

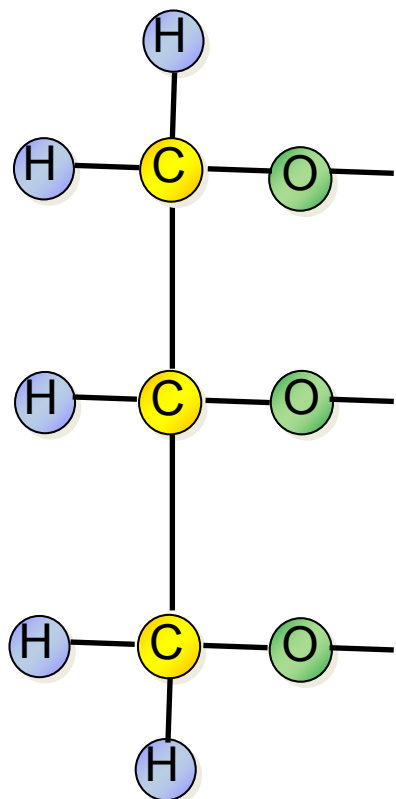
Lesson 4: The Lipids



In Lesson 3, we discussed the first group of important compounds found in living things: carbohydrates. In this lesson, we will explore a second very important group of compounds known as lipids. A more commonly used term for lipids is fats. As we did in Lesson 3, first we will look at the structure of lipids. Then, we'll examine how lipids behave and, finally, we'll discuss how lipids are used in living organisms.

Like carbohydrates, lipids are composed of the elements carbon, hydrogen and oxygen. Lipids do not have any nitrogen atoms present. However, unlike carbohydrates, lipids are large molecules. Their large size gives us insight to one of their very important uses in living things. So, first, let's look at the structure of lipids.

All lipids have two basic parts to their structure: the glycerol portion and the fatty acid portion. Let's look at the glycerol portion first. The glycerol portion consists of three carbon atoms, each bonded to each other and hydrogen atoms to make up the four bonds that carbon desires to form.

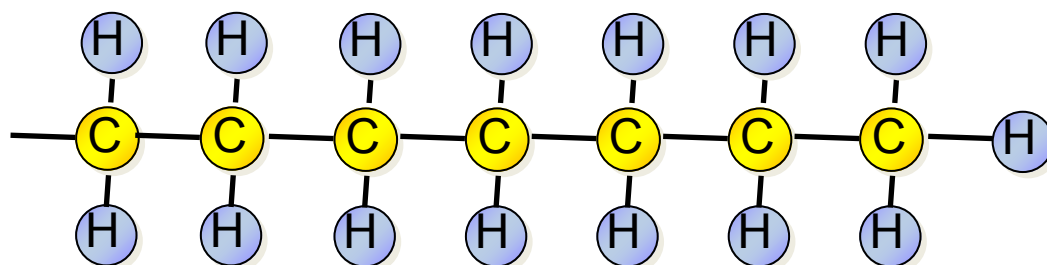


Glycerol portion of a lipid. Note how each carbon atom has formed four bonds and how each oxygen atom desires to form two bonds and how each hydrogen atom has formed one bond.

Note that on one side of the glycerol portion of a lipid, there are three oxygen atoms. The glycerol portion can be found in all lipids. Let's look at the fatty acid portion of lipids next.

Fatty acids or fatty acid chains, as they are often called, are just that: chains of carbon atoms ranging in length from 4 to 24 carbon atoms long. They have various names according to their lengths (and possible presence of other elements such as nitrogen and sulfur). For this course, we will limit our discussion to understanding the basic structure of a fatty acid chain.

