Introduction to Carbohydrates

By
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Carbohydrates

Carbohydrates (saccharides) are the most abundant organic molecules in nature. They have a wide range of functions, including providing a significant fraction of the dietary calories for most organisms, acting as a storage form of energy in the body, and serving as cell membrane components that mediate some forms of intercellular communication. Carbohydrates also serve as a structural component of many organisms, including the cell walls of bacteria, the exoskeleton of insects, and the fibrous cellulose of plants. [Note: The full set of carbohydrates produced by an organism is its glycome.] The empiric formula for many of the simpler carbohydrates is $(CH_2O)_n$, where $n \geq 3$, hence the name "hydrate of carbon."

Carbohydrates

- Carbohydrates include not only sugar, but also the starches that we find in foods, such as bread, pasta, and rice.

- The term "carbohydrate" comes from the observation that when you heat sugars, you get carbon and water (hence, *hydrate* of *carbon*).

Carbohydrates and Biochemistry

- Carbohydrates are compounds of tremendous biological importance:

– they provide energy through oxidation

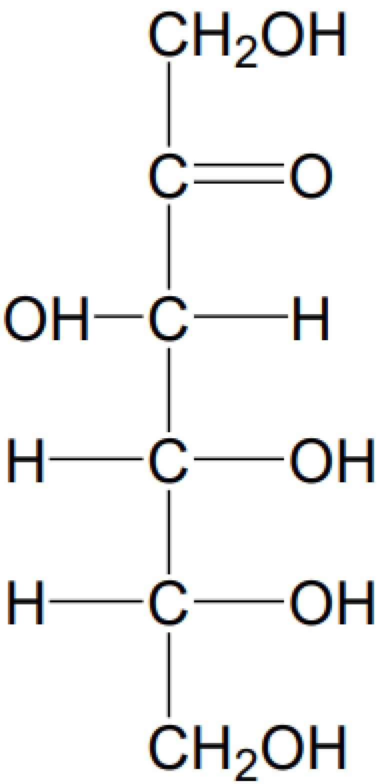
– they supply carbon for the synthesis of cell components

– they serve as a form of stored chemical energy

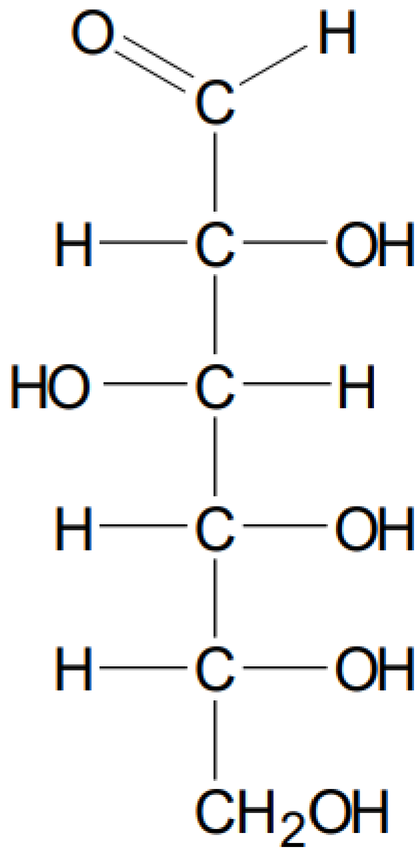
– they form part of the structures of some cells and tissues

- Carbohydrates, along with lipids, proteins, nucleic acids, and other compounds are known as biomolecules because they are closely associated with living organisms.

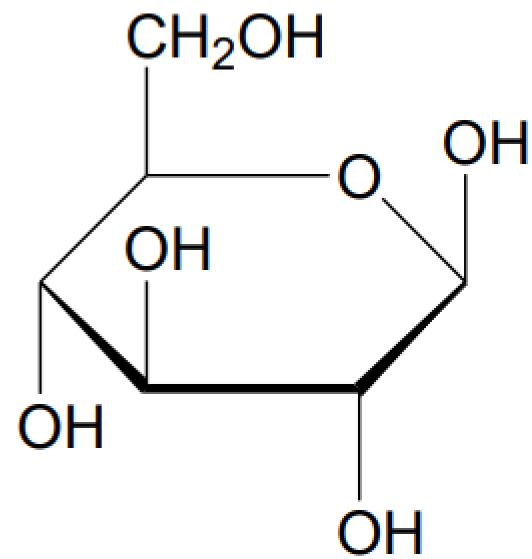
- Carbohydrates, or saccharides (saccharo is Greek for “sugar”) are polyhydroxy aldehydes or ketones, or substances that yield such compounds on hydrolysis.



fructose



glucose



β-D-glucose

Difference Between Sugars and Carbohydrates

Carbohydrates are complex molecules made up from an aggregation of one or more types of simple sugars.

