The Solid Facts about Trans Fats

By Doris R. Kimbrough

You can transport yourself via transcontinental transportation. Even in transit, you can carry out transactions that are transparent, transitional, or transferable. But *trans* fat? What's that? Why should you care, and why are they being singled out for warnings and even bans?

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Today, food labels and advertising are hyping products with zero grams of trans fat. In fact, beginning January 2006, the U.S. Food and Drug Administration required food manufacturers to list the quantity of trans fats on nutritional labels. So, what makes a fat *trans*?

In order to understand what a "trans" fat is, we first have to understand what a "regular" fat is. Fats and oils are produced by plants and animals as a way to store energy. "Oil" usually refers to fats that are liquids at normal room temperature, while the term "fats" is commonly used for solids at normal room temperature.

All fats and oils have similar chemical structures. They all have a three-carbon glycerol backbone with long-chain fatty acids. The resulting compound resembles the capital letter, **E**, with super-long, and kind of wavy horizontal lines (Figure 1). When a long-chain fatty acid reacts to join with glycerol, a water molecule (H_2O) is subtracted in the process. Chemists call fats and oils triglycerides (tri-GLIH-ser-ides) or triglyceryl esters, tri = three and glyceride = glycerol backbone. The long-chain fatty acids typically range from 12 to 20 carbons in length.

Saturated Fats

Animals, particularly mammals, and some tropical plants typically produce **saturated fats**. Carbon atoms almost always have four bonds to other atoms. For the long chains that make up a saturated fat, all of the carbon-carbon bonds are *single* bonds, and each carbon is attached to two hydrogens, except for the last one, the chain ender, which gets three. Why call them *saturated*? That's because each carbon atom in a particular chain is bonded to the maximum number of hydrogen atoms possible. Thus, the carbon chains are saturated with hydrogen atoms.

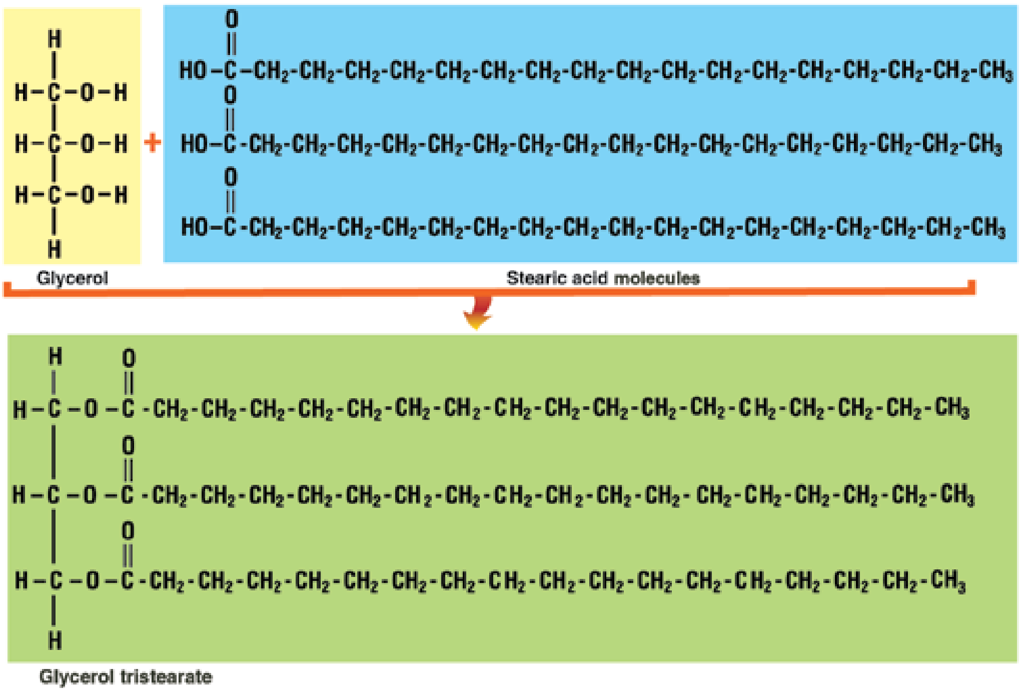

Figure 1. Glycerol and 3 fatty acids (stearic acid in this case) react to form a triglyceride molecule-glycerol tristearate.

Because all of the carbon chains are saturated, their overall three-dimensional geometry is like a long tube, even though the bonds are zigzagging, the space-filling model in Figure 2 shows that the overall physical arrangement of atoms is long and straight. These long straight chains allow the molecules to stack up like long bricks or logs in the walls of a log cabin.

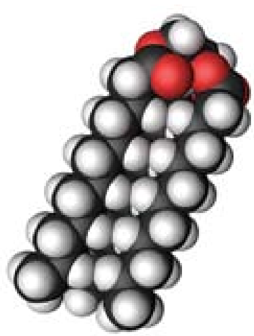

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Figure 2. Saturated fat molecules have an overall physical arrangement of atoms that is long and straight. Several saturated fat molecules can easily stack and align.

Saturated fats are typically solids at room temperature—think of butter, lard, beef tallow, and the white fat that you are supposed to cut off of a steak before you cook it. What makes them solid?

Fats are nonpolar hydrocarbons. Without attractive positive and negative poles found in molecules like water (H_2O), fats rely on weak intermolecular forces called van der Waals forces for their attraction to one another. The stronger these forces, the more the molecules will stick to each other and the harder the fat will be to melt. With their long $-CH_2-CH_2-CH_2-$ stackable chains, saturated fat molecules align nicely with their neighbors, packing together with lots of molecular surfaces in contact. With more molecular surface contact, van der Waals forces increase. The more the molecules attract one another, the more energy it takes to get them apart, and the melting point rises.

