Fats and Oils 2.7

We are familiar with many different fats and oils produced by living systems for energy storage: corn oil and vegetable shortening from plants; butter from cows' milk; and lard from pork or beef fat (**Figure 1**). Fats are usually solid at ordinary room temperatures and oils are liquid; they both belong to a class of organic compounds called lipids that includes other substances such as steroids and waxes.

Chemically, fats and oils are **triglycerides**: esters formed between the alcohol glycerol and long-chained carboxylic acids called **fatty acids**. Glycerol is a 3-carbon alcohol with three hydroxyl groups (**Figure 2**). The three fatty acids that are attached to each molecule of glycerol may be identical (simple triglyceride) or may be different (mixed triglyceride); most fats and oils consist of mixed triglycerides.

Figure 1
In the aqueous environment of living cells, fats and oils usually exist as droplets. In some animals, they are stored in specialized fat cells called adipocytes (shown here). In many types of plants, such as corn, peanut, and olive, they are stored as oil droplets.

triglyceride an ester of three fatty acids and a glycerol molecule

fatty acid a long-chain carboxylic acid

Fatty Acids

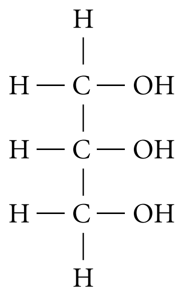
The hydrocarbon chains of fatty acids may be 4 to 36 carbons long (**Table 1**). These long carbon chains are generally unbranched, and may be saturated or unsaturated. Except for the carboxylic acid group, fatty acids are very similar to hydrocarbons, and burn as efficiently. When fatty acids are "burned" in the cell, the amount of energy produced is equivalent to that of burning fossil fuels, and is much greater than the energy released from an equal mass of carbohydrates. Lipids, which can be metabolized into fatty acids, are an efficient form of energy storage.

Table 1 Formula and Source of Some Fatty Acids

Name	Formula	Source
butanoic acid	$CH_3(CH_2)_2COOH$	butter
lauric acid	$CH_3(CH_2)_{10}COOH$	coconuts
myristic acid	$CH_3(CH_2)_{12}COOH$	butter
palmitic acid	$CH_3(CH_2)_{14}COOH$	lard, tallow, palm, and olive oils
stearic acid	$CH_3(CH_2)_{16}COOH$	lard, tallow, palm, and olive oils
oleic acid	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$	corn oil
linoleic acid	$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$	vegetable oils

Triglycerides

An example of a simple triglyceride, one with three identical fatty acids, is palmitin. It is found in most fats and oils: palm oil, olive oil, lard, and butter. The fatty acid in palmitin is palmitic acid, $CH_3(CH_2)_{14}COOH$. Palmitin is the tripalmitate ester of glycerol. Another simple triglyceride found in palm oil and olive oil is stearin. The fatty acid that composes this oil is stearic acid, $CH_3(CH_2)_{16}COOH$.



glycerol

Figure 2
Structure of glycerol, 1,2,3-propanetriol

saponification: the reaction in which a triglyceride is hydrolyzed by a strong base, forming a fatty acid salt; soap making

You may recall from our study of esters in Section 1.7 that esters can be hydrolyzed, or broken down into their alcohols and acids. When triglycerides are hydrolyzed with sodium hydroxide, we get glycerol and the sodium salt of the fatty acids. These salts of fatty acids are what we call soap, and the process is called soap making, or **saponification**. Palmitin and stearin from palm oil and olive oil are often used to make soap.

$$\begin{array}{l} CH_3(CH_2)_{14}COO - CH_2 \\ \qquad\qquad\qquad\qquad\;\; | \\ CH_3(CH_2)_{14}COO - CH + 3\,NaOH \xrightarrow[\text{heat}]{} 3\,CH_3(CH_2)_{14}COONa + CH_2(OH) - CH(OH) - CH_2OH \\ \qquad\qquad\qquad\qquad\;\; | \\ CH_3(CH_2)_{14}COO - CH_2 \end{array}$$

palmitin (triglyceride) — sodium palmitate (soap: Na^+ salt of fatty acid) — glycerol

ACTIVITY 2.7.1

Making Soap (p. 143)
Now that you know the chemistry, you can make soap from kitchen fats and oils.

