

## 6.S: Carbohydrates (Summary)

To ensure that you understand the material in this chapter, you should review the meanings of the bold terms in the following summary and ask yourself how they relate to the topics in the chapter.

**Carbohydrates**, a large group of biological compounds containing carbon, hydrogen, and oxygen atoms, include sugars, starch, glycogen, and cellulose. All carbohydrates contain alcohol functional groups, and either an aldehyde or a ketone group (or a functional group that can be converted to an aldehyde or ketone). The simplest carbohydrates are **monosaccharides**. Monosaccharides can be classified based on the carbonyl functional group and number of carbon atoms present. These compounds can combine to form more complex carbohydrates. Those with two monosaccharide units are **disaccharides**, those with three to nine monosaccharide units are **oligosaccharides**, and those with ten or more monosaccharide units are **polysaccharides**. Most sugars are either monosaccharides or disaccharides. Cellulose, glycogen, and starch are polysaccharides.

Many carbohydrates exist as **stereoisomers**, in which the three-dimensional spatial arrangement of the atoms in space is the only difference between the isomers. These particular stereoisomers contain at least one **chiral carbon**, a carbon atom that has four different groups bonded to it. A molecule containing a chiral carbon is nonsuperimposable on its mirror image, and two molecules that are nonsuperimposable mirror images of each other are a special type of stereoisomer called **enantiomers**. Enantiomers have the same physical properties, such as melting point, but differ in the direction they rotate polarized light.

A sugar is designated as being a D sugar or an L sugar according to how, in a Fischer projection of the molecule, the hydrogen atom and OH group are attached to the *penultimate* carbon atom, which is the carbon atom immediately before the terminal alcohol carbon atom. If the structure at this carbon atom is the same as that of D-glyceraldehyde (OH to the right), the sugar is a **D sugar**; if the configuration is the same as that of L-glyceraldehyde (OH to the left), the sugar is an **L sugar**.

Monosaccharides of five or more carbon atoms readily form cyclic structures when the carbonyl carbon atom reacts with an OH group on a carbon atom three or four carbon atoms distant. Consequently, glucose in solution exists as an equilibrium mixture of three forms, two of them cyclic ( $\alpha$ - and  $\beta$ -) and one open chain. In Haworth projections, the **alpha** form is drawn with the OH group on the “former” carbonyl carbon atom (**anomeric carbon**) is trans (opposite) to carbon 6; the **beta** form, with the OH group is cis (same) to carbon 6; these two compounds are stereoisomers and are given the more specific term of **anomers**. Any solid sugar can be all alpha or all beta. Once the sample is dissolved in water, however, the ring opens up into the open-chain structure and then closes to form either the  $\alpha$ - or the  $\beta$ -anomer. These interconversions occur back and forth until a dynamic equilibrium mixture is achieved in a process called **mutarotation**.

Three abundant hexoses in living organisms are the aldohexoses **D-glucose** and **D-galactose** and the ketohexose **D-fructose**. D-glucose and D-galactose are **epimers** because the molecules are identical, except at C4. D-glucose and D-fructose are structural isomers that both have the  $C_6H_{12}O_6$  molecular formula.

The carbonyl group present in monosaccharides is easily oxidized by Tollens’ or Benedict’s reagents (as well as others). Any mono- or disaccharide containing a free anomeric carbon is a **reducing sugar**. The disaccharide *maltose* contains two glucose units joined in an  $\alpha$ -1,4-glycosidic linkage. The disaccharide *lactose* contains a galactose unit and a glucose unit joined by a  $\beta$ -1,4-glycosidic linkage. Both maltose and lactose contain a free anomeric carbon that can convert to an aldehyde functional group, so they are reducing sugars; they also undergo mutarotation. Many adults, and some children, have a deficiency of the enzyme lactase (which is needed to break down lactose) and are said to be **lactose intolerant**. A more serious problem is the genetic disease **galactosemia**, which results from the absence of an enzyme needed to convert galactose to glucose.

The disaccharide **sucrose** (table sugar) consists of a glucose unit and a fructose unit joined by a **glycosidic linkage**. The linkage is designated as an  $\alpha$ -1, $\beta$ -2-glycosidic linkage because it involves the OH group on the first carbon atom of glucose and the OH group on the second carbon atom of fructose. Sucrose is not a reducing sugar because it has no anomeric carbon that can reform a carbonyl group, and it cannot undergo mutarotation because of the restrictions imposed by this linkage.

**Oligosaccharides** play important roles in the blood markers. The types of monosaccharide units present in the oligosaccharide attached to the red blood cell indicates the ABO blood type. All blood types include the N-acetylglucosamine, galactose, and fucose; but differ in the absence or presence of additional units. Type O blood is considered the **universal donor**, while Type AB blood is considered the **universal acceptor**.

*Starch*, the principal carbohydrate of plants, is composed of the polysaccharides **amylose** (10%–30%) and **amylopectin** (70%–90%). When ingested by humans and other animals, starch is hydrolyzed to glucose and becomes the body’s energy source. *Glycogen* is the polysaccharide animals use to store excess carbohydrates from their diets. Similar in structure to amylopectin,

glycogen is hydrolyzed to glucose whenever an animal needs energy for a metabolic process. The polysaccharide *cellulose* provides structure for plant cells. It is a linear polymer of glucose units joined by  $\beta$ -1,4-glycosidic linkages. It is indigestible in the human body but digestible by many microorganisms, including microorganisms found in the digestive tracts of many herbivores.

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