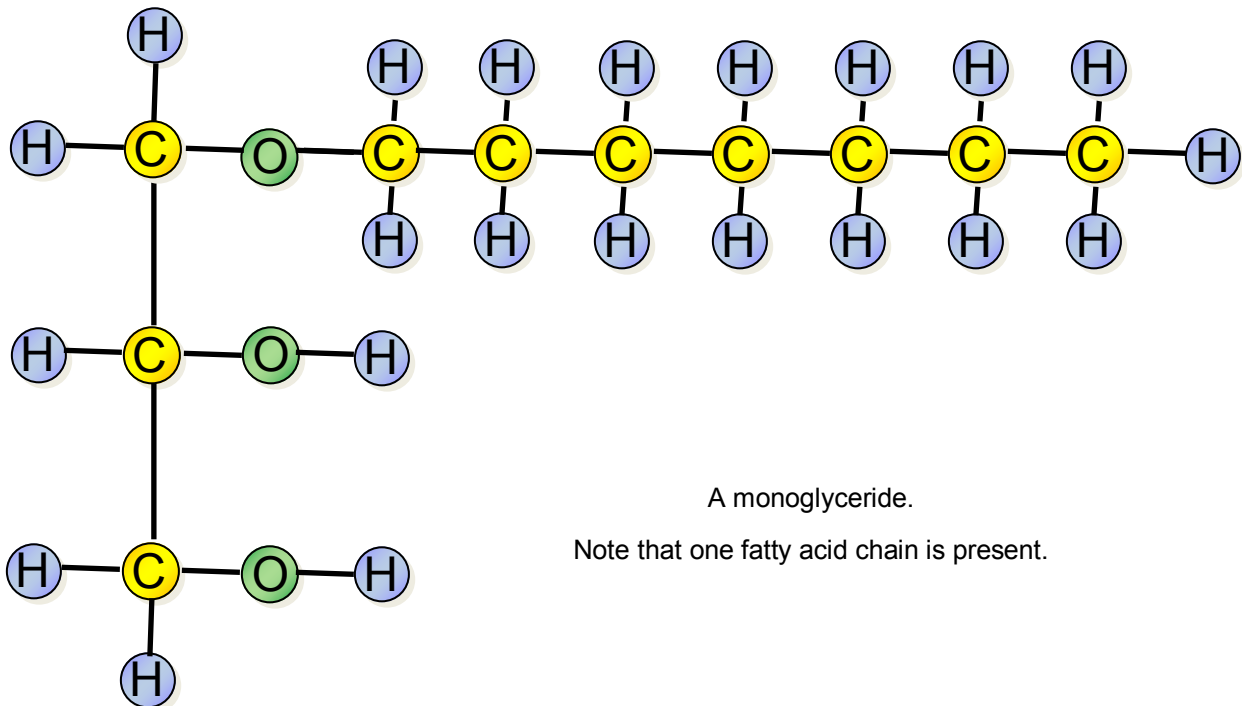
As we mentioned above, fatty acid chains range in length from 4 to 24 carbons. Bound to these carbon atoms are hydrogen atoms. Look at the diagram below to see a simple fatty acid chain.



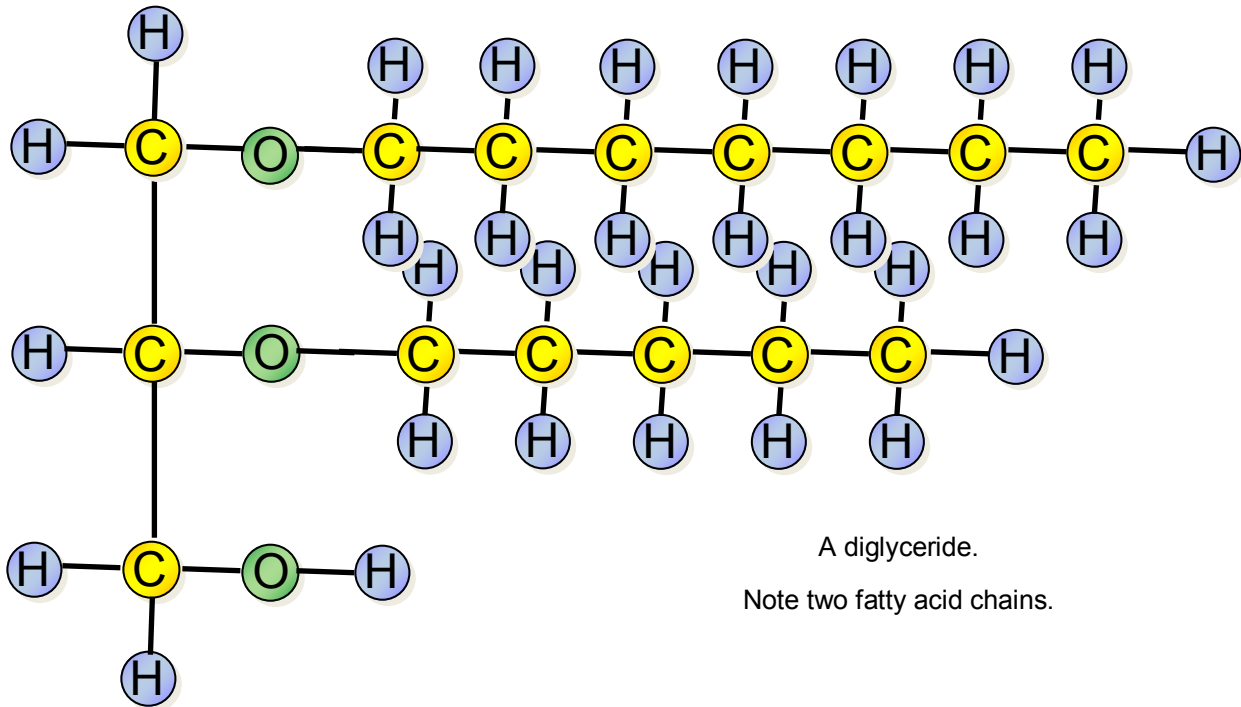
Fatty acid chain portion of a lipid. Again, look at the number of bonds formed by each atom.

