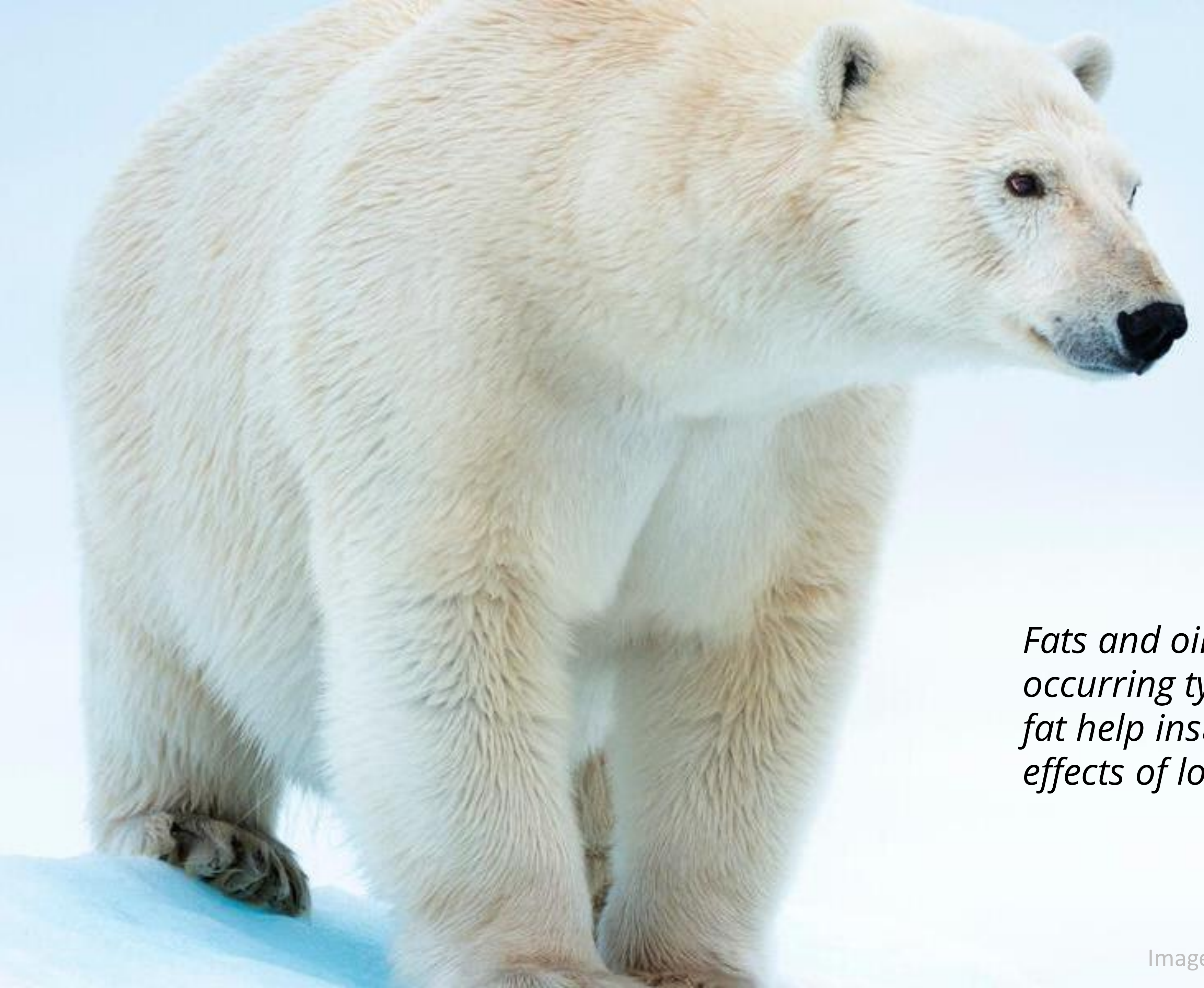
CHAPTER 6
Lipids

Image: https://www.worldwildlife.org/species/polar-bear



Fats and oils are the most widely occurring types of lipids. Thick layers of fat help insulate polar bears against the effects of low temperatures.

Image: https://www.worldwildlife.org/species/polar-bear

Biological Functions of Lipids

Unlike most other classes of compounds, lipids **do not have a common structural feature** that serves as the basis for defining such compounds. Instead, **their characterization is based on solubility characteristics**.

A **lipid** (from the Greek word *lipos*, meaning "*fat*" or "*lard*") is an organic compound found in living organisms that is insoluble (or only sparingly soluble) in water but soluble in nonpolar organic solvents.

When a biochemical material (human, animal, or plant tissue) is homogenized in a blender and mixed with a nonpolar organic solvent, the substances that dissolve in the solvent are the lipids.

Biological Functions of Lipids

Lipids may be subdivided into four main types:

- **Fatty acids** (saturated and unsaturated)
- **Glycerides** (glycerol-containing lipids)
- **Nonglyceride lipids** (sphingolipids, steroids, waxes)
- **Complex lipids** (lipoproteins)

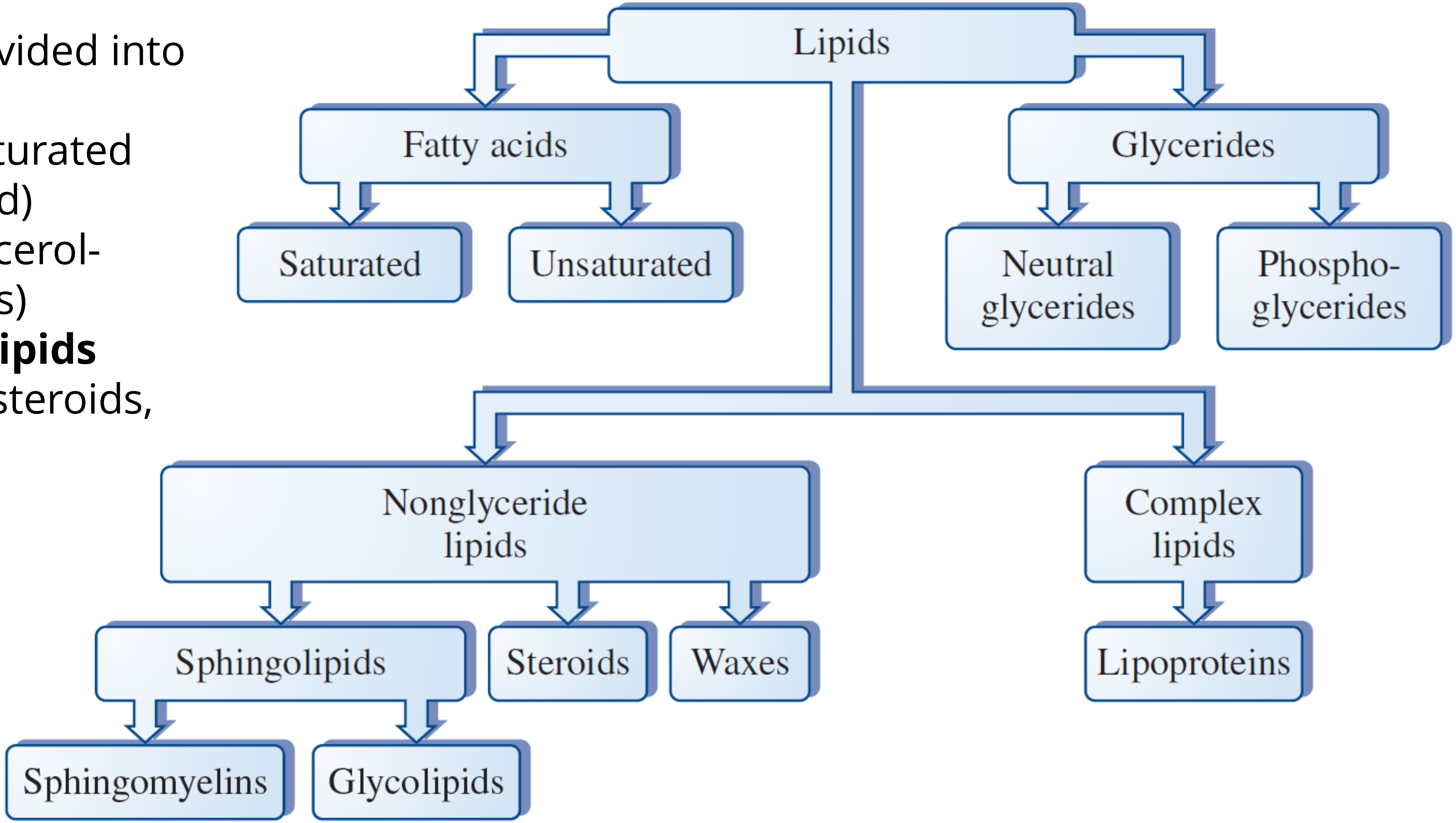
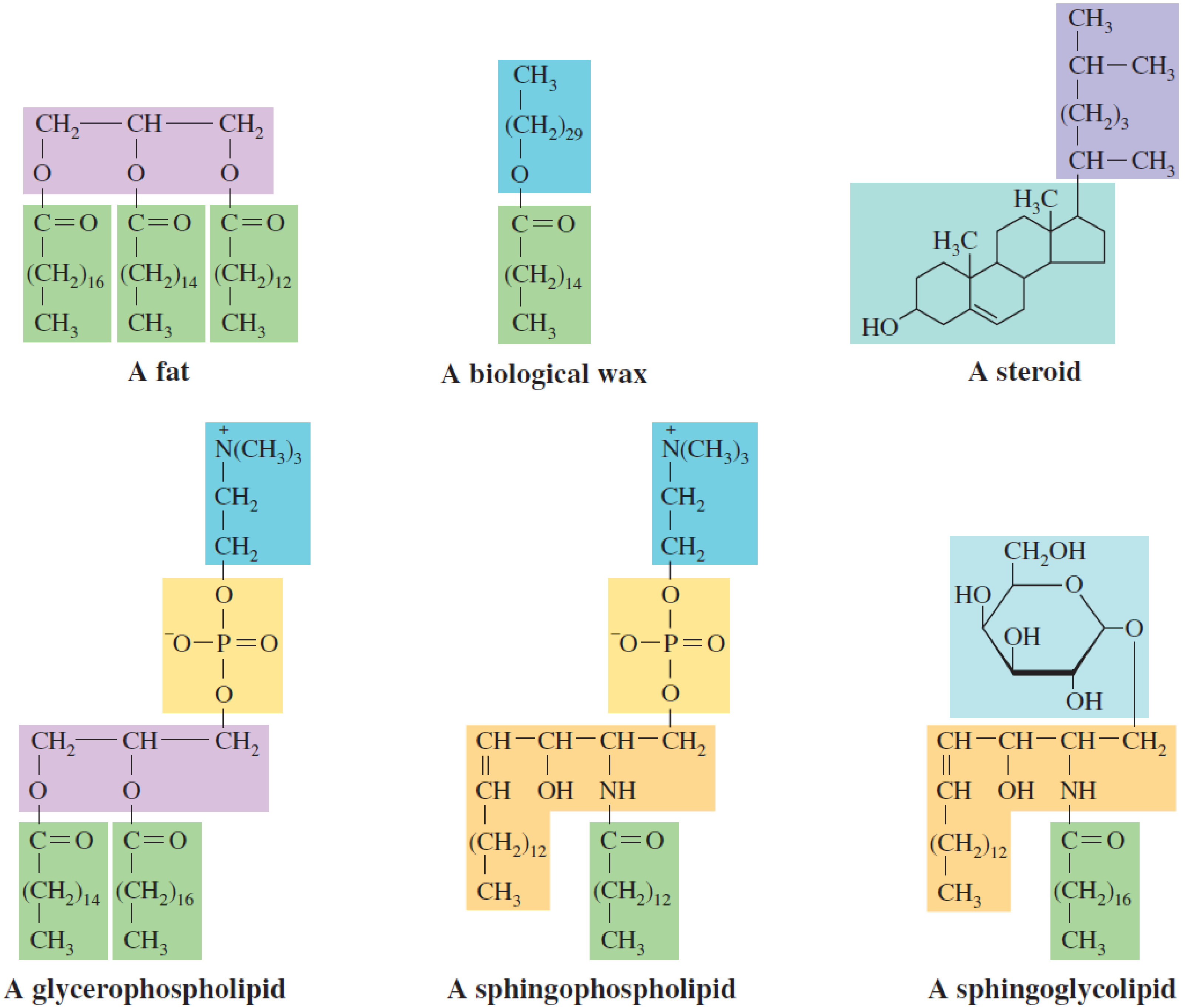


Figure 8-1 The structural formulas of these types of lipids illustrate the great structural diversity among lipids. The defining parameter for lipids is solubility rather than structure.

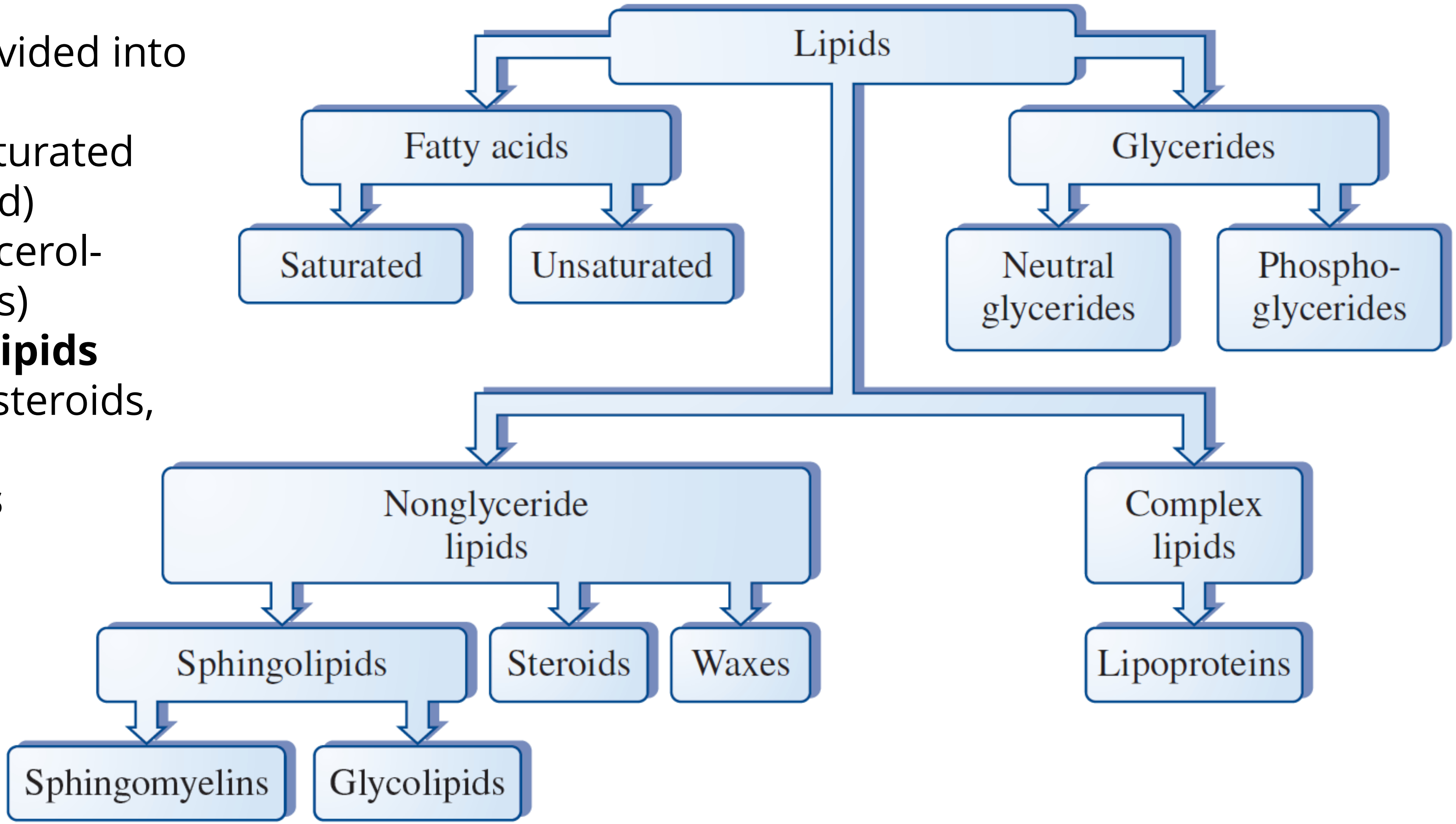


Fatty acids are found in many types of lipids.