Soap molecules are effective in washing fats and oils from fabrics or from skin because they have both a nonpolar end and a polar end. When in water, many soap molecules together form roughly spherical structures, called *micelles*, on the surface of the skin or fabric being washed. The ionic "heads" of the soap molecules readily dissolve in water, and form the outer surface of the micelles. The long hydrocarbon "tails" are held together by van der Waals forces at the centre of the micelles. Any other nonpolar molecules such as fats and oils are also held in the interior of the micelles, and are thus washed away with the soap, by the water.

$$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2COONa$$

non-polar "tail" — polar "head"

Structure and Properties of Fats and Oils

Fats and oils are largely insoluble in water. For example, an oil and vinegar salad dressing needs to be shaken to mix the two liquids, as the oil does not dissolve in the aqueous vinegar. Butter for a recipe can be measured by immersing the solid fat in water to determine its volume, without losing any in solution. The immiscibility of fats and oils in water is due to the nonpolar nature of the triglyceride molecules. All the polar C=O groups and OH groups are bound in ester linkages, and the extending fatty acids contain long hydrocarbon chains that are nonpolar.

The hydrocarbon chains in fatty acids also affect the physical state of the fat or oil. The shape of the fatty acids dictates how closely the fat and oil molecules can be packed together. This, in turn, affects their melting point (**Table 2**).

DID YOU KNOW?

Rancid Butter
One of the fatty acids incorporated in the fat of butter is butanoic acid, $CH_3CH_2CH_2COOH$, commonly called butyric acid. It is a foul-smelling liquid at room temperatures, and its presence as a free fatty acid in rancid butter accounts for the distinctive odour.

Table 2 Melting Points of Some Saturated and Unsaturated Fatty Acids

Name	Formula	# Carbons	m.p. (°C)
caproic acid	$CH_3(CH_2)_3COOH$	6	−3
lauric acid	$CH_3(CH_2)_{10}COOH$	12	44
myristic acid	$CH_3(CH_2)_{12}COOH$	14	58
palmitic acid	$CH_3(CH_2)_{14}COOH$	16	63
stearic acid	$CH_3(CH_2)_{16}COOH$	18	70
oleic acid	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$	18	4
linoleic acid	$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$	18	−5
linolenic acid	$CH_3CH_2CH{=}CHCH_2CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$	18	−12

If *saturated* hydrocarbon chains are present, the chain can rotate freely about the single C–C bonds. The carbon backbone of each chain has a flexible zig-zag shape, allowing the chains to pack together tightly, with maximum van der Waals interaction between molecules. More thermal energy is therefore needed to separate the saturated fatty acids, leaving these triglycerides solids at 25°C.

However, *unsaturated* hydrocarbon chains *cannot* rotate about their double bonds (**Figure 3**). This restriction introduces one or more "bends" in the molecule, a result of a *cis* configuration at the double bonds (**Figure 4**). These bent fatty acids cannot pack together as tightly, reducing the strength of their van der Waals attractions; triglycerides with these unsaturated fatty acids are generally oils.

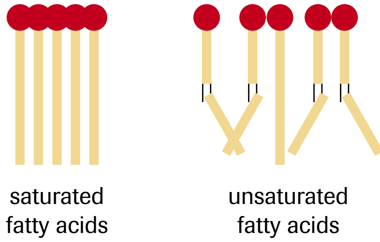
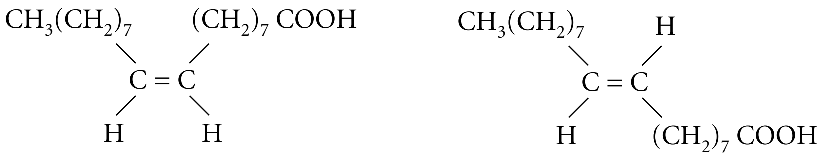


Figure 3
Saturated fatty acids can pack together much more closely than unsaturated molecules, allowing more bonding.



cis-oleic acid

trans-oleic acid

Figure 4
Geometric isomers differ in the position of attached groups relative to a double bond. In a *cis* isomer, two attached groups are on the same side of the double bond; in a *trans* isomer, they are across from each other.

Vegetable oils contain more unsaturated fatty acids than do animal fats, and are said to be polyunsaturated compounds. When oils such as corn oil or canola oil are made into margarine, the oils are hydrogenated to convert the double bonds into single bonds. The increase in saturation of the hydrocarbon chains leads to a decrease of bending of the hydrocarbon chains, and thus closer packing, converting the liquid oil into a solid. Whether saturated fats made from vegetable oils are better for our health than naturally saturated fats from animal sources is yet unclear.

The high caloric value of fats and oils makes them a good energy source, although their poor solubility in water makes them less readily convertible to energy than carbohydrates. Many animals rely on their fat stores to survive long periods of food deprivation. Bears hibernate for up to seven months each year, oxidizing their stored fat for heat and metabolic processes. The cellular "burning" of fats and oils also produces CO_2 and large amounts of water, which the animal uses to replace lost moisture. Camels are able to make long journeys through the desert using the energy and water released from the stored fat in their humps. Another advantage of lipids is their low density, compared to that of carbohydrates or proteins—a lighter load for a migratory bird to carry.

