Lesson 3: The Carbohydrates

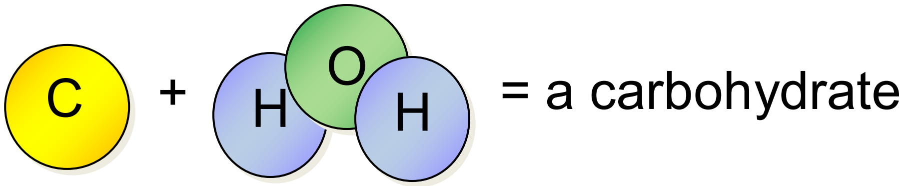
In Lesson 2, we introduced the idea that there were four elements that were very important to all living things. Those elements were carbon, hydrogen, oxygen and nitrogen. We also discussed how the atoms of elements desire to form compounds in order to gain greater stability. These stable compounds, such as water, for example, are extremely important for the well-being of all living creatures.

Beginning with this lesson, we will explore four groups of compounds that are vital to living things.   We will introduce each group of compounds first by looking at the elements which make up that group of compounds. Second, we'll look at the structure of those compounds. Then, finally, we will look at how they are used in living things. The first set of compounds we will look at are known as the **carbohydrates**, more commonly known as **sugars**.

Let's begin our discussion of carbohydrates by examining the elements from which carbohydrates are built. If we look at the name, carbohydrate, we can see two word parts: carbo– and –hydrates. The part carbo– tells us that the element carbon is a main component of carbohydrates. The second portion, —hydrate, is the root word of Greek origin for water. Water, as we discussed earlier, consists of hydrogen and oxygen atoms. So, carbohydrates consist of carbon, hydrogen and oxygen atoms. There are no nitrogen atoms found in carbohydrates.

Carbo- refers to the element carbon.

-Hydrate = water = H_2O



There are many kinds of carbohydrates, but they all have a generic formula or recipe regarding how many atoms of carbon, hydrogen and oxygen each contains. This generic formula looks like this:

$$C_n(H_2O)_n$$

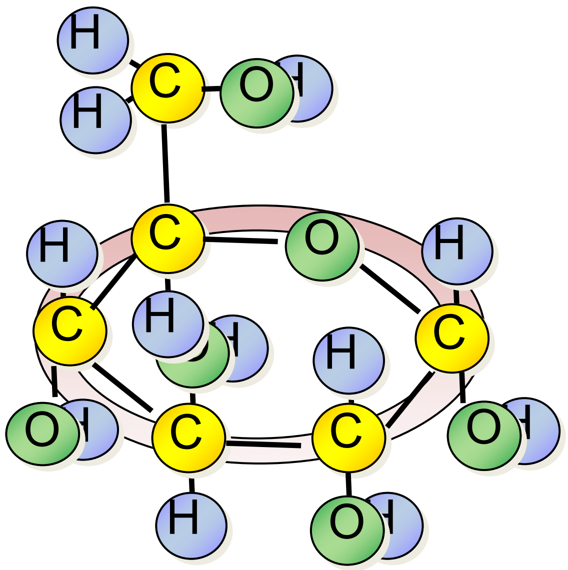
Recall, that the element symbol for carbon is C and water is H_2O. Note the little "n's" written as subscripts following the carbon and water parts of the carbohydrate formula. These subscripts tell us that the number of carbons and water parts can be adjusted, but the number of each is always equal. For example, if there are 6 atoms of carbon (n=6), then there would also be 6 parts of water. This carbohydrate would have the following formula:

$$C_6(H_2O)_6$$

This carbohydrate happens to be one the most important sugars of all! Its name is glucose, more commonly known as "blood sugar." Another way to write the formula for glucose is:

$$C_6H_{12}O_6$$

Note we just multiplied the water portion of the glucose molecule times six to get this result.



The glucose molecule is thought to exist as a circular, ring-shaped structure of carbon atoms. Note how each carbon atom has formed four bonds, each oxygen atom has formed two bonds and how each hydrogen atom has formed one bond.

