

7.1: Fatty Acids

Learning Objectives

- Recognize the structures of common fatty acids.
- Classify fatty acids based on chemical composition.
- Generate omega and delta designations for fatty acids.

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-carbon double bonds. **Saturated fatty acids** contain no carbon-carbon double bonds, **monounsaturated fatty acids** contain one carbon-carbon double bond, and **polyunsaturated fatty acids** contain two or more carbon-carbon double bonds.

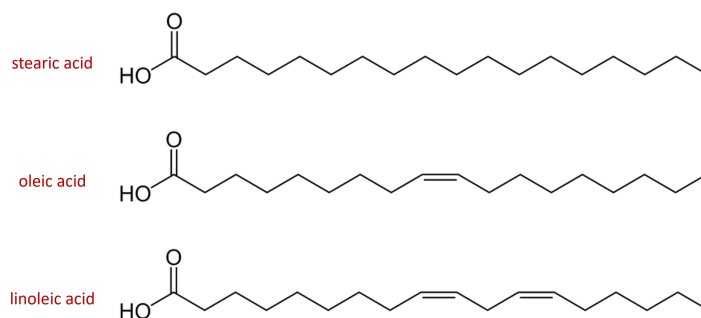


Figure 7.1.1 : Structure of an 18-carbon saturated (top), monounsaturated (middle), and polyunsaturated (bottom) fatty acid.

Table 7.1.1 lists some common fatty acids and one important source for each. The atoms or groups around the double bonds in unsaturated fatty acids can be arranged in either the cis or trans isomeric form. Naturally occurring fatty acids are generally in the cis configuration.

Table 7.1.1: Some Common Fatty Acids Found in Natural Fats

Name	Abbreviated Structural Formula	Condensed Structural Formula	Melting Point (°C)	Source
lauric acid	$C_{11}H_{23}COOH$	$CH_3(CH_2)_{10}COOH$	44	palm kernel oil
myristic acid	$C_{13}H_{27}COOH$	$CH_3(CH_2)_{12}COOH$	58	oil of nutmeg
palmitic acid	$C_{15}H_{31}COOH$	$CH_3(CH_2)_{14}COOH$	63	palm oil
palmitoleic acid	$C_{15}H_{29}COOH$	$CH_3(CH_2)_5CH=CH(CH_2)_7COOH$	0.5	macadamia oil
stearic acid	$C_{17}H_{35}COOH$	$CH_3(CH_2)_{16}COOH$	70	cocoa butter
oleic acid	$C_{17}H_{33}COOH$	$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$	16	olive oil
*linoleic acid	$C_{17}H_{31}COOH$	$CH_3(CH_2)_3(CH_2CH=CH)_2(CH_2)_7COOH$	−5	canola oil
*α-linolenic acid	$C_{17}H_{29}COOH$	$CH_3(CH_2CH=CH)_3(CH_2)_7COOH$	−11	flaxseed
arachidonic acid	$C_{19}H_{31}COOH$	$CH_3(CH_2)_4(CH_2CH=CH)_4(CH_2)_2COOH$	−50	liver

*Essential fatty acid.

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.

To Your Health: Prostaglandins

Prostaglandins are chemical messengers synthesized in the cells in which their physiological activity is expressed. They are unsaturated fatty acids containing 20 carbon atoms and are synthesized from arachidonic acid—a polyunsaturated fatty acid—when needed by a particular cell. They are called *prostaglandins* because they were originally isolated from semen found in the prostate gland. It is now known that they are synthesized in nearly all mammalian tissues and affect almost all organs in the body. The five major classes of prostaglandins are designated as PGA, PGB, PGE, PGF, and PGI. Subscripts are attached at the end of these abbreviations to denote the number of double bonds outside the five-carbon ring in a given prostaglandin.

The prostaglandins are among the most potent biological substances known. Slight structural differences give them highly distinct biological effects; however, all prostaglandins exhibit some ability to induce smooth muscle contraction, lower blood pressure, and contribute to the inflammatory response. Aspirin and other nonsteroidal anti-inflammatory agents, such as ibuprofen, obstruct the synthesis of prostaglandins by inhibiting cyclooxygenase, the enzyme needed for the initial step in the conversion of arachidonic acid to prostaglandins.