Sugars

Sugars are simple molecules which are released into the body by the process of digestion of the polysaccharides of starchy foods. The few most common types of sugars are: glucose, fructose, galactose, etc. which are present in commonly used substances such as table sugar, fruit juice, milk, yogurt, molasses, brown sugar, and honey. Sugars may be divided into two categories according to the type of molecules present in the structure as the monosaccharides and the disaccharides. Monosaccharides are sugars having one molecule of sugar such as glucose, fructose, etc. When two molecules of similar or different types of monosaccharides combine, they form a disaccharide such as lactose and sucrose. The monosaccharides are further classified as tetroses, pentoses, hexoses, and heptoses on the basis of the number of carbon atoms present in their structure.Sugars are soluble in water and have a sweet taste. Physically, they are white, crystalline substances.

1.Sugars are soluble in water while carbohydrates are insoluble in water.

2.Sugars have a sweet taste while carbohydrates are not sweet.

3.Sugars are readily digested in the body while carbohydrates have to be broken down into simpler molecules before being digested.

4.The chemical formula of sugars is $C(H_2O)_y$ while that of carbohydrates is $C_x(H_2O)_y$.

CLASSIFICATION AND STRUCTURE of Carbohydrate

Monosaccharides (simple sugars) can be classified according to the number of carbon atoms they contain. Examples of some monosaccharides commonly found in humans are listed in Figure 1. They can also be classified by the type of carbonyl group they contain. Carbohydrates with an aldehyde as their carbonyl group are called aldoses, whereas those with a keto as their carbonyl group are called ketoses (Fig. 2). For example, glyceraldehyde is an aldose, whereas dihydroxyacetone is a ketose. Carbohydrates that have a free carbonyl group have the suffix -ose. [Note: Ketoses have an additional “ul” in their suffix such as xylulose. There are exceptions, such as fructose, to this rule.]

Monosaccharides can be linked by glycosidic bonds to create larger structures (Fig. 3). Disaccharides contain two monosaccharide units, oligosaccharides contain three to ten monosaccharide units, and polysaccharides contain more than ten monosaccharide units and can be hundreds of sugar units in length.

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

Figure 1 Examples of monosaccharides found in humans, classified according to the number of carbons they contain.

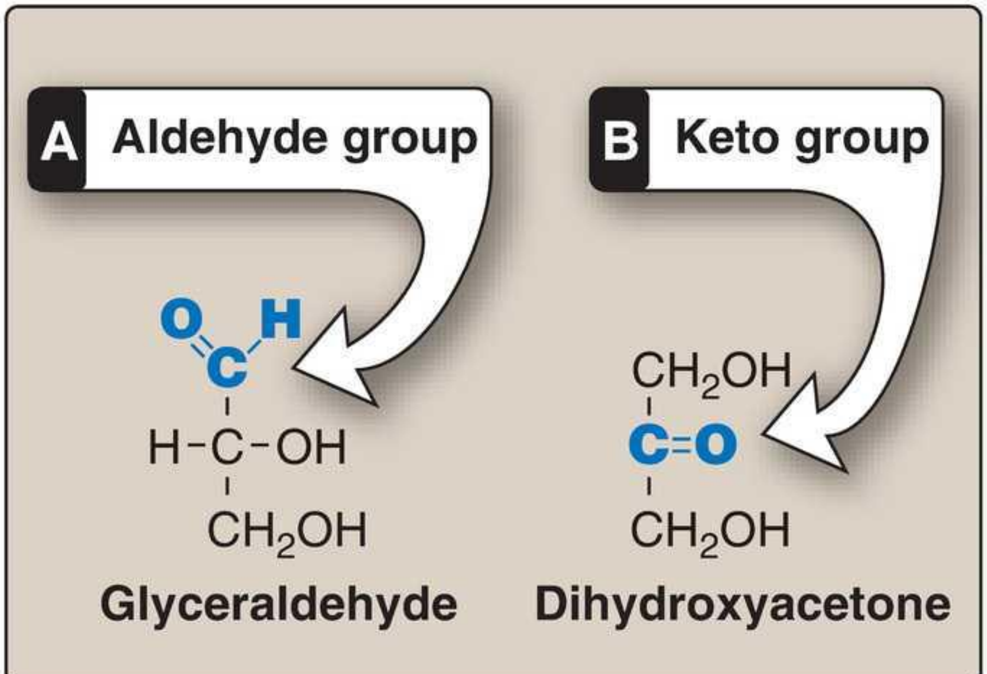


Figure 2 Examples of an aldose (A) and a ketose (B) sugar.