Another carbohydrate that is found in many fruits is the sugar known as fructose. If we look at the formula for fructose, we see that the value for n is also six (n = 6.) The formula for fructose looks identical to that of glucose:

$$C_6(H_2O)_6$$

While glucose and fructose both have the same number of carbon atoms and water molecules in their formulas, the way these atoms are arranged in relation to each other results in differences between these two carbohydrates. These two different structures are known as **isomers.**

The natural sugar found in fruits is fructose.

To review, we've discussed that carbohydrates are composed of carbon atoms and molecules of water. The "generic" formula for a carbohydrate is $C_n(H_2O)_n$. Glucose, where n = 6, is one of the most important carbohydrates to living things. Glucose is more commonly known as blood sugar. A variation on the structure of glucose is fructose, a sugar found in fruits,/ and this variation is called an isomer.

Let's continue our exploration of carbohydrates. Both glucose and fructose are considered monosaccharides. The prefix for this term is mono– which means one. The suffix is –saccharide which means sugar. Monosaccharides are carbohydrates composed of one type of sugar.

Mono = one

Saccharide = sugar

Monosaccharide = carbohydrate made up of one kind of sugar molecule.

Now consider disaccharides. The prefix di– means two so a disaccharide is a carbohydrate that consists of two types of sugars.

Di = two

Saccharide = sugar

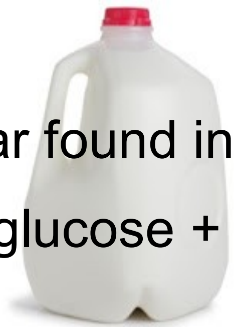
Disaccharide = carbohydrate made up of two kinds of sugar molecules.

Let's consider an example of a disaccharide. Sucrose, commonly known as table sugar, is a disaccharide. Sucrose is made up of one molecule of glucose and one molecule of fructose. These two molecules are bonded together to form this disaccharide.

Table sugar is sucrose.

Sucrose = glucose + fructose

Another very important disaccharide is lactose. Lactose is made up of one molecule of glucose and one molecule of galactose. Together, they form the disaccharide lactose. Lactose is the sugar naturally found in milk and, because of this, is the primary carbohydrate consumed by baby mammals as they nurse from their mothers. Obviously, lactose is a very important carbohydrate! Lactose can be found in all sorts of foods which contain dairy products such as milk, ice cream, yogurt and cheeses.



The natural sugar found in milk is lactose.

Lactose = glucose + galactose

Earlier we mentioned that the monosaccharide glucose is the most important carbohydrate for living things. Glucose is the primary fuel from which energy is produced in living organisms. It's like the gasoline that runs our cars. Glucose is the gasoline for our bodies! In the previous paragraphs, we noted that the carbohydrates sucrose and lactose were disaccharides, being composed of a combination of two carbohydrates. Note that glucose was found in both of those carbohydrates (sucrose = fructose + glucose and lactose = galactose + glucose) When we eat foods containing sucrose and lactose, our bodies have the capability of splitting these disaccharides back into monosaccharides thereby making glucose available for fuel. This splitting is accomplished through the use of chemicals known as enzymes.

Glucose is the "gasoline" for living things.

Enzymes are very interesting chemicals that do all sorts of amazing jobs in living things. Most of these jobs can be categorized into two main categories: matchmaking and cutting. Let's take a look at each of these jobs.

What is matchmaking? By definition, matchmaking is the process in which someone assists in the relationship of two other individuals. Think about this situation: suppose you were interested in meeting someone but were too timid or shy to just go up and introduce yourself. You might consider getting the assistance of a friend who could go to this person you would like meet and tell him or her you were interested in meeting. Your friend is functioning like a matchmaker. The friend was helping to speed-up the "reaction" between you and this new person you desired to meet, but the friend was not changed by the reaction. Enzymes work in a very similar fashion. Enzymes in living things work to speed-up reactions, but, in the process, they themselves do not get changed. This job of enzymes is essential when glucose is converted into energy for living things. We will discuss this idea in greater detail later in this course.

Enzymes can work like matchmakers.

