24.1 Structure and Classification of Lipids

- **Lipid**: A naturally occurring molecule from a plant or animal soluble in nonpolar organic solvents.

- **Fatty acid**: A long-chain carboxylic acid; those in animal fats and vegetable oils often have 12–22 carbon atoms.

- **Waxes** are carboxylic acid esters, $RCOOR'$, with long, straight hydrocarbon chains in both $R$ groups; they are secreted by sebaceous glands in the skin of animals and perform mostly external protective functions.
**Triacylglycerols** are carboxylic acid triesters of glycerol, a three-carbon trialcohol. They make up the fats stored in our bodies and most dietary fats and oils. They are a major source of biochemical energy.

![Diagram](image-url)
• **Glycerophospholipids** are triesters of glycerol that contain charged phosphate diester groups and are abundant in cell membranes. Together with other lipids, they help to control the flow of molecules into and out of cells.

• **Sphingomyelins**, amides derived from an amino alcohol (sphingosine), also contain charged phosphate diester groups; they are essential to the structure of cell membranes and are abundant in nerve cell membranes.

• **Glycolipids**, different amides derived from sphingosine, contain polar carbohydrate groups; on cell surfaces the carbohydrate portion is recognized by and connects to intracellular messengers.
• The previously listed groups of lipids are all esters or amides of fatty acids, the next two groups of lipids are not: the steroids and the eicosanoids.

• **Steroids** are tetracyclic molecules that act as hormones and contribute to the structure of cell membranes.

• The **eicosanoids** are carboxylic acids that are a special type of intracellular chemical messenger.
A few representative lipid structures are shown below.

- **A wax**
  \[\text{CH}_3\text{(CH}_2\text{)}_{28}\text{CH}_2\text{O-}\text{C-}(\text{CH}_2\text{)}_{14}\text{CH}_3\]

- **A triacylglycerol**
  \[\begin{align*}
  \text{CH}_2\text{O-C-(CH}_2\text{)}_{16}\text{CH}_3 \\
  \text{CH}_2\text{O-C-(CH}_2\text{)}_7\text{CH=CH(CH}_2\text{)}_7\text{CH}_3
  \end{align*}\]

- **Cholesterol, a steroid**

- **A prostaglandin**

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24.2 Fatty Acids and Their Esters

- The naturally occurring fats and oils are triesters formed between glycerol and fatty acids.

- **Saturated fatty acid:** A long-chain carboxylic acid containing only carbon–carbon single bonds.

- **Unsaturated fatty acid:** A long-chain carboxylic acid containing one or more carbon–carbon double bonds.

- If double bonds are present in naturally occurring fats and oils, the double bonds are usually cis rather than trans.
A saturated fatty acid (palmitic acid)

A cis unsaturated fatty acid (linolenic acid)
Polyunsaturated fatty acids have more than one C=C double bond. Linoleic and linolenic acids are essential in the human diet because the body does not synthesize them and they are needed for the synthesis of other lipids.

TABLE 24.1 Structures of Some Common Fatty Acids

<table>
<thead>
<tr>
<th>NAME</th>
<th>TYPICAL SOURCE</th>
<th>NUMBER OF CARBONS</th>
<th>NUMBER OF DOUBLE BONDS</th>
<th>CONDENSED FORMULA</th>
<th>MELTING POINT (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Saturated</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lauric</td>
<td>Coconut oil</td>
<td>12</td>
<td>0</td>
<td>CH₃(CH₂)₁₀COOH</td>
<td>44</td>
</tr>
<tr>
<td>Myristic</td>
<td>Butter fat</td>
<td>14</td>
<td>0</td>
<td>CH₃(CH₂)₁₂COOH</td>
<td>58</td>
</tr>
<tr>
<td>Palmitic</td>
<td>Most fats and oils</td>
<td>16</td>
<td>0</td>
<td>CH₃(CH₂)₁₄COOH</td>
<td>63</td>
</tr>
<tr>
<td>Stearic</td>
<td>Most fats and oils</td>
<td>18</td>
<td>0</td>
<td>CH₃(CH₂)₁₆COOH</td>
<td>70</td>
</tr>
<tr>
<td><strong>Unsaturated</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oleic</td>
<td>Olive oil</td>
<td>18</td>
<td>1</td>
<td>CH₃(CH₂)₇CH═CH(CH₂)₇COOH(cis)</td>
<td>4</td>
</tr>
<tr>
<td>Linoleic</td>
<td>Vegetable oils</td>
<td>18</td>
<td>2</td>
<td>CH₃(CH₂)₄CH═CHCH₂CH═CH(CH₂)₇COOH(all cis)</td>
<td>-5</td>
</tr>
<tr>
<td>Linolenic</td>
<td>Soybean and canola oils</td>
<td>18</td>
<td>3</td>
<td>CH₃CH₂CH═CHCH₂CH═CHCH₂CH═CH(CH₂)₇COOH(all cis)</td>
<td>-11</td>
</tr>
<tr>
<td>Arachidonic</td>
<td>Lard</td>
<td>20</td>
<td>4</td>
<td>CH₃(CH₂)₄(CH═CHCH₂)₄CH₂CH₂COOH(all cis)</td>
<td>-50</td>
</tr>
</tbody>
</table>
The simplest fatty acid esters in nature are waxes. A **wax** is a mixture of fatty acid—long-chain alcohol esters. The acids usually have an even number from 16 to 36 carbons, whereas the alcohols have an even number from 24 to 36 carbons.