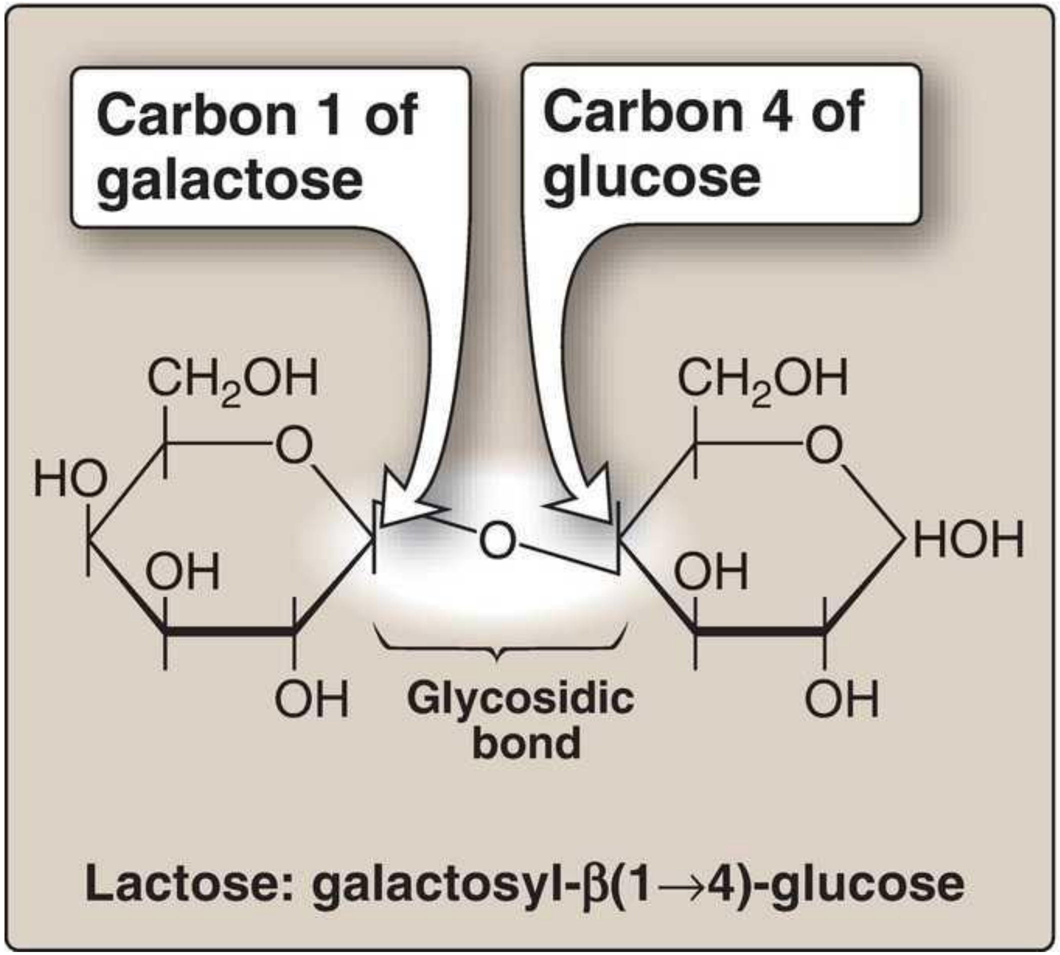
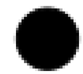


Figure 3 A glycosidic bond between two hexoses producing a disaccharide.

Classes of Carbohydrates

- **Monosaccharides** contain a single polyhydroxy aldehyde or ketone unit (e.g., glucose, fructose).