Health-wise, saturated fats are fine in small amounts, but if your diet is too high in saturated fats, you are more likely to experience a variety of health problems, including obesity, high blood pressure, heart disease, and some types of cancers. This is why health care professionals advise us to eat a diet that is low in saturated fats.

Unsaturated fat

Plants and some fish make **unsaturated** fats. Unsaturated fats have the same overall triglyceride structure, but the long chain fatty acids have occasional carbon-carbon *double* bonds, rather than all single bonds. Recall that carbon atoms usually have four bonds; so a double bond means that two carbon atoms are bonded to each other twice. The double bond uses up two of the four bonds that each carbon is allowed, meaning each of these carbons has one bond to the chain and only one hydrogen atom attached instead of the usual two (see Figure 3). Thus, the carbon chain is not saturated with hydrogen atoms. It is *unsaturated*.

If each chain has one double bond, the fat is **monounsaturated**. If each chain has more than one double bond, we call it **polyunsaturated**. Overall, unsaturated fats are healthier choices than saturated fats. In fact, the latest studies show that the *type* of fat you eat directly affects your health. Today, food manufacturers advertise their products as "heart healthy" by emphasizing unsaturated fats in their foods. But all fats pack a lot of calories. Don't think you can eat only French fries and ice cream and stay healthy!

CIS and Trans

In naturally occurring unsaturated fats, the double bonds are *cis* double bonds. *Cis* comes from Latin and means "on this side." This means that both hydrogen atoms are on the same side of the double bond, and both ends of the long carbon chains are on the same side (see Figure 4). The opposite of a *cis* double bond is one that is *trans*—also Latin, meaning "across." In a *trans* double bond the hydrogen atoms are on opposite sides of the double bond, and the chains are on opposite sides.

One very interesting feature about the *cis* double bonds found in unsaturated fats is that the chains with *cis* bonds are not three-dimensional long tubes like saturated fatty acids. The *cis* bonds create "kinks" in the chains, so the chains don't stack up in a nice well-behaved, orderly fashion like saturated

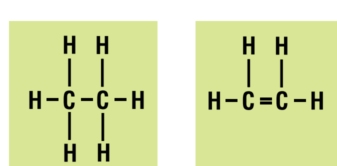

Figure 3. The molecule on the left shows all carbons are saturated (have the maximum # of hydrogen atoms). The molecule at right is unsaturated.

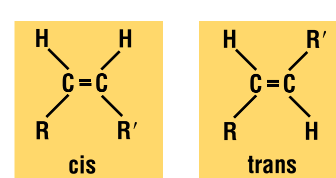

Figure 4. The molecule on the left is in the cis configuration–the hydrogen atoms are on the same side of the double bond. In the trans configuration both hydrogen are on opposite side of double bond.

fats (see Figure 5). With less attractive molecular surface in contact with neighboring molecules, these plant fats or oils are not solids, but rather are liquids at room temperature. Think corn oil, peanut oil, or olive oil.

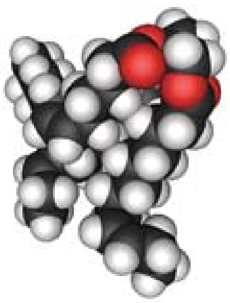

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Figure 5. Unsaturated fat molecules have kinks and shape irregularity due to th e double bonds present. They are less able to align and stack; intermolecular attractions are fewer and they remain under normal conditions.

The other feature of naturally occurring unsaturated fats is important from a food production and shelf-life standpoint. Fats with *cis* double bonds are more likely to react with the oxygen in the air (oxidation) than those with either *trans* double bonds or all single bonds (saturated fats). This is linked to the fact that *cis* fats are less stable and more reactive than *trans* fats or saturated fats. Oxidation of fats breaks the long chains into shorter chains to yield stinky and unpleasant-tasting products—in other words, *rancid*. No one wants to eat a rancid potato chip! Manufacturers are well aware of the problem.

On the one hand, companies understand the importance of positive health claims. On the other hand, if they use healthier natural unsaturated fats, they run the risk of having the product turn rancid before it finds its way into the vending machine or convenience store. So what is a manufacturer to do? To the rescue: *partial* hydrogenation! A process for hydrogenating vegetable oils was developed in Europe about 100 years ago. In 1911, the U.S. company, Proctor & Gamble first marketed the vegetable shortening, Crisco, which was composed predominantly of hydrogenated and partially hydrogenated cottonseed oil. Partial hydrogenation was also used to convert corn oils into margarine for a low-cost alternative to butter. First called “oleo,” margarine gained wide acceptance in this country during the two World Wars and the Great Depression. Let’s take a look at the hydrogenation process and see how it can turn a liquid plant oil into a semisolid like solid shortening or margarine.

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Partial hydrogenation

During hydrogenation, a *cis* fat is heated at high pressure in the presence of hydrogen gas, H_2 (g), and a metal catalyst, such as nickel. In the process, hydrogen is added across the double bond, one H atom to each carbon atom, and the carbon-carbon double bond becomes a single bond (see Figure 6). If all the double bonds are hydrogenated, the unsaturated fat becomes saturated. However, if only some of the double bonds are hydrogenated, the fat is described as “partially hydrogenated.” But another important thing happens to the double bonds in the partial hydrogenation process: The double bonds that are NOT hydrogenated are converted from *cis* to *trans*. Overall, the fat is still unsaturated, but now the double bonds are *trans* rather than *cis*. And that’s how a trans fat is born!

Manufacturers appreciated the fact that trans fats lasted longer on the shelves of stores and in our kitchens because the trans double bonds were less inclined to oxidize than the naturally occurring *cis* double bonds. Consumers liked the trans fat’s semisolid property, making it a convenient substitution for saturated fats in food preparation.