Fatty acid chains are named according to their structure. Examples of fatty acids include butyric acid found in butter and arachidonic acid found in peanuts. Others include stearic acid and palmitic acid.

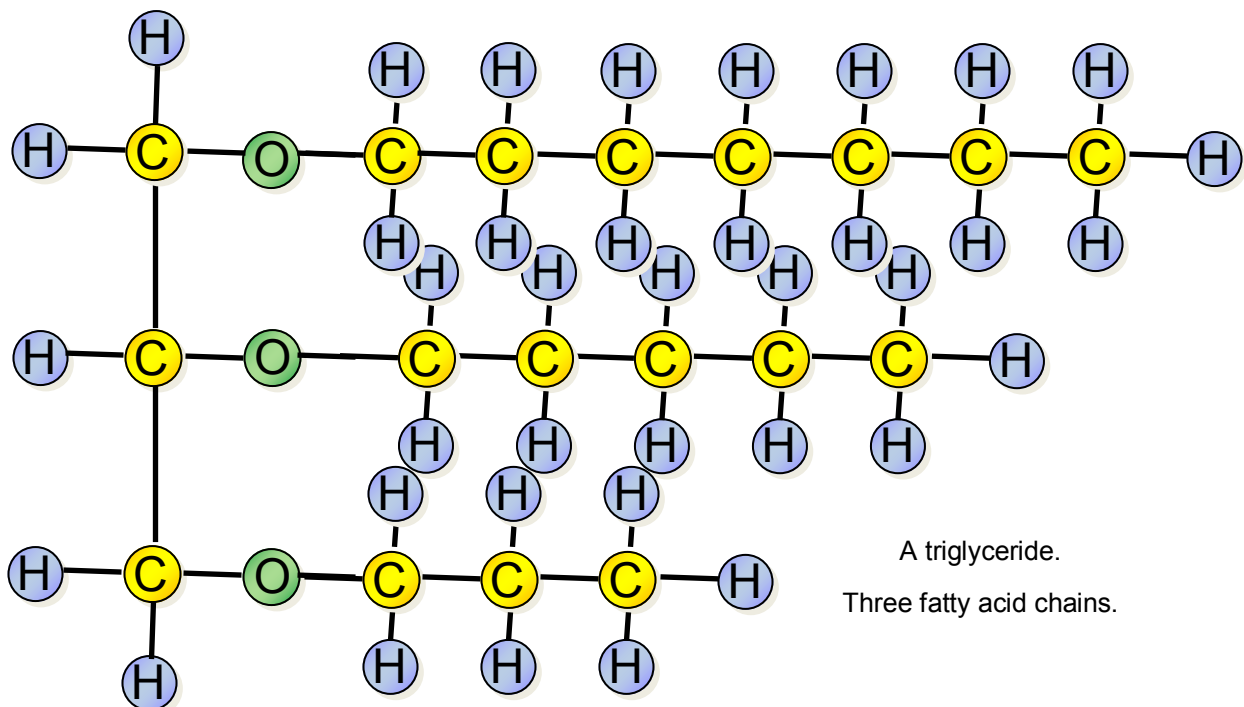
How are these fatty acid chains connected to the glycerol portion of a lipid? These fatty acid chains are linked to the oxygen atoms in the glycerol portion of the lipid. Because there are three oxygen atoms present in glycerol, there can be up to three fatty acid chains linked there (one chain to each oxygen atom). If one fatty acid chain is present, the lipid is called a monoglyceride, where the prefix mono- means one and glyceride refers to lipid or fat. Look at the diagram below of a monoglyceride. Note that there are only hydrogen atoms bound to the other two potential bonding sites on the glycerol molecule.



If two fatty acid chains are bound to the oxygen atoms of the glycerol unit, this lipid is called a diglyceride, where the prefix di- means two. Here is a diagram of a diglyceride.