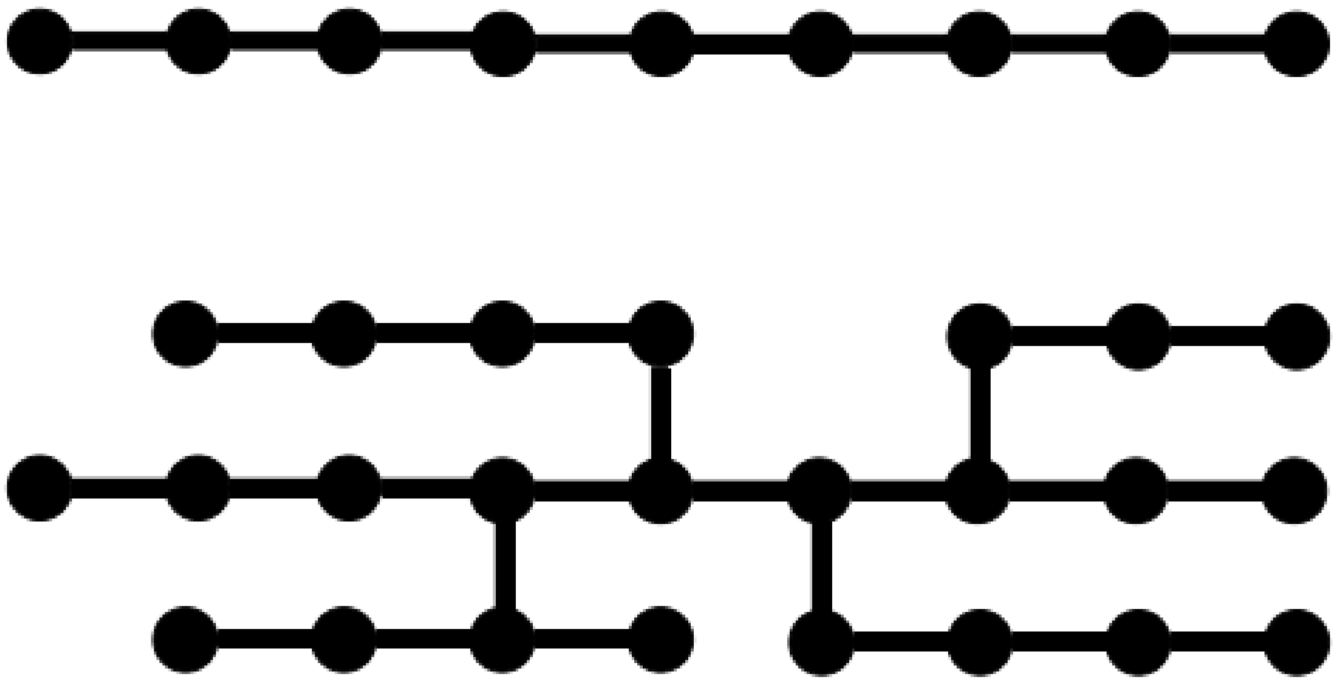


- **Disaccharides** consist of two monosaccharide units linked together by a covalent bond (e.g., sucrose).

- **Oligosaccharides** contain from 3 to 10 monosaccharide units (e.g., raffinose).