Biological Functions of Lipids

Lipids may be subdivided into four main types:

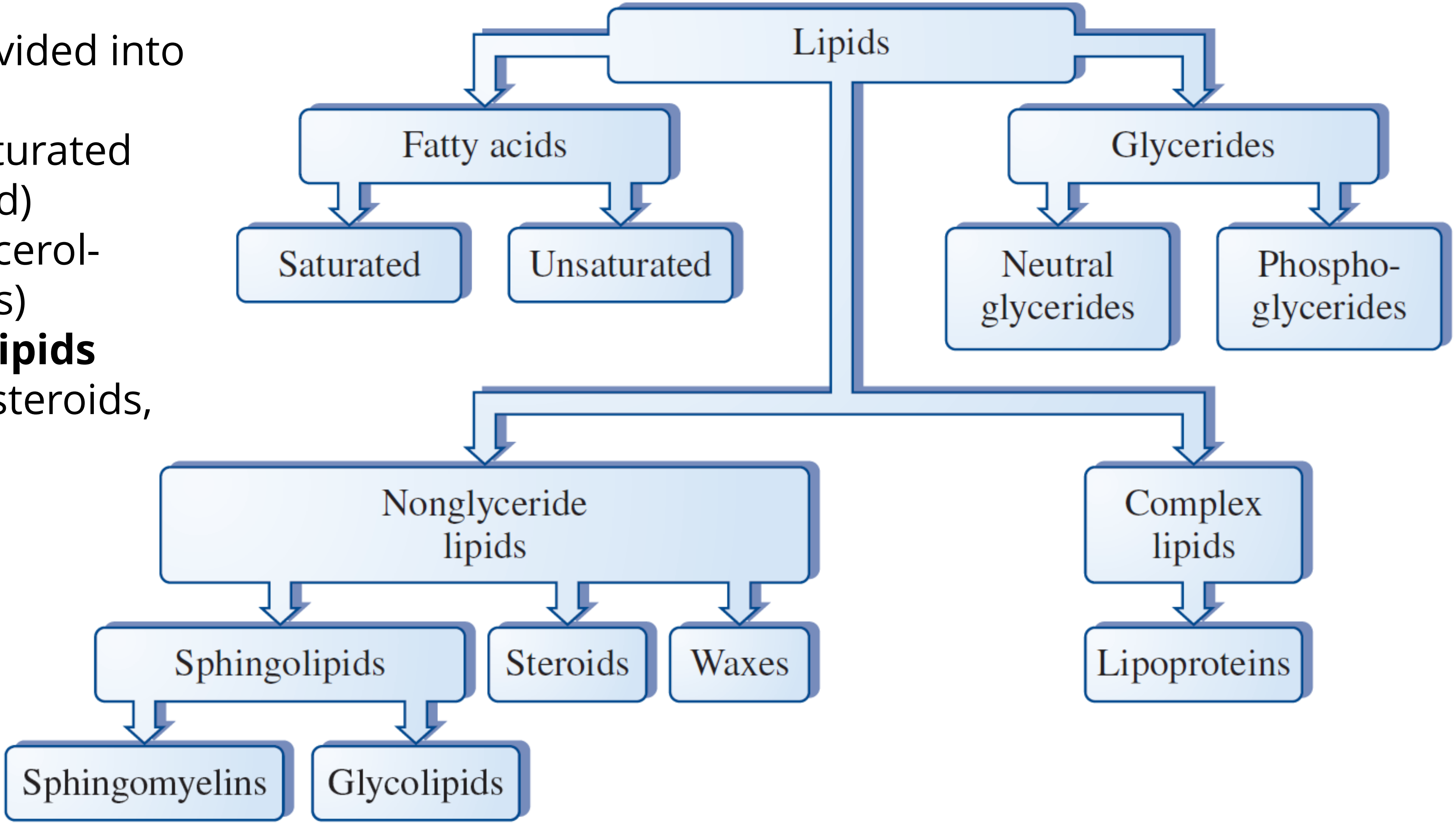
- **Fatty acids** (saturated and unsaturated)
- **Glycerides** (glycerol-containing lipids)
- **Nonglyceride lipids** (sphingolipids, steroids, waxes)
- **Complex lipids** (lipoproteins)



Biological Functions of Lipids

Lipids may be subdivided into four main types:

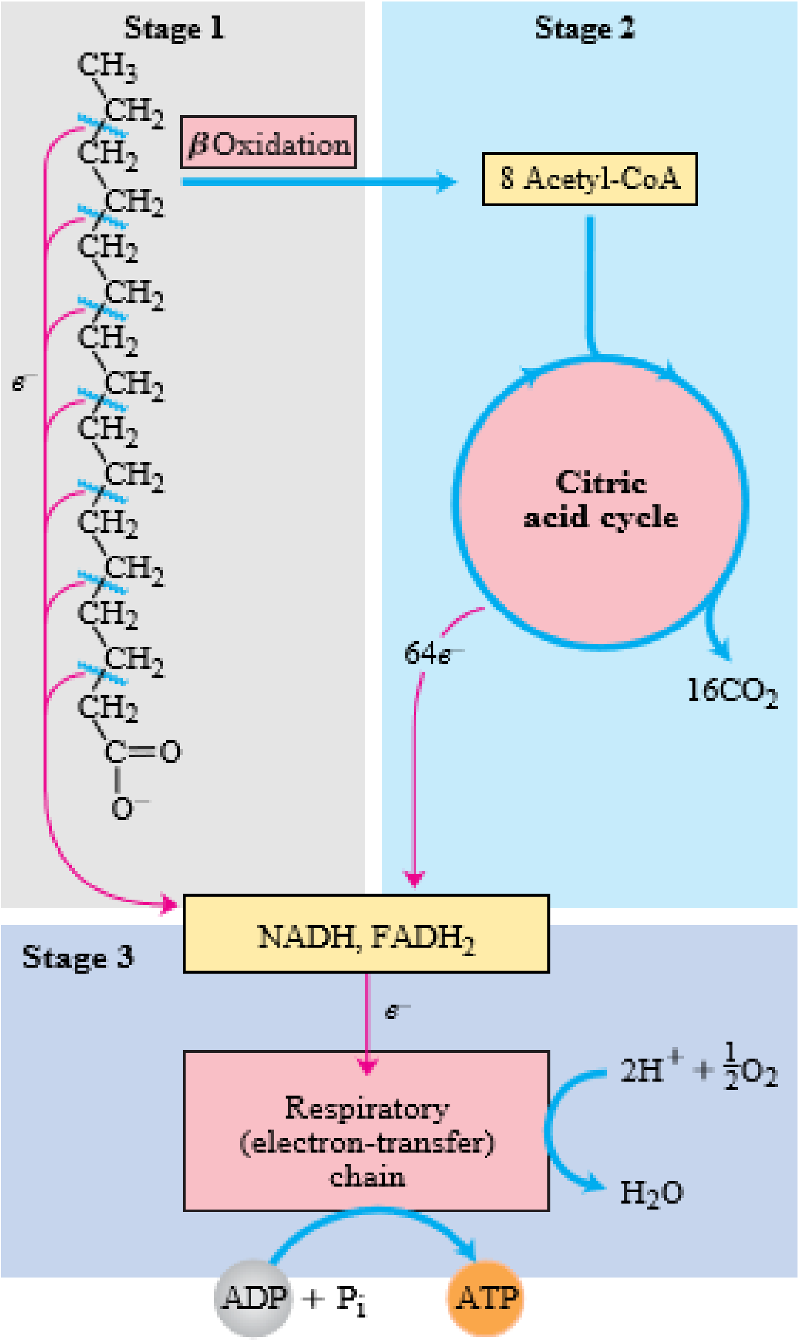
- **Fatty acids** (saturated and unsaturated)
- **Glycerides** (glycerol-containing lipids)
- **Nonglyceride lipids** (sphingolipids, steroids, waxes)
- **Complex lipids** (lipoproteins)



Biological Functions of Lipids

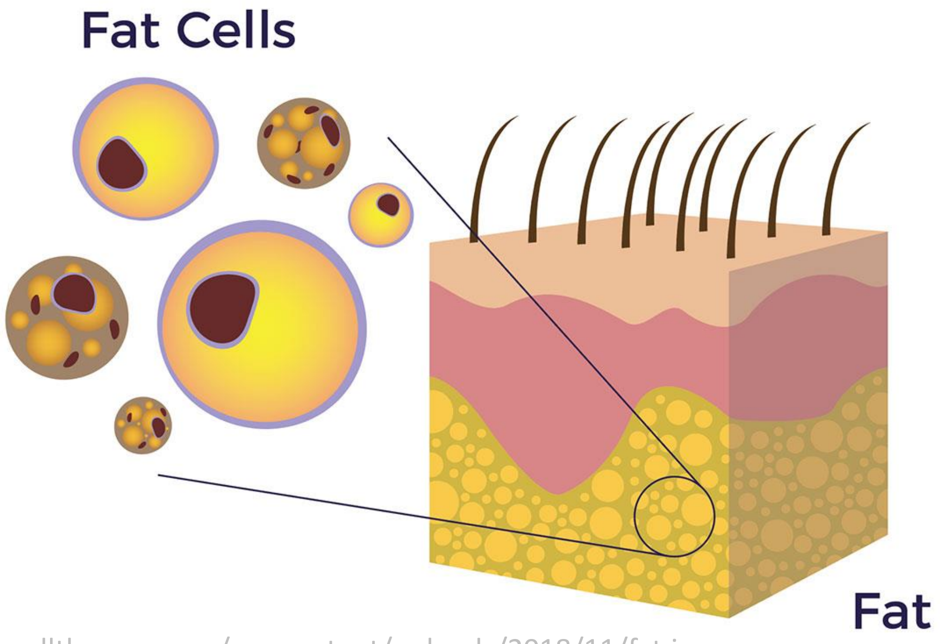
1. **Energy source (*triacylglycerols*)**
   Like carbohydrates, lipids are an excellent source of energy for the body. When oxidized, each gram of fat releases 9 kilocalories (kcal) of energy, or more than twice the energy released by oxidation of a gram of carbohydrate (4 kcal).

Nutrients		Calorific value
	Proteins	4 kcal/g
	Carbohydrates	4 kcal/g
	Fats	9 kcal/g

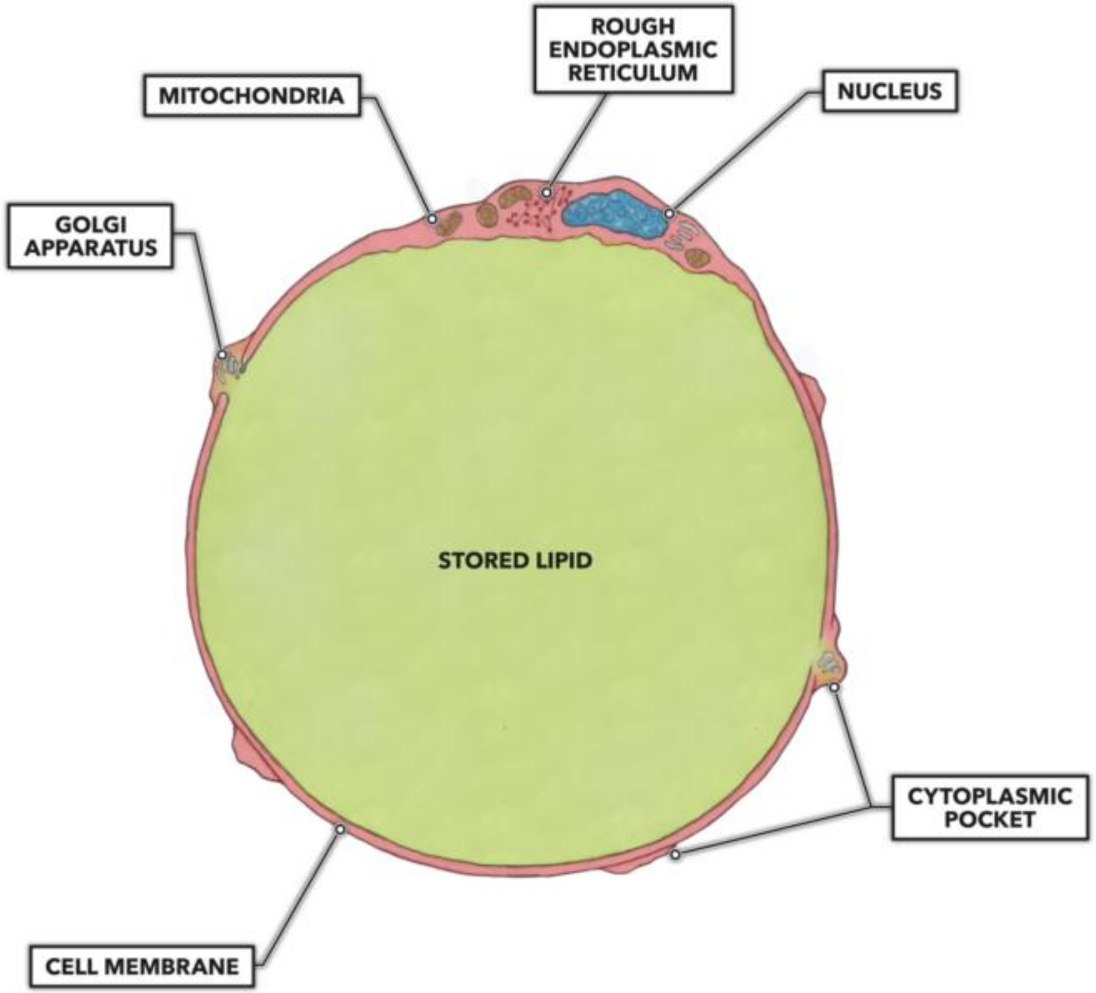


Biological Functions of Lipids

2. **Energy storage (*tricaylglycerols*)**
   Most of the energy stored in the body is in the form of lipids (**triglycerides**). Stored in **fat cells** called **adipocytes**, these fats are a particularly rich source of energy for the body.



