

CARBOHYDRATES

Carbohydrates are exceptionally important biological compounds. They are a major source of energy the body needs to drive other processes. The name carbohydrate gives some indication as to the nature of the compound. It is carbon with water attached (hydrate refers to water). In other words, CH_2O . At least, that is the case in some of the simple carbohydrates. More appropriately, in simple carbohydrates, the ratio of carbon to hydrogen to oxygen is 1:2:1.

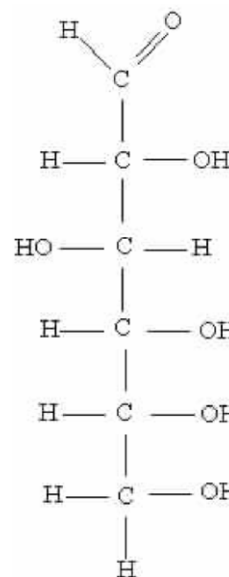
Glucose ($\text{C}_6\text{H}_{12}\text{O}_6$)

The most important carbohydrate in biology is glucose. It is not the simplest, nor the most complex, but it is the most important. Glucose is a six carbon compound. Think of stringing six carbons in a row (remember carbon typically forms 4 covalent bonds). From those six carbons, functional groups will be attached. On carbon # 1, carbon will be doubly bonded to oxygen and singly bonded to hydrogen. This forms the aldehyde functional group and because there is an aldehyde group on the #1 carbon, glucose is sometimes referred to as an *aldose* sugar.

On carbon #2, there is a hydroxyl (OH) group on the right and a hydrogen on the left. Carbon #3 reverses the hydroxyl and hydrogen with hydrogen on the right and the hydroxyl on the left. For carbons #4 and #5, the hydroxyl goes back to the right side and the hydrogens are on the left. The last carbon (#6) has the hydroxyl on the right, the hydrogen on the left. There is one additional location to add something to carbon. That is a hydrogen on the tail of the carbon. Glucose thus has 6 carbons, 12 hydrogens and 6 oxygens (with the oxygens tied to the hydrogens as hydroxyl groups). Note that for every carbon, there are two hydrogens and 1 oxygen ($\text{C}_6\text{H}_{12}\text{O}_6$ or the CH_2O ratio).

A very common source of glucose is found in honey from bees. Glucose is also referred to as a monosaccharide. The prefix *mono* means one and *saccharide* means sugar (one sugar or simple sugar).

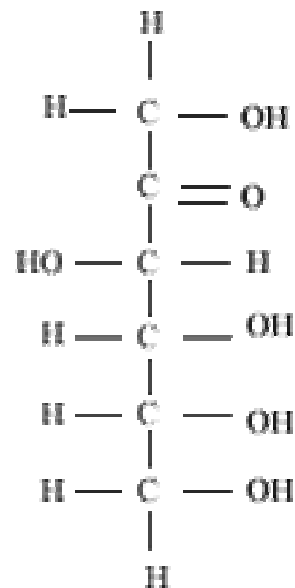
So far, you have been give four names for this compound: (1) a carbohydrate (2) glucose (3) an aldose sugar and (4) a monosaccharide.



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Fructose

Another simple sugar is fructose. Fructose also has six carbons. On carbon # 1 there is a hydroxyl group on the right, a hydrogen on the left and a hydrogen at the top of the carbon. On carbon #2, there is a double bond to oxygen (a ketone functional group) and thus fructose is often referred to as a *ketose* sugar). The third carbon has the hydroxyl on the left and the hydrogen on the right. The fourth carbon shifts the hydroxyl back to the right and the hydrogen is on the left. This continues for the remaining two carbons. The last carbon has an additional hydrogen, just like glucose.



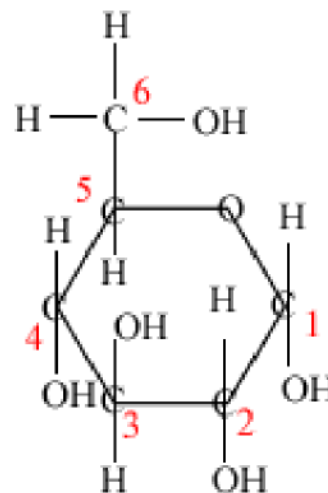
Isomers

The formula for fructose is $C_6H_{12}O_6$, the same as glucose! How can that be? They both have the same formula but different structures. Any material that has the same formula but different structure is considered an isomer of the other.

There are also four names for fructose: (1) a carbohydrate (2) fructose (3) a ketose sugar (4) a monosaccharide

Ring Structures

Just as in hydrocarbon chemistry, ring structures can form. In reality, glucose generally does not exist in “straight-chain” structures as previously described. Virtually all of the glucose in nature occurs as a ring compound. The ring structure of glucose occurs when the #1 carbon bends inward to join with the hydroxyl group of the #5 carbon. Think of a hexagonal shaped figure. On the right point of the hexagon, place a carbon. Continue placing carbons at each juncture of the lines until you get to the top right portion of the hexagon. There, insert an oxygen. The carbons are numbered 1-5 clockwise from the beginning. Oxygen is in the sixth place of the hexagon, therefore the #6 carbon is found attached above #5 carbon of the hexagon.