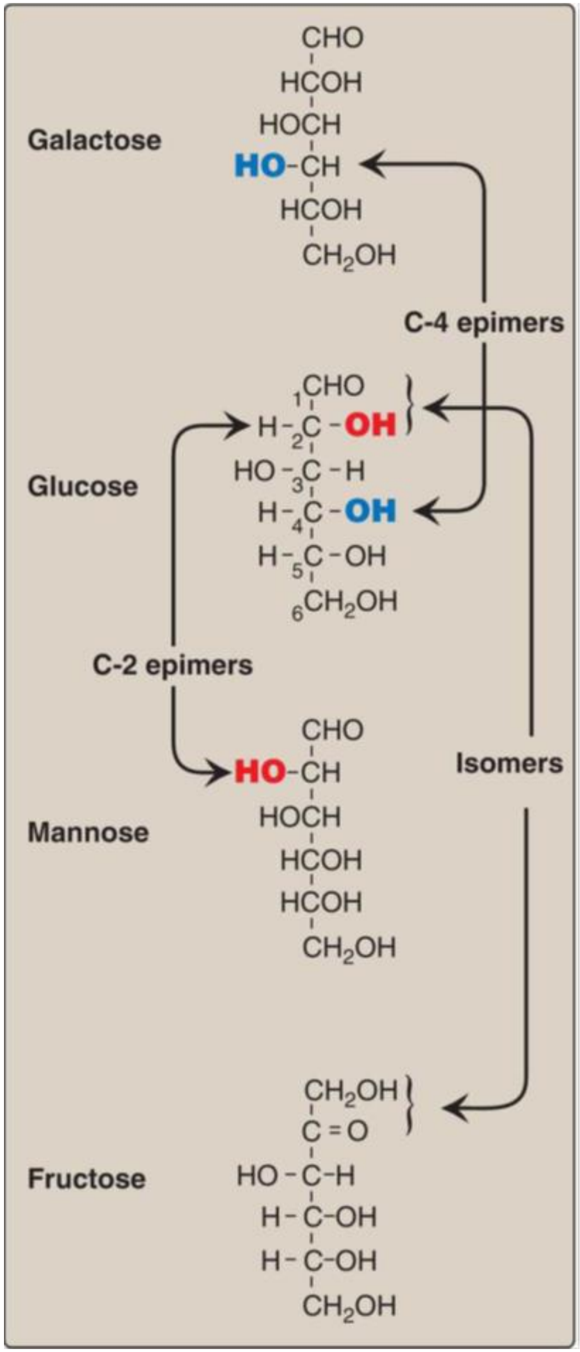
Classes of Carbohydrates

- **Polysaccharides** contain very long chains of hundreds or thousands of monosaccharide units, which may be either in straight or branched chains (e.g., cellulose, glycogen, starch).



A. Isomers and epimers

Compounds that have the same chemical formula but have different structures are called isomers. For example, fructose, glucose, mannose, and galactose are all isomers of each other, having the same chemical formula, C6H12O6. Carbohydrate isomers that differ in configuration around only one specific carbon atom (with the exception of the carbonyl carbon, see C.1. below) are defined as epimers of each other. For example, glucose and galactose are C-4 epimers because their structures differ only in the position of the –OH (hydroxyl) group at carbon 4. [Note: The carbons in sugars are numbered beginning at the end that contains the carbonyl carbon (that is, the aldehyde or keto group), as shown in Fig. 4.] Glucose and mannose are C-2 epimers. However, because galactose and mannose differ in the position of –OH groups at two carbons (carbons 2 and 4), they are isomers rather than epimers (see Fig. 4).



B. Enantiomers

A special type of isomerism is found in the pairs of structures that are mirror images of each other. These mirror images are called enantiomers, and the two members of the pair are designated as a D- and an L-sugar (Fig.5). The vast majority of the sugars in humans are D-isomers. In the Disomeric form, the –OH group on the asymmetric carbon (a carbon linked to four different atoms or groups) farthest from the carbonyl carbon is on the right, whereas in the L-isomer, it is on the left. Most enzymes are specific for either the D or the L form, but enzymes known as *isomerases* are able to interconvert D- and L-isomers.