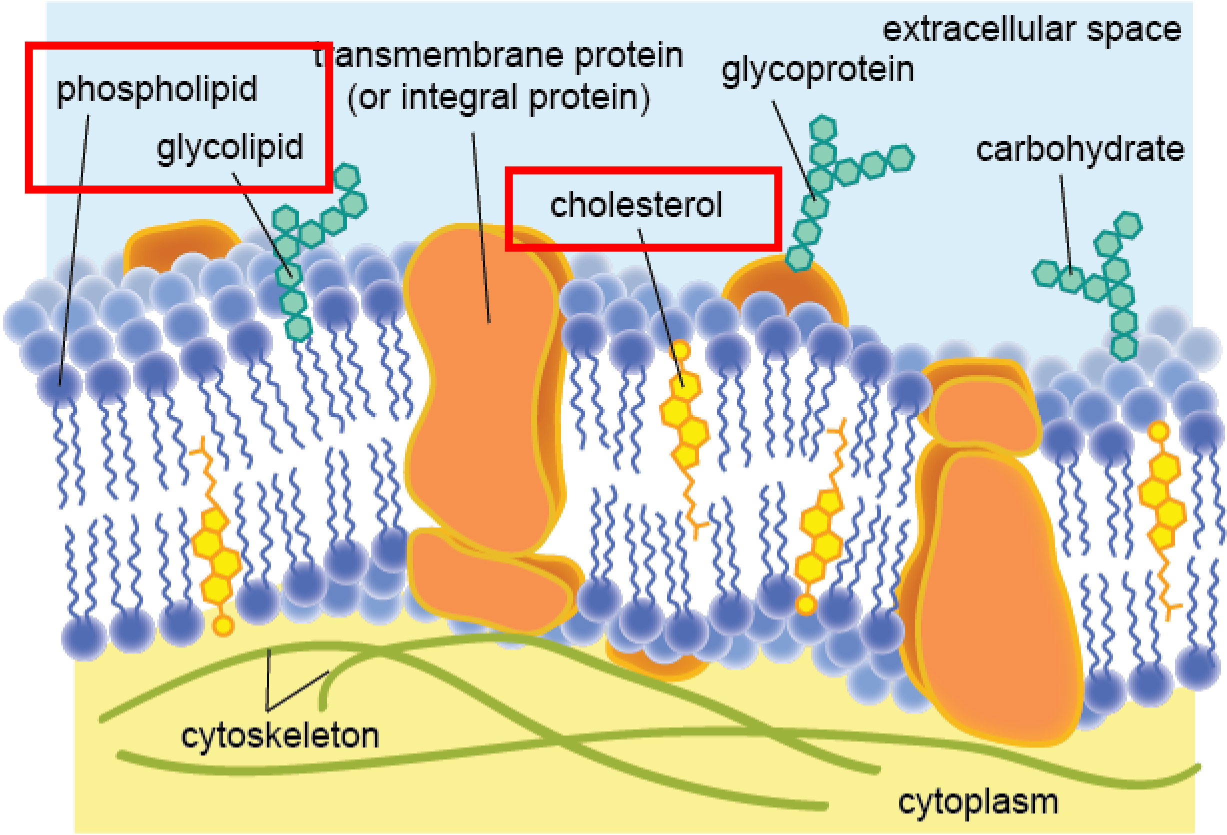
https://ambrosecelltherapy.com/wp-content/uploads/2018/11/fat.jpg



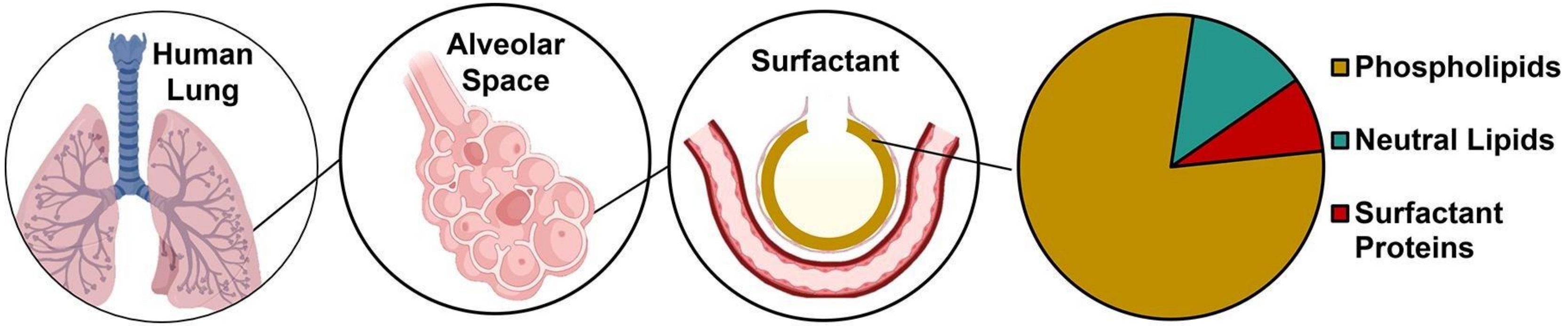
https://www.crossfit.com/essentials/fat-part-2-microanatomy

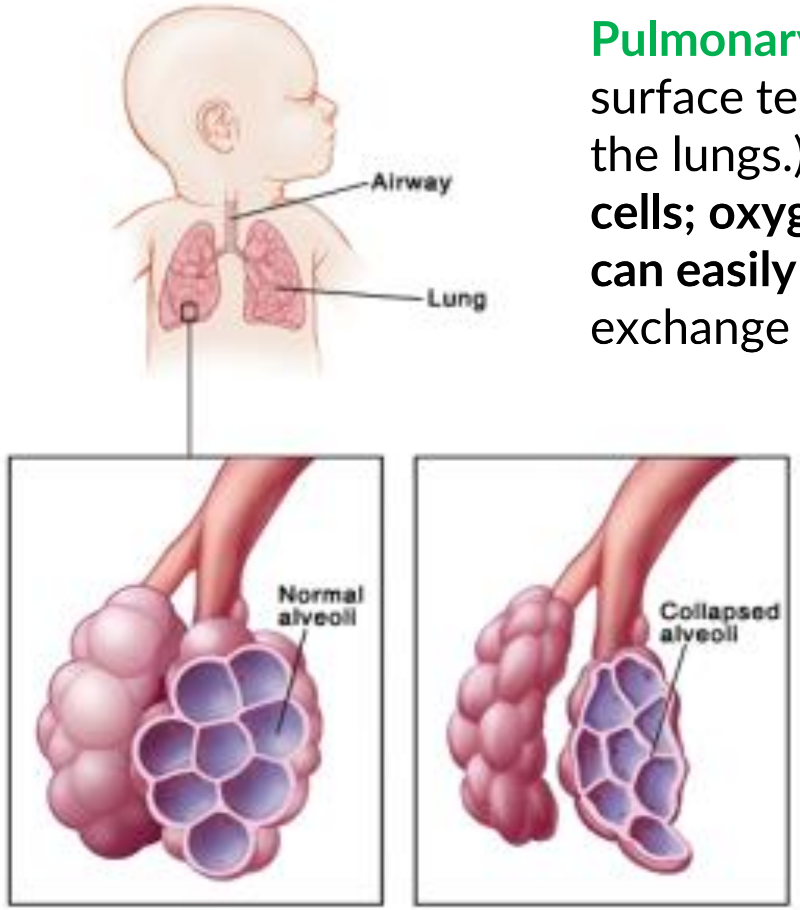
Biological Functions of Lipids

2. **Cell membrane structural components.** **Phosphoglycerides**, **sphingolipids**, and **steroids** make up the basic structure of all cell membranes. These membranes control the flow of molecules into and out of cells and allow cell-to-cell communication.



https://www.quora.com/Glycolipids-are-non-ionic-lipids-that-can-orient-themselves-into-bilayers-in-a-manner-similar-to-that-of-phospholipids-Suggest-a-reason-why-they-can-accomplish-this-feat-despite-their-lack-of-ionic-group-similar-to https://www.sciencedirect.com/science/article/pii/S2666027X2200038X





Pulmonary surfactant is a combination of phospholipids and proteins that reduces surface tension in the alveoli of the lungs. (Alveoli are the small, thin-walled air sacs in the lungs.) **This allows efficient gas exchange across the membranes of the alveolar cells; oxygen can more easily diffuse from the air into the tissues, and carbon dioxide can easily diffuse from the tissues into the air.** Without pulmonary surfactant, gas exchange in the lungs is very poor.

Pulmonary surfactant is not produced until early in the sixth month of pregnancy. Premature babies born before they have begun secretion of natural surfactant suffer from *respiratory distress syndrome* (RDS), which is caused by the severe difficulty they have obtaining enough oxygen from the air that they breathe.

A fine aerosol of an artificial surfactant is administered directly into the trachea. Artificial pulmonary surfactant therapy has dramatically reduced premature infant death caused by RDS and appears to have reduced overall mortality for all babies born weighing less than 700 g.

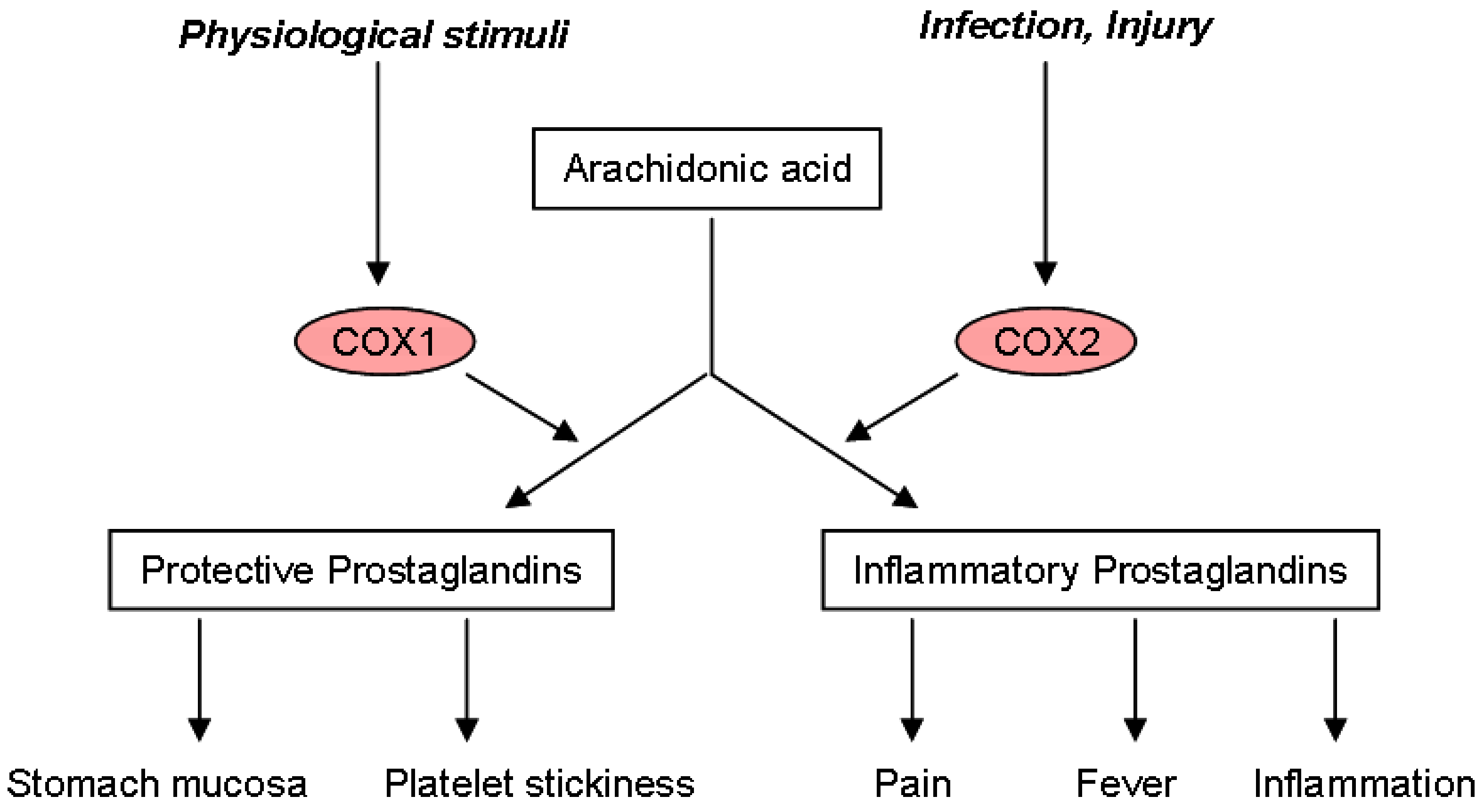
https://www.bravebeginnings.org/respiratory-distress-in-infants-and-adults/

Biological Functions of Lipids

3. **Hormones (*steroid hormones and eicosanoids*)**

The steroid hormones are critical chemical messengers that allow tissues of the body to communicate with one another.

The hormonelike **prostaglandins** exert strong biological effects on both the cells that produce them and other cells of the body.



NSAIDs (nonsteroidal anti-inflammatory drugs) can reduce pain, fever and other types of inflammation by inhibiting the COX enzymes.

Biological Functions of Lipids

4. Vitamins and vitamin absorption.

The lipid-soluble vitamins, **A, D, E, and K**, play a major role in the regulation of several critical biological processes, including blood clotting and vision.

Dietary fat serves as a carrier of the lipid-soluble vitamins. All are transported into cells of the small intestine in association with fat molecules. Therefore, a diet that is too low in fat (less than 20% of calories) can result in a deficiency of these four vitamins.

Biological Functions of Lipids

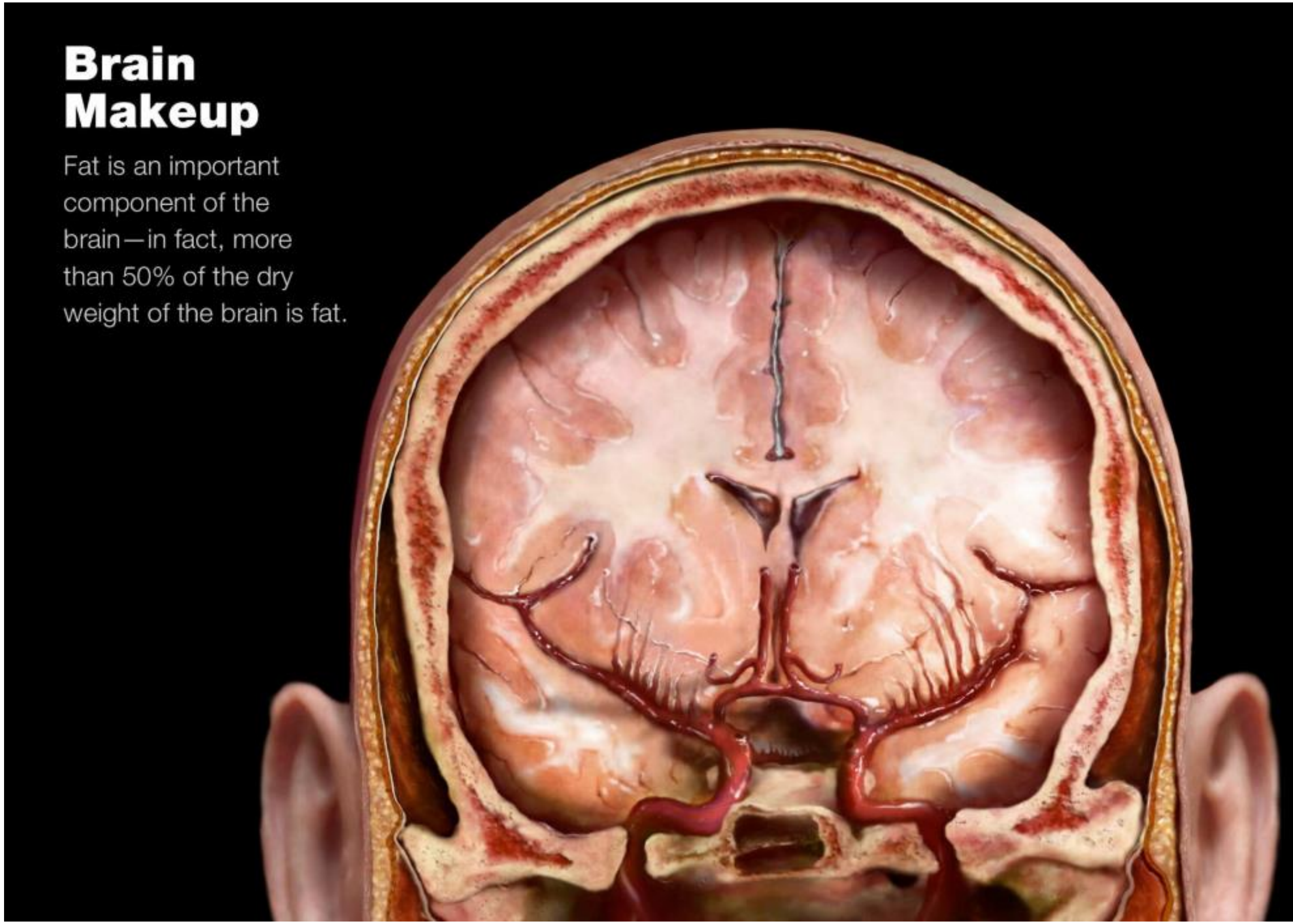
5. Protection (*biological waxes*)

Fats serve as a **shock absorber**, or protective layer, for the vital organs. About 4% of the total body fat is reserved for this critical function.

Biological Functions of Lipids

5. Protection (*biological waxes*)

Fats serve as a **shock absorber**, or protective layer, for the vital organs. About 4% of the total body fat is reserved for this critical function.



Biological Functions of Lipids

6. Insulation.

Fat stored beneath the skin (subcutaneous fat) serves to insulate the body from extremes of cold temperatures.

Two categories of lipids based on hydrolysis

Saponification reaction: A hydrolysis reaction that occurs in basic solution; a lipid can be broken down into smaller units through reaction with water (hydrolysis) under basic conditions.

1. **Saponifiable lipids:** triacylglycerols, phospholipids, sphingoglycolipids, and biological waxes

2. **Nonsaponifiable lipids:** cholesterol, steroid hormones, bile acids, and eicosanoids

Saponifiable lipids are converted into two or more smaller molecules when hydrolysis occurs. Nonsaponifiable lipids cannot be broken up into smaller units since they do not react with water.

