Activity 6

Changing the Fat: Does Unsaturation Make a Difference?

What Do You Think?
Health and nutrition reports often talk about eating “good” fats and avoiding “bad” fats.

What is a “good” fat and what is a “bad” fat?
Record your ideas about this question in your Active Chemistry log. Be prepared to discuss your responses with your small group and the class.

Investigate
There is another feature of carbon chains that can be varied: degree or amount of unsaturation. Unsaturation is a measure of the number of multiple (double or triple) bonds in a molecule. In Part A of this activity, you will use a model to predict the melting point of three fatty acids with the same number of carbons but with different degrees of unsaturation. Then you’ll determine the melting temperatures of the three fatty acids and see how well your predictions worked. In Part B, you will examine the behaviors of four soaps made from fats with four different degrees of unsaturation.You can combine what you conclude in this activity with what you learned from the previous one to design a soap that has a variety of properties.
Part A: Effects of Varying the Degree of Unsaturation in a Hydrocarbon

1. You will compare the melting points of three fatty acids shown above. These fatty acids are the primary carbon-chain components of the major ingredients in the three soaps you already made. Once you know more about how these three fatty acids differ, you can explain why the properties of the three soaps differ.

Look at the structural formulas of each molecule. How are these molecules similar? How are they different?

2. Atoms can twist around single bonds. However, when there is a double bond in a molecule, atoms that are around it are locked in place because they can't twist or rotate around a double bond. Double bonds also give rise to specific atom-to-atom bond angles. In a carbon chain with a double bond between two carbons in the middle of the chain (as in oleic acid), there are two ways the double bond can be arranged as shown below.
The *trans* double bond arrangement allows for the zig-zag shape shown. A *cis* double bond has a different three-dimensional arrangement of atoms, also shown. The double bonds in naturally occurring fatty acids are nearly always in *cis* arrangements.

When molecules are in the solid state, even though they can twist a bit around their C—C single bonds, they mostly stretch out into long straight zig-zag shapes wherever possible. This means that for solid stearic acid, the molecules can be modeled as long sticks. For oleic acid (with one double bond), the molecules can be modeled as bent sticks, like the shape of a boomerang. And for linoleic acid (with two double bonds), the molecules can be modeled as zig-zag shapes with two bends, like a picture of a lightning bolt.

3. To model how molecules are arranged in the solid state in these three fatty acids, you will create models out of paper clips. Take about 60 paper clips in total. Stretch each paper clip by unfolding it and making it as straight as possible. Set aside 20 of the straight paper clips to serve as stearic acid molecule models. Take another 20 and make a single bend in the middle of each one, at about a 120° angle, to represent oleic acid molecules. With the remaining 20, make two bends, at about 120° angles, to represent linoleic acid molecules.

a) Draw the shapes of the three molecules in the table you created in Step 1.

4. To get a picture of the arrangement of molecules when stearic acid molecules are in the solid state, take the stearic acid paper clip molecules and set them all in a paper clip box. Close the cover of the box, and then shake the box gently a few times. Open the box. How are the molecules arranged?

a) Make a drawing of the arrangement of the molecules in your *Active Chemistry* log, and label the drawing “stearic acid (solid).”

b) Repeat the procedure for oleic-acid paper clip molecules. Label the drawing in your *Active Chemistry* log, “oleic acid (solid).”

c) Do the same for the linoleic acid model. How is this arrangement different than the other two? Label this drawing, “linoleic acid (solid)” in your *Active Chemistry* log.
5. All three of these fatty acids have the same numbers of carbons. They do differ in their melting points (which you will measure shortly), but it is not due to having different chain lengths, as in the previous activity. Use what you learned about dispersion forces (van der Waals attractions) in the previous activity, and the drawings you just made, to make a prediction about which fatty acid will have the lowest melting point and which will have the highest.

   a) Write down your prediction in your Active Chemistry log, and explain how you arrived at it.

6. In the previous activity, you already measured the melting temperature of stearic acid. Now you will repeat that measurement technique and measure the melting points of oleic acid and linoleic acid.

   a) Record that melting temperature of stearic acid in a table.

   b) Both oleic acid and linoleic acid exist as liquids at room temperature. What does this already tell you about their melting points?