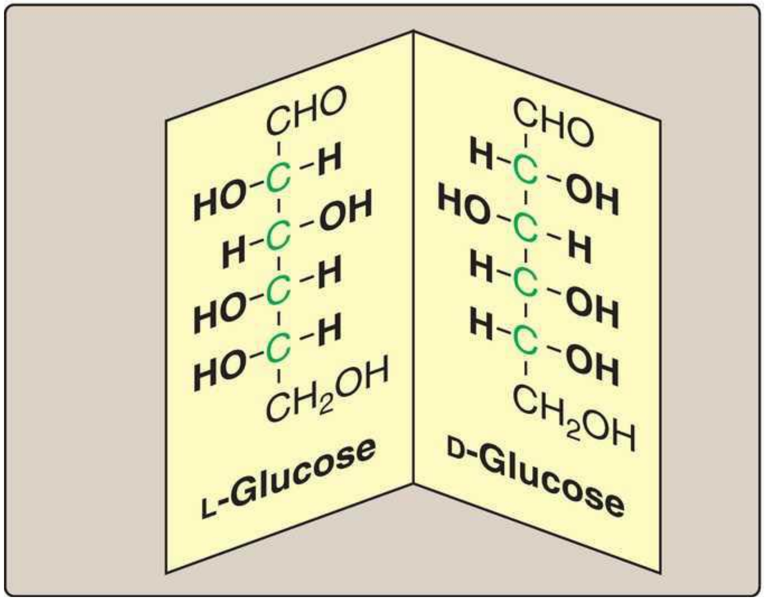
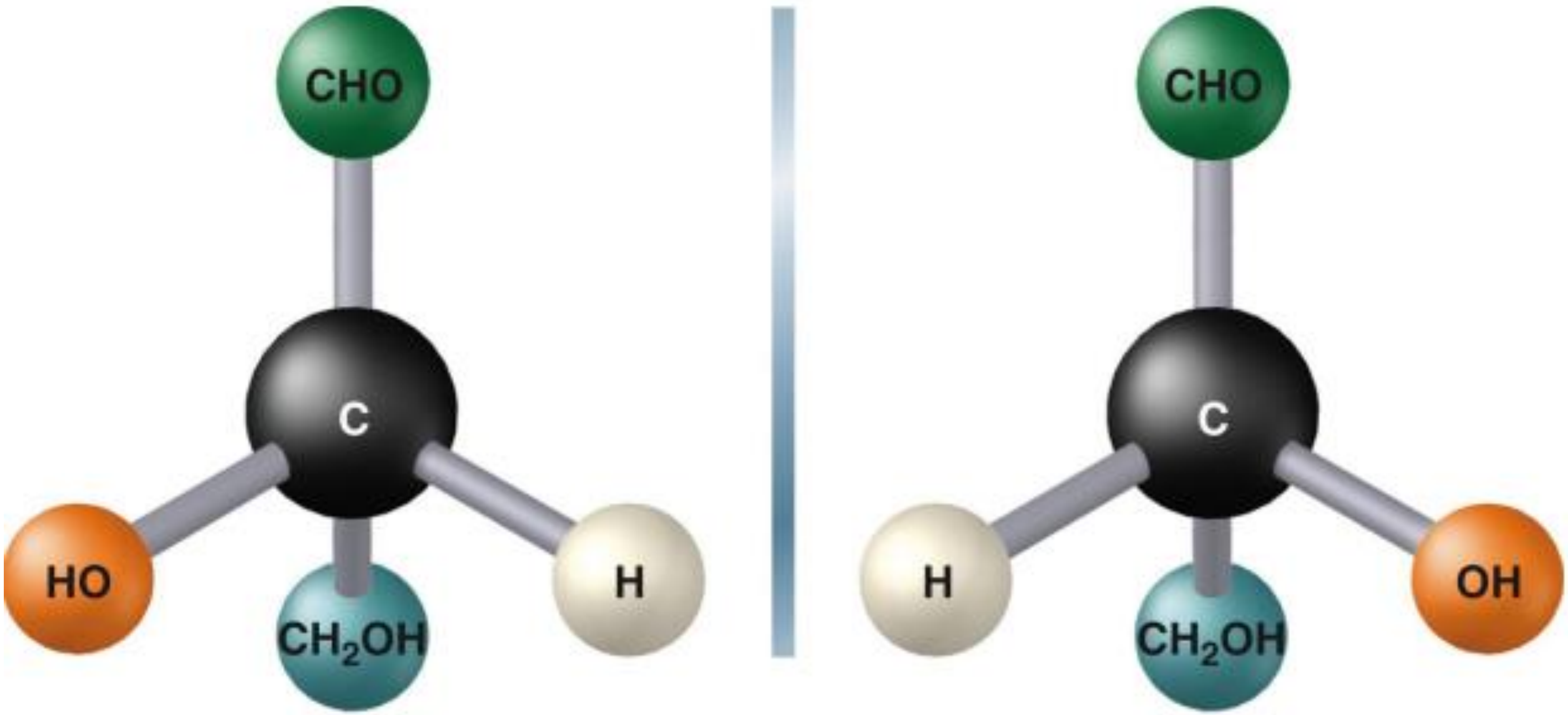


Figure 5 Enantiomers (mirror images) of glucose. Designation of D and L is by comparison to a triose, glyceraldehyde. [Note: The asymmetric carbons are shown in green.]

Two Forms of Glyceraldehyde

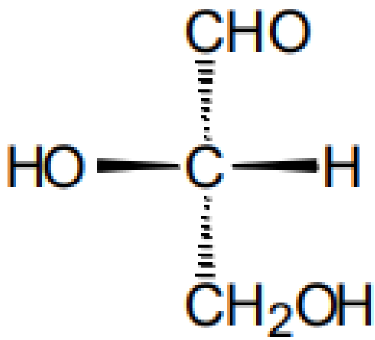
- Glyceraldehyde, the simplest carbohydrate, exists in two isomeric forms that are mirror images of each other:



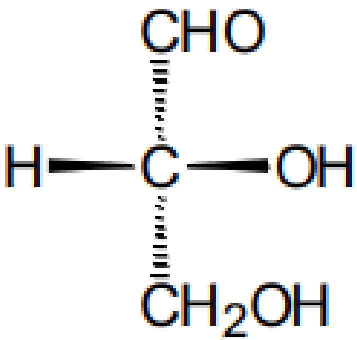
L-glyceraldehyde **Mirror** D-glyceraldehyde

Stereoisomers

- These forms are **stereoisomers** of each other.
- Glyceraldehyde is a **chiral** molecule — it cannot be superimposed on its mirror image. The two mirror-image forms of glyceraldehyde are **enantiomers** of each other.