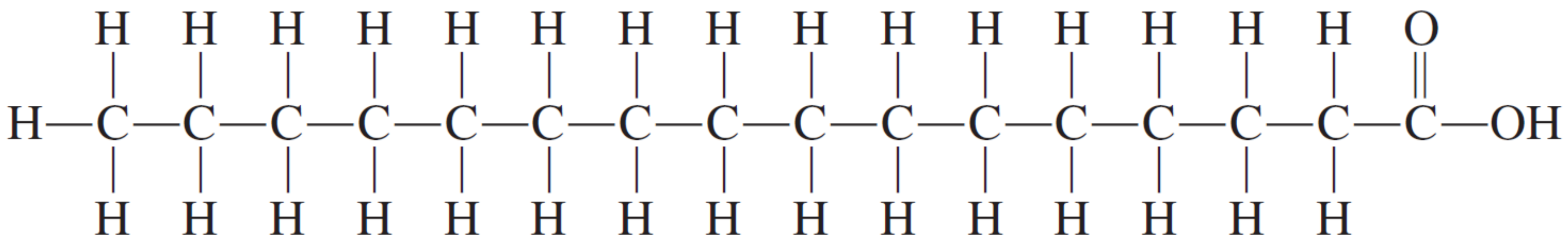
Section 8-1 Quick Quiz

1. A lipid is any substance of biochemical origin that is
   a. soluble in water but insoluble in nonpolar solvents
   b. insoluble in water but soluble in nonpolar solvents
   c. soluble in both water and nonpolar solvents
   d. no correct response
2. Which of the following is *not* a biochemical function classification for lipids?
   a. membrane lipid
   b. messenger lipid
   c. emulsification lipid
   d. no correct response
3. The saponifiable/nonsaponifiable classification system for lipids is based on
   a. lipid behavior in acidic solution
   b. lipid behavior in basic solution
   c. ability of lipids to react with alcohols
   d. no correct response

Fatty Acids

Fatty acids

- are long-chain monocarboxylic acids
- generally contain an even number of carbon atoms as a consequence of their biosynthesis
- follows the general formula $CH_3(CH_2)_nCOOH$ (saturated fatty acids), in which ***n*** in biological systems is an even number.
- are rarely found free in nature but rather occur as part of the structure of more complex lipid molecules.



IUPAC name: hexadecanoic acid
Common name: palmitic acid

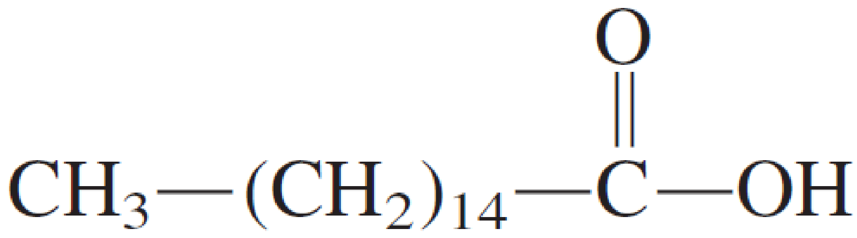
Structural formula

$CH_3(CH_2)_{14}COOH$

“Saturated” with hydrogen

Fatty Acids: Saturated

Usually written in a more condensed form or skeletal formula:



Condensed formula

Line-angle/skeletal formula

$CH_3(CH_2)_{14}COOH$

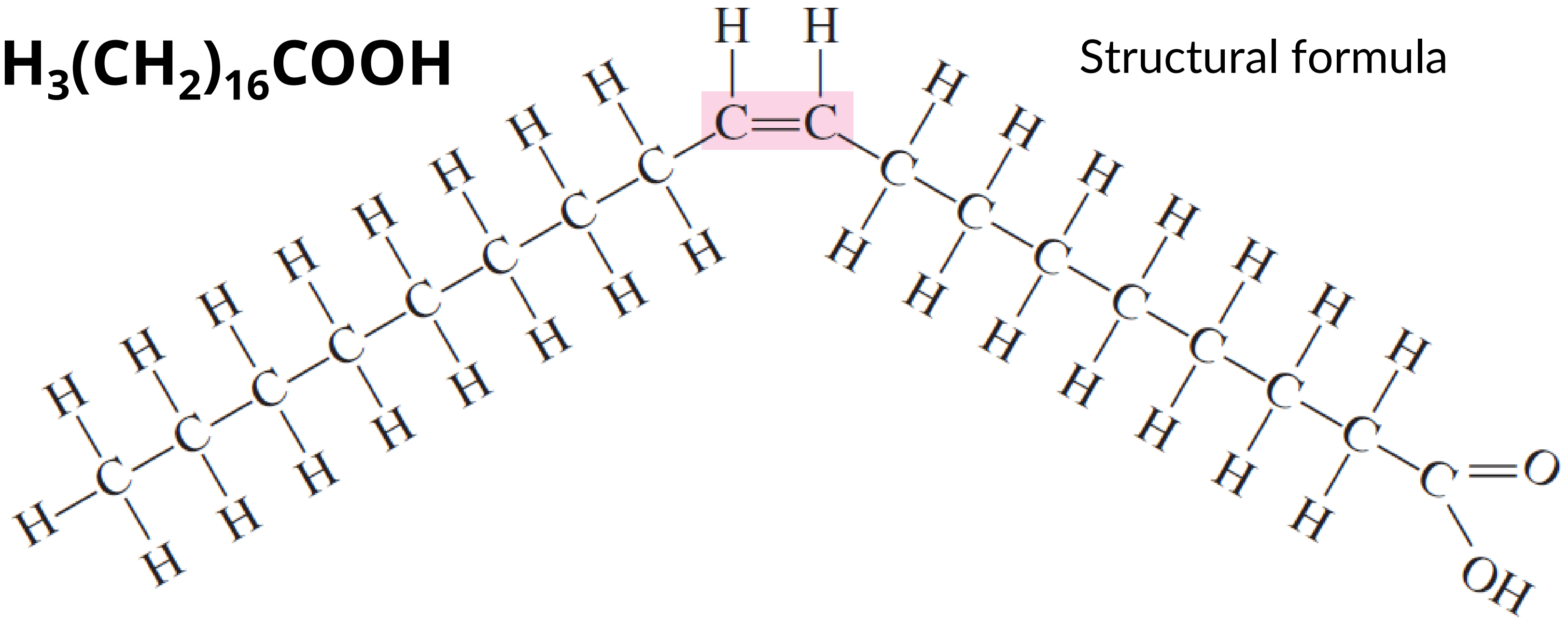
Fatty Acids: Unsaturated

“Unsaturated” with hydrogen

- An **unsaturated fatty acid** is one that contains at least one carbon-to-carbon double bond. Oleic acid, an 18-carbon unsaturated fatty acid, has the following structural formula:

$CH_3(CH_2)_{16}COOH$

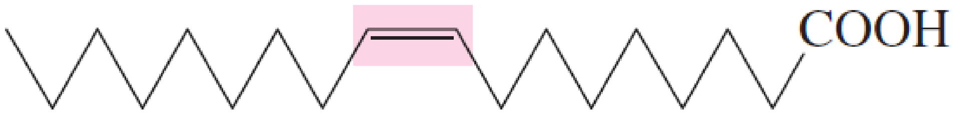
Structural formula



- The double bonds found in almost all naturally occurring unsaturated fatty acids are in the ***cis-configuration***.

$$CH_3-(CH_2)_7-CH{=}CH-(CH_2)_7-\overset{\displaystyle O}{\overset{\|}{C}}-OH$$

Condensed formula



Skeletal formula

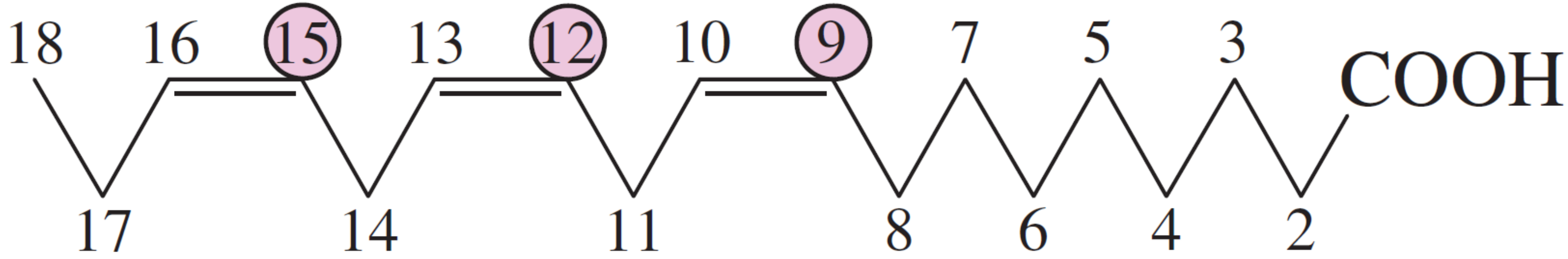
IUPAC name: *cis*-9-octadecaenoic acid
Common name: oleic acid

Fatty Acids: Unsaturated

- The double bonds found in almost all naturally occurring unsaturated fatty acids are in the ***cis-configuration*** that puts a rigid 30° bend in the chain.
- In addition, the double bonds are ***not randomly located in the hydrocarbon chain***. Both the placement and the geometric configuration of the double bonds are dictated by the enzymes that catalyze the biosynthesis of unsaturated fatty acids.
- A **monounsaturated fatty acid (MUFA)** is a fatty acid with a carbon chain in which one carbon–carbon double bond is present.
- A **polyunsaturated fatty acid (PUFA)** is a fatty acid with a carbon chain in which two or more carbon–carbon double bonds are present. ***Up to six double bonds*** are found in biochemically important PUFAs.

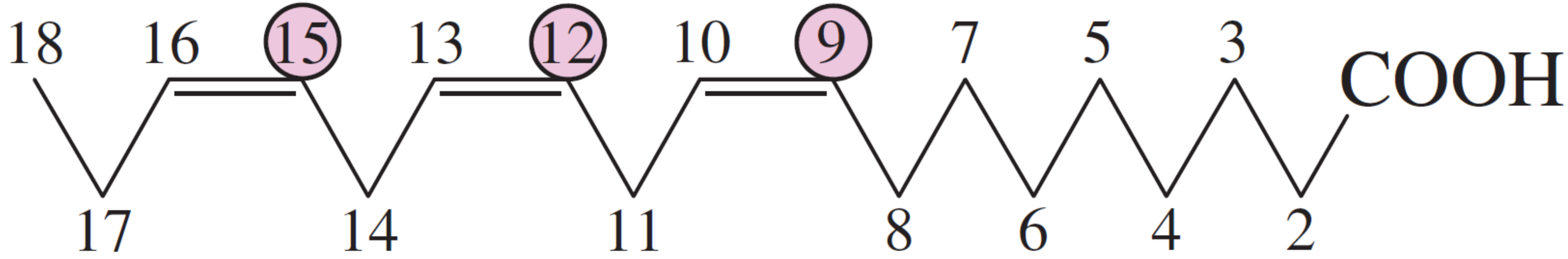
Fatty Acids: *Unsaturated Fatty Acids and Double-Bond Position*

- The notation **18:0** denotes a C_{18} fatty acid with **no double bonds**
- The notation **18:2** signifies a C_{18} PUFA in which **two double bonds**
- The notation **18:3($\Delta^{9,12,15}$)** denotes a C_{18} PUFA with **three double bonds** at locations between carbons **9** and 10, **12** and 13, and **15** and 16.



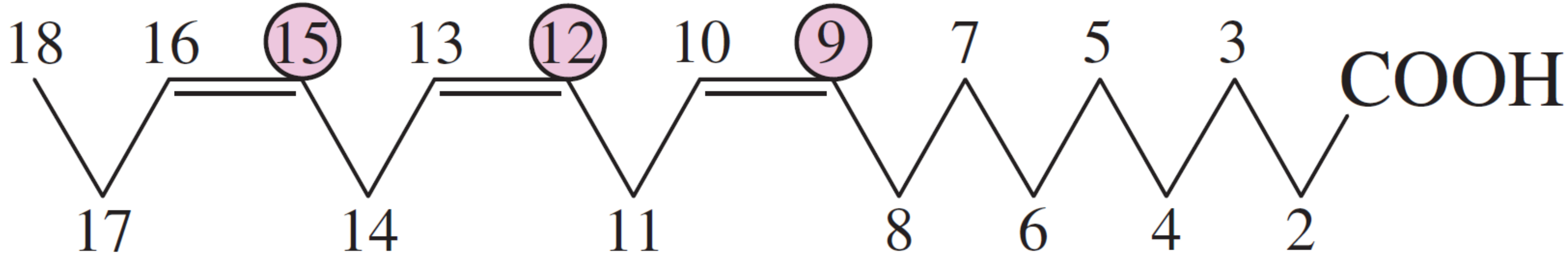
Fatty Acids: *Unsaturated Fatty Acids and Double-Bond Position*

- MUFAs are usually Δ^9 acids, and the first two additional double bonds in PUFAs are generally at the Δ^{12} and Δ^{15} locations.
- A notable exception to this generalization is the biochemically important arachidonic acid, a PUFA with the structural parameters 20:4($\Delta^{5,8,11,14}$).]



Fatty Acids: *Unsaturated Fatty Acids and Double-Bond Position*

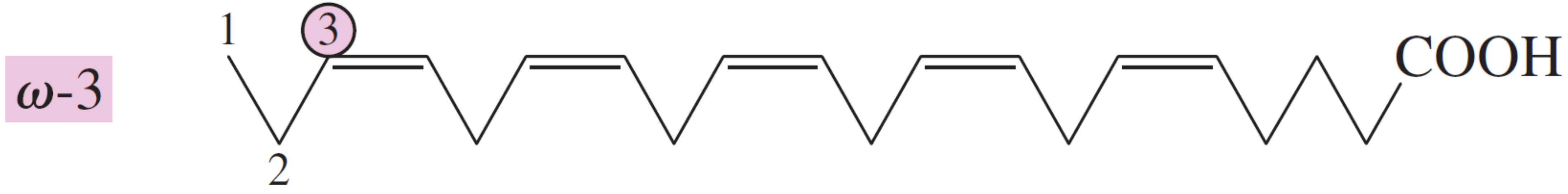
- MUFAs are usually Δ^9 acids, and the first two additional double bonds in PUFAs are generally at the Δ^{12} and Δ^{15} locations.
- A notable exception to this generalization is the biochemically important arachidonic acid, a PUFA with the structural parameters 20:4($\Delta^{5,8,11,14}$).



Fatty Acids: *Unsaturated Fatty Acids and Double-Bond Position*

- "families" of unsaturated fatty acids exist when double-bond position is specified relative to the **methyl (noncarboxyl) end** of the fatty acid carbon chain.

Omega-3 FA: is an unsaturated fatty acid with its endmost double bond three carbon atoms away from its methyl end.



Fatty Acids: *Unsaturated Fatty Acids and Double-Bond Position*

Omega-6 FA: is an unsaturated fatty acid with its endmost double bond six carbon atoms away from its methyl end.