7. In preparation for measuring the melting points, you will need to have temperatures that go below 0°C. In a large plastic cup, make an ice-saltwater slurry. First, place crushed ice in the cup. Then, add salt to the crushed ice. Add a tiny amount of water, only enough to make it possible to stir the slurry. Use a spoon to stir the slurry until the salt is well mixed in. Place a thermometer in the slurry. What is the temperature? If the temperature is not below –10°C, add more salt and stir, until the temperature reaches –10°C.

8. Take the thermometer out of the slurry and gently wash it. Label the two test tubes: “oleic acid” and “linoleic acid.” Add some oleic acid to the oleic acid test tube, and add some linoleic acid to its test tube. Do not fill the test tubes more than a quarter of the way. Carefully place a thermometer in each test tube, making sure not to puncture the bottoms of the test tubes. Set the test tubes in the cold slurry. Observe the test tubes for the first crystals.

   a) Record the freezing/melting points for the two acids.

   b) Compare your data with the rest of the class. Compare your data with your predictions. Did you predict the order of the melting points correctly? Write down some conclusions in your Active Chemistry log.

9. Dispose of the materials as directed by your teacher. Clean up your workstation.
Part B: Comparing Soaps Made with Four Fatty Acids of Differing Numbers of Double Bonds

You will now compare the properties of the four soaps made from four naturally occurring fats. You will try to relate trends in the properties of the four soaps to the number of double bonds in their soap-molecule carbon chains.

1. Obtain small amounts of the four soaps you made a month or so ago. Observe the physical properties of the four soaps.
   a) Make a data table in your *Active Chemistry* log with four columns:
      - Beef tallow soap (stearic acid soap, no double bonds)
      - Olive oil soap (oleic acid soap, one double bond)
      - Safflower/sunflower oil soap (linoleic acid soap, two double bonds)
      - Linseed oil soap (linolenic acid soap, three double bonds)
   b) Record your observations.

2. Return to your *Active Chemistry* log notes from *Activity 1*. Use the procedure you developed in that activity to compare quantitatively the effectiveness of the four soaps.
   a) Record your results.
   b) What relation or relations exist between the properties of the four soaps and the number of double bonds (zero, one, two, or three)? Write down your conclusions.

Part C: Putting Together Chain-Length and Double-Bonding Data

You have now investigated two different ways of modifying the non-polar part of a soap molecule. Since there are two different modifications you can do, you can also work with combinations of these differences.

1. Copy the following table into your *Active Chemistry* log. Organize your observations of the behaviors of soaps made of different chain lengths and numbers of double bonds into the table.

<table>
<thead>
<tr>
<th>Length of carbon chain</th>
<th>Number of double bonds</th>
<th>Increased lathering</th>
<th>Property 2</th>
<th>Property 3</th>
<th>Property 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zero</td>
<td>One</td>
<td>Two</td>
<td>Three</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>beef tallow</td>
<td>olive oil</td>
<td>safflower oil</td>
<td>sunflower oil</td>
<td>linseed oil</td>
</tr>
<tr>
<td>16</td>
<td>palm oil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased soap hardness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Property 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Property 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For example, you investigated the effect of soaps with different chain lengths (C12, C16, and C18) on how much the soaps lathered. Indicate in the table the direction that the lathering increased. Draw an arrow pointing up if the longest carbon chain produced the most lathering. Draw an arrow pointing down if the longest carbon chain produced the least lathering.

An opportunity is also provided to investigate the effect of the number of double bonds on the soap’s hardness. Use an arrow pointing left or right to show the results of your investigation. Organize all your other observations from the previous activity and from this one in the same table.

SATURATED AND UNSATURATED FATS

Animal and Vegetable Fats and What They Contain

All fats have sizable numbers of carbon chains that often contain double bonds (unsaturated fats). These fats vary a great deal. Beef tallow and lard have many more fats with chains that look like stearic acid (all C–C single bonds). A month or so ago, you also used three other fats to make soaps. Olive oil is made mostly of fats with chains that look like oleic acid (one C=C double bond). Safflower and sunflower oils are made mostly of fats with chains that look like linoleic acid (two C=C double bonds). And linseed oil is made mostly of fats with chains that look like linolenic acid (three C=C double bonds.) You probably have an idea now of where some of the fatty acids get their names. No animal or vegetable fat is purely one kind of fat. And no soap made from animal or vegetable fats can be purely one kind of soap molecule. While the fats used to make...
the soaps you experimented with were mostly made of one kind of fatty acid each, there were other fatty acids present in them as well. Since it is not possible to obtain a naturally occurring fat that is made entirely of one kind of fatty acid, you experimented with pure fatty acids first, in order to understand the effects on the properties of soaps due to the features of the different fatty acids.