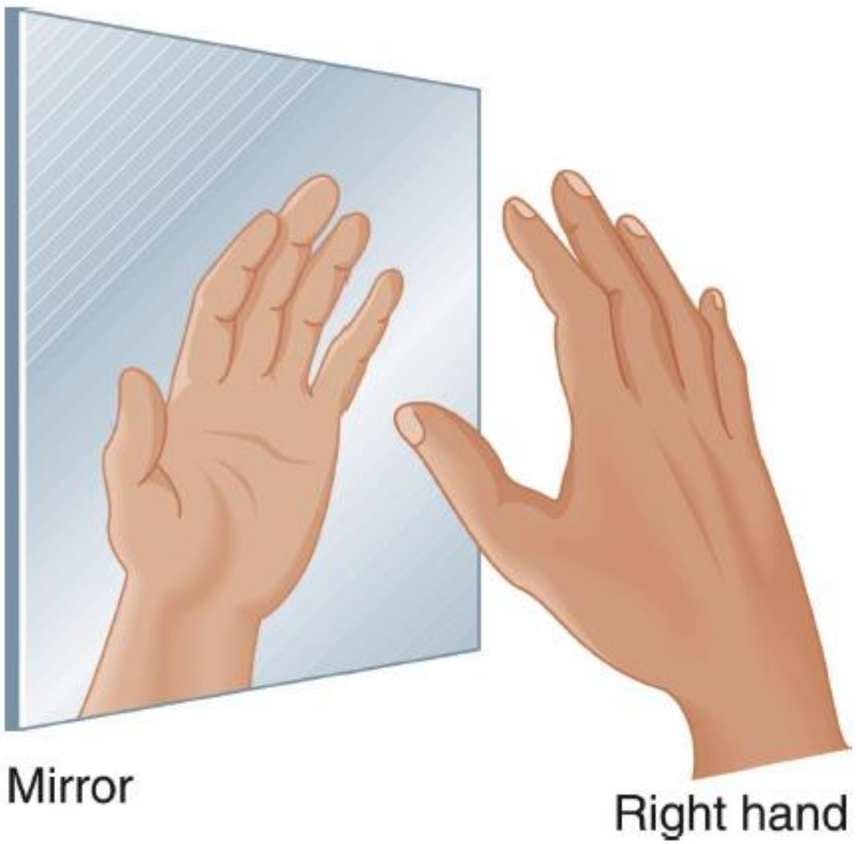
L-glyceraldehyde



D-glyceraldehyde

Chirality and Handedness

- Chiral molecules have the same relationship to each other that your left and right hands have when reflected in a mirror.

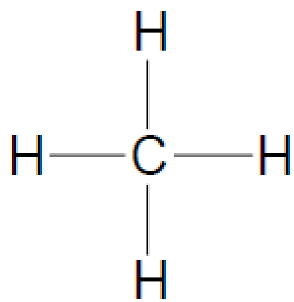
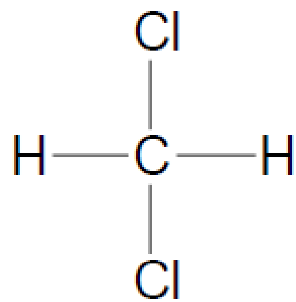
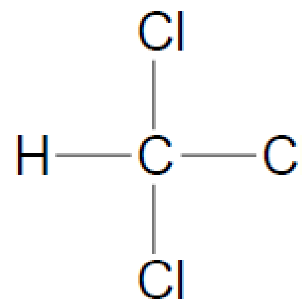
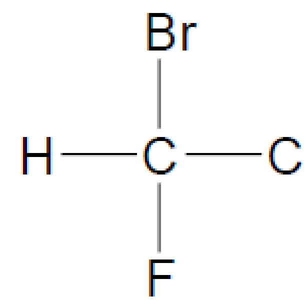
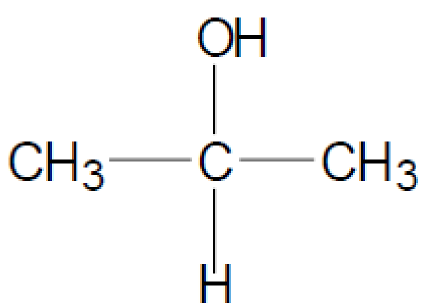
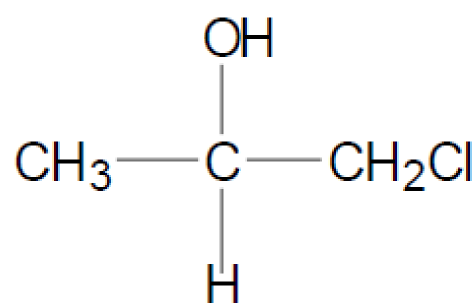
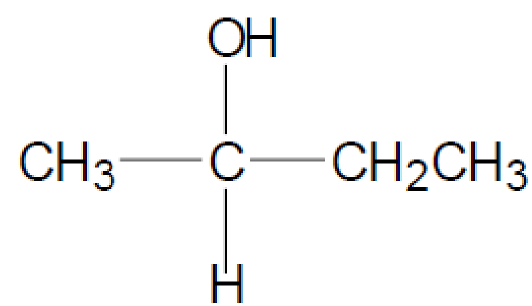
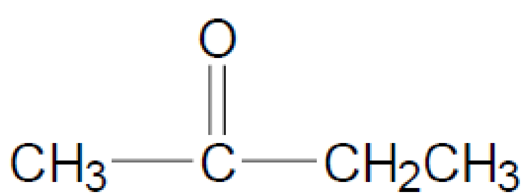
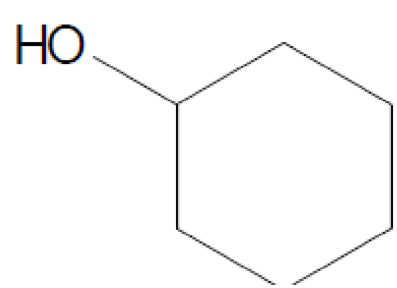
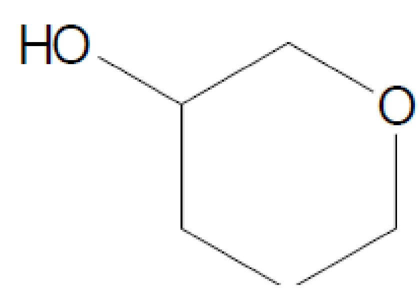