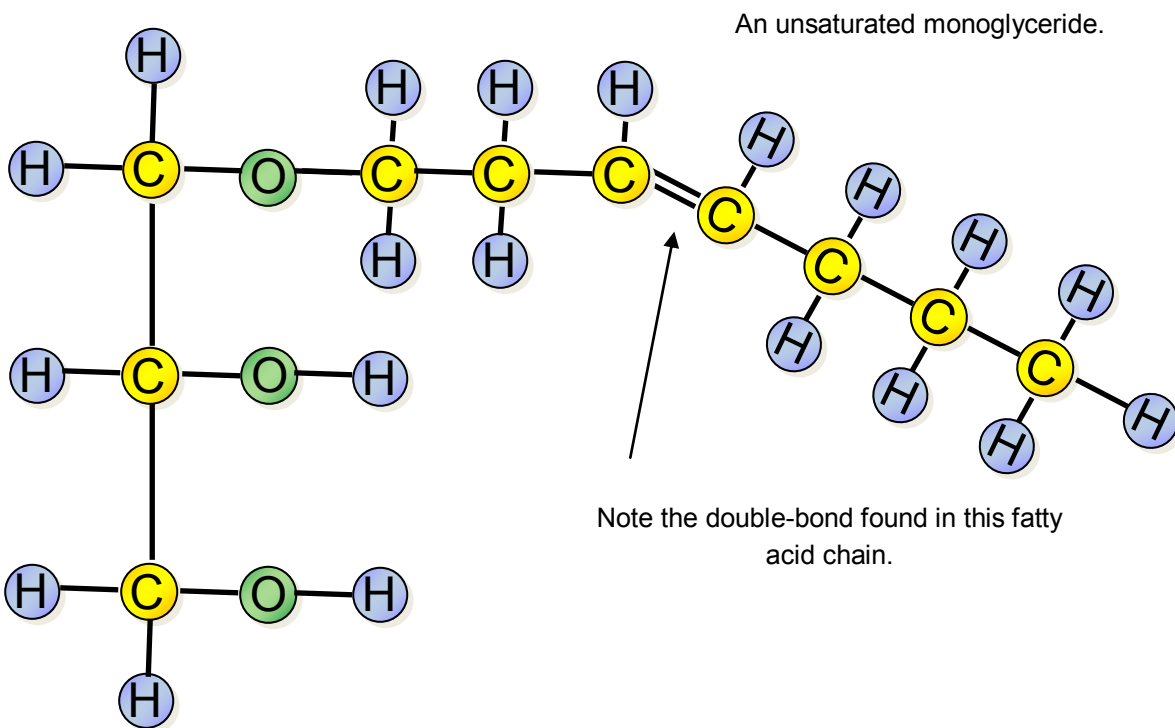


If all three oxygen atoms have a fatty acid chain present, the lipid is called a triglyceride. The prefix tri- means three. Here is a diagram of a triglyceride.

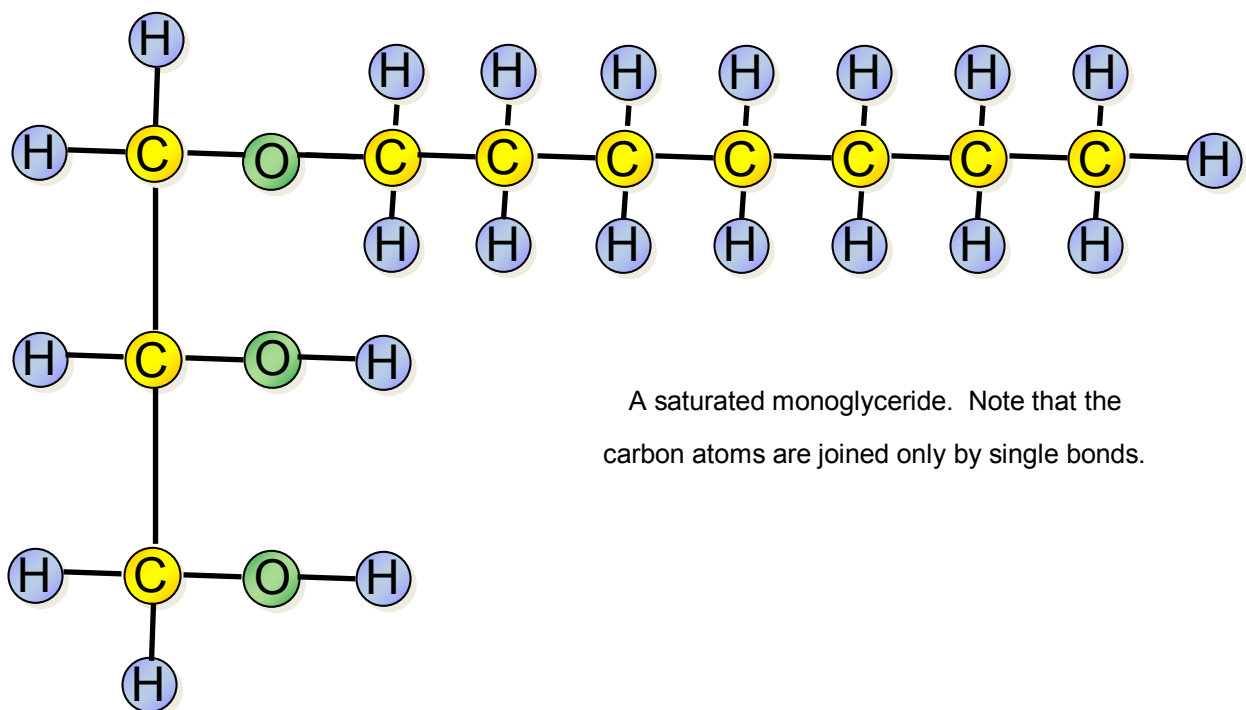


Let's pause and review. In this lesson we've introduced a second set of compounds which are extremely important to living things. They are known as the lipids or fats. We learned that lipids contain carbon, hydrogen and oxygen atoms and that lipids are much larger molecules than carbohydrates. We learned that lipids consist of two main structures: the glycerol portion and the fatty acid chains. We learned that there can be up to three fatty acid chains bound to the glycerol portion of a fat. A monoglyceride has one fatty acid chain, a diglyceride has two and a triglyceride has three fatty acid chains attached to the glycerol molecule. Let's continue now.