Until recently, partially hydrogenated fats were thought to be as healthy as the unsaturated fats they were made from. Indeed, as recently as the late 1980s, margarine was promoted as the healthy alternative to butter, and patients with heart disease or high cholesterol were put on diets that included margarine and other partially hydrogenated vegetable oils. Further study of how trans fats are recognized and metabolized by our bodies have shown this to be a misguided strategy at best. Although trans fats and saturated fats share several properties, research is showing that they behave differently as they are transported and metabolized in our bodies.

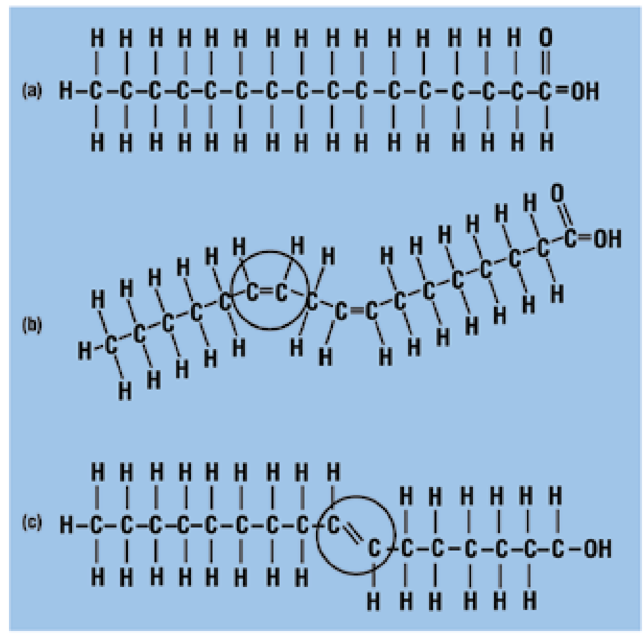

Figure 6. Molecule (a) represents a saturated fatty acid. All carbon atoms in the chain have the maximum number of hydrogens. Molecules (b) and (c) are unsaturated and represent *cis* and *trans* fatty acids respectively. *Cis* fatty acids are converted to *trans* fatty acids during the partial hydrogenation process.

The revised health concerns associated with the consumption of trans fats have led to bans in many communities and food industries, including several fast food companies. Even the popular shortening Crisco has been reformulated to contain less than 1 gram of trans fat per serving. Food scientists continue to research the dietary effects of trans fats on various diseases and health conditions, but one thing is clear: they are not the healthy alternatives once thought.

Long story short? Stick with the whole grains, fresh fruits, and veggies. And when it comes to fat, stick to “cis” and ban the “trans.”

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CHEMMATTERS

December 2007
Teacher's Guide

"The Solid Facts About Trans Fats"

Student Questions

The Solid Facts About Trans Fats

1. What is the function of fats and oils in plants and animals?
2. What is the difference between a fat and an oil?
3. Translate the word “triglyceride” in chemical terms.
4. What is meant by a saturated bond in a carbon-containing compound?
5. What is the difference between a saturated and an unsaturated bond in carbon-carbon bonding?
6. What is the difference between a monounsaturated fat and a polyunsaturated one?
7. What is the physical state (solid, liquid, gas) of a saturated fat? Of an unsaturated fat? For each type of fat, what is the source—plant or animal?
8. What happens to fat molecules that makes them rancid?
9. What is meant by the process called “hydrogenation”?
10. What is the difference, structurally, between an unsaturated fat that has undergone complete hydrogenation and one that is only partially hydrogenated?

Answers to Student Questions

The Solid Facts About Trans Fats

1. **What is the function of fats and oils in plants and animals?**
   Fats and oils are molecules for the storage of energy.
2. **What is the difference between a fat and an oil?**
   A fat is solid at room temperature and an oil is liquid.
3. **Translate the word "triglyceride" in chemical terms.**
   Tri- means three and refers to the three fatty acids that bond to one glycerol molecule (glyceride backbone) at each of three –OH groups on the glycerol molecule.
4. **What is meant by a saturated bond in a carbon-containing compound?**
   A saturated bond is one in which a carbon atom is bonded to the maximum number of hydrogen atoms possible, hence saturated. This means all the carbon-carbon bonds are single bonds.
5. **What is the difference between a saturated and an unsaturated bond in carbon-carbon bonding?**
   In carbon-to-carbon bonding, if there is but one single bond between the two carbon atoms, it is saturated. If there is a double bond between the two carbon atoms, then it is possible to add additional hydrogen atoms to each of the carbon atoms, which translates to the idea of unsaturated bonds.
6. **What is the difference between a monounsaturated fat and a polyunsaturated one?**
   In a monounsaturated fat, there is one unsaturated C-C bond. In a polyunsaturated fat, there are many unsaturated C-C bonds.
7. **At room temperature, what is the physical state (solid, liquid, gas) of a saturated fat? Of an unsaturated fat? For each type of fat, what is the source-plant or animal?**
   A saturated fat is a solid at room temperature and is found in animals. An unsaturated fat is a liquid and is found in plants.
8. **What changes occur in fat molecules that make them rancid?**
   Unsaturated fat molecules that are of the cis-form more easily react with oxygen in the air, which in turn causes them to break apart into smaller molecules, many of which have unpleasant smell and taste properties.
9. **What is meant by the process called "hydrogenation"?**
   "Hydrogenation" is the process whereby hydrogen atoms bond to unsaturated carbon atoms under high pressure and in the presence of a metal catalyst, such as nickel.
10. **What is the difference, structurally, between an unsaturated fat that has undergone complete hydrogenation and one that is only partially hydrogenated?**
    Complete hydrogenation means all unsaturated carbon bonds are saturated through the addition of hydrogen atoms. Partially hydrogenated molecules contain some unsaturated carbon bonds after other unsaturated bonds have taken on enough hydrogen to become saturated.

