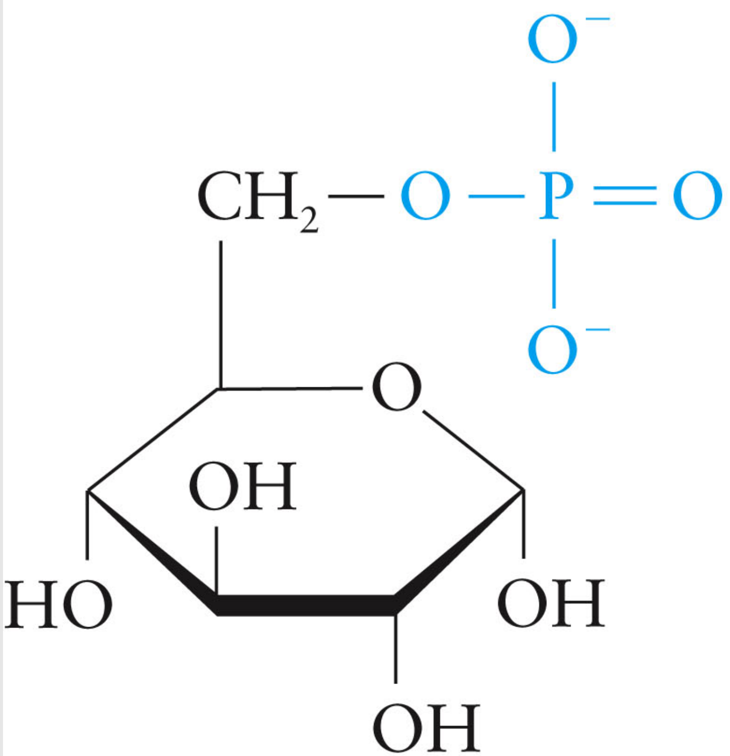
orange-red precipitate



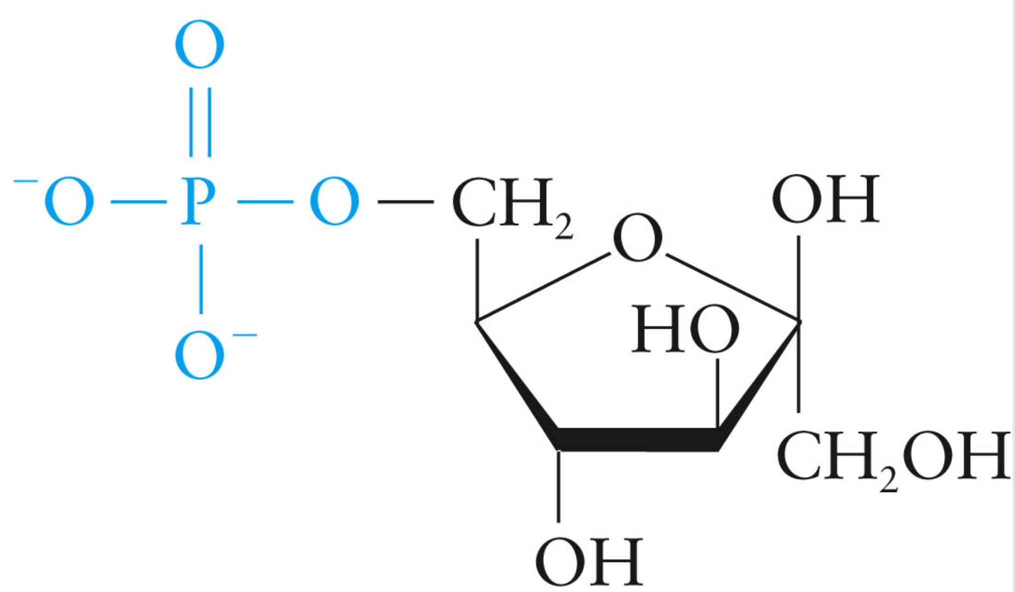
The addition of Benedict's reagent produces colors (due to the red Cu_2O) that indicate the amount of glucose present.

MONOSACCHARIDE REACTIONS (continued)

- The –OH groups of **monosaccharides** can behave as alcohols and react with acids (especially phosphoric acid) to form esters.