Mulan

Fiddler on the Roof

The second job of enzymes is to cut. Enzymes can literally cut other compounds into pieces. A more scientific term for cutting is to lyse. Enzymes can lyse disaccharides into monosaccharides. Recall that sucrose is a disaccharide. The enzyme known as sucrase can lyse sucrose into its two components: fructose and glucose. Note that the ending of the word sucrose was changed to –ase in the enzyme name of sucrose.

Enzymes can also work like scissors to take things apart.

As we discussed previously, lactose is another disaccharide. The enzyme lactase can lyse lactose molecules into its two components: galactose and glucose. Note again how we changed the name of lactose to lactase when the enzyme was named. You may be familiar with someone who suffers from the digestive problems of being lactose intolerant. People who suffer from this problem generally have a deficiency in the enzyme lactase which prevents them from being able to digest lactose found in dairy products. They find that when they drink milk or eat ice cream or other dairy products they suffer a lot of digestive system discomfort. The lactose molecules are not lysed and bacteria that normally live in the digestive system begin having a "feast" on the new supply of lactose. As the bacteria begin consuming the lactose, they produce a byproduct of gas which causes the discomfort often associated with lactose intolerance. People who suffer from this problem often find it best to avoid eating dairy products, however, some find that taking lactase supplements helps to replace the low levels of naturally occurring lactase.

There are hundreds of other enzymes which work to speed-up reactions in our bodies as well as cut or lyse things. Enzymes are not particular only to carbohydrates. They work on all sorts of molecules and compounds in living things. As we move through this course we will discuss those enzymes and understand how very important they are in living things.

Let's go back to our discussion of various carbohydrates that are important to living things. We've talked about glucose (blood sugar), fructose (fruit sugar), sucrose (table sugar) and lactose (milk sugar). Maltose is another carbohydrate found in living things. Like lactose and sucrose, maltose is a disaccharide and is composed of two glucose molecules linked together. Maltose is found in seeds and grains of plants. Can you think of the enzyme name which can lyse maltose into its components? Yes, that enzyme is maltase.

We said maltose consists of two glucose units bound together. Plants have the ability to continue adding glucose units onto maltose sugars to create very large complex structures known as starches. Starches have a more scientific name which is amylose.

Because amylose consists of many, many glucose units bound together, amylose can be thought of as a storage mechanism of fuel for plants. You see, plants have the unique ability to produce their own glucose through the process known as photosynthesis. This process, for the most part, takes place in the plant's leaves. Other living creatures, like you and I, can't directly make our own glucose which is why we must continually consume food that contains glucose (or other carbohydrates that contain glucose). We will discuss photosynthesis later in greater detail. Amylose works like fuel that's been stored-up in a big tank outside your house. During times when the plant is actively growing and making glucose through photosynthesis, it continues to build amylose and store it up. In times of the year when the plant doesn't have leaves, it relies upon these stock-piles of amylose. Plants create these stockpiles in their seeds as well as their roots in the form of tubers like potatoes or bulbs.

Amylose is stored in a plant's seeds or roots.

Consider the seeds of plants which have these stockpiles of amylose. When seeds are planted, they are exposed to appropriate conditions of moisture and warmth in the hopes of getting them to sprout or germinate. The tiny baby plant inside the seed requires energy to begin growing. It will begin taking some of the amylose out of storage and turning it back into glucose for energy production. You might think of the situation like this: the "mother plant" which originally produced the seeds has kindly packed a "lunch" for each of its seeds in the form of amylose neatly packed within the seed. When conditions are right, the "lunch box" gets opened and the baby plant can use the fuel source until it grows its own leaves and can make its own supply of glucose.

Seeds, packed with amylose, are like packed lunch boxes.

If you were able to get your potato plant underway, by now you can see some shoots growing upward at the surface of the potting soil. The energy source for this growth came from the stored amylose in the potato. Because you placed the potato in optimum growing conditions, it responded by beginning to utilize the stored glucose in the potato. As soon as the shoots emerge from the soil surface they will grow leaves which will begin producing glucose for the plant's continued growth. With proper care, your potato plant will likely produce a large bushy plant which will produce lots and lots of glucose molecules which will be stored in "new" potatoes.