NSES Correlation

National Science Education Content Standard Addressed

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	**The Solid Facts about Trans Fats**
Science as Inquiry Standard A: and abilities to do scientific inquiry.	
Science as Inquiry Standard A: about scientific inquiry.	✔
Physical Science Standard B: of the structure and properties of matter.	✔
Physical Science Standard B: of chemical reactions.	✔
Physical Science Standard B: of interaction of energy & matter.	
Science and Technology Standard E: about science and technology.	✔
Science in Personal and Social Perspectives Standard F: of personal and community health.	✔
Science in Personal and Social Perspectives Standard F: about natural resources.	
Science in Personal and Social Perspectives Standard F: of environmental quality.	
Science in Personal and Social Perspectives Standard F: of natural and human-induced hazards.	✔
Science in Personal and Social Perspectives Standard F: of science and technology in local, national, and global challenges.	✔
History and Nature of Science Standard G: of science as a human endeavor.	
History and Nature of Science Standard G: of the nature of scientific knowledge.	
History and Nature of Science Standard G: of historical perspectives.	✔

Anticipation Guides

Anticipation guides help engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss their responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

Directions for all Anticipation Guides: In the first column, write "A" or "D" indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

The Solid Facts about Trans Fats

Me	Text	Statement
		1. Fats that are liquids at room temperatures are called oils.
		2. Unsaturated fats are produced by many animals, particularly mammals.
		3. Unsaturated fats have the maximum number of hydrogen atoms possible bound to carbon atoms.
		4. Fats contain only hydrogen and carbon.
		5.*Trans* fats have a longer shelf life than other types of fats.
		6. "Partially hydrogenated" fats are trans fats.

		7.*Trans* fats contain only single bonds.
		8. Margarine is healthier than butter.

Content Reading Guides

These matrices and organizers are provided to help students locate and analyze information from the articles. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the articles. The use of bullets helps them do this. If you use these reading strategies to evaluate student performance, you may want to develop a grading rubric such as the one below.

Score	Description	Evidence
4	Excellent	Complete; details provided; demonstrates deep understanding.
3	Good	Complete; few details provided; demonstrates some understanding.
2	Fair	Incomplete; few details provided; some misconceptions evident.
1	Poor	Very incomplete; no details provided; many misconceptions evident.
0	Not acceptable	So incomplete that no judgment can be made about student understanding

The Solid Facts about Trans Fats

Directions: Please complete each chart below, comparing and contrasting the fats listed. Write the differences in the rectangles to the left, and the similarities in the rectangle on the right.

Fats		**Similarities**
Oils		

Saturated fats		**Similarities**

Unsaturated Fats		

<table>
<tr><td>Cis Fats</td><td></td><td rowspan="2">Similarities</td></tr>
<tr><td>Trans Fats</td><td></td></tr>
</table>

The Solid Facts About Trans Fats

Background Information

More on Categories of Lipids

Lipids or fats can be grouped according to source, structure, and use. One scheme is as follows:

- Waxes are *esters of long-chain fatty acids and long chain alcohols.*
- Triglycerides are triesters of long-chain fatty acids and glycerol (a three carbon chain).
- Complex lipids comprise cell membranes. Complex lipids include two subgroups, phospholipids and glycolipids. Phospholipids are esters of phosphoric acid, utilizing long-chain fatty acids, glycerol and phosphoric acid. Glycolipids are lipid molecules that contain carbohydrates, usually simple sugars such as glucose and galactose
- Steroids are lipids found in plants and animals. Steroid molecules are derived from the same basic three ring (benzene) structure, phenanthrene, to which is attached a saturated five carbon ring, cyclopentane. The ring structures are saturated compared with the phenanthrene from which they are derived. Steroid molecules are formed from this nucleus by adding hydrocarbon chains, functional groups or introducing carbon-to-carbon double bonds into one or more of the cyclohexane rings. Steroid molecules that contain a hydroxyl group (-OH) and no carboxyl (-COOH) or aldehyde (-CHO) groups are called *sterols*. Cholesterol, a waxy solid, is a sterol found only in animals. Cholesterol provides rigidity to cell membranes (think also of plaques and increased rigidity in blood vessels due to deposits of cholesterol in the vessel walls).

More on Foods, Fats, and Health

Although the article is focusing on one type of fat relative to health issues, there is obviously a concern about the content of individual diets' effect on body weight, blood levels of such things as cholesterol (both high density and low density lipoprotein), and possible development of diabetes, particularly in younger people. Although fat is a major source of calories (kilocalories or large "C" calories), the concern is not only how much fat is in the diet but also the type of fat with regard to health issues, particularly related to long-term cardiovascular health. Looking at the categories of fat, one has to distinguish between saturated and unsaturated fats as well as the presence or absence of the *cis-* and *trans-* forms of unsaturated fats. A good source of basic information in the realm of nutrition and trans fats can be found at the website of the Food and Drug Administration (FDA), http://www.fda.gov/default.htm, http://www.cfsan.fda.gov/~dms/qatrans2.html#s4q3, and http://www.fda.gov/FDAC/features/2003/503_fats.html. This last URL gives lots of detailed information about major sources of trans fats for American adults as well as a chart listing the more common foods, their fat content (total fat, saturated fat, trans fat), cholesterol, and daily value (%) for saturated fats.

A second article that provides data on fat content of various common foods is found in the December, 1989 *ChemMatters* titled "Oil Changes", pp.7-9. Another *ChemMatters* article, "Fast Fats", is found in the February, 1990 issue, pp.13-15. Useful charts are provided that show the fat content of the more popular foods ordered at the fast food places such as Wendy's,

Burger King, and McDonald's. Another reference article on the basics of fats and health is found in the *ChemMatters* article, "Fats – Fitting Them Into a Healthy Diet", October, 2000, pp.6-8. Back issues of *ChemMatters* can be found on the CD, *ChemMatters*, Version 3.0 and can be purchased at
http://acswebapplications.acs.org/portaltools/shopper/productDetail.cfm?prod_cd=1-CMCD3.