DID YOU KNOW?

Waxes—Another Lipid

$$CH_3(CH_2)_{14}-\overset{\displaystyle O}{\overset{\|}{C}}-O-CH_2-(CH_2)_{28}-CH_3$$

Beeswax is a type of lipid made by bees to create their combs, in which their larvae grow and honey is stored. Waxes are another form of lipid made by both plants and animals. Being nonpolar, waxes are water-repellent. Beeswax is formed from a long-chain alcohol and a long-chain acid, and may be over 40 carbon atoms long. The long lipid molecules are closely packed, with many interchain forces, so waxes have relatively high melting points (60°C to 100°C).

DID YOU KNOW?

The Diving Sperm Whale

Sperm whales dive 1 to 3 km into cold water to feed on squid. To facilitate descent and ascent, the whale regulates the buoyancy of its body. Its head is almost entirely filled with oil. As the whale dives down, its body cools from 37°C to about 31°C, at which temperature the oil solidifies, becoming more dense. This helps the whale stay at the bottom of the ocean, with its prey. As the whale ascends, it warms up, melting the oil to its more buoyant state.

Practice

Understanding Concepts

1. Draw a structural diagram for the simple triglyceride of oleic acid, $CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$, the fatty acid found in corn oil.
2. Given the physical properties of corn oil, would you expect the fatty acid components to be saturated or unsaturated? What process may be necessary to convert corn oil into margarine?
3. Write a balanced chemical equation for the saponification of a simple triglyceride of stearic acid.
4. Explain, with the aid of a sketch, why the presence of double bonds in fatty acids tends to lower the melting points of their triglycerides.
5. Suggest reasons why fats and oils are an efficient form of energy storage for living systems.

Applying Inquiry Skills

6. Describe the general conditions required for making soap, given vegetable oil or animal fat as a starting material. List the main reactants and experimental conditions, and safety precautions needed.

Section 2.7 Questions

Understanding Concepts

1. Describe three different functions that fats and oils serve in living organisms.
2. Write a balanced chemical equation for the esterification of glycerol with lauric acid, $CH_3(CH_2)_{10}COOH$, the fatty acid found in coconuts.
3. There are claims that some oils in fish, when consumed, can lower blood cholesterol levels. Some of these oils are called omega-3 fatty acids, referring to the presence of a carbon–carbon double bond at the third C atom from the hydrocarbon end. Draw a structural diagram for an omega-3 fatty acid that contains 16 carbon atoms.
4. Distinguish between the terms in the following pairs:
   (a) glycerol and triglyceride
   (b) fatty acids and fats
   (c) fats and oils
   (d) lipids and fats
   (e) saponification and esterification
5. Write a balanced equation to represent the saponification of a triglyceride of myristic acid, $CH_3(CH_2)_{12}COOH$, a fatty acid found in butter.
6. Describe how intramolecular and intermolecular forces act in fats and oils. How do these forces affect their melting points?
7. Explain, with reference to molecular structure, why fats and oils are insoluble in water even though their components, glycerol and fatty acids, contain polar functional groups.
8. (a) Draw structural diagrams to illustrate an example of a saponification reaction.
   (b) Explain why soap molecules are soluble in water as well as in fats and oils.
9. Summarize your learning in this chapter by creating a table of at least 12 polymers synthesized by biological systems. For each polymer, provide the name, list the characteristic functional groups, describe the formation reactions, and describe the function.

Applying Inquiry Skills

10. From what you know of reactions of alkenes, design a test for identifying a fat or an oil as saturated or unsaturated. Describe briefly the materials needed, the procedural steps, and an interpretation of possible results.
11. From your knowledge of reactions of alkenes, suggest a laboratory method to "harden" a vegetable oil into a margarine. Write a chemical equation to illustrate your answer.

Making Connections

12. Commercial drain-cleaners often contain sodium hydroxide. Explain how this ingredient may help to clear a grease-clogged drainpipe.
13. Research the following aspects of linseed oil, and write a report to present your findings:
    (a) chemical composition
    (b) properties
    (c) common uses
    (d) safety precautions in its use and disposal
    (e) classification as natural, organic, or synthetic

    GO www.science.nelson.com
14. Research to find out why olive oil is considered to be a better dietary choice than coconut oil. Summarize your findings in a pamphlet to be distributed at a cooking class for people recovering from heart attacks.