Let's take a closer look at fatty acids. Fatty acids can be classified into two main sub-groups: the saturated fatty acids and the unsaturated fatty acids. This division is made according to the presence of double bonds found in the chain of carbon atoms. When a double bond is found between two consecutive carbon atoms in a fatty acid chain, those carbon atoms require fewer hydrogen atoms to be bonded to them in order for the carbon atoms to acquire their four desired bonds. Because, at this point, there are fewer hydrogen atoms present, this type of fatty acid is said to be unsaturated.



If a fatty acid chain has only single bonded carbon atoms throughout its length, each carbon atom has its desired number of four bonds fulfilled by hydrogen atoms. We can say that the fatty acid is “filled to the brim” with hydrogen atoms and is therefore considered saturated.



When we investigate the sources of naturally occurring fats, we find that saturated fats come from animal sources. Fats like lard, which comes from hogs, is a saturated fat. Tallow is the fat which comes from beef animals and is also considered to be a saturated fat. Fats from animal sources are solids at room temperature. Consider a piece of uncooked bacon. Note the meaty portion and the fatty portion. Before the bacon is cooked, the fatty portion is a solid at room temperature.

Saturated lipids are usually solids at room temperature and are derived from animal sources.



On the other hand, fats which originate from plant sources are unsaturated fats. There are many of these fats that are used in your kitchen. Salad oil is made from fats extracted from corn. Soybean oil, which comes from soybeans, and canola oil, which comes from seeds of the canola plant, are two other commonly used oils in cooking. Cookies purchased from the grocery store are often prepared with palm oil made from seeds of palm trees. Cottonseed oil is also used in many commercially prepared baked items. Another oil often used in the preparation of foods is olive oil which, obviously, comes from olive trees. All of these fats originate from plants. Are they solids or liquids at room temperature? If you said, *liquids*, you are correct. Unsaturated fats which originate from plants are liquids at room tem-

Unsaturated lipids are usually liquids at room temperature and are derived from plant sources.



Let's pause and review, once again, before we continue our discussion of lipids. We said that:

- Lipids are composed primarily of carbon, hydrogen and oxygen atoms.
- There are two main portions of lipid molecules: the glycerol portion and the fatty acid portion.
- The glycerol portion consists of three carbon atoms each with an attached oxygen atom and the necessary hydrogen atoms to make carbon's desired four bonds.
- Fatty acids are chains of carbon atoms ranging from 4 to 24 carbons in length.
- The lipid is classified as being a monoglyceride, diglyceride or triglyceride according to the number of fatty acid chains present in the lipid.
- Saturated fatty acids are solids at room temperature and originate from animal sources.
- Unsaturated fatty acids are liquids at room temperature and originate from plant sources.

Let's continue our discussion of lipids. The way that the lipid molecule is designed allows it not to mix with watery substances. Try this lab activity.

Lesson 4 Lab Activity 1: Behavior of Lipids

Fill a clear, one quart canning jar half-full of water. To the water, add a cup of salad (corn) oil. Any other cooking oil will do. Do not mix the two liquids. What do you observe?

Does the water mix with the oil?

Which liquid stays on top of the other?

Gently stir the two liquids. What happens?

Will the oil mix with the water? (Don't shake the jar just yet as we'll use it again shortly.)

Lipids are said to be insoluble in water. They do not mix with water. Have you ever gotten a fat on your hands, like butter or margarine? You probably know that you can't wash these fats off of your hands with water alone. Water will not mix with the fats to carry them away from your hands and down the drain of the sink. This inability to mix with water is due to the way the carbon, oxygen and hydrogen atoms are arranged in lipid molecules. Substances which do mix or dissolve in water have their atoms arranged in a way similar to that of water. These substances are said to be water soluble.

Now, take some food coloring and drop a few drops into the oily top layer. Watch closely what happens. Does the food coloring mix with the oil? Where does the food coloring go? What happens when the food coloring meets the water? Continue to make observations while you gently stir the oil and water mixture. What happens? Does the oil change color? What does this tell you about the solubility of the food coloring? You should find that the food coloring is not soluble in the oil and therefore does not color the oil. On the other hand, the food coloring is water soluble and does mix or color the water in the jar.



Lipids are not soluble in water. They are hydrophobic.

Friendly Biology

Knowing that lipids are insoluble in water is important because lipids are used in living organisms to keep water in or out of certain places. You might think of lipids as being like raincoats which can keep water off of you! Lipids are used like barriers or walls to keep water in or out of the cells of living things. We will discuss this capability in much greater detail in a later lesson. For now, knowing that lipids are insoluble in water is important.