The September, 2007 issue of *Scientific American* is a special issue on diet, health, and the food supply. Some of the topics include "Feast and Famine: the Global Paradox of Obesity and Malnutrition", which states that there are more people in developing countries who are overweight than hungry! The question is then raised as to how the poorest countries are going to fight obesity. It could be the starting point for a class discussion about obesity. Additional articles of interest include some of the more recent ideas about obesity and the role of the brain, in particular the hypothalamus, and feedback mechanisms involving a hormone-like chemical called leptin which, when released by fat tissue, can reduce appetite and energy expenditure once the leptin reaches the brain. Are there malfunctions of leptin production that contribute to the obese situation of some individuals?   Some of the articles are available at the *Scientific American* website, http://www.sciam.com/issue.cfm?issueDate=Sep-07. Other articles in that issue are available only through electronic subscription. Perhaps your library has the electronic subscription. Another reliable source of health information for understanding trans fats is found in the Mayo Clinic electronic health newsletter at www.mayoclinic.com/health/trans-fat/CL00032. The article of interest is titled *"Trans Fat: Avoid This Cholesterol Double Whammy".*

Another interesting aspect of obesity and secondary diabetes (that results from obesity in some people) is the existence of what is called the "slow gene" in the general population and certain groups in particular, such as Native Americans. This gene seems to be an inheritance from ancestors who in their time experienced very uncertain food supplies (particularly non-agrarian, hunter groups). Natural selection produced a gene that essentially reduced the rate of metabolism of food in order to "spread out" the availability of the digested food over a period of time during which there might not be additional food consumption. This gene remains in the DNA of some people today but complicates things because it continues to keep metabolism slower than for those without the gene. With more food available compared with the prehistoric times of hunting and gathering, people with the slow gene are essentially "stockpiling" the excess food not metabolized into usable energy. This stockpiling takes the form of converting unused calories into storage as fat.

On the commercial front, there is scientific response to the search for alternatives to trans fat-containing food. Archer Daniels Midland (ADM) company, along with Novozymes, have developed an enzymatic method to produce a line of zero- and reduced- trans fat oil used in food processing. The product line is called NovaLipids. In order to avoid the conversion of the *cis*- isomer to the *trans*- isomer of an unsaturated fat undergoing hydrogenation, the new process starts with fully hydrogenated oil, then "inter-esterifies" it with unhydrogenated oil. In the process, sodium methoxide (a catalyst) along with the enzyme, lipase, is used to cut and randomly exchange the positions of the three fatty chains of the various triglycerides in oils (p. 4, http://pubs.acs.org/cen/science/83/print/8326sci1.html). This inter-esterification avoids formation of the unwanted trans fats. Additional manufacturing procedures deal with eliminating some of the by-products that are not needed or wanted. The sodium methoxide is also used in another important application, the production of biodiesel fuel from plant oils. It is used to initiate transesterification in the biodiesel manufacturing process. One important consideration in its usage is that it must operate in a near-zero water environment. Otherwise, in the presence of water, the triglycerides present will react to form soap, an unwanted by-product.

Although the emphasis of this article is trans fats, there are two interesting topics that rely on the use of fats of the triglyceride type—soap /detergent production and the development of explosives! In the case of making soap, a chemical reaction in the category of esterification (synthesizing an ester) uses fatty acids (from animals) and the trihydroxy alcohol, glycerol, to form the ester. The ester is then broken apart in the presence of an alkali solution such as sodium or potassium hydroxide to form the salt of the fatty acid (and the by product of glycerol once again). The solid formed is the soap. This process is called "saponification". The root word is *"sapo"*, Latin for soap. The Italian word for soap is *sapone.* The choice of the alkali determines the "hardness" of the soap; sodium produces a harder soap, potassium a softer soap (as in liquid hand soaps). Soap production has a long history, perhaps second in time after the fermentation of grapes! Soap making has its origins in ancient Babylon around 2500-2800 BC. (see also http://inventors.about.com/library/inventors/blsoap.htm)

Students can make soap in the lab. Some may want to duplicate the process used by the early settlers to this country in which the alkali solution was made in crocks with wood ash soaking in water for several days. Several references to soap making, from the historical to the "do-it-yourself" include:

"Saponification is 'Clean' Chemistry",
http://www.chemistry.org/portal/a/c/s/1/printit.html?id=5db3b51ae2cd11d6f6b6ed9fe800100
"What is Saponification?"
http://www.realhandmadesoap.com/folders/FAQ/what_is_saponification.htm
"How Does Soap Clean?", from About.com: Chemistry at
http://chemistry.about.com/library/weekly/aa081301a.htm?p=1
This reference also includes additional links to topics related to soap including molecular structures.

A useful summary about soap synthesis with good molecular models (in color) is found at the Elmhurst College Chemistry Department website:
http://elmhcx9.elmhurst.edu/~chm/vchembook/554soap.html
There are various references to making soap in the lab or kitchen. One such reference on procedure is found at: http://www.chem.latech.edu/~deddy/chem122m/L06U00Soap122.htm

Lets turn now to a completely different story about the use of one fat component, glycerol. This time the trihydroxy alcohol when reacted with nitric acid (and sulfuric acid), rather than fatty acids as in soap synthesis, produces a compound in which each hydroxyl group (-OH) is replaced by $-NO_2$ to form nitroglycerine, an unstable and violent explosive. This substance was first discovered by the Italian chemist, Ascanio Sobrero (1812-1888). Because of the later use by Alfred Nobel of Sobrero's nitroglycerine for munitions manufacture, Sobrero was shocked and dismayed about its becoming a weapon of mass destruction (compared with earlier weapons!) and was ashamed to admit to being its discoverer. But Nobel went on to find ways to stabilize pure nitroglycerine (his brother and a number of coworkers were killed in the lab experimenting with the explosive). He eventually used a special Swedish clay called *kieselguhr* that changed the liquid nitroglycerine into a paste. This product, called *dynamite* could now be formed into stable rods of various sizes for inserting into drilling holes in quarrying or mining operations. In present day, dynamite used in the USA is composed of nitroglycerin, ammonium nitrate and sodium nitrate (two other explosives), wood pulp (replacing the clay) and a trace of calcium carbonate to neutralize traces of acids that might form in storage. In later years, after earning huge profits from the war machines, Nobel created the Nobel Prizes after reading his pre-mature obituary in which he was remembered only as the person who created death and destruction through his explosives. (Equations for the synthesis of nitroglycerin and background on Alfred Nobel can be found at :
http://www.ch.ic.ac.uk/rzepa/mim/environmental/html/nitroglyc_text.htm.