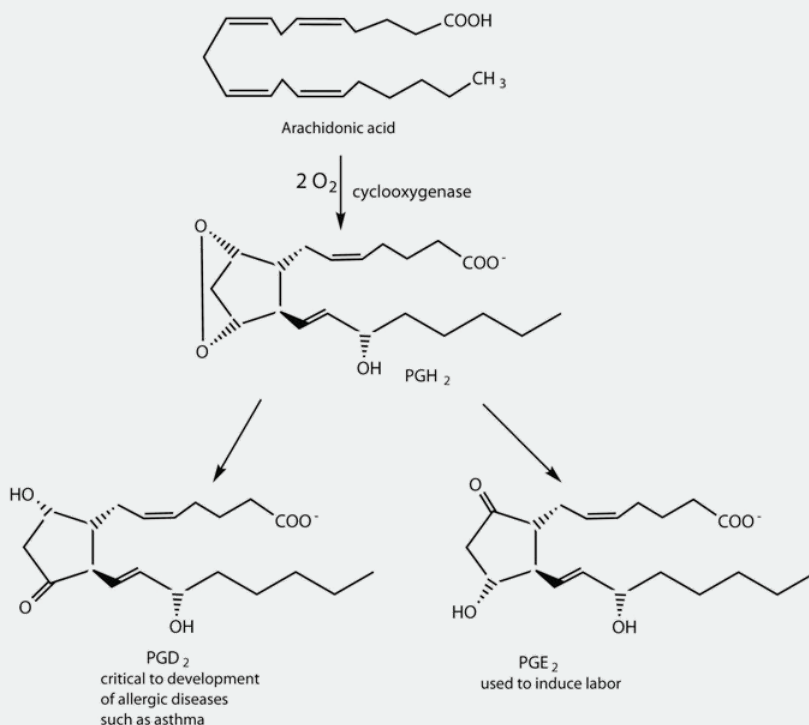


Figure 7.1.2: Conversion of arachidonic acid into prostaglandins.

Their wide range of physiological activity has led to the synthesis of hundreds of prostaglandins and their analogs. Derivatives of PGE₂ are now used in the United States to induce labor. Other prostaglandins have been employed clinically to lower or increase blood pressure, inhibit stomach secretions, relieve nasal congestion, relieve asthma, and prevent the formation of blood clots, which are associated with heart attacks and strokes.

Although we often draw the carbon atoms in a straight line, they actually have more of a zigzag configuration (Figure 7.1.3a). Viewed as a whole, however, the saturated fatty acid molecule is relatively straight (Figure 7.1.3b). Such molecules pack closely together into a crystal lattice, maximizing the strength of dispersion forces and causing fatty acids and the fats derived from them to

have relatively high melting points. In contrast, each *cis* carbon-carbon double bond in an unsaturated fatty acid produces a pronounced bend in the molecule, so that these molecules do not stack neatly. As a result, the intermolecular attractions of unsaturated fatty acids (and unsaturated fats) are weaker, causing these substances to have lower melting points. Most are liquids at room temperature.

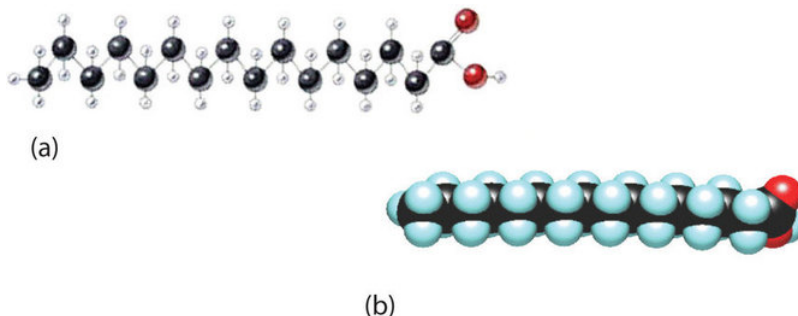


Figure 7.1.3: The Structure of Saturated Fatty Acids. (a) There is a zigzag pattern formed by the carbon-to-carbon single bonds in the ball-and-stick model of a palmitic acid molecule. (b) A space-filling model of palmitic acid shows the overall straightness of a saturated fatty acid molecule.

Fatty Acid Numbering Systems

Although fatty acids are long-chained carboxylic acids, they are not always named as such. Instead fatty acids are often named using systems that provide details about the atoms present in the molecule. A **carbon designation** is given to indicate the number of carbon atoms in the fatty acid, number of carbon-carbon double bonds, and the location of the carbon-carbon double bond(s). There are two systems that provide details on the location of carbon-carbon double bonds: the **delta (Δ) system** and the **omega (ω) system**. The delta system uses the numbering system used in the IUPAC name of carboxylic acids. In this system, carbon 1 is assigned to the carbon of the functional group and the chain is numbered to assign locator numbers to the first carbon in each carbon-carbon double bond present in the molecule. This numbering system is shown as $\Delta^{\#,\#,\dots}$, where the # symbol is replaced with the locator numbers. The omega system, which is often used in nutrition, begins numbering the carbon chain at the opposite end of the molecule. In this system, carbon 1 is assigned to the carbon farthest from the functional group. Another difference is that the omega system only indicates the location of the first carbon of the first carbon-carbon double bond. This numbering system is shown as $\omega\text{-}\#$, where the # symbol indicates the position of first double bond only.