Before we leave the discussion of how lipids and water behave, we need to learn two other pairs of terms which are used to describe this behavior. In addition to describing lipids as being insoluble in water, we can also say that lipids are immiscible in water. Substances that do mix with water are said to be miscible. For example, we can say that butter is immiscible in water (does not mix) while something like pancake syrup is miscible (it does mix.)

The second set of terms used to describe lipid and water interactions are the terms hydrophobic and hydrophilic. Recall from Lesson 3 when we discussed carbohydrates. We said that hydro– is the root word for water. In this case, we have the term hydrophobic. Phobic or phobia means fearing. You may be familiar with the term arachnophobia which means fear of spiders. Hydrophobic, therefore, literally mean water-fearing. Lipids are hydrophobic: they fear (or, maybe more accurately, repel or do not mix with water). On the other hand, substances that mix with water, like the pancake syrup referred to above, are considered to be hydrophilic. Again, hydro– refers to water while –philic translates to loving: water-loving! Pancake syrup or anything else that dissolves or mixes well with water is hydrophilic.

Hydro = water

Phobic = resisting or fearing

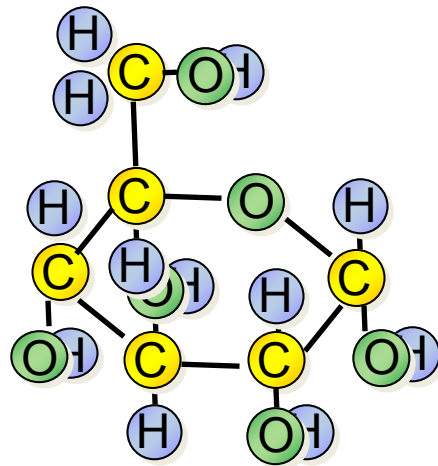
Philic = attracting or loving

Water soluble = miscible = hydrophilic

Water insoluble = immiscible = hydrophobic

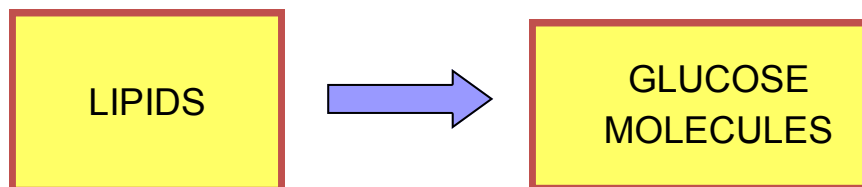
In this lesson so far, we've explored the structure of lipids and how they behave with other substances (mainly water) and how that's important to living organisms. There is another concept regarding lipids that is very important when it comes to living organisms.

Take a look at a major similarity between the structure of a lipid and the structure of glucose. Both glucose and lipids are composed of the same elements: carbon, hydrogen and oxygen. Recall that the chemical formula for glucose was $C_6H_{12}O_6$.