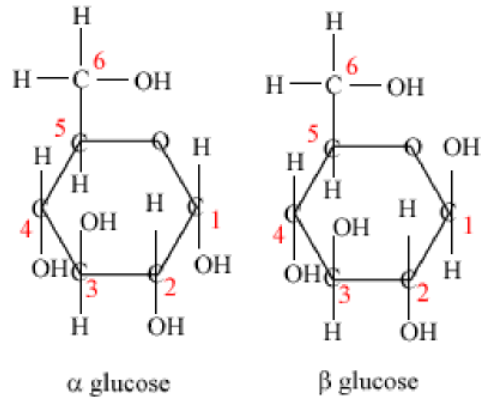
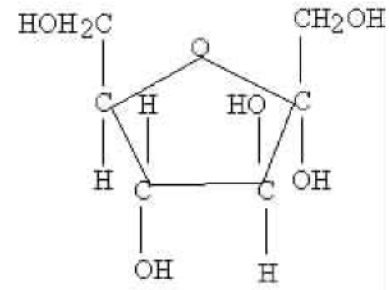
On the #1 carbon, the hydroxyl group is attached pointing down and the hydrogen is pointing up. For carbon #2, it is the same. For carbon #3 the hydroxyl points up and the hydrogen points down (remember the description above for the “straight-chain” structure). Carbon #4 has the hydroxyl pointing down and the hydrogen up. Carbon #5 no longer has a hydroxyl group (since it combined with carbon # 1). The hydrogen that remains points down. Oxygen is in the sixth location of the hexagon. Above carbon #5 is another carbon (#6) with a hydroxyl to the right, a hydrogen to the left and a hydrogen at the top. This is glucose in the ring structure.

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Fructose also forms a ring structure. Instead of a six membered ring (hexagon), fructose forms a five-membered ring (pentagon). Again, the carbons are numbered 1-6 but two of the carbons are outside the ring.

Alpha and B- Glucose

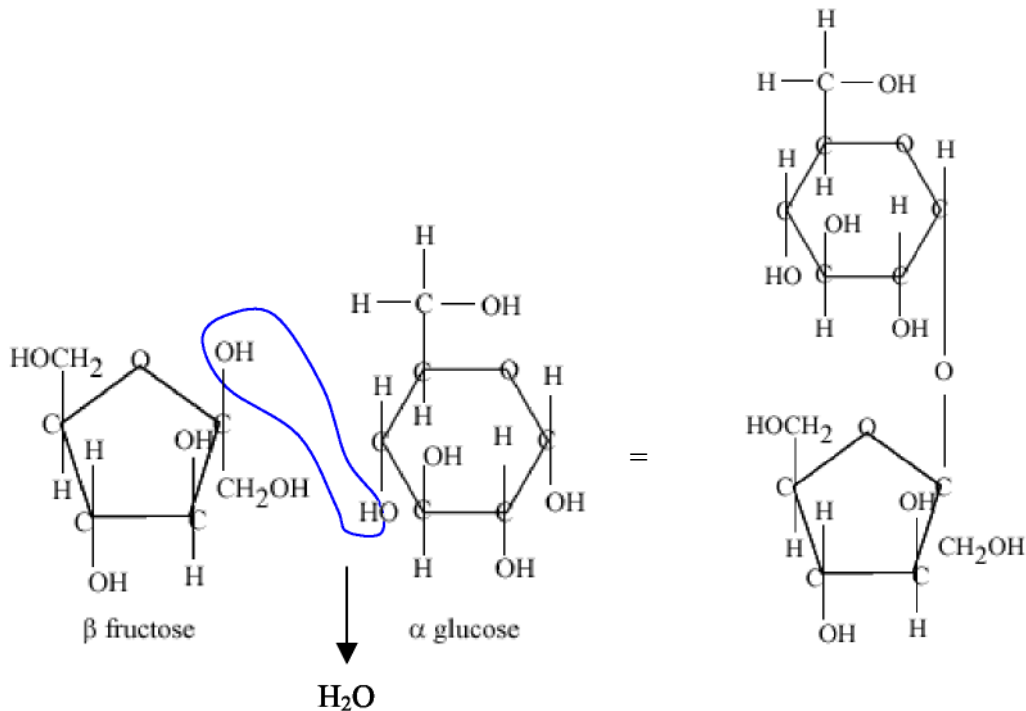
To complicate your life even more, there are two forms of glucose (as well as fructose or any carbohydrate). The glucose previously discussed is α -glucose. Another form exists in nature: β -glucose. β -glucose is exactly the same as alpha with one difference. In β - glucose, the hydroxyl group points up on the #1 carbon. It points down in alpha. One would think there would be equal amounts of each form of glucose. In reality, there is far more β -glucose in the world than α .