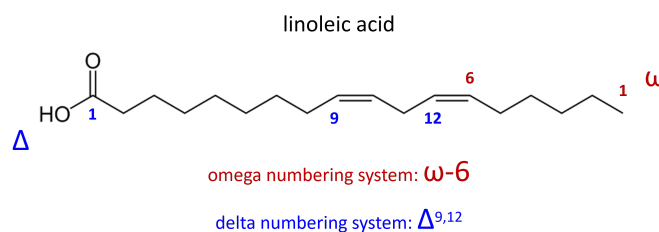


Figure 7.1.4: Applying the omega (red) and delta (blue) numbering systems to linoleic acid.

With the location of the carbon-carbon double bonds identified, the carbon designation can be determined. The carbon designation is shown as:

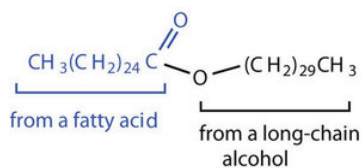
[# of carbon:# of carbon-carbon double bonds], numbering system

The carbon designation of linoleic acid (Figure 7.1.4) would be shown as $[18:2]$, $\Delta^{9,12}$ or $[18:2]$, $\omega\text{-}6$.

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)

Figure \(\PageIndex{5}\): Structure of a wax.

✓ Example 7.1.1

Classify the following fatty acids and indicate the number of carbon atoms in each molecule.

- palmitoleic acid
- myristic acid
- linoleic acid

Solution

- monounsaturated; 16 carbon atoms
- saturated; 14 carbon atoms
- polyunsaturated; 18 carbon atoms

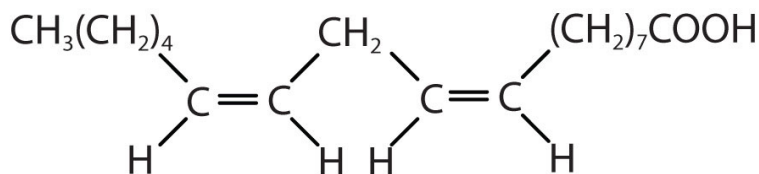
? Exercise 7.1.1

Classify each fatty acid as saturated or unsaturated and indicate the number of carbon atoms in each molecule.

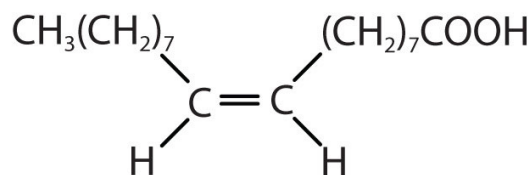
- stearic acid
- oleic acid
- palmitic acid

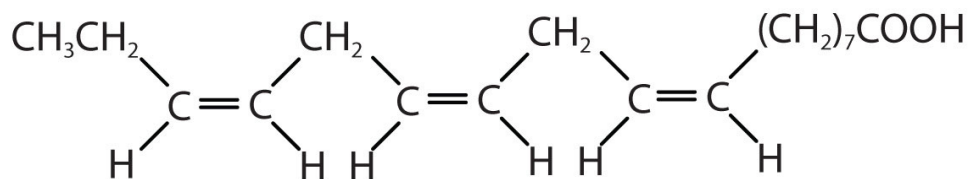
✓ Example 7.1.2

Arrange these fatty acids (all contain 18 carbon atoms) in order of increasing melting point. Justify your arrangement.



-
-





c.

Solution

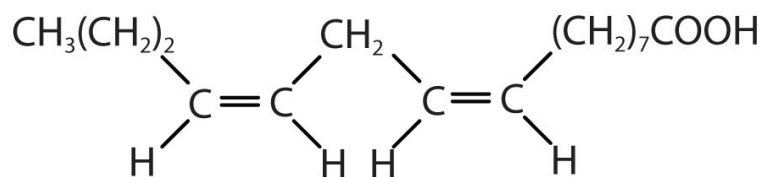
c < a < b; an increase in the number of double bonds will lower the melting point because it is more difficult to closely pack the fatty acids together.

? Exercise 7.1.2

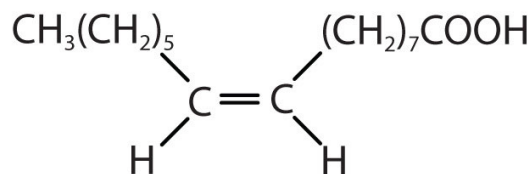
Arrange these fatty acids (all contain 16 carbon atoms) in order of increasing melting point. Justify your arrangement.

a. $\text{CH}_3(\text{CH}_2)_{14}\text{COOH}$

b.



c.



Summary

Fatty acids are carboxylic acids that are the structural components of many lipids. They may be saturated or unsaturated. Most fatty acids are unbranched and contain an even number of carbon atoms. Unsaturated fatty acids have lower melting points than saturated fatty acids containing the same number of carbon atoms. The delta and omega systems can be used in the carbon designation to indicate the location of carbon-carbon double bonds in a fatty acid.

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