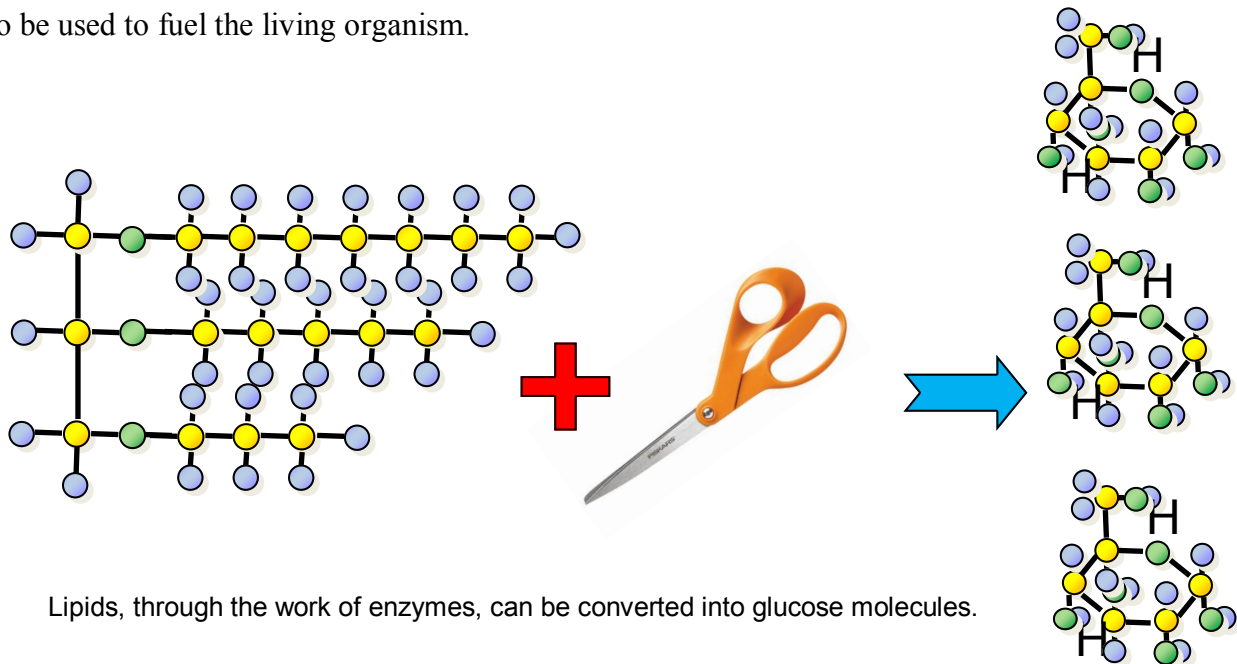


The glucose molecule: $C_6H_{12}O_6$.

Recall, also, that glucose is the “gasoline” on which our bodies run. Lipids, if “cut into pieces” can be “turned into” glucose molecules! Think about all the carbon, oxygen and hydrogen atoms present in one lipid molecule! You can imagine quite a number of glucose molecules which can be generated from one lipid molecule. In essence, lipid molecules work like storage locations or stockpiles of the elements necessary to make glucose when conditions require the living thing do so. When glucose supplies get low in a living organism, lipid molecules are taken out of storage and converted into glucose.



This “cutting-up” of lipid molecules is accomplished by enzymes in living organisms. Can you think of the name given to enzymes which “cut-up” lipids? Recall from Lesson 3 where we first introduced enzymes, that we said that enzymes have two primary functions: matchmakers or “cutters” of other compounds in the living organism. We also learned that enzyme names usually ended in –ase. Therefore, an enzyme which breaks down lipid molecules is called...can you guess it? Yes, a lipase enzyme. There are many types of lipase enzymes which together accomplish the task of breaking down the complex lipid molecules and transforming them into glucose molecules to be used to fuel the living organism.



An interesting “tidbit” of information regarding the amount of stored-up energy inside lipid molecules is the fact that fats hold about nine times the potential amount of energy found in glucose. In other words, if you compared a cup of glucose to a cup of a fat, the fat would have the potential to produce about nine times the amount of energy as that of the cup of glucose. This explains why animals that live in cold, Artic areas can survive for long periods of time utilizing their stores of fat on their bodies! Lipids work like storage locations for vast amounts of potential energy.



The energy stored in one cup of a lipid is roughly equal to NINE cups of glucose!

Lesson 4 Lab Activity 2: Making Butter

Let's do a fun lab activity next: making butter! The purpose of this lab will be to make some butter, obviously, but in the process you will be able to observe first-hand how lipids are hydrophobic. This hydrophobia, in the case of preparing butter, is very useful in the process. Let's begin.

Items to gather:



- Clean pint jar with lid.
- Heavy whipping cream (this works better than table cream). A pint is enough for one student. (Note that this is whipping cream, not whipped topping or the aerosol squirt topping.)
- Table spoon or wooden spoon.
- Source of running water.



Procedure:

1. Pour 1 pint of heavy whipping cream into the clean jar. Tightly screw on the lid.
2. Gently shake. Gently agitate. Gently rock back and forth. Continue doing so for several minutes. After a few minutes, you may sense that the whipping cream is no longer a liquid. It doesn't seem to splash around inside the jar as it once did. Carefully open the jar and take a peek inside. At this point the cream is more like whipped cream. It's not butter yet! Replace the lid on the jar and continue shaking.
3. After 15-20 minutes of shaking, suddenly you'll feel another change in the liquid inside the jar. If you look through the side of the jar, you'll see a lump of butter bouncing back and forth within the watery buttermilk. Continue to agitate the butter 1-2 more minutes. If you've been agitating your cream longer than 20 minutes with no sign of butter forming, sometimes the heat of your hand delays the butter formation. Try running cold water over the jar for a few minutes and then shake some more. Usually, the butter will readily form.
4. After you see your lump of butter in the jar, carefully open the lid and observe. The butter is fat which has clumped together to form one large "glob." The buttermilk surrounding the butter is the water that was once part of the cream.

Friendly Biology

Let's pause here and discuss some things about milk and cream and cows. Cows, like all mammals, produce milk for their offspring. Because milk provides all of the nutrition for the baby mammal, it includes a beautiful assortment of carbohydrates (remember the lactose we discussed in Lesson 3), proteins, vitamins, minerals *and fats!* As the cow is milked, all of these milk components are evenly dispersed in the milk. If the freshly milked milk is allowed to sit undisturbed, the fat portion will rise to the surface of the milk as cream. (Think back to the water and oil lab activity we completed earlier in this lesson.) If all of the cream that rises to the top is skimmed-off, the milk that remains is called skim milk. The fat content of skim milk is 0% (all of the fat has been removed.)



Milk straight from the cow can range in fat content from 3-6%.