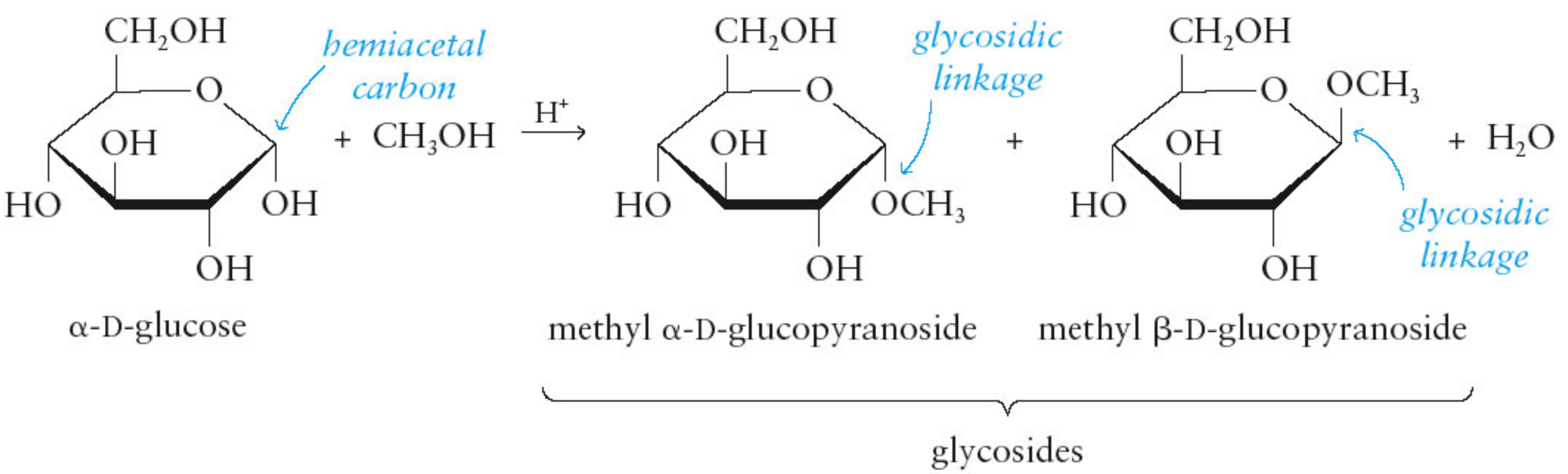
glucose 6-phosphate



fructose 6-phosphate

MONOSACCHARIDE REACTIONS (continued)

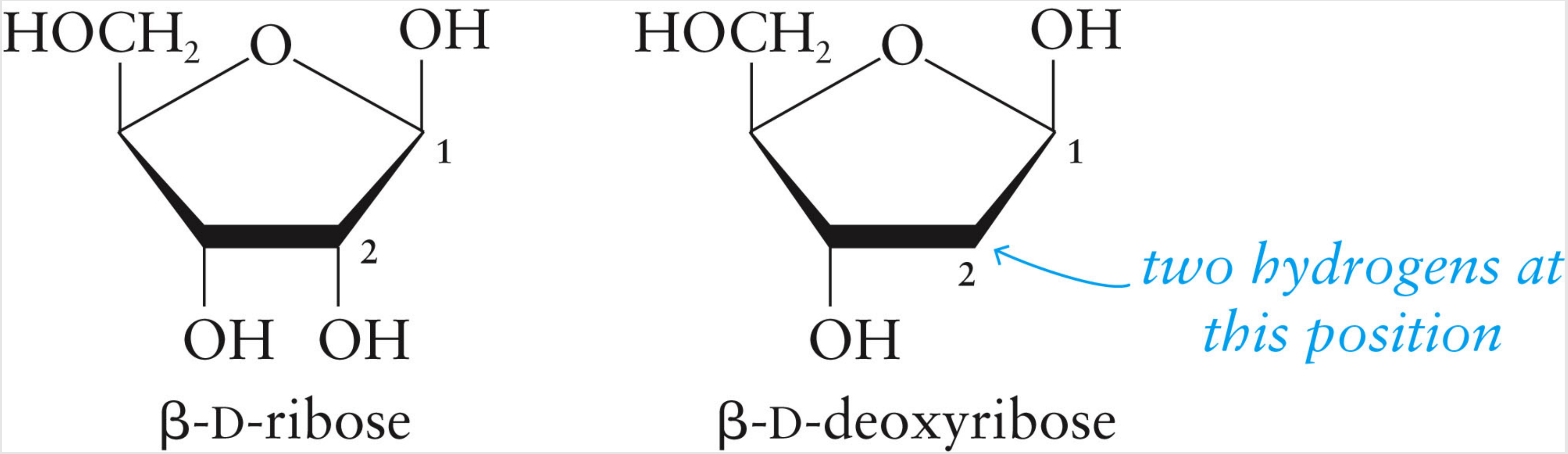
- Cyclic **monosaccharide** hemiacetals and hemiketals react with alcohols to form acetals and ketals, referred to as **glycosides**.



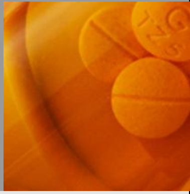
- The new carbon-oxygen-carbon linkage that joins the components of the **glycoside** is called a **glycosidic linkage**.
- **Glycosides** do not exhibit open-chain forms.
- **Glycosides** are not **reducing sugars**.