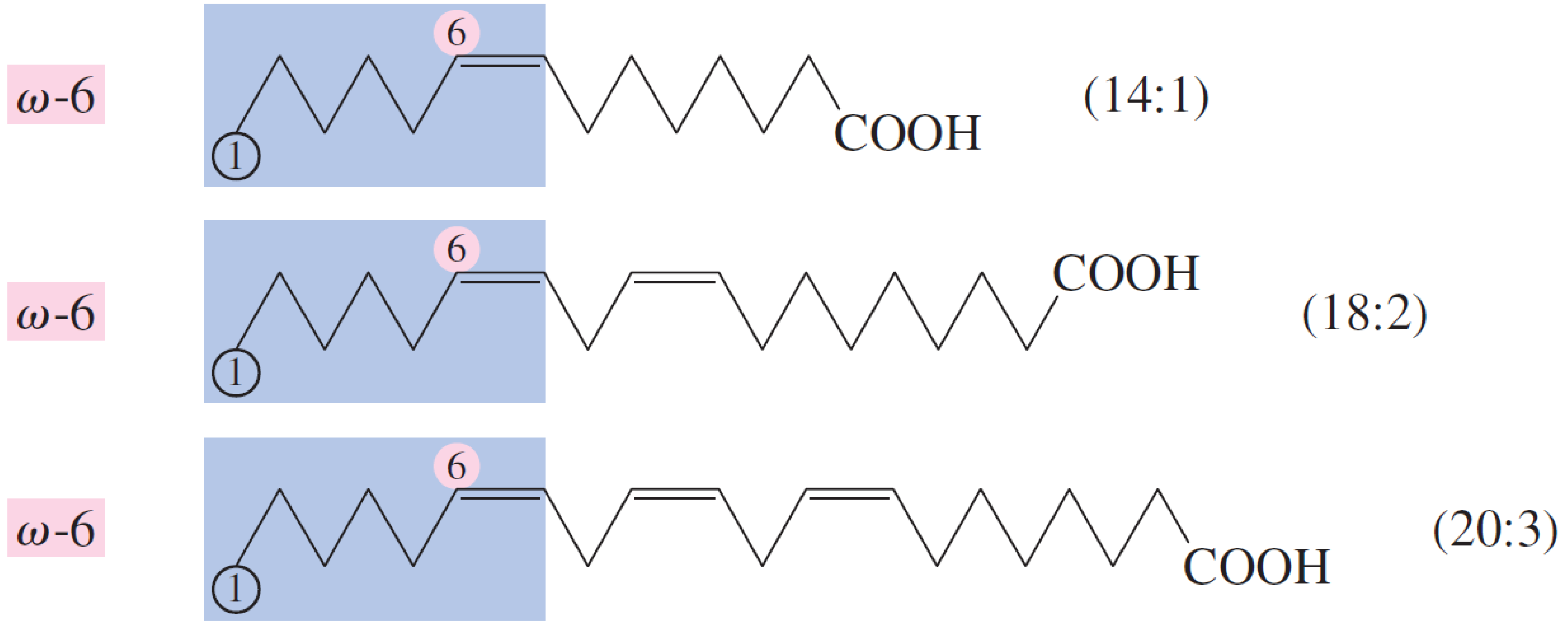


Table 8-1 Selected Fatty Acids of Biological Importance

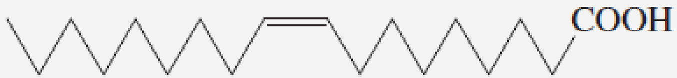
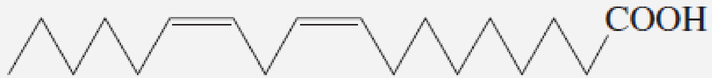
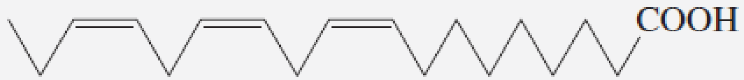
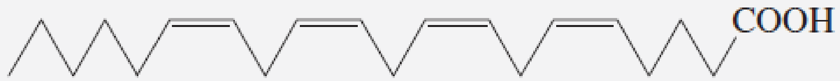
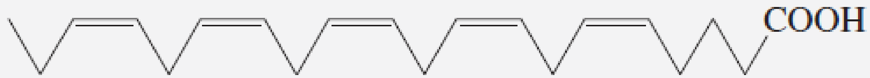
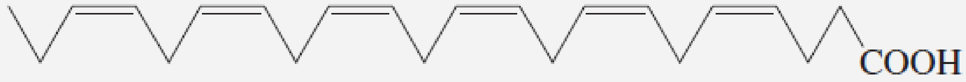
Structural Notation			Common Name	Structure
Saturated Fatty Acids				
12:0			lauric acid	
14:0			myristic acid	
16:0			palmitic acid	
18:0			stearic acid	
20:0			arachidic acid	
Monounsaturated Fatty Acids				
16:1	Δ^{9}	ω-7	palmitoleic acid	
18:1	Δ^{9}	ω-9	oleic acid	
Polyunsaturated Fatty Acids				
18:2	$\Delta^{9,12}$	ω-6	linoleic acid	
18:3	$\Delta^{9,12,15}$	ω-3	linolenic acid	
20:4	$\Delta^{5,8,11,14}$	ω-6	arachidonic acid	
20:5	$\Delta^{5,8,11,14,17}$	ω-3	EPA (eicosapentaenoic acid)	
22:6	$\Delta^{4,7,10,13,16,19}$	ω-3	DHA (docosahexaenoic acid)	

TABLE 17.1 Common Saturated and Unsaturated Fatty Acids

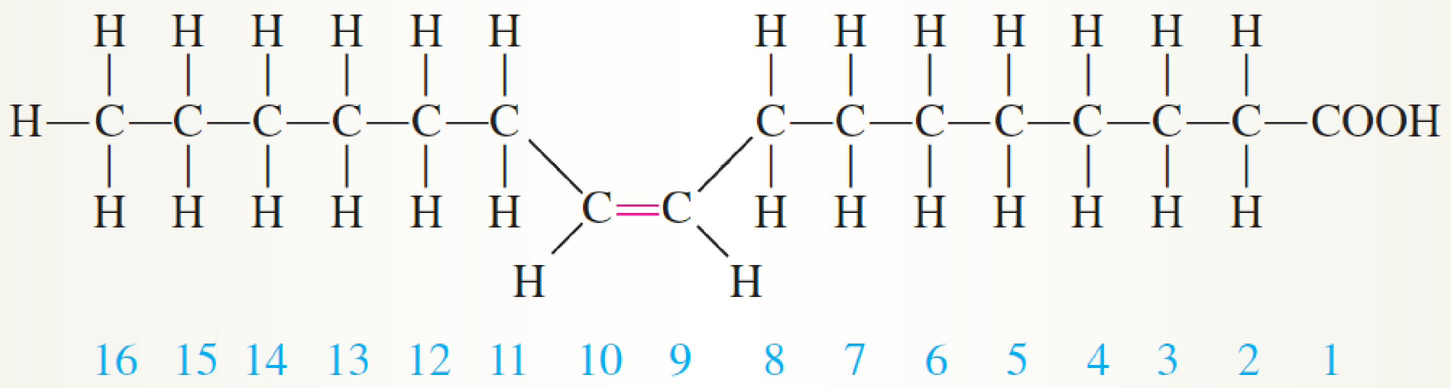
Common Saturated Fatty Acids					
Common Name	**IUPAC Name**	**Melting Point (°C)**	**Molar Mass**	**Condensed Formula**	
Capric	Decanoic	32	172.26	$CH_3(CH_2)_8COOH$	
Lauric	Dodecanoic	44	200.32	$CH_3(CH_2)_{10}COOH$	
Myristic	Tetradecanoic	54	228.37	$CH_3(CH_2)_{12}COOH$	
Palmitic	Hexadecanoic	63	256.42	$CH_3(CH_2)_{14}COOH$	
Stearic	Octadecanoic	70	284.48	$CH_3(CH_2)_{16}COOH$	
Arachidic	Eicosanoic	77	312.53	$CH_3(CH_2)_{18}COOH$	
Common Unsaturated Fatty Acids					
Common Name	**IUPAC Name**	**Melting Point (°C)**	**Molar Mass**	**Number of Double Bonds**	**Position of Double Bond(s)**
Palmitoleic	*cis*-9-Hexadecenoic	0	254.41	1	9
Oleic	*cis*-9-Octadecenoic	16	282.46	1	9
Linoleic	*cis,cis*-9,12-Octadecadienoic	5	280.45	2	9, 12
Linolenic	All *cis*-9,12,15-Octadecatrienoic	−11	278.43	3	9, 12, 15
Arachidonic	All *cis*-5,8,11,14-Eicosatetraenoic	−50	304.47	4	5, 8, 11, 14
Condensed Formula					
Palmitoleic	$CH_3(CH_2)_5CH = CH(CH_2)_7COOH$				
Oleic	$CH_3(CH_2)_7CH = CH(CH_2)_7COOH$				
Linoleic	$CH_3(CH_2)_4CH = CH{-}CH_2{-}CH = CH(CH_2)_7COOH$				
Linolenic	$CH_3CH_2CH = CH{-}CH_2{-}CH = CH{-}CH_2{-}CH = CH(CH_2)_7COOH$				
Arachidonic	$CH_3(CH_2)_4CH = CH{-}CH_2{-}CH = CH{-}CH_2{-}CH = CH{-}CH_2{-}CH = CH(CH_2)_3COOH$				

EXAMPLE 17.1 Writing the Structural Formula of an Unsaturated Fatty Acid

Draw the structural formula for palmitoleic acid.

Solution

The IUPAC name of palmitoleic acid is *cis*-9-hexadecenoic acid. The name tells us that this is a 16-carbon fatty acid having a carbon-to-carbon double bond between carbons 9 and 10. The name also reveals that this is the *cis*-isomer.



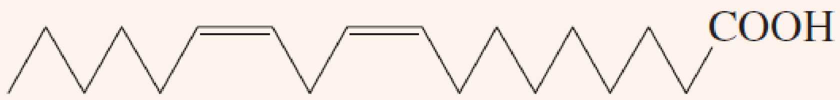
Practice Problem 17.1

Draw the line formulas for (a) oleic acid and (b) linoleic acid.

EXAMPLE 8-1

Classifying Fatty Acids on the Basis of Structural Characteristics

Classify the fatty acid with the following structural formula in the ways indicated.



a. What is the type designation (SFA, MUFA, or PUFA) for this fatty acid?
b. On the basis of carbon chain length and degree of unsaturation, what is the numerical shorthand designation for this fatty acid?
c. To which "omega" family of fatty acids does this fatty acid belong?
d. What is the "delta" designation for the carbon chain double-bond locations for this fatty acid?

Solution

a. Two carbon–carbon double bonds are present in this molecule, which makes it a *polyunsaturated fatty acid (PUFA).*
b. Eighteen carbon atoms and two carbon–carbon double bonds are present. The shorthand numerical designation for this fatty acid is thus *18:2.*
c. Counting from the methyl end of the carbon chain, the first double bond encountered involves carbons 6 and 7. This fatty acid belongs to the *omega-6* family of fatty acids.
d. Counting from the carboxyl end of the carbon chain, with C1 being the carboxyl group, the double-bond locations are 9 and 12. This is a $\Delta^{9,12}$ *fatty acid.*

Section 8-2 Quick Quiz

1. Which of the following statements concerning fatty acids is *correct*?
   - **a.** They are naturally occurring dicarboxylic acids.
   - **b.** They are rarely found in the free state in nature.
   - **c.** They almost always contain an odd number of carbon atoms.
   - **d.** no correct response
2. In which of the following pairs of fatty acids are both members of the pair polyunsaturated fatty acids?
   - **a.** 18:0 acid and 18:1 acid
   - **b.** 18:1 acid and 18:2 acid
   - **c.** 18:2 acid and 18:3 acid
   - **d.** no correct response
3. Which of the following fatty acids is an omega-6 fatty acid?
   - **a.** $CH_3—(CH_2)_{18}—COOH$
   - **b.** $CH_3—(CH_2)_7—CH{=}CH—(CH_2)_7—COOH$
   - **c.** $CH_3—(CH_2)_4—CH{=}CH—(CH_2)_8—COOH$
   - **d.** no correct response
4. The double bond present in a monounsaturated fatty acid almost always
   - **a.** is in a *cis*-configuration
   - **b.** involves the second carbon from the carboxyl end of the carbon chain
   - **c.** involves the second carbon from the methyl end of the carbon chain
   - **d.** no correct response

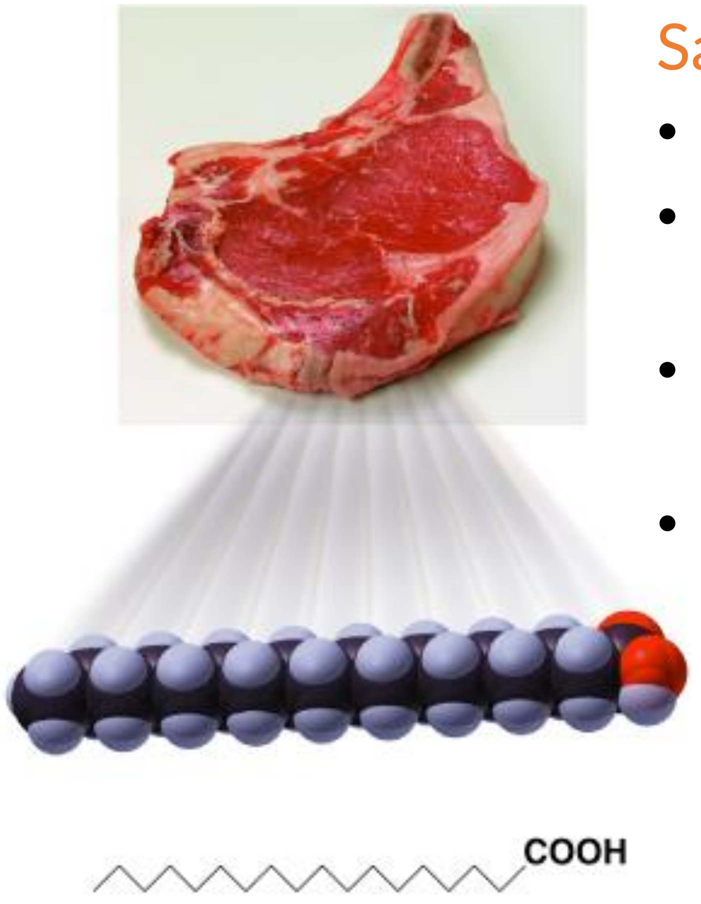
Fatty Acids: *Physical Properties*

The physical properties of fatty acids, and of lipids that contain them, are largely determined by the **length** and **degree of unsaturation** of the fatty acid carbon chain.

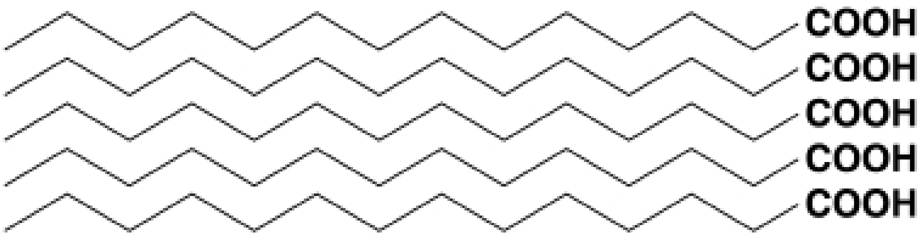
Water solubility:
The slight solubility of short-chain fatty acids is related to the polarity of the carboxyl group present. In longer-chain fatty acids, the nonpolar nature of the hydrocarbon chain completely dominates solubility considerations.

Saturated fatty acids (left) have

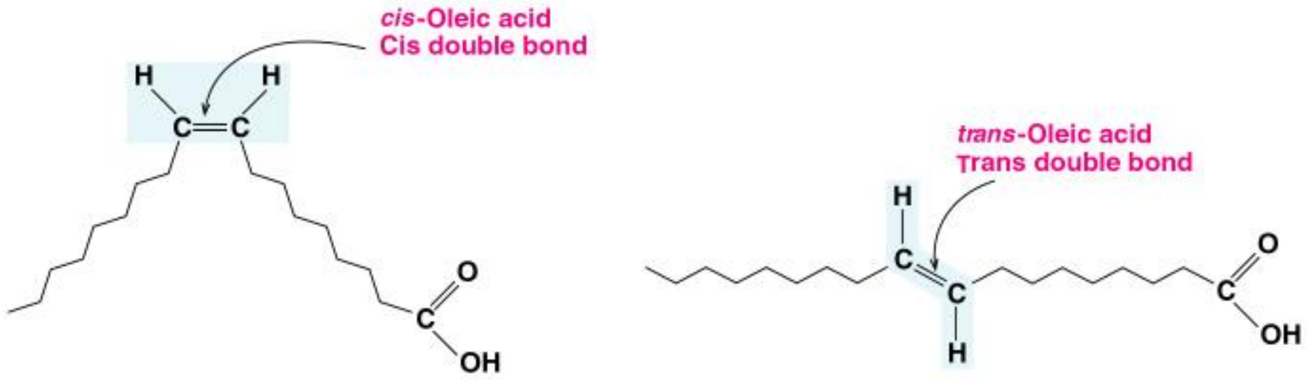
- Single C–C bonds.
- Molecules that fit closely together in a regular pattern.
- Strong attractions between fatty acid chains.
- High melting points that make them solids at room temperature.