You may be familiar with 1%, 2% and whole milk that you buy at the grocery store. Each of these percentages reflects the amount of fat in the milk. Milk straight from the cow ranges from 3-6%, with Holstein cows giving milk at 3-4% fat and Jersey cows giving milk at 5-6% fat. Within these breeds, the amount of fat produced by individual cows also varies. In other words, some Holstein cows may produce milkfat at the 4-5% level while other Holstein cows may produce milkfat at the 3-4% level.

At the milk processing plant, *all* of the fat (cream) is separated from the milk by machines. If you or your parents or grandparents grew up on a farm, you may be familiar with machines called cream separators. Cream separators were used on the farm to separate the cream from the fresh milk before the milk was sold to the milk plant. The cream could then be sold or used to make butter. Before cream separators were invented, farmers simply allowed the milk to set overnight to allow the cream to rise to the top. It was then skimmed off using ladles.

Once the cream is removed from the milk, then, according to needs of the customers of the dairy plant, the fat is returned to the milk at the specified levels of 1%, 2% or whole milk which is usually 3% fat. And then, of course, you can buy skim milk with 0% fat. In this way, you can be assured the milk you purchase at the grocery store has a consistent amount of fat present.



The milk you buy at the grocery store varies in how much fat is in the milk. Whole milk is 3%. You can also purchase, depending upon where you live, 2%, 1% and 0% or skim milk.

You might wonder why milk (other than skim milk) you buy from the grocery store does not separate with the fat rising to the top once again. At the processing plant, not only is the fat put back into the milk at specified levels, the milk is also homogenized. The prefix homo– means the same and the meaning of the root word –genize (from genesis) is to make or generate. Homogenization means to make the milk the same throughout and in this case, the fat is evenly dispersed throughout in the watery portion of the milk. The fat is made into very tiny droplets which remain suspended in the milk and do not separate. Homogenization results in a milk product where the fat no longer separates from the watery portion of the milk.

Homo = same

Genize (genesis) = to make or create, generate

Homogenize = to make the same throughout

The heavy whipping cream that you began your butter with is usually produced at 36% fat. So even though it has quite a bit more fat in it compared to whole milk (3%), it still has a good bit of water present. So, as the fatty components within the milk clumped together to form the butter in your jar, the liquid portion that remained is this watery portion of the milk. This watery portion is known as buttermilk.

Before you can eat your butter, your next job will be to “wash” your butter. You may be wondering, “How do I *wash* butter?” Washing your butter means you need to wash away all of the buttermilk. By removing the buttermilk your butter will remain fresher for a longer period of time and not spoil as quickly.

5. Because the buttermilk is water soluble, you can use water to wash it away. To wash your butter, first drain-off the buttermilk. Open the lid to your jar and then carefully pour-off the liquid portion of the milk. Use the lid of the jar to keep the butter from also pouring out.

Then add fresh cold water to your butter in your jar and, using your spoon, smash your “ball” of butter over and over again to push out any remaining milk. The water will get cloudy as the buttermilk leaves the butter and moves into it. Pour off this “dirty” water and add more fresh water. Be careful not to let your butter escape your jar. Add more cold water and smash the butter again to remove more milk. Pour off and repeat the process until the water you pour off is crystal clear. Pour off any remaining water and you can now taste your butter. You may add a sprinkle of salt if you desire. A slice of bread or soda cracker is a great tool for testing your butter. Enjoy your fresh butter!

As we end this lesson, let’s recall what we’ve learned about lipids:

- Lipids are composed primarily of carbon, hydrogen and oxygen atoms.
- There are two main portions of lipid molecules: the glycerol portion and the fatty acid portion.
- The glycerol portion consists of three carbon atoms each with an attached oxygen atom and the necessary hydrogen atoms to make carbon’s desired four bonds.
- Fatty acids are chains of carbon atoms ranging from 4 to 24 carbons in length which can potentially attach to the oxygen atoms of the glycerol portion of the lipid molecule.
- The lipid is classified as being a monoglyceride, diglyceride or triglyceride depending upon the number of fatty acid chains present in the lipid.
- Saturated fatty acids are solids at room temperature and originate from animal sources. Examples include bacon or meat fats.
- Unsaturated fatty acids are liquids at room temperature and originate from plant sources. Examples include corn, soybean or palm oils.

Friendly Biology

- Because lipids are made from many, many carbon, hydrogen and oxygen atoms, they are used in living things like stock-piles of raw materials to be converted into glucose, the fuel for living things.
- Lipids are broken down by enzymes known as lipases.
- Lipids are insoluble in water. We can also say that lipids are immiscible in water and are hydrophobic. Substances which are soluble in water are said to be miscible or hydrophilic.
- Milk produced from cows varies in fat content. At milk processing plants, all milk fat is removed from milk and then reintroduced at specified levels. Milk with no fat reintroduced is called skim milk. The fat portion of milk is what is used to make butter.