23.2: Fatty Acids and Their Esters

Learning Objectives

- To recognize the structures of common fatty acids and classify them as saturated, monounsaturated, or polyunsaturated.
- Describe characteristics of fatty acid esters.

Fatty acids are carboxylic acids that are structural components of fats, oils, and all other categories of lipids, except steroids. More than 70 have been identified in nature. They usually contain an even number of carbon atoms (typically 12–20), are generally unbranched, and can be classified by the presence and number of carbon-to-carbon double bonds. Thus, Fatty acids may be **saturated**, containing all carbon-carbon *single* bonds, or **unsaturated**, containing at least one or more carbon-carbon *double* bonds. Saturated fatty acids are *saturated with hydrogens*; in other words, the number of hydrogen atoms attached to the carbon skeleton is maximized. Stearic acid is an example of a saturated fatty acid (Figure 23.2.1).

When the hydrocarbon chain contains a double bond, there are less hydrogens attached to the carbon skeleton and the fatty acid is said to be unsaturated. Oleic acid is an example of a *monounsaturated* fatty acid (Figure 23.2.1), because it contains one double bond. A fatty acid with two or more double bonds is a *polyunsaturated* fat. The atoms or groups around the double bonds in unsaturated fatty acids can be arranged in either the *cis* or *trans* isomeric form, compare *cis* vs. *trans* oleic acid in (Figure 23.2.1). Naturally occurring fatty acids are generally in the *cis* configuration.

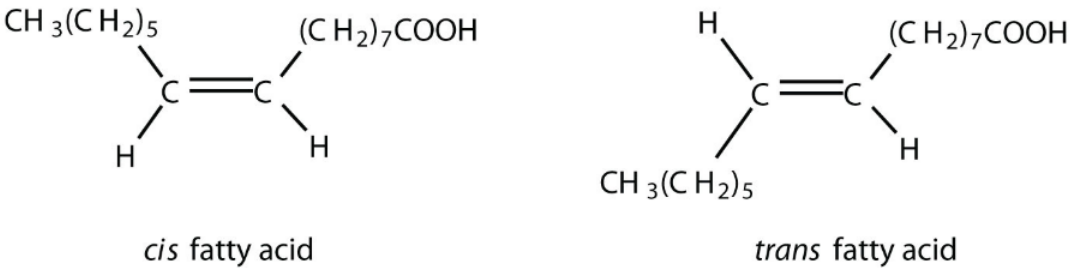


Figure 23.2.1: Saturated fatty acids have hydrocarbon chains connected by single bonds only. Unsaturated fatty acids have one or more double bonds. Each double bond may be in a *cis* or *trans* configuration. In the *cis* configuration, both hydrogens are on the same side of the hydrocarbon chain. In the *trans* configuration, the hydrogens are on opposite sides. A *cis* double bond causes a kink in the chain.

Table 23.2.1 lists some common fatty acids. Chemists use a shorthand notation for fatty acids rather than the common name because they are all carboxylic acids with different numbers of carbons and **degree of unsaturation** (number of double bonds). This notation gives the number of carbons followed by the number of double bonds present. For example: palmitic acid, a 16 carbon saturated fatty acid, would be represented by C16:0 and palmitoleic acid, a 16 carbon monounsaturated fatty acid, would be C16:1.

Table 23.2.1: Some Common Fatty Acids Found in Natural Fats

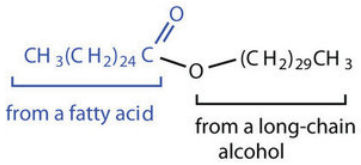
Name	Number of Carbons	Number of Double Bonds	Condensed Structural Formula	Melting Point (°C)	Shorthand Notation	Source
lauric acid	12	0	$CH_3(CH_2)_{10}COOH$	44	C12:0	palm kernel oil
myristic acid	14	0	$CH_3(CH_2)_{12}COOH$	58	C14:0	oil of nutmeg
palmitic acid	16	0	$CH_3(CH_2)_{14}COOH$	63	C16:0	palm oil

Name	Number of Carbons	Number of Double Bonds	Condensed Structural Formula	Melting Point (°C)	Shorthand Notation	Source
palmitoleic acid	16	1	$CH_3(CH_2)_5CH=CH(CH_2)_7COOH$	0.5	C16:1	macadamia oil
stearic acid	18	0	$CH_3(CH_2)_{16}COOH$	70	C18:0	cocoa butter
oleic acid	18	1	$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$	16	C18:1	olive oil
linoleic acid	18	2	$CH_3(CH_2)_3(CH_2CH=CH)_2(CH_2)_7COOH$	−5	C18:2	canola oil
α-linolenic acid	18	3	$CH_3(CH_2CH=CH)_3(CH_2)_7COOH$	−11	C18:3	flaxseed
arachidonic acid	20	4	$CH_3(CH_2)_4(CH_2CH=CH)_4(CH_2)_2COOH$	−50	C20:4	liver

Two polyunsaturated fatty acids—linoleic and α-linolenic acids—are termed essential fatty acids because humans must obtain them from their diets. Both substances are required for normal growth and development, but the human body does not synthesize them. The body uses linoleic acid to synthesize many of the other unsaturated fatty acids, such as arachidonic acid, a precursor for the synthesis of prostaglandins. In addition, the essential fatty acids are necessary for the efficient transport and metabolism of cholesterol. The average daily diet should contain about 4–6 g of the essential fatty acids.