Stearic acid, mp 69˚C

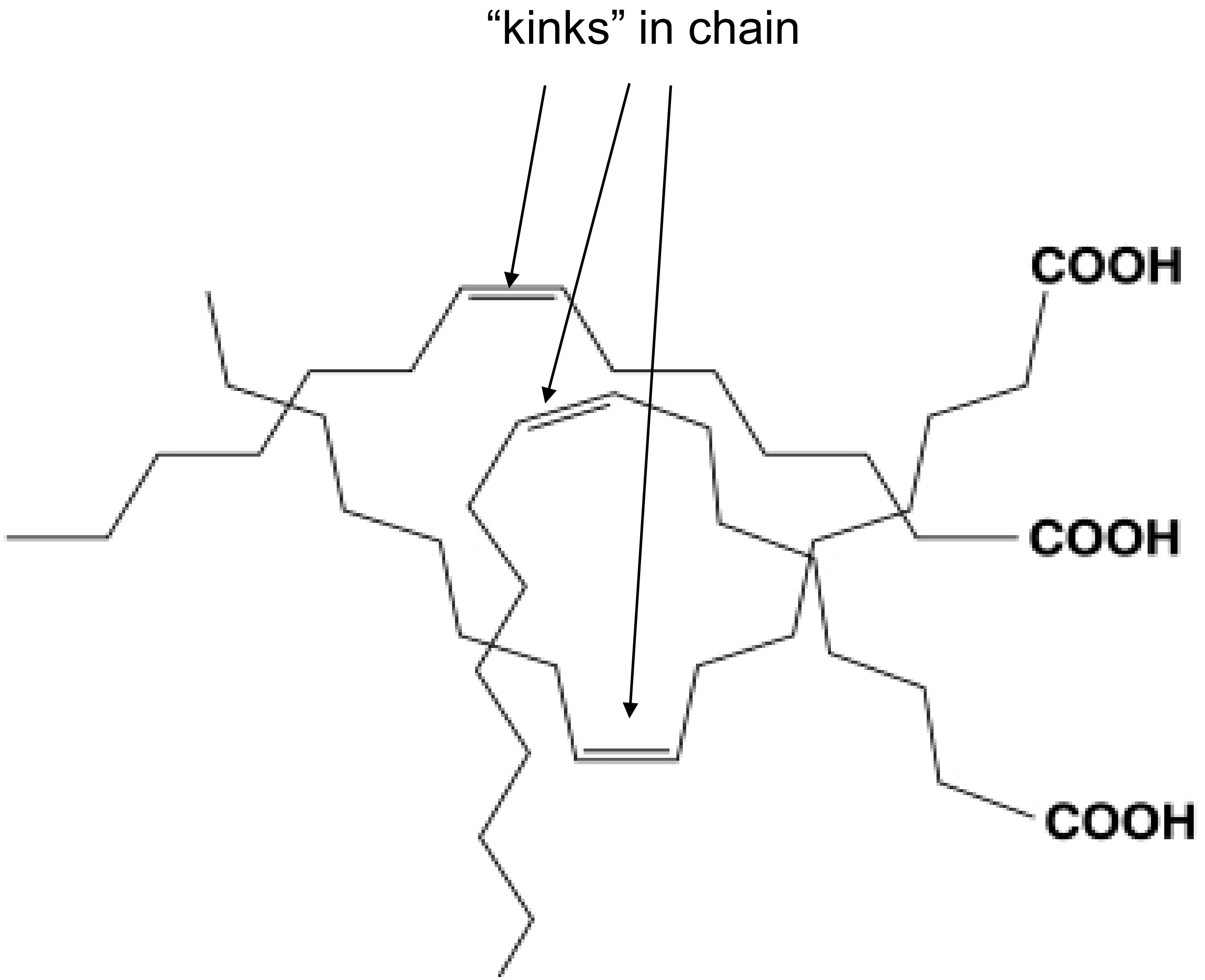


Oleic acid, mp 13˚C



Unsaturated fatty acids

- Have “kinks” in the fatty acid chains.
- Do not pack closely.
- Have few attractions between chains.
- Have low melting points.
- Are liquids at room temperature.



Fatty Acids: *Physical Properties*

Melting point:
As carbon chain length increases, melting point increases. This trend is related to the greater surface area associated with a longer carbon chain and to the increased opportunities that this greater surface area affords for intermolecular attractions between fatty acid molecules.

Saturated fatty acids containing ten or more carbons are solids at room temperature.

The greater the degree of unsaturation, the greater the reduction in melting points.

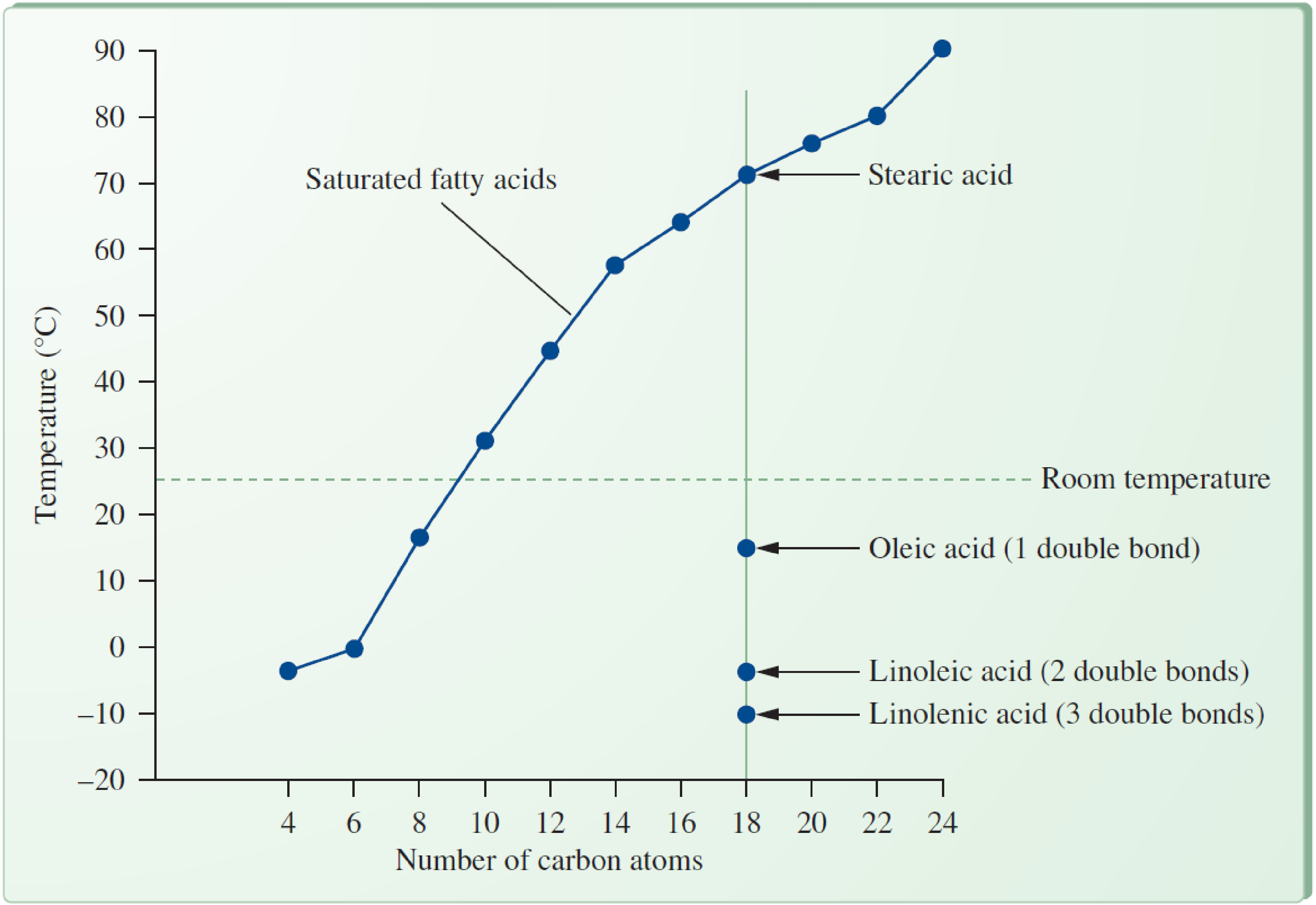
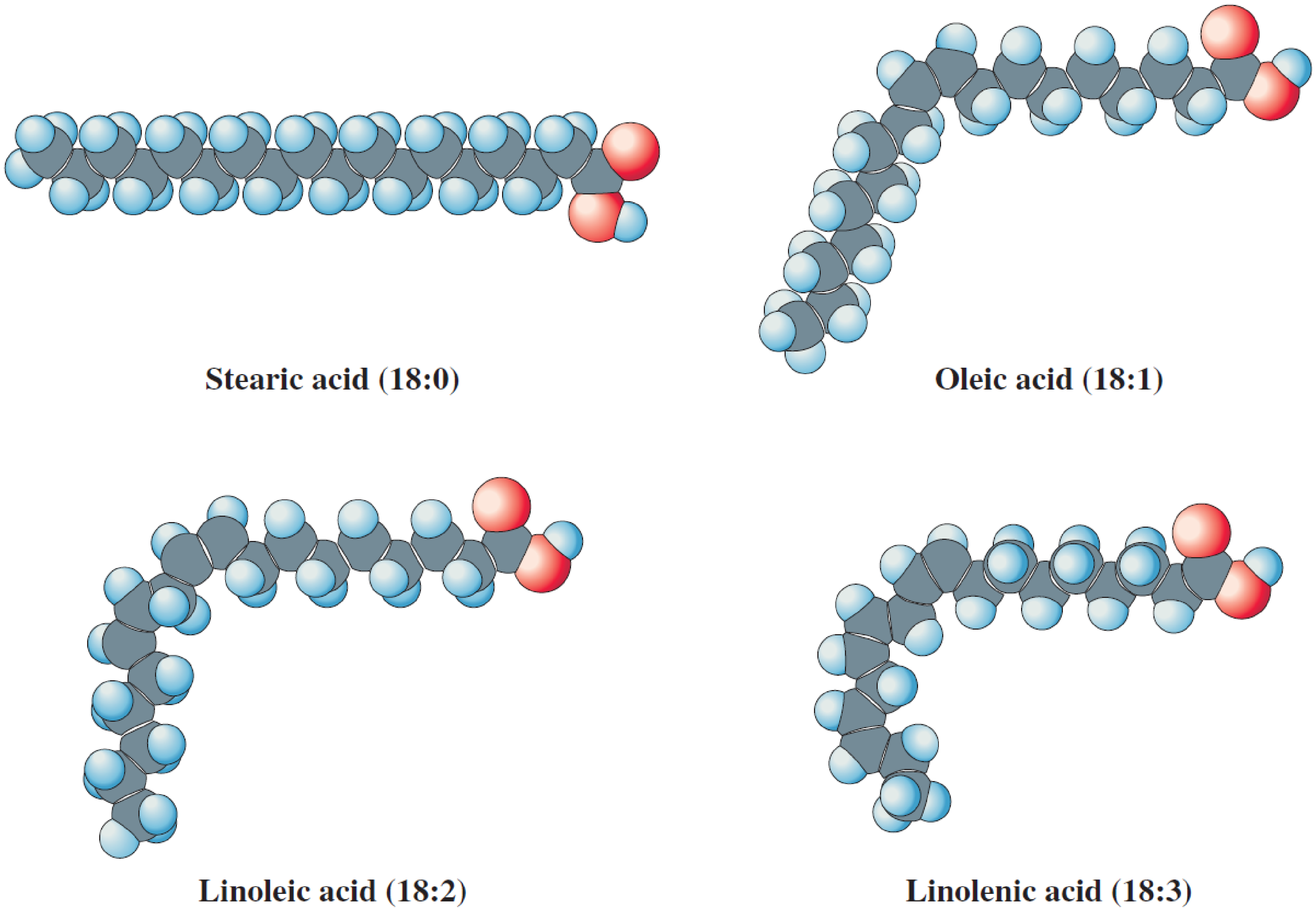


Figure 17.2 The melting points of fatty acids. Melting points of both saturated and unsaturated fatty acids increase as the number of carbon atoms in the chain increases. The melting points of unsaturated fatty acids are lower than those of the corresponding saturated fatty acid with the same number of carbon atoms. Also, as the number of double bonds in the chain increases, the melting points decrease.



“kinked” molecules cannot stack in an organized arrangement and thus have lower intermolecular attractions and lower melting points.

Figure 8-3 Space-filling models of four 18-carbon fatty acids, which differ in the number of double bonds present. Note how the presence of double bonds changes the shape of the molecule.

Section 8-3 Quick Quiz

1. In which of the following pairs of fatty acids does the first listed acid have a greater water solubility than the second listed acid?
   a. 18:0 acid and 14:0 acid
   b. 16:0 acid and 18:0 acid
   c. 20:0 acid and 16:0 acid
   d. no correct response

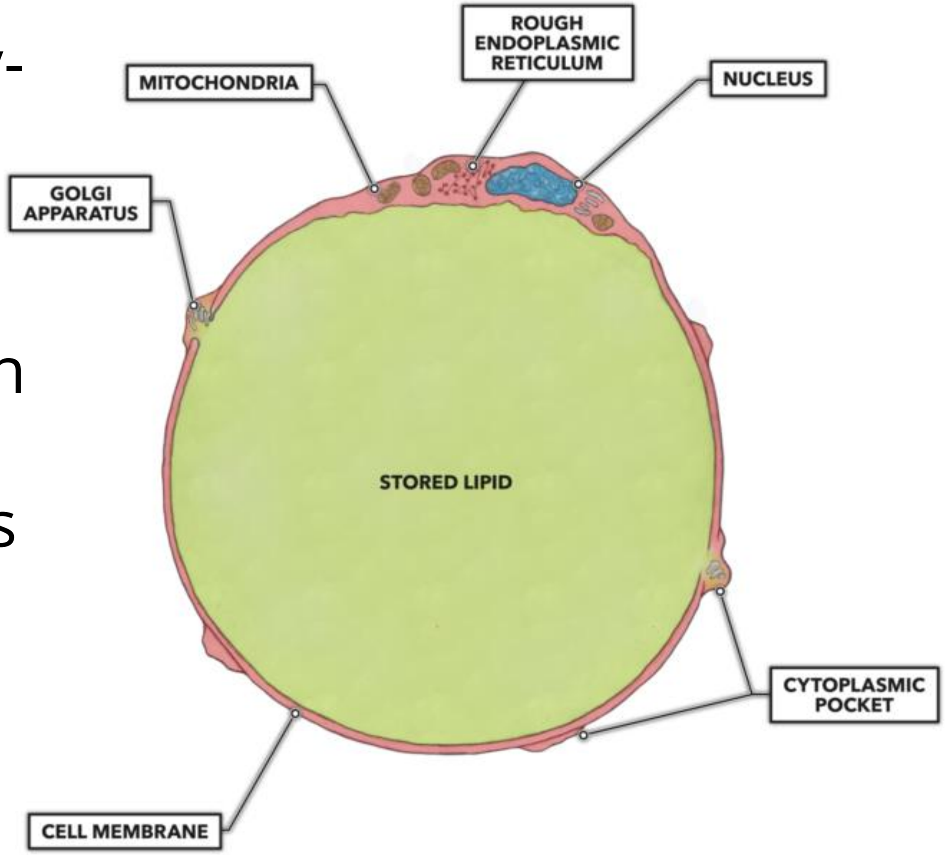
2. In which of the following pairs of fatty acids does the first listed acid have a lower melting point than the second listed acid?
   a. 16:0 acid and 16:1 acid
   b. 18:2 acid and 18:0 acid
   c. 18:2 acid and 18:3 acid
   d. no correct response

Energy-Storage Lipids: Triacylglycerols

With the notable exception of nerve cells, human cells store small amounts of energy-providing materials for use when energy demand is high. The most widespread energy-storage material within cells is the carbohydrate **glycogen** (next chapter).

Lipids known as **triacylglycerols** also function within the body as energy-storage materials. Rather than being widespread, triacylglycerols are ***concentrated primarily in special cells (adipocytes)*** that are nearly filled with the material.