Connections to Chemistry Concepts

1. **Cis-trans isomers**—These occur in molecules of the same molecular formula but different geometric arrangements of groups attached next to each other; if across from each other, then it is a *trans* arrangement; if adjacent, then it is a *cis* form. (Note that this is only possible in structures that have groups like carbon-carbon double bonds which cannot rotate easily; different geometric arrangements in straight-chain compounds containing only carbon-carbon single bonds would not normally be isomers since they could interconvert by rapid rotation around the single bonds.) Because of these different isomeric structures, the molecules possess different physical and chemical properties. In the case of *cis* and *trans* fats, there are different properties due to the shape of the molecules ("bent" vs. "straight").
2. **Hydrogenation**—This is the process of adding hydrogen atoms (with a metal catalyst and high pressure) to a molecule with double or triple bonds reduces or eliminates these bonds, creating single bonds. The molecule has gone from an unsaturated to a saturated molecule. In the case of fats, that is usually not desirable in terms of health; unsaturated molecules are preferred.
3. **Catalyst**—These substances increase the rate of a reaction without themselves undergoing change (or are regenerated). The metal nickel is an important catalyst in the hydrogenation process for fats and oils.
4. **Oxidation**—Oxidation is a category of chemical reaction in which an element or compound loses electrons due to the presence of an oxidizing agent, such as oxygen, that is an electron acceptor. In the case of fats, this is the process whereby some fat molecules are broken up into smaller units, producing what is known as rancidity.
5. **Double bond**—Double bonds are chemical bonds in which two atoms share two pairs of electrons. In the case of double or triple bonds for organic molecules, the bond is considered unsaturated and additional atoms such as hydrogen can be added (bonded) producing a different molecule. The difference in such properties between saturated and unsaturated molecules is especially important for health reasons in the case of fats and oils.
6. **Saturated**—These molecules contain all single bonds between carbon atoms. They do not allow for additional bonds through the addition of an element such as hydrogen.
7. **Unsaturated**—Molecules of this type all contain carbon-carbon bonds that are double or triple bonds. These molecules can accept additional elements such as hydrogen, reducing the number of double or triple bonds. This process of accepting additional hydrogen atoms changes the physical characteristics of fats and oils.
8. **Monounsaturated**—These molecules contain only one double bond in the chain of carbon atoms.
9. **Polyunsaturated**—Molecules of this type contain multiple double or triple bonds in a carbon chain. The more unsaturated a fat, the healthier it is as a food product. It is also more likely to be a liquid rather than a solid at room temperature since the fat most likely has many *cis* double bonds which create bent molecules that cannot pack as closely as *trans* double bonds that tend to be tubular for stronger intermolecular forces because of closer packing.
10. **Triglycerides**—This is the name given to the ester formed between fatty acids (three or tri-) and glycerol, the tri-hydroxy alcohol. Triglycerides are the molecules of fats and oils.
11. **Fatty Acids**—These organic molecules are acids because of their functional group known as the carboxyl group, -COOH. It is this end of the acid molecule that reacts with the hydroxyl end(s) of an alcohol such as glycerol to form an ester such as a triglyceride or fat, depending on the length of the fatty acid.

1. **Polarity of molecules**—Polar molecules have regions where electrons are shared unequally between atoms, thus creating regions of excess negative or excess positive charge. These regions can interact with the complementarily charged regions of other polar molecules, which in turn can interact with other polar molecules. Non-polar molecules have symmetrical distribution of bonding electrons about any two nuclei within the molecule, hence no regions of

partial negative or positive “charge”. These two types of molecules determine, among other things, solubility between two or more different types of molecules. Fats, as very large carbon-based molecules, tend to be non-polar and will not mix in something like water that is polar. In order for mixing to happen, one has to introduce something called a “soap” that, as a large molecule, has both polar and non-polar ends. Since “like” dissolves “like”, the non-polar fat binds to the non-polar end of the soap molecule and the polar end of the soap bind to the polar water, hence “dissolving”. On the other hand, fats can dissolve in other non-polar solvents such as gasoline or carbon tetrachloride (used to be used in dry cleaning, dry meaning without water!).