IMPORTANT **MONOSACCHARIDES**

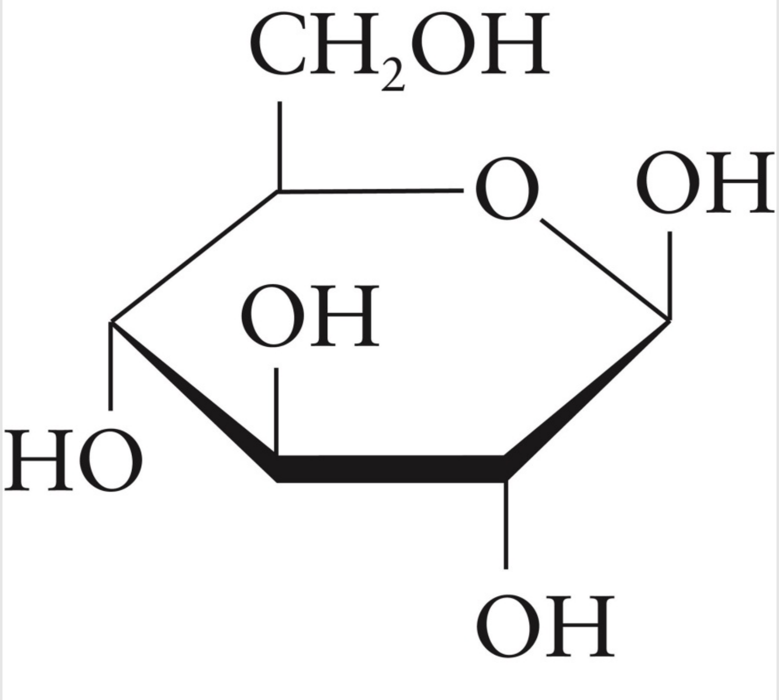
- Ribose and Deoxyribose
  - Pentoses
  - Used in the synthesis of DNA and RNA



IMPORTANT **MONOSACCHARIDES** (continued)



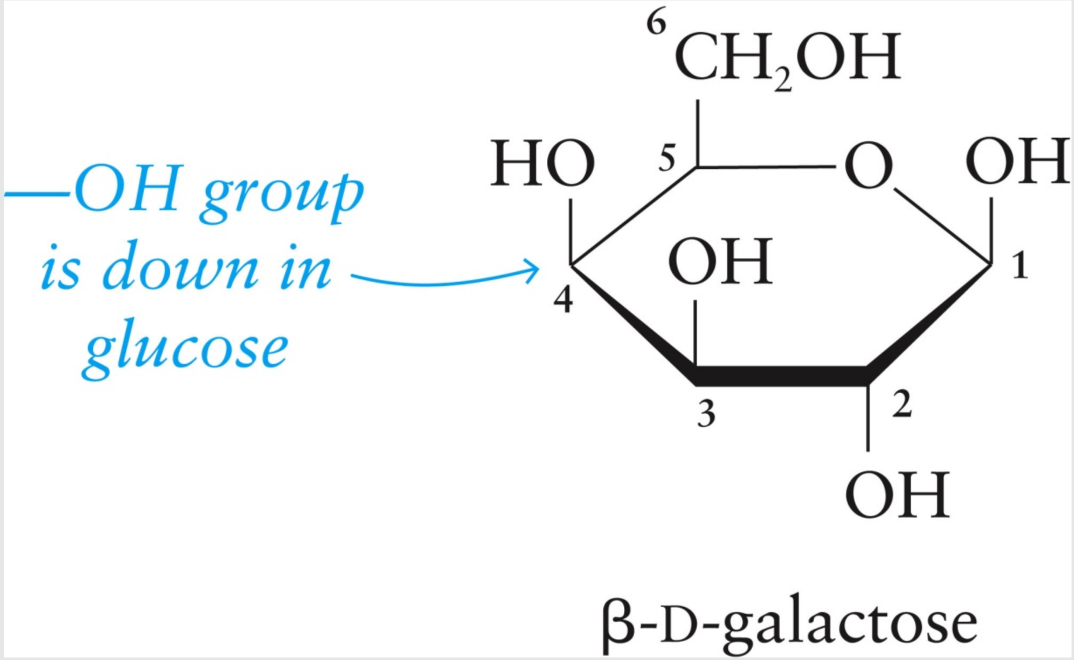
- Glucose is:
  - a hexose.
  - the most nutritionally important **monosaccharide**.
  - sometimes called dextrose or blood sugar.
  - the compound to which other sugars absorbed into the body must be converted in the liver.
  - used as a sweetener in confections and other foods.



β-D-glucose

IMPORTANT **MONOSACCHARIDES** (continued)

- Galactose is:
  - a hexose.
  - similar structure to glucose.
  - a component of lactose (milk sugar).
  - a component of substances present in nerve tissue.



IMPORTANT **MONOSACCHARIDES** (continued)

- Fructose is:
  - a ketohexose.
  - the sweetest **monosaccharide**.
  - sometimes called levulose or fruit sugar.
  - present in honey in a 1:1 ratio with glucose.
  - abundant in corn syrup.