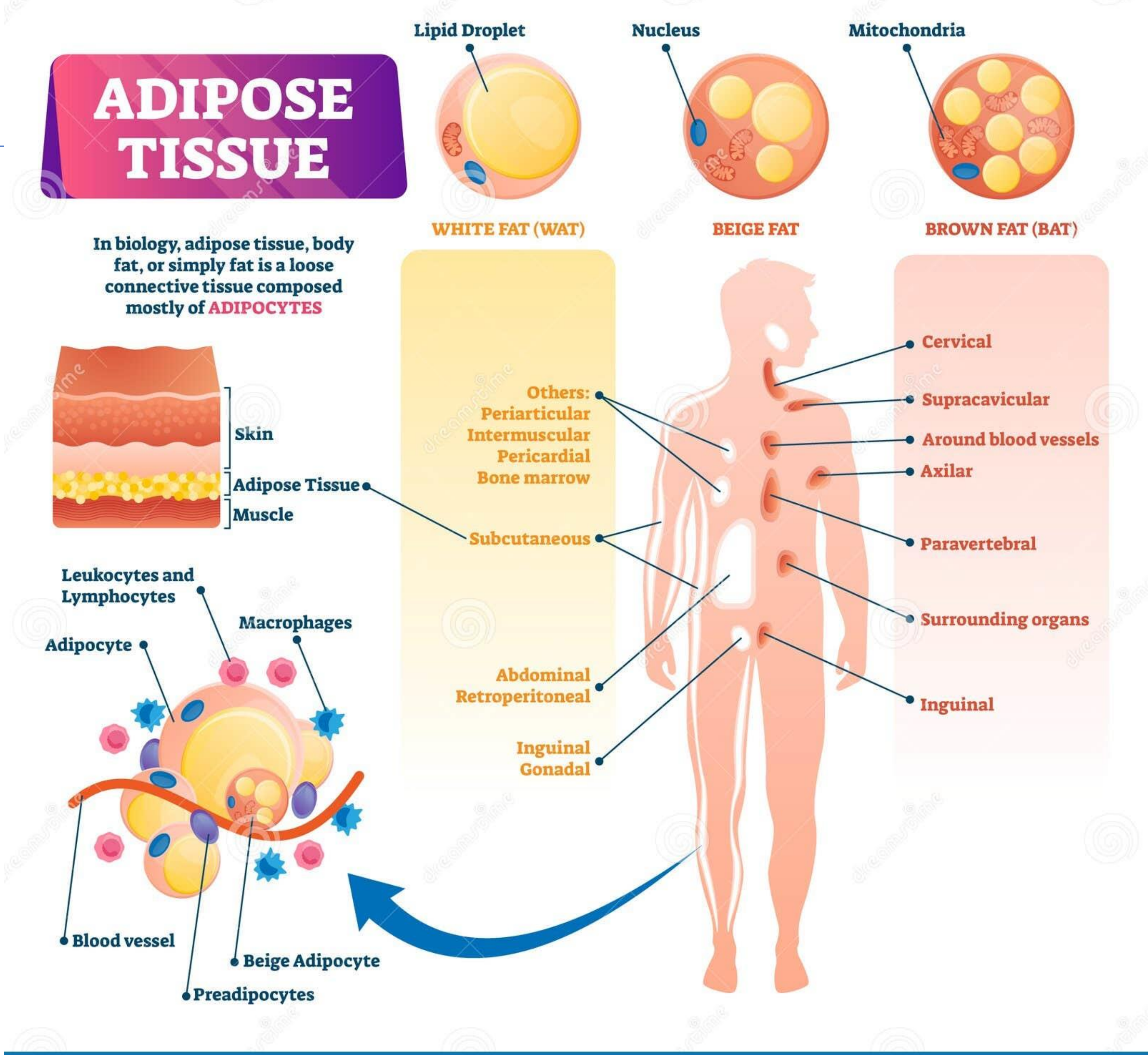
adipocyte



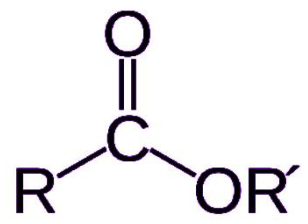
Triacylglycerols

Adipose tissue containing adipocytes is found in various parts of the body: under the skin, in the abdominal cavity, in the mammary glands, and around various organs.

Although monoglycerides and diglycerides are present in nature, the most important neutral glycerides are the triglycerides, the major component of fat cells.

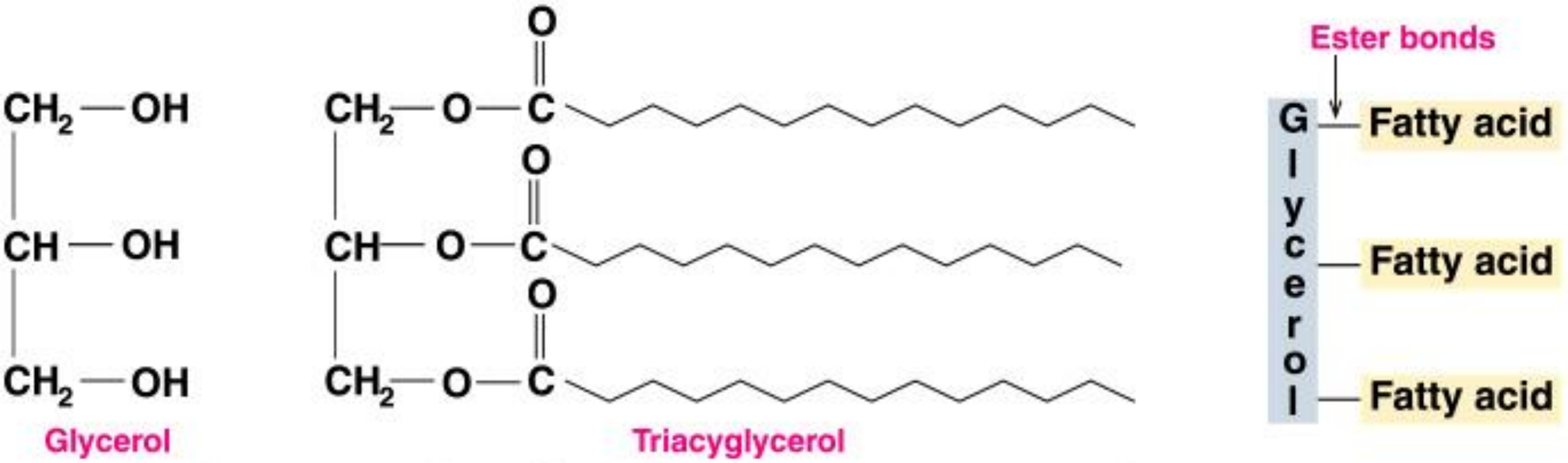


Energy-Storage Lipids: Triacylglycerols

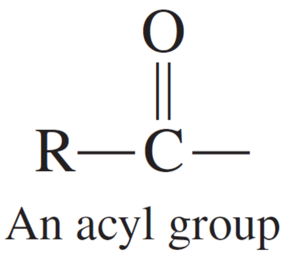


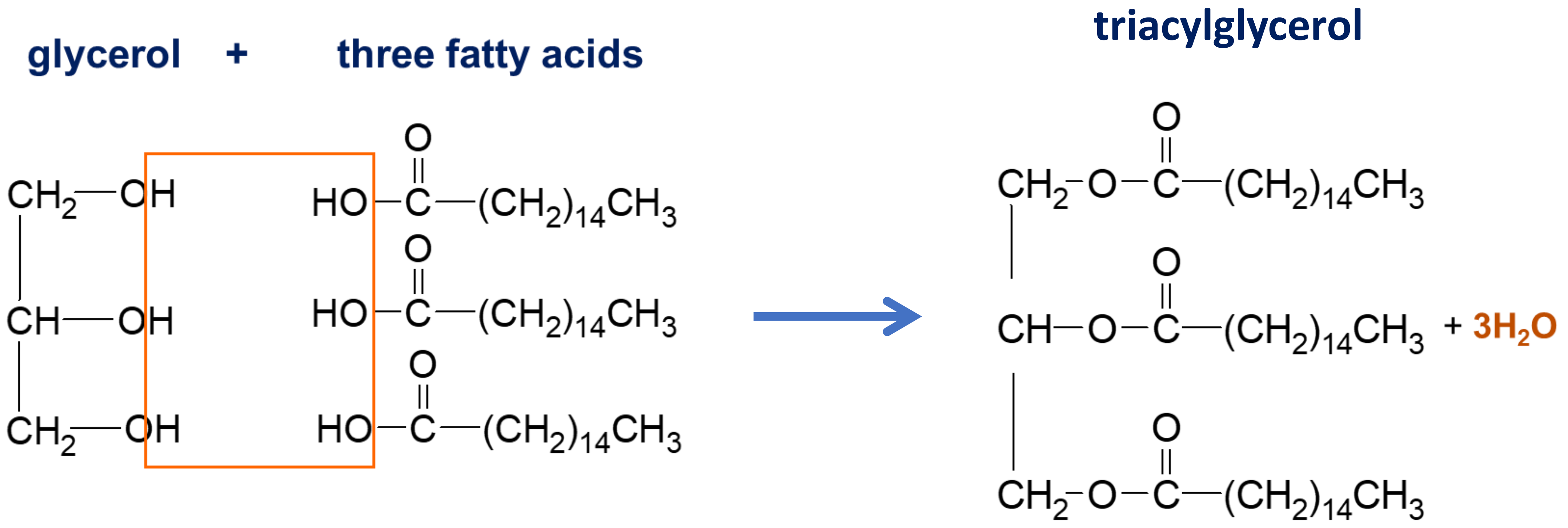
In terms of functional groups present, **triacylglycerols are triesters**; three ester functional groups are present.

Recall: an **ester** is a compound produced from the reaction of an alcohol with a carboxylic acid.



Timberlake, *General, Organic, and Biological Chemistry*. Copyright © Pearson Education Inc., publishing as Benjamin Cummings



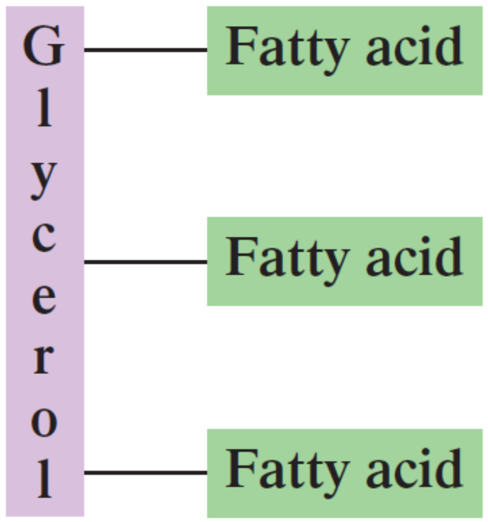


Formed when the hydroxyl groups of glycerol react with the carboxyl groups of fatty acids. Because there are no charges (+ or −) on these molecules, they are called **neutral glycerides**. These long molecules **readily stack with one another** and constitute the majority of the lipids stored in the body's fat cells.

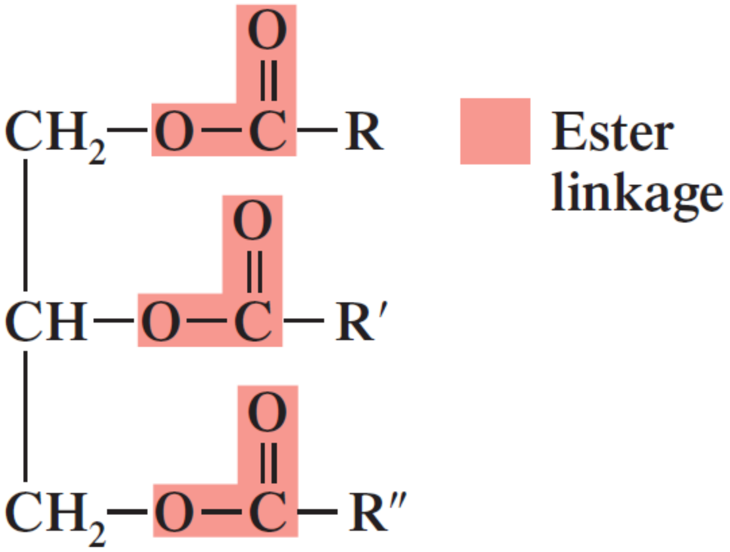
Energy-Storage Lipids: Triacylglycerols

Two general ways to represent the structure of a triacylglycerol are

▶ *Triacylglycerols do not actually contain glycerol and three fatty acids, as the block diagram for a triacylglycerol implies. They actually contain a glycerol* residue *and three fatty acid* residues. *In the formation of the triacylglycerol, three molecules of water have been removed from the structural components of the triacylglycerol, leaving residues of the reacting molecules.*



A block diagram

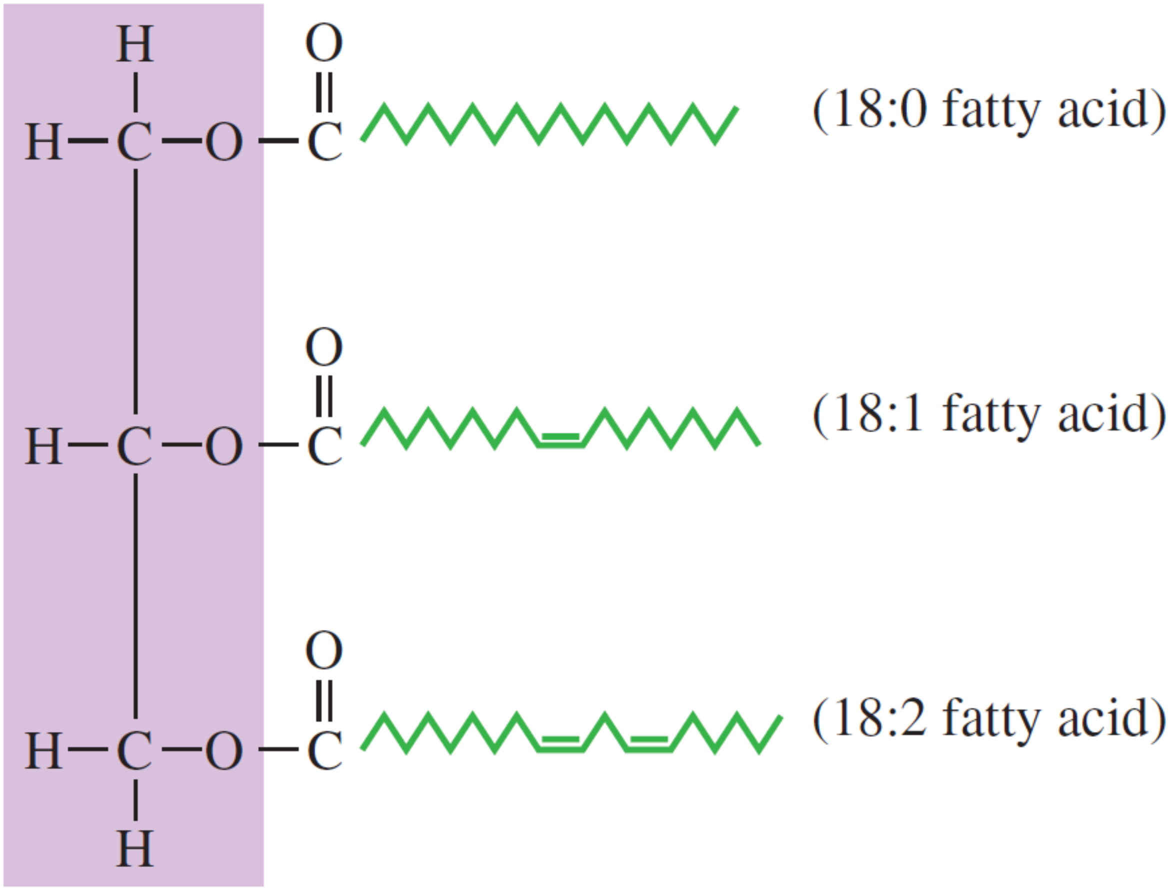


A general structural formula

Energy-Storage Lipids: Triacylglycerols

- Simple triacylglycerol - with three identical fatty acid residues
- Mixed triacylglycerol - with more than one kind of fatty acid residue

Figure 8-6 Structure of a mixed triacylglycerol in which three different fatty acid residues are present.



Triacylglycerols: *Fats and Oils*

Fats and oils are naturally occurring mixtures of triacylglycerol molecules in which ***many different kinds of triacylglycerol molecules are present.***

What distinguishes a fat from an oil?