**Two Classes of Fatty Acids**

Fatty acids are grouped into two classes, saturated and unsaturated. Saturated means that none of the carbon atoms form double or triple bonds with other carbon atoms. Unsaturated molecules contain carbon-carbon double bonds and/or triple bonds. Hydrogen atoms can be added to the carbon-carbon double bonds and triple bonds of unsaturated molecules to make less unsaturated or fully saturated molecules. Here are examples of saturated and unsaturated versions of a five-carbon molecule.

Saturated fatty acids come primarily from animal products like meat and dairy products. Unsaturated fatty acids come primarily from plants and are usually vegetable oils: peanut oil, safflower oil, corn oil, soybean oil, sesame oil, and sunflower oil.

Hydrogen atoms can be easily added to a double bond to change an unsaturated compound into a saturated compound. This process is called hydrogenation and requires a platinum catalyst. At any double bond, the weaker of the two bonds can be broken, allowing a hydrogen atom to be attached to each of the two carbons.

\[
\text{CH}_3\text{CH} &= \text{CHCH}_2\text{CH}_3 + \text{H}_2(g) \overset{Pt}{\rightarrow} \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3
\]

Hydrogenation is used commercially to manufacture saturated fats for cooking that are more stable to heat and oxidation. However, they are more difficult to digest. The reverse process of making an unsaturated compound from a saturated one is far more difficult.
Some fats are **mono-unsaturated**, meaning that carbon chains have only one double bond (like olive and canola oils, as well as some fish oils), and others are **poly-unsaturated**, meaning carbon chains have more than one double bond (like corn or soybean oils).

Keep in mind the distinction between unsaturated **fatty acids** and unsaturated **fats**. Unsaturated fatty acids clearly possess one or more double bonds. Unsaturated fats (which contain three fatty acid chains) can possess chains that are both unsaturated and saturated, and can still be called unsaturated. That is, you might encounter a fat that has one unsaturated chain and two saturated chains and it will still fall into the category of unsaturated fats.

**Unsaturated and Saturated Fats and Diet**

You have probably heard the terms unsaturated and saturated fats in discussions of food and nutrition. Saturated fats have been linked to cardiovascular diseases. Arterial plaque is a complex mixture of substances that clogs up the passageways through which blood flows. High levels of saturated fat in a diet is correlated to high cholesterol levels. In turn, high cholesterol levels are linked to the amount of plaque in the blood. That is why saturated fats are called “bad” fats. It turns out that the mono-unsaturated fats are considered to be the most healthy, although it’s not well understood why.

In their pure form, one of the ways in which saturated fats differ from unsaturated fats is in the temperature at which they change from liquid to solid. Saturated fats are usually solids at room temperature (although sometimes barely, as in the case of butter). Unsaturated fats are usually liquids at room temperature. This is because the double bonds in unsaturated fats cause “kinks” in the carbon chains that interfere with their packing closely together as their temperature drops. Remember that if molecules are packed more closely together, the attractive dispersion forces (van der Waals interactions) are stronger, so it takes more energy to separate the molecules in the solid state. Another way of thinking of this is that to be a solid, the molecules have to pack...
themselves closely enough so that attractive dispersion forces (van der Waals interactions) can hold them together. Saturated fats, lacking these “kinks,” pack together easily as they are cooled, and remain solids at higher temperatures. Unsaturated fats must be cooled to lower temperatures before they pack together tightly enough to become solid. This changes the feel of these fats. Saturated fats feel greasy, while unsaturated fats feel oily.

Within these two large categories, saturated and unsaturated, fatty acids also differ from each other in the lengths of their carbon chains. Some are long, some are short, and some are intermediate. The lengths of the carbon chains also affect the properties of the soap. To design a soap, you have to take both of these factors (chain length and amount of unsaturation) into account.

Checking Up

1. What is the difference between a saturated and an unsaturated fatty acid?
2. What would you call an unsaturated fat that has three carbon-carbon double bonds?
3. A vegetable oil would contain mostly what kind of fats?

What Do You Think Now?

At the beginning of the activity you were asked:

- What is a “good” fat and what is a “bad” fat?