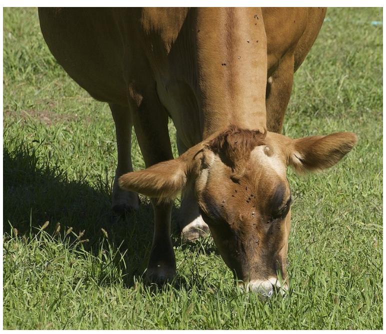
Can you guess the guess the name of the enzyme which breaks down this stored-up starch into individual glucose molecules? As you might imagine, the enzyme which breaks down amylose is amylase. Amylase is not only found in plants but in you and me, as well. Amylase is found in our saliva (spit) and works to begin digesting starches as soon as we begin chewing them in our mouths. Can you think of foods you eat that are high in starches? How about those foods made from grounds seeds, especially wheat seeds? Yes, flour, which is made from ground (milled) wheat seeds is just about all starch. Any food you eat which contains flour, such as breads, cookies, muffins or cakes, contains lots of amylose. As soon as you mix a bite of these foods with the saliva in our mouth, amylase enzymes go to work breaking them down into glucose molecules. The potatoes we discussed earlier are also loaded with amylose. As you eat a French fry or baked potato or any type of food made from the root of a plant (carrots, turnips, beets, etc.), amylase in your saliva begins to do its job of lysing amylose into glucose molecules.

Before we end our discussion of carbohydrates, there is one other carbohydrate that we need to consider. That carbohydrate is known as cellulose. Cellulose is not a sweet carbohydrate like the other carbohydrates we have discussed so far in this lesson. Nonetheless, cellulose is a carbohydrate made up of carbon, hydrogen and oxygen atoms. In fact, cellulose consists of glucose molecules which link themselves into very long and very strong chains. Cellulose is the carbohydrate which gives plants their strength. Cellulose is found readily in celery! Have you ever taken a piece of celery and pulled-off little "strings" of celery or maybe had the misfortune of getting one of those strings stuck between your teeth? Cellulose is the carbohydrate which makes these strings.

Cellulose gives the crunchiness to fresh vegetables. Cellulose is also the carbohydrate which makes wood in larger plants and trees. In fact, cellulose is what's left over in the cell walls of trees after the tree is cut down and made into boards. You might think of cellulose as being like the "bones" of plants.

Cellulose makes the crunch in celery and carrots.

Can you think of the enzyme which breaks down cellulose? Yes, cellulase is the name given to a group of enzymes which are able to lyse long strands of cellulose into smaller pieces. Most mammals, including humans, are limited in the amount of cellulase we have available to digest cellulose. However, animals like cows, sheep, deer and goats, known as ruminants, have the ability to break-down cellulose and "harvest" this great supply of glucose. Actually, these ruminants also lack cellulase enzymes, however, they have an enormous supply of very tiny living creatures in their stomachs (microorganisms) which *do* have the ability to produce cellulase. These microorganisms digest the cellulose (grass or hay or leaves, etc.). Together, the ruminant and the microorganisms form a very special relationship where both of them benefit. The host ruminant provides the microorganisms with a continual supply of cellulose. In return, the microorganisms supply cellulase to break down the cellulose into useable glucose molecules which can be absorbed and utilized by the host animal. Not on-



Ruminants consume large amounts of cellulose to be broken down in their rumens.

ly do these ruminants have this capability, but termites do, too! Within the stomachs of termites, they, too, have microorganisms that assist them in digesting the wood products the termites consume. Again, a relationship exists which benefits both of the living creatures involved. Relationships between living creatures where each "partner" in the relationship may (or, in some cases, may not) benefit are called **symbiotic relationships**.

A relationship between two living things where one partner may or may not benefit is called a symbiotic relationship.

In cases, where both "partners" benefit, a **mutual symbiotic relationship** is said to exist. This is the case between the microorganisms which live in the stomachs of ruminants and termites and their hosts. Both the ruminant (cow, sheep, deer, etc.) and termites and the microorganisms benefit from the relationship.