Possible Student Misconceptions

1. **“You can eliminate cholesterol in the blood by not eating cholesterol-containing food”** *The body synthesizes cholesterol all the time because it is needed to form other chemical compounds needed by the body. So ingestion of food that is without cholesterol will not eliminate cholesterol in the body.*
2. **“Because fat is a storage form for food, it contains less energy per gram than carbohydrates in metabolism.”** *Actually, fat is the most concentrated form of energy compared with carbohydrates and proteins (the least). Fat provides 9 kcal of energy per gram and carbohydrates provide 4 kcal per gram.*

Demonstrations and Lessons

1. Students can Isolate fat from milk (see *ChemSource*, Food & Chemistry[FOOD] unit, Volume II, p. 15-21; http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education%5Ccurriculum%5Cteachres.html.
2. You can demonstrate the amount of water in regular, light and “extra light” margarines. See “Light Margarine, Paying More for Less”, an activity found on p.22-23 of the FOOD unit above in *ChemSource*.
3. You can demonstrate the solubility of oils (fats) in polar and non-polar solvent.
4. Synthesize soap from a fatty acid and glycerol (Esterification, Saponification).
5. Test chemical properties of soap—suds, dispersion, pH, “scum” production in hard and soft water, etc.
6. Have students read food labels for fats of every category (refer to the *Chemical Matters* article, “Oil changes”, Dec. 1989, pp 7-9; also “Fats, Fitting them into a Healthy Diet”, Oct., 2000, pp. 6; “Fast Fats”, Feb. 1990, pp. 13-15). What is listed? Any olestra? Hydrogenation?
7. Have students investigate the esterification process; make aromatic esters rather than soap. Use molecular models to illustrate the dehydration reaction.
8. Use molecular models to illustrate *cis-trans* arrangements; translate molecular formulas (partial structural formulas) into 3-D models.
9. Compare different organic alcohols in terms of viscosity (effect of size of molecule, number of –OH groups per molecule (mono-, di-, tri-hydroxy alcohols). Account for differences in terms of intermolecular bonds (hydrogen bonding)
10. Investigate weight and diet; fat vs. calories (what vs. how much); BMI (Body Mass Index) calculation as homework (not in class to protect student’s self-esteem); read food container labels of common foods that individuals eat to determine: type of food categories, specific fat categories, and % of daily totals ingested—“what vs. how much (calories)”.

Student Projects

1. Students can investigate all aspects of olive oil production; virgin vs. extra virgin.
2. See # 3,4,5,9 in Demos/Lessons above.
3. Students can design an experiment to determine the length of time for rancidity to begin with a variety of fat-containing foods such as nuts, butter products, margarine products (those with and without trans fats). What conditions delay onset of rancidity? (temperature, degree of exposure to air)
4. Students can investigate and compare the chemistry of soap and detergent synthesis.

Anticipating Student Questions

1. **"How can the fat food flavoring called Olestra not provide either calories or fat molecules for our body's use ?"** *Olestra is a fat substitute that tastes like a fat but is indigestible. It cannot be metabolized in the body because it is unable to be absorbed from the digestive system into the bloodstream to be carried to body cells to be metabolized (cellular "digestion"). Like real fat, olestra is synthesized from fatty acids of cottonseed or soybeans but uses sucrose rather than glycerol to form a type of "triglyceride" . The resultant molecule (an "ester") has as many as 6-8 fatty acids attached to the hydroxyl (–OH) groups of the sucrose which is more than the three of glycerol. The olestra molecule is a larger molecule than a triglyceride and is not digested by enzymes in the digestive system. Therefore it passes out of the intestines undigested and is unabsorbed because the molecule is too large to pass into the blood vessels (capillaries) of the digestive tract.*
2. **"If fats are insoluble in water, how is it possible for fat to be absorbed into the blood stream since blood is primarily water ?"** *Fats, either saturated or unsaturated, are made soluble in blood by first dissolving in the digestive tract through the use of a biological detergent called bile, which is produced in the liver and stored in the gall bladder. The mixing (emulsifying) of the detergent with the fats allows for the non-polar end of the detergent to interact with the non-polar end of the fat (the fatty acid end) while the polar end of the detergent bonds with the polar end of the fat (the glyceride ends) just as regular soaps and detergents would do when you wash greasy dishes with soap or detergent. Once the fat is emulsified in the digestive "juices", it can be broken apart by hydrolysis (water and enzymes) to yield water soluble fatty acids, glycerols, soaps or mono- and di-glycerides which are then small enough and soluble enough to pass through the intestinal wall into the blood stream, although it is not clear what form the digested fat takes in passing through the intestine. Lipids are found in the blood stream but are in the form of lipoproteins that are soluble. This is important because lipids are needed in various locations of the body including the liver and the brain.*
3. **"What is the difference between a soap and a detergent?"** *A soap and a detergent are similar in terms of their synthesis, each undergoing what is known as an ester-forming (esterification) reaction in which fatty acids bonds to the -OH (hydroxyl) group of a trihydroxy alcohol called a glycerol in the case of a soap. The fat so formed is reacted in an alkaline solution (sodium or potassium) to form a soap, which is the salt (sodium or potassium) of the original fatty acid. In the case of a detergent, a fat, oil or some other long-chain hydrocarbon reacts with some chemical such as an inorganic acid (sulfuric acid) or ethylene oxide in the presence of an alkali (sodium or potassium hydroxide as in soap). The detergent formed contains chemicals called surfactants which result from the addition of the alkali to the acid-derived molecule first formed in the "esterification reaction". It is these surfactants that,*

depending on their chemical composition, enable the detergent to operate in a variety of water conditions (such as hard water) compared with regular soap. See the following sites for more information: http://inventors.about.com/library/inventors/blsoap.htm and http://chemistry.about.com/gi/dynamic/offsite.htm?site=http://vm.cfsan.fda.gov/%7Edms/cos%2D215.html.