Now that you have investigated saturated and unsaturated fats, in what category would you place saturated fats? Why?
Reflecting on the Activity and the Challenge

The amount of unsaturation that a fatty acid molecule contains is another feature that determines the properties of the soap it will make. *Cis*-double bonds in fatty acids keep them from packing together as tightly and therefore decrease their melting points. In soap, *cis*-double bonds make the soap softer; the hardest soaps have more saturated fatty acid salts. Now you have a sense of how to line up the properties of a soap, based on the fats you chose to use in the recipe. In the table at the end of this activity are listed most of the fats that you can obtain in stores. Consider what fat or fats you would like to use in your recipe to give your soap particular important properties.
1. Identify the following hydrocarbons as saturated or unsaturated.

a) \[\text{H}_2\text{C} = \text{CH} - \text{CH}_2 - \text{CH}_2 - \text{CH} = \text{CH} - \text{CH} - \text{CH}_3\]

b) \[\text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3\]

c) \[\text{H}_2\text{C} = \text{CH} - \text{CH}_3\]

d) \[\text{H}_3\text{C} - \text{CH}_3\]

e) \[\text{H}_2\text{C} \equiv \text{CH}\]

f) \[\text{CH}_2 - \text{CH} = \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_3\]

2. Answer the following questions based on the three molecular structures shown below.

\[\text{H}_2\text{C} = \text{CH} - \text{CH}_3\]

\[\text{H}_2\text{C} = \text{CH}_2\]

\[\text{CH}_3 - \text{CH} = \text{CH}_2 - \text{CH}_2 - \text{CH}_3\]

a) Arrange the molecules (1–3) above in order from lowest melting temperature to highest melting temperature.

b) Which of these hydrocarbons would solidify first if you placed a little of each one in its own container and placed all the containers in a very cold place? Explain.

3. When testing the properties, you observed differences in the four soaps. One difference was how hard the soaps were. Given what you learned about the properties of the fatty acids you tested in Part A of this activity, explain why the hardness of a soap depends on the degree of unsaturation (the number of double bonds) of the soap molecules.
4. The following hydrocarbons all have ten carbons in them. The chains are all liquids at room temperature and have melting points below room temperature. (Decane is a component of gasoline.) Naphthalene (moth balls) is a solid at room temperature. Based on what you know about the interactions between molecules in the solid state, explain why the melting points are in the order shown.

<table>
<thead>
<tr>
<th>Chemical structure</th>
<th>Chemical name</th>
<th>Melting point</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Decane" /></td>
<td>decane</td>
<td>−30°C</td>
</tr>
<tr>
<td><img src="image" alt="Naphthalene" /></td>
<td>naphthalene (molecule has a flat shape due to double bonds)</td>
<td>81°C</td>
</tr>
<tr>
<td><img src="image" alt="cis-5-decene" /></td>
<td>cis-5-decene</td>
<td>−112°C</td>
</tr>
<tr>
<td><img src="image" alt="trans-5-decene" /></td>
<td>trans-5-decene</td>
<td>−73°C</td>
</tr>
</tbody>
</table>

5. Palm kernel oil has the same amount of lauric acid as coconut oil, but it also has a significant amount of oleic acid. What would you expect a soap made from palm kernel oil to do that a soap made from coconut oil would not do?

6. Cocoa butter is nearly equal portions of palmitic, oleic, and stearic acids. Based on what you know from the last activity and this one, what properties might you expect a soap made from cocoa butter to have?
7. Corn oil is almost entirely oleic and linoleic acids. Based on what you know from the last activity and this one, what properties might you expect a soap made from corn oil to have?

8. Which one of the following fatty acids is most likely to be found in greater amounts in an animal fat?

   a) cis-oleic acid  
   b) linoleic acid  
   c) palmitic acid  
   d) trans-oleic acid

9. **Preparing for the Chapter Challenge**

    As part of the *Chapter Challenge*, you’ll need to explain why you chose the ingredients you did to give your soap the properties you desire. Now that you’ve completed two studies of how the two features of fats (chain length and degree of unsaturation) affect the properties of a soap, and you have a table organizing fats according to the number of C=C double bonds and chain length, you can make some predictions about which fats (or combination of fats) might give your soap the properties you desire. In your *Active Chemistry* log, make a prioritized list of properties you desire your soap to have. Decide which properties can be controlled by the features of fats that you have control over. Then, for each property of the soap you wish to design, predict which fat (or combination of fats) would give the soap the desired property. Write down some possible recipes based on these predictions.