Other symbiotic relationships can be observed in living creatures where one member of the relationship benefits while the other member does not. A good example of this relationship involves the fleas and ticks which you may find on your pets. The fleas and ticks require a constant supply of blood (glucose) to survive and do so by extracting it from your dog or cat. This type of relationship where one benefits (the fleas and ticks) while the other suffers (your dog or cat) is referred to as **parasitic symbiosis** or **parasitism.**

Ticks, which suck blood from their hosts, are parasites.

A relationship where one member benefits to the detriment of the other is called parasitism.

Another type of symbiosis exists where one member of the relationship benefits while the other is not harmed. This type of relationship is termed **commensalism**. A good example of commensalism is the relationship between cattle egrets and cattle. Cattle egrets are large white birds which can often be found feeding on insects in tall grasses alongside cattle. As the cattle move along grazing, they stir up insects which are quickly consumed by the egrets. The egrets do no harm to the cattle, yet benefit from the movements of the cattle. In this case, the egrets benefit while the cattle are not affected.

Cattle egrets benefit from the movement of cattle in the grass. This is an example of commensalism.

A relationship where one member benefits while the other is unaffected is known as commensalism.

At this point, we will bring our introductory lesson on carbohydrates to a close. We will definitely visit the topic of carbohydrates again in Lesson 7 where we will discuss in greater detail how living things utilize carbohydrates (glucose in particular) to carry on life's processes.

Let's review:

- Carbohydrates are composed of carbon, hydrogen and oxygen atoms with the generic formula of $C_n(H2O)_n$.
- Glucose is the most important carbohydrate for living things in that glucose is the fuel on which living things "run." The formula for glucose is $C_6H_{12}O_6$.
- Some carbohydrates (sugars) are single molecules (monosaccharides) while others are composed of two types of carbohydrates (disaccharides). Enzymes work to join carbohydrates as well as cut

or lyse carbohydrates into simpler units. Enzymes are named similarly to the carbohydrate on which they act; the ending of the carbohydrate name is changed to –ase.

- Fructose is the carbohydrate found in fruits and vegetables. Lactose is found in milk and milk products. Sucrose is table sugar. Maltose is found in grains.
- Plants can make their own glucose and store it in their seeds and roots for later use. This storage form of glucose in plants is known as amylose.
- Cellulose, while not sweet, is an important carbohydrate in that it provides strength and structure for plant cells.
- Interesting relationships, known at symbiotic relationships, exist between living creatures where one or both "partners" in the relationship benefits. Where both benefit, a mutualistic symbiotic relationship is said to exist. This relationship is important for ruminants who host microorganisms that help them break down the important carbohydrate, cellulose, into usable glucose.

Lesson 3 Lab Activity: Testing for the Presence of a Starch (Amylose)

PLEASE READ ALL OF THESE INSTRUCTIONS BEFORE BEGINNING THIS LAB ACTIVTY.

The purpose of this lab activity is to allow you to test various substances in your kitchen for the presence of starch (amylose.) Recall that amylose is formed by plants in an effort to store glucose to be used later.

Things you'll need for this lab include:

- Several small lids from plastic containers. Lids from yogurt cups, baby food, whipped topping work well. If you don't have these handy, you can use small Styrofoam plates or cups. The idea is to have a container with low sides on which you can place your powder for testing. If you use cups, plan on cutting down the sides to make them more shallow.
- Toothpicks or coffee stirrers. These will be used to stir your test powders with the testing solution. Plastic or regular household spoons can work, also.
- Eye dropper or syringe. These will be used to transfer your testing solution to your powders. We recommend you NOT use a drinking straw to transfer your test solution as your test solution is POISONOUS and should NOT be taken into your mouth or swallowed.
- Tincture of iodine. Tincture of iodine is a concentrated iodine solution which can be found in the first aid section of your grocery store or pharmacy. Note that iodine is POISONOUS and should **not be taken internally**. It can also stain one's skin or clothing. You will only need a very small amount for this lab so a small bottle is all you will need. Consider wearing an old shirt or lab coat to protect your clothes in this lab.
- Old newspapers on which to cover your work surface and a supply of paper towels or napkins to clean up spills.
- An assortment of powders in which to test. We recommend you test the following powders: white flour, whole wheat flower, granulated sugar, powdered sugar, corn starch, baking soda, baking powder, table salt, cornmeal and any other sugar products such as turbinado or sucanat, cake or biscuit or pancake mixes. **Do not use any sort of household detergents, cleaners or drain openers.**

- Foods you can test include; breads, muffins, potatoes, crackers, unpopped and popped popcorn, uncooked oatmeal and any sort of cold cereal. Fresh white potatoes or dehydrated potatoes are also recommended for testing.