**Example of a wax**

A component in beeswax is the ester formed from a 30-C alcohol (triacontanol) and a 16-C acid (palmitic acid).

![Chemical structure of triacontanyl hexadecanoate](image)
Animal fats and vegetable oils are the most plentiful lipids in nature. All fats and oils are composed of triesters of glycerol (1,2,3-propanetriol, also known as glycerine) with three fatty acids. They are named chemically as triacylglycerols, but are often called triglycerides.

**Triacylglycerols**

\[
\begin{align*}
\text{CH}_2\text{OH} & \quad \text{RC}—\text{OH} \\
\text{CHOH} + \text{R'}\text{C}—\text{OH} & \quad \text{CH}_2—\text{O}—\text{C}—\text{R} \\
\text{CH}_2\text{OH} & \quad \text{R''C}—\text{OH} \quad \text{CH}_2—\text{O}—\text{C}—\text{R''} \\
\end{align*}
\]
• The three fatty acids of any specific triacylglycerol are not necessarily the same. The fat or oil from a given natural source is a complex mixture of many different triacylglycerols.
• Vegetable oils consist almost entirely of unsaturated fatty acids, whereas animal fats contain a much larger percentage of saturated fatty acids. This difference in composition is the primary reason for the different melting points of fats and oils.

*Example of a triacylglycerol*

\[
\text{CH}_2 \text{O} \text{C} \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_3 \quad \text{Palmitic acid}
\]

\[
\text{CH} \text{O} \text{C} \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH} \equiv \text{CHCH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_3 \quad \text{Oleic acid}
\]

\[
\text{CH}_2 \text{O} \text{C} \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \equiv \text{CHCH}_2 \text{CH} \equiv \text{CHCH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_2 \text{CH}_3 \quad \text{Linoleic acid}
\]
### TABLE 24.2 Approximate Composition of Some Common Fats and Oils*

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>SATURATED FATTY ACIDS (%)</th>
<th>UNSATURATED FATTY ACIDS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$C_{12}$ LAURIC</td>
<td>$C_{14}$ MYRISTIC</td>
</tr>
<tr>
<td>Lard</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>Butter</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Human fat</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Whale blubber</td>
<td>—</td>
<td>8</td>
</tr>
<tr>
<td>Corn</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>Olive</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>Peanut</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Soybean</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

*Where totals are less than 100%, small quantities of several other acids are present, with cholesterol also present in animal fats.
24.3 Properties of Fats and Oils

• Triacylglycerols in natural fats and oils are nonpolar, hydrophobic molecules with no ionic charges.

• **Oil:** A mixture of triacylglycerols that is liquid because it contains a high proportion of unsaturated fatty acids.

• **Fat:** A mixture of triacylglycerols that is solid because it contains a high proportion of saturated fatty acids.
The hydrocarbon chains in saturated acids are flexible and uniform in shape, allowing them to nestle together. By contrast, the carbon chains in unsaturated acids have rigid kinks wherever they contain cis double bonds. The kinks make it difficult for such chains to fit next to each other in the orderly fashion necessary to form a solid.

Stearic acid, an 18-carbon saturated fatty acid

Linoleic acid, an 18-carbon unsaturated fatty acid
The more double bonds there are in a triacylglycerol, the harder it is for it to solidify.