Chiral Carbons

- *Chiral* objects cannot be superimposed on their mirror images — e.g., hands, gloves, and shoes.
- *Achiral* objects *can* be superimposed on the mirror images — e.g., drinking glasses, spheres, and cubes.
- Any carbon atom which is connected to *four different groups* will be chiral, and will have two nonsuperimposable mirror images; it is a **chiral carbon** or a **center of chirality**.
  - If *any* of the two groups on the carbon are the same, the carbon atom *cannot be chiral*.
- Many organic compounds, including carbohydrates, contain more than one chiral carbon.

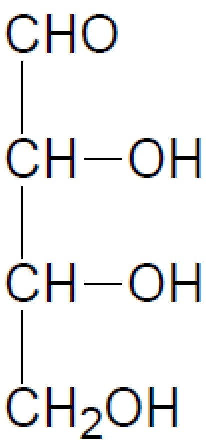
Examples: Chiral Carbon Atoms

- Identify the chiral carbon atoms (if any) in each of the following molecules:

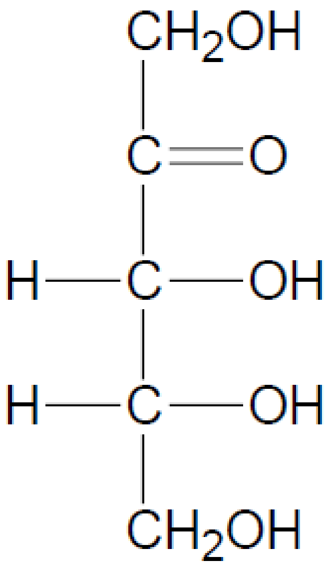











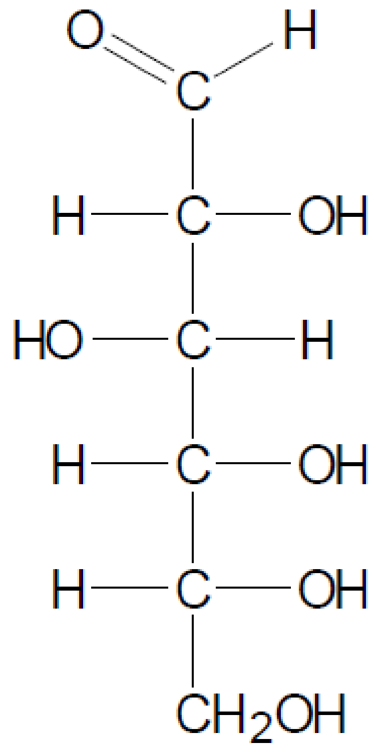
Examples: Chiral Carbons in Carbohydrates

- Identify the chiral carbons (if any) in the following carbohydrates:



erythrose





glucose