Preparation of Iodine Testing Solution

Because tincture of iodine is highly concentrated, you'll need to make a dilute solution of it for this lab (a little goes a long way.) Make this solution by getting about 1/4 cup of tap water. Add to it a teaspoon or so of the tincture of iodine. The amount is not critical. Your goal is to create a solution which resembles brewed tea (light brown color.) Note that if you get the iodine on your hands or clothing it will stain. Stains on your hands are not permanent but may require a few days to wear off. It will not hurt you if you get it on your hands. Make sure to recap the container tightly and keep it out of reach of younger children. Iodine is used to cleanse the skin in the case of minor cuts and bruises as well as rid the skin of germs prior to surgery. It can also be used to kill skin fungi like ringworm. It works by creating "holes" in the coverings of germs and messing up their proteins inside.

Once you've prepared your iodine testing solution, label its container and set it aside. You might draw a "skull and crossbones" on the container just to remind you not to drink any!

Preparation of your Powders to be Tested

For each test powder, you will use one lid or prepared cup (see above for details.) With a pen or marker, label the lid with the powder you plan on placing in it. Then, with a clean spoon, transfer approximately 1 Tablespoon of each powder to each lid. It's important to use a clean spoon for each powder or clean and dry the one you are using between powders.

Testing Procedure

Begin testing your powders by testing corn starch first. Corn starch is basically pure amylose and will definitely give you a positive test result. Begin your test by getting some iodine solution in your dropper. Then, carefully add some drops to your corn starch powder. Using a toothpick or coffee stirrer, mix in the iodine with the powder. A positive test for amylose is an immediate color change of the iodine from the light brown color to an almost-black, purple color. Avoid touching the tip of your eyedropper to the powder which might contaminate your next test powder. If you should touch the powder, rinse the eyedropper in water and begin again.

To see a negative test result, test granulated table sugar next. Repeat the steps you followed when you tested the corn starch. You should find that granulated sugar does not create a color change in the iodine solution, but rather the iodine remains it original brown color. Recall that table sugar consists of sucrose which is obviously not amylose. Table sugar is usually made from two plant sources depending upon the location of where you live. If you live in the northern United States, table sugar generally is made from sugar beets whereas in the southern USA, table sugar is made from sugar cane. Both plants supply plant "juices" which are dried and processed into table sugar. Because sucrose has not yet been changed into amylose for storage, it will give you the negative starch test result.

On the next page you will find a data table in which to record your results as you move from powder to powder. Note in the first column, you will write the identify of the powder you are testing. In the second column, make a hypothesis (educated guess based on your previous experiences with the powder) as to the results of your test. Then, make your test and record your results.

When you test baking mixes, such as cake or biscuit mixes, think about the ingredients present in the mix. Check the label on the box and then make your hypothesis. You may find "interesting" results. One other thing to note is regarding powdered confectioners sugar. One might usually think that powdered sugar is just that: sugar that's been pulverized into a fine sugar. However, you might check the label on the bag or box and find that many times corn starch is added to help the powder flow more freely. Because of this, the negative result you'd normally expect may not occur due to the presence of the corn starch.

Testing the popped popcorn is fun, also! Try as many different foods as you can.

One other fun thing to do is have your teacher prepare some unknown powders for you to test. Based on your observations, see if you can determine the identify of these powders. Remember to only use powders that are safe for you to make observations of (no chemical or powdered cleaners.)

Finally, clean-up your work area when you are finished. The iodine solution is safe to pour down the drain followed by a good flush of water. Dispose of your powders in a trash container and wash any of the lids or utensils for future use.

Powder	**Hypothesis**	**Observed Results**	**Positive or Negative for Amylose**