Waxes

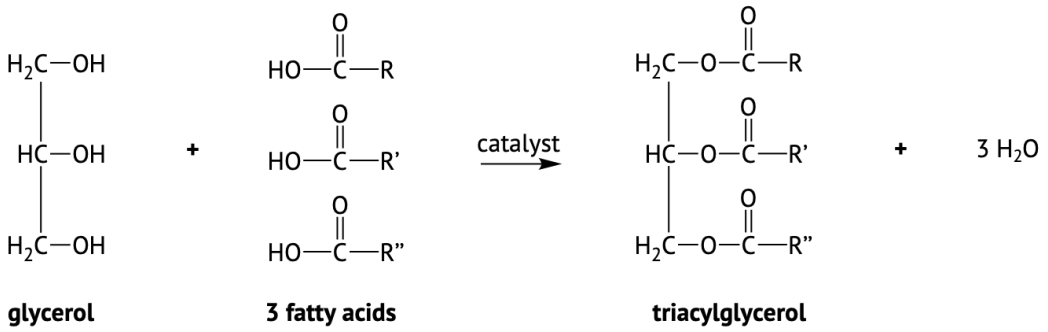
Waxes are esters formed from long-chain fatty acids and long-chain alcohols. Most natural waxes are mixtures of such esters. Plant waxes on the surfaces of leaves, stems, flowers, and fruits protect the plant from dehydration and invasion by harmful microorganisms. Carnauba wax, used extensively in floor waxes, automobile waxes, and furniture polish, is largely myricyl cerotate, obtained from the leaves of certain Brazilian palm trees. Animals also produce waxes that serve as protective coatings, keeping the surfaces of feathers, skin, and hair pliable and water repellent. In fact, if the waxy coating on the feathers of a water bird is dissolved as a result of the bird swimming in an oil slick, the feathers become wet and heavy, and the bird, unable to maintain its buoyancy, drowns.



Myricyl cerotate
(found in carnauba wax)

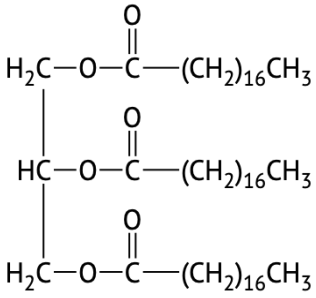
Triacylglycerols

Animal fats and vegetable oils are called *triacylcylgerols* (or triglycerides) because they are esters composed of three fatty acid units joined to *glycerol*, a trihydroxy alcohol:



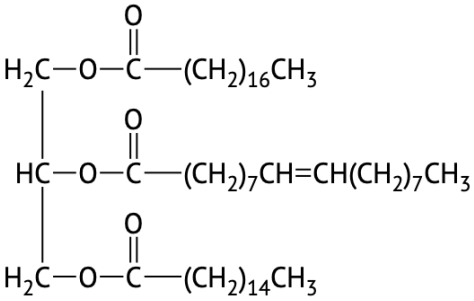
glycerol **3 fatty acids** **triacylglycerol**

If all three OH groups on the glycerol molecule are esterified with the same fatty acid, the resulting ester is called a *simple triglyceride*. Although simple triglycerides have been synthesized in the laboratory, they rarely occur in nature. Instead, a typical triacylglycerols obtained from naturally occurring fats and oils contains two or three different fatty acid components and is thus termed a *mixed triglyceride*.



Tristearin

a simple triglyceride



a mixed triglyceride

A triacylglycerol is called a **fat** if it is a solid at 25 °C; it is called an **oil** if it is a liquid at that temperature. These differences in melting points reflect differences in the degree of unsaturation and number of carbon atoms in the constituent fatty acids. Triglycerides obtained from animal sources are usually solids, while those of plant origin are generally oils. Therefore, we commonly speak of animal fats and vegetable oils.

No single formula can be written to represent the naturally occurring fats and oils because they are highly complex mixtures of triglycerides in which many different fatty acids are represented. Table 23.2.2 shows the fatty acid compositions of some common fats and oils. The composition of any given fat or oil can vary depending on the plant or animal species it comes from as well as on dietetic and climatic factors. To cite just one example, lard from corn-fed hogs is more highly saturated than lard from peanut-fed hogs. Palmitic acid is the most abundant of the saturated fatty acids, while oleic acid is the most abundant unsaturated fatty acid.

Table 23.2.2: Average Fatty Acid Composition of Some Common Fats and Oils (%)*

Source	Lauric (C12:0)	Myristic (C14:0)	Palmitic (C16:0)	Stearic (C18:0)	Oleic (C18:1)	Linoleic (C18:2)	Linolenic (C18:3)

*Totals less than 100% indicate the presence of fatty acids with fewer than 12 carbon atoms or more than 18 carbon atoms.

†Coconut oil is highly saturated. It contains an unusually high percentage of the low-melting C_8, C_{10}, and C_{12} saturated fatty acids.

Source	Lauric (C12:0)	Myristic (C14:0)	Palmitic (C16:0)	Stearic (C18:0)	Oleic (C18:1)	Linoleic (C18:2)	Linolenic (C18:3)
Fats							
butter (cow)	3	11	27	12	29	2	1
tallow		3	24	19	43	3	1
lard		2	26	14	44	10	
Oils							
canola oil			4	2	62	22	10
coconut oil†	47	18	9	3	6	2	
corn oil			11	2	28	58	1
olive oil			13	3	71	10	1
peanut oil			11	2	48	32	
soybean oil			11	4	24	54	7

*Totals less than 100% indicate the presence of fatty acids with fewer than 12 carbon atoms or more than 18 carbon atoms.

†Coconut oil is highly saturated. It contains an unusually high percentage of the low-melting C_8, C_{10}, and C_{12} saturated fatty acids.

Terms such as *saturated fat* or *unsaturated oil* are often used to describe the fats or oils obtained from foods. Saturated fats contain a high proportion of saturated fatty acids, while unsaturated oils contain a high proportion of unsaturated fatty acids. The high consumption of saturated fats is a factor, along with the high consumption of cholesterol, in increased risks of heart disease.