4. **"Aren't all fats bad?"** *There are both "good" and "bad" fats. Our bodies need fat for a variety of purposes, including synthesizing cell membrane structures, hormones, nerve tissue, and body insulation against temperature changes, among other things. Saturated fats and trans fats have bad effects on cholesterol levels (cholesterol is needed by our bodies but too much is not good), while polyunsaturated fats and monounsaturated fats have good effects on cholesterol levels.*
5. **"Cholesterol is a fat—how is it related to trans fats?"** *Cholesterol levels are affected by trans fats. There are two kinds of cholesterol, low density lipoprotein (LDL) which transports cholesterol throughout the body and high density lipoprotein (HDL) which picks up excess cholesterol in the blood and takes it back to the liver. High levels of LDL build up in the walls of the arteries, making them hard and narrow. Trans fats elevate LDL and reduce HDL rather than the reverse. It is thought that trans fats also elevate blood levels of triglycerides, which in high levels may create the same effects on the blood vessels as that from LDL. Trans fats may also increase the rate of inflammation by damaging the cells that line the blood vessels. Inflammation may contribute to formation of fatty blockage in heart blood vessels.*
6. **"How much fat (% of total daily calories) should be consumed per day?"** *Guidelines suggest that no more than 30% of your daily calories should come from fats of every kind. And only 7 % of the daily calorie total should come from saturated fats. Monounsaturated fats (from plant oils) along with what are known as omega-3 unsaturated fatty acids (from fish and nuts) should be the major source of fat-derived calories in the 30% total. The % of daily requirements (calories) that are provided by saturated and unsaturated fats in a specified portion of a particular food is found on the labels of food containers. You need to determine the number of calories required by your body which can be approximated by consulting reference charts in which your life style (demands) and physical size (height and weight) determine average caloric needs.*
7. **"If cholesterol is bad, should you avoid all cholesterol-containing food?"** *The body needs cholesterol for synthesizing a variety of cholesterol-based molecules, including steroidal compounds such as the sex hormones. The body synthesizes cholesterol. So, zero consumption of cholesterol in food will not eliminate cholesterol found in the blood stream. But the quantity of cholesterol or even trans fats ingested effects the total blood levels of cholesterol. So limiting cholesterol- and trans fat- containing foods is desirable.*

References

A reference that all teachers might consider for their professional library is the *Sourcebook* 2.1 from the ChemSource Project. It is available from the American Chemical Society at the following web address: http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education%5Ccurriculum%5Cteachres.html.

Websites for Additional Information

More sites on Soaps and Detergents

This site, http://inventors.about.com/library/inventors/blsoap.htm, gives a wonderful history about the commercial development of soaps, beginning back in the 19th C. Do you realize that liquid soap was first developed in 1865? And how did Ivory soap come to be the floating soap? Some of the soaps may not be familiar to students these days but again the history of their commercial development is interesting. For good illustrations, with equations and with color "3-D" models of important molecules in the synthesis of soap and the various types of detergents, refer to the following websites from Elmhurst College chemistry department:
http://elmhcx9.elmhurst.edu/~chm/vchembook/554soap.html and
http://elmhcx9.elmhurst.edu/~chm/vchembook/558detergent.html.

For a different and less technical discussion of soap and detergent synthesis and the chemistry behind the reactions, refer to
http://www.cleaning101.com/sdalatest/html/soapchemistry1.htm

More sites on Fats

For an interesting history of the development of margarine that began in the 19th C., refer to http://pubs.acs.org/cen/whatstuff/print/8233margarine.html. We tend to think of modern issues related to technology as having a recent history. But a lot of good commercial chemistry was happening more than a century ago, with and without health hazards identified later. But the identification of the hazards still depends on additional chemistry! The next two sites, again from the Elmhurst College chemistry department, nicely illustrate the hydrogenation process with molecular structures in color. These structures will make good overheads or LCD-projected illustrations for the classroom. The olestra molecule is very clearly a large molecule that, because of its size and geometry, resists chemical interaction with solvents and enzymes; hence it is excreted without being chemically "digested" to smaller molecules that can be absorbed into the blood stream.
http://elmhcx9.elmhurst.edu/~chm/vchembook/558hydrogenation.html (hydrogenation with good molecular structures in color)
http://elmhcx9.elmhurst.edu/~chm/vchembook/558olestra.html (molecular structure of olestra)

For discussion purposes and for student activities related to the frequency and amounts of various lipids in foods, the following websites provide handy references in chart form:
http://elmhcx9.elmhurst.edu/~chm/vchembook/550lipids.html This site shows an organizational chart for different classes of lipids.

http://elmhcx9.elmhurst.edu/~chm/vchembook/552triglycerides.html This site shows structural formulas in color of triglycerides and a chart to summarize % fatty acids in each.
http://elmhcx9.elmhurst.edu/~chm/vchembook/551fattyacids.html This site provides fatty acid structural formulas and charts showing the amount of saturated and unsaturated fatty acids, both from plant and animal sources in various common foods.

The Federal Government's FDA (Food and Drug Administration) has a very useful website that includes a section on how to read labels on food containers to determine the amount of fat content present (all categories). Refer to:
http://www.cfsan.fda.gov/~dms/transfat.html .

Another reference from the FDA that deals specifically with trans fats provides a series of questions that people might ask. In addition, there are charts listing a variety of common foods with the % trans fat present. Find it here: http://www.fda.gov/FDAC/features/2003/503_fats.html. Again, this might prove a useful reference for students who are into investigating the extent to which trans fats occur in a variety of food categories (including diet programs!).

In case there is a need to delve into the basics of bonding in organic molecules and to illustrate the specific molecules in the fatty acid and lipid categories, the following websites provide user-friendly illustrations for students and teachers alike.
http://www.accessexcellence.org/RC/VL/GG/chemBonds1.html (good basic diagrams of organic molecules with bonding illustrated)
http://www.accessexcellence.org/RC/VL/GG/fattyAcids1.html (more diagrams and structural formulas of fatty acids and lipids)
http://www.accessexcellence.org/RC/VL/GG/fattyAcids2.html (part II of diagrams and structural formulas of fatty acids and lipids)

Finally, for the student who has had biology, she might want to check out where lipids (as phospholipids) fit into the structure of the cell membrane. There are interesting chemical and structural issues with the cell membrane as a selectively permeable membrane—how do water soluble and partially soluble molecules pass across a membrane that contains lipid and non-lipid structural elements?
http://elmhcx9.elmhurst.edu/~chm/vchembook/553bilayer.html The site shows structural formulas of phospholipids and their position in cell membrane diagrams.