Disaccharides

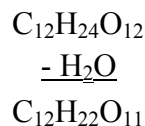
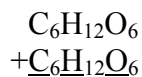
Although there are many different monosaccharides (glucose, fructose, galactose, etc.) monosaccharides may be combined to form larger molecules. For example, if you add glucose to fructose (and remove water from between the two molecules by a process known as condensation synthesis or dehydration synthesis) you will form the carbohydrate known as sucrose, a disaccharide.

Sucrose is also known as table sugar.



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The formula for sucrose is a little different than that of the basic carbohydrate formulation of 1 carbon, 2 hydrogens and 1 oxygen. The formula is not the product of adding two molecules each with the formula of $C_6H_{12}O_6$. Instead, it is the combination of both *minus* the water that is removed to form the compounds, or $C_{12}H_{22}O_{11}$.



Condensation Synthesis or Dehydration Synthesis

The process of removing water to form a larger, more complex molecule is called condensation synthesis (the process of pulling water out) or dehydration synthesis (the prefix *de* means “without”). In the oil industry, the process of joining two smaller molecules to form a larger molecule is called polymerization. Condensation synthesis or dehydration synthesis is a type of polymerization.

Some examples of disaccharides are

Monosaccharide #1	Monosaccharide #2	Disaccharide	Example
Glucose	+ Glucose	= Maltose	Malt sugar
Glucose	+ Fructose	= Sucrose	Table sugar
Glucose	+ Galactose	= Lactose	Milk sugar

(Each of the above are formed in the presence of enzymes and with the removal of water.)

Hydrolysis

If you add water to a disaccharide (along with enzymes) then you break the molecule apart into its component monosaccharides. For example add water and enzymes to table sugar and it breaks apart to form glucose and fructose. This breaking apart of larger molecules to form smaller ones with the addition of water is called hydrolysis. The same concept applies in the oil industry which was called “cracking”. Hydrolysis is a form of cracking.

Polysaccharides

When you combine three monosaccharides by condensation synthesis (dehydration synthesis), you form a trisaccharide. Four make a tetrasaccharide, etc. However, anything over two is usually referred to as a polysaccharide.

There are two major classes of polysaccharides important in biology: starches and celluloses. Starches come in various forms and combinations of sugars, but the three most important to this biology course are amylose, amylopectin, and glycogen. The most important cellulose is the cellulose making up plant cells.

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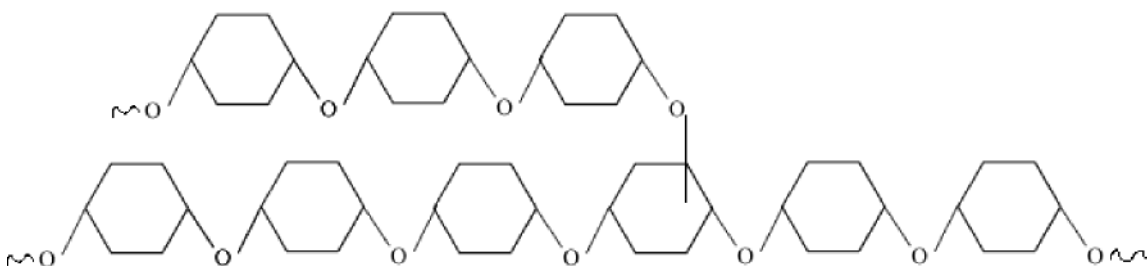
Amylose

Amylose is a starch composed of long, straight chains of α -glucose in 1,4 linkages. This means that glucose is joined to the next glucose molecule by the removal of water (condensation synthesis) at the #1 and #4 carbon. Some of the smallest amylose molecules are 100 glucose chains and some of the largest are 1000 glucose strung together. Amylose is one of the components of plant starch, so when you eat a baked potato, you are eating amylose.



Amylopectin

Amylopectin is a branched chain structure. The structure begins with an amylose molecule but with branch chains arising from the main chain every 20-25 glucose units. The glucose are linked in α -1,4 linkages as amylose. The branch chains may have 15 to 25 glucose units. Amylopectin is also found in plants.



Glycogen

Glycogen is sometimes referred to as animal starch although there are other organisms besides animals that produce glycogen. In any case, it is almost identical to amylopectin but it has branch chains arising every 8-12 glucose units. In other words, glycogen is more highly branched than amylopectin.

Celluloses

There are many different kinds of celluloses, but this course is concerned with the one redundantly named cellulose – the woody component of plants. Cellulose is identical to amylose except the glucose is not α -glucose, instead it is β -glucose. The result is the bonds between the glucose alternate pointing up and down from each other. The reason humans (and all other life forms except bacteria) cannot digest cellulose is that humans cannot break the β -1,4 linkages in cellulose.