The answer is physical state at room temperature.

A fat is a triacylglycerol mixture that is a **solid or a semi-solid** at room temperature (25°C); generally obtained from **animal sources**.

An oil is a triacylglycerol mixture that is a **liquid** at room temperature (25°C); generally obtained from **plant sources**.

Triacylglycerols: *Fats and Oils*

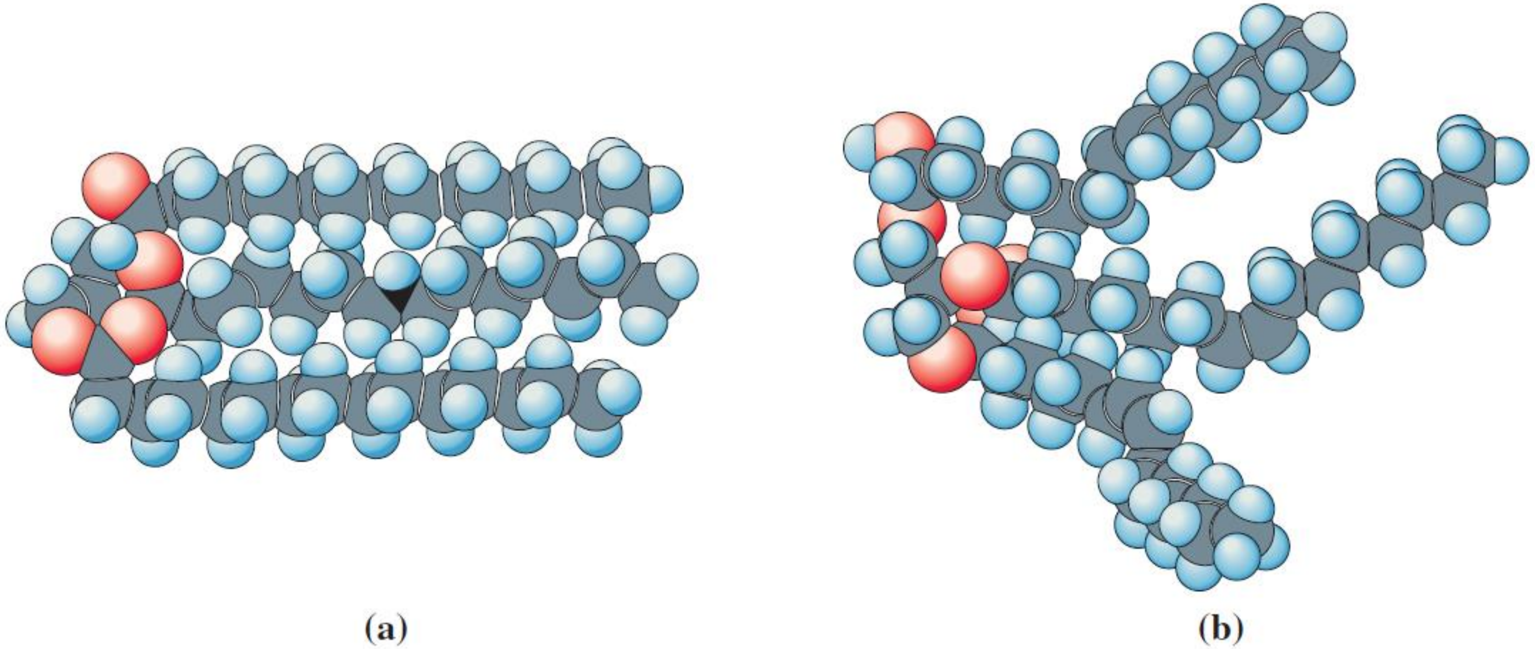
- The actual composition of a fat or oil varies even for the species from which it is obtained. ***Composition depends on both dietary and climatic factors***. For example, fat obtained from corn-fed hogs has a different overall composition than fat obtained from peanut-fed hogs. Flaxseed grown in warm climates gives oil with a different composition from that obtained from flaxseed grown in colder climates.

Triacylglycerols: *Fats and Oils*

Additional generalizations and comparisons between fats and oils:

1. **Fats** are composed largely of triacylglycerols in which ***saturated fatty acids predominate***, although some unsaturated fatty acids are present. **Oils** contain triacylglycerols with ***larger amounts of mono- and polyunsaturated fatty acids*** than those in fats.

Figure 8-7 Representative triacylglycerols from (a) a fat and (b) an oil.



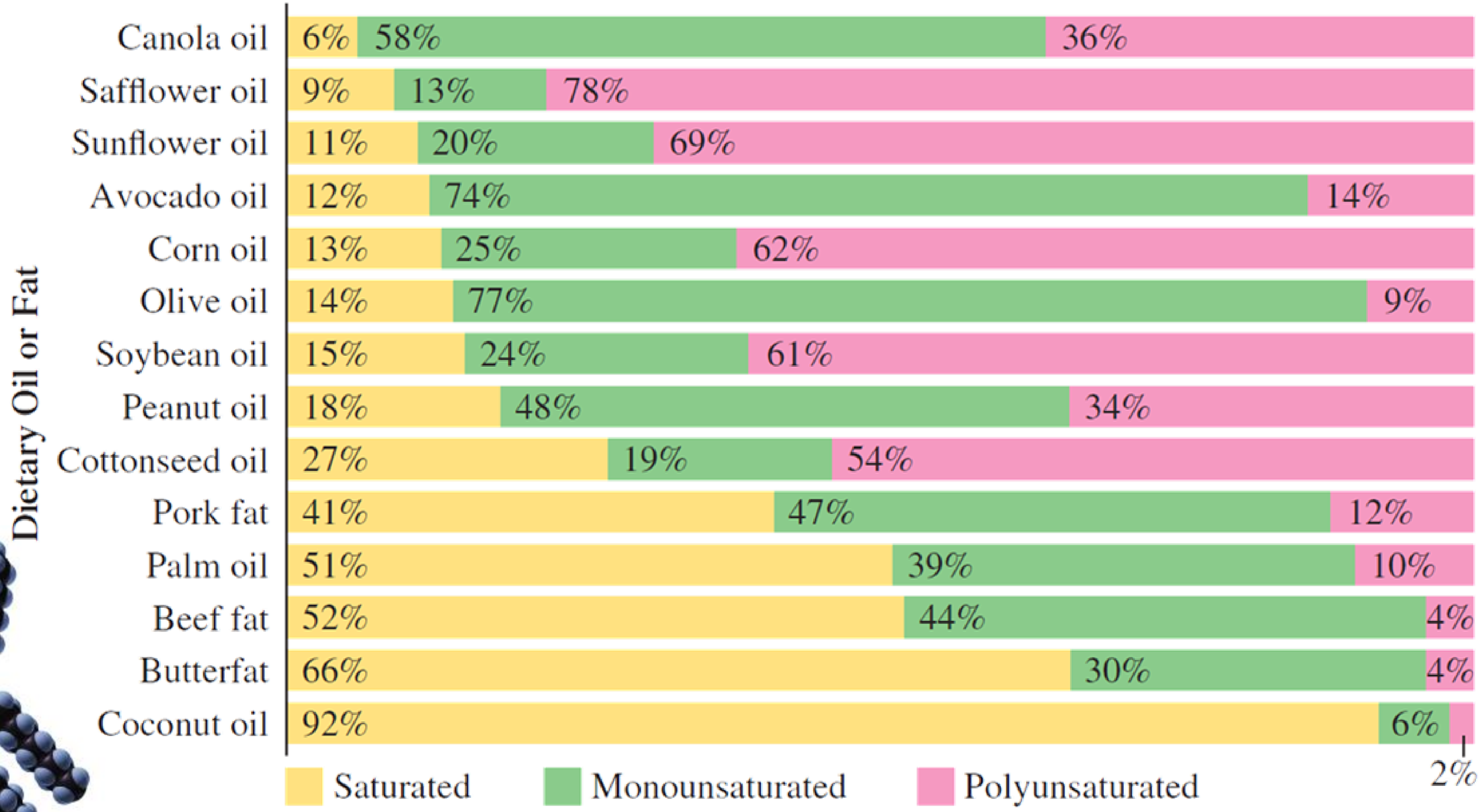
Triacylglycerols: *Fats and Oils*

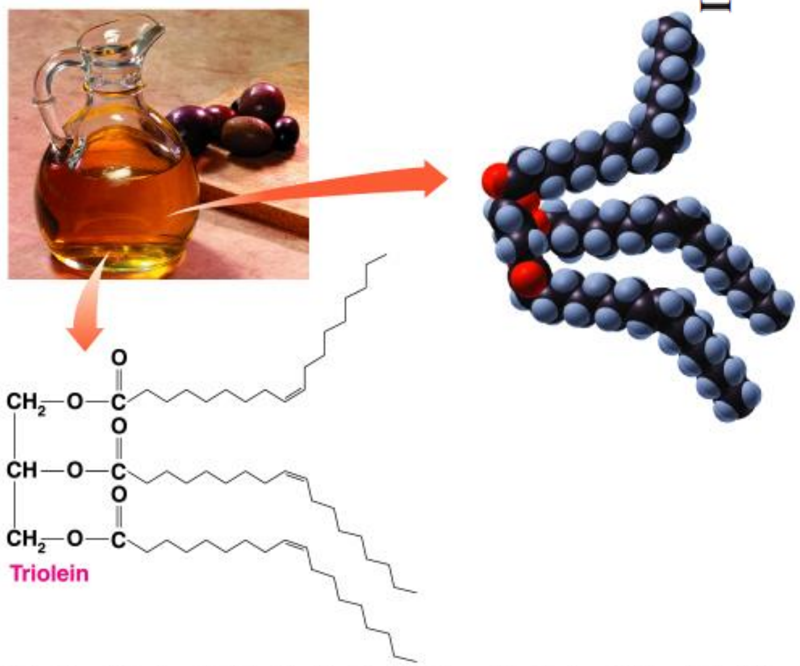
Additional generalizations and comparisons between fats and oils:

2. ***Fats are generally obtained from animals***; hence the term *animal fat*. ***Oils typically come from plants***, although there are also fish oils. A fish would have some serious problems if its triacylglycerols "solidified" when it encountered cold water.

3. ***Pure fats and pure oils are colorless, odorless, and tasteless***. The tastes, odors, and colors associated with dietary plant oils are caused by small amounts of other naturally occurring substances present in the plant that have been carried along during processing.

Figure 8-8 Percentages of saturated, monounsaturated, and polyunsaturated fatty acids in the triacylglycerols of various dietary fats and oils.

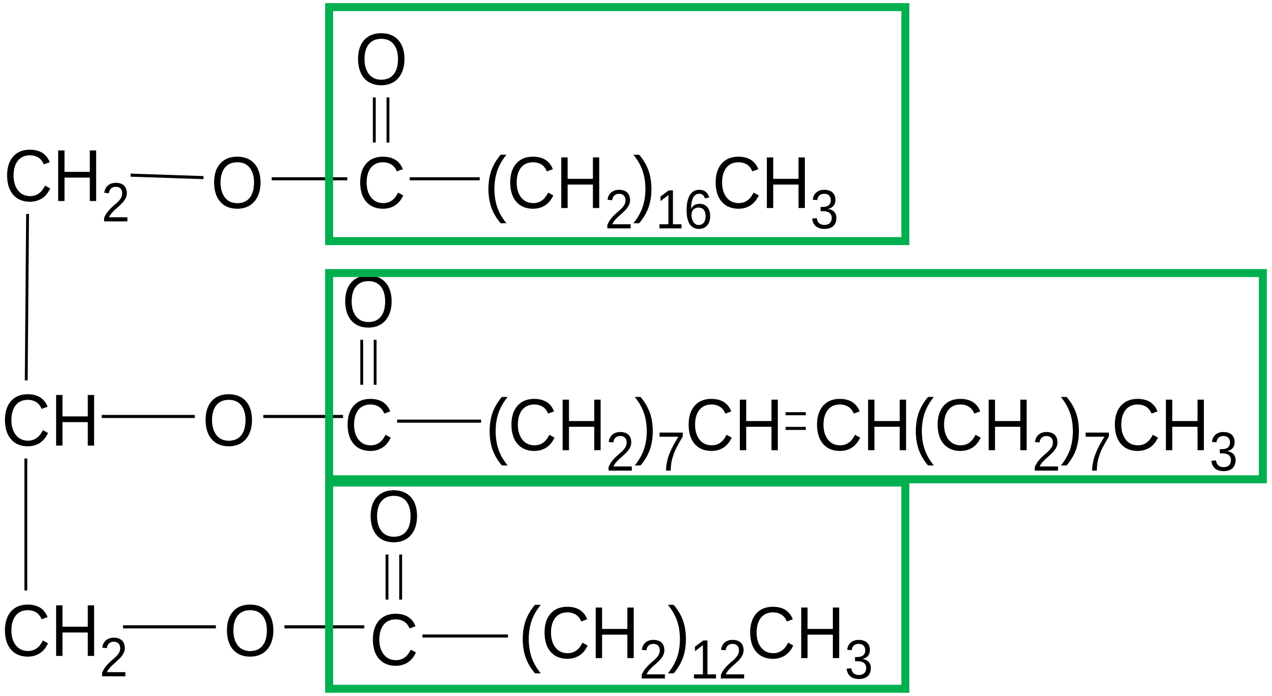




Olive oil contains a high percentage of oleic acid, which is a MUFA with one *cis* double bond.

Learning Check:

What are the fatty acids in the following triacylglycerol?



Stearic acid (18:0)

Oleic acid (18:1)

Myristic acid (14:0)

Section 8-4 Quick Quiz

1. How many structural "subunits" are present in the block diagram for a triacylglycerol?
   - **a.** two
   - **b.** three
   - **c.** four
   - **d.** no correct response

2. How many ester linkages are present in a triacylglycerol molecule?
   - **a.** zero
   - **b.** two
   - **c.** four
   - **d.** no correct response

3. How many different *simple* triglyceride molecules can be produced that include glycerol, stearic acid, and palmitic acid as part of their structure?
   - **a.** zero
   - **b.** one
   - **c.** two
   - **d.** no correct response

4. How many different *mixed* triglyceride molecules can be produced that include glycerol, stearic acid, and palmitic acid as part of their structure?
   a. two
   b. three
   c. four
   d. no correct response
5. Which of the following is a distinguishing characteristic between fats and oils?
   a. physical state at room temperature
   b. number of structural subunits present
   c. number of fatty acid residues present
   d. no correct response
6. Unsaturated fatty acid residues are structural components of
   a. both fats and oil
   b. fats but not oils
   c. oils but not fats
   d. no correct response

Dietary Considerations and Triacylglycerols

Numerous studies have shown that, ***in general***, nations whose citizens have high dietary intakes of triacylglycerols (fats and oils) tend to have higher incidences of heart disease and certain types of cancers.

Contrary to the general trend, however, there are several areas of the world where ***high dietary fat intake does not translate into high risks*** for cardiovascular disease, obesity, and certain types of cancers. These exceptions, which include some Mediterranean countries and the Inuit people of Greenland, suggest that **relationships between dietary triacylglycerol intake and risk factors for disease involve more than simply the total amount of triacylglycerols consumed**.

Dietary Considerations and Triacylglycerols

"Good Fats" Versus "Bad Fats"

Fat is used as a substitute for the term *triacylglycerol*; thus, *dietary fat* is either a "fat" or an "oil".

Both the **type of dietary fat consumed** and the **amount of dietary fat consumed** are important factors in determining human body responses to dietary fat.

Current recommendation:

- total fat intake should be limited to 30% of total calories
- Up to 15% monounsaturated fat, up to 10% polyunsaturated fat, and less than 10% saturated fats

Dietary Considerations and Triacylglycerols

Different organisms differ in the overall structural characteristics of the fatty acids present.

1. Humans and animals have 5%–7% of fatty acids with **20 or 22 carbon atoms**, while fish have **25%–30%.**
2. Humans and animals have less than 1% of their fatty acids with **5–6 double bonds**, while plants have **5%–6%**, and fish **15%–30%.**

Dietary Considerations and Triacylglycerols

Not all fish are equal in omega-3 fatty acid content. Cold-water fish, also called fatty fish because of the extra amounts of fat they have for insulation against the cold, contain more omega-3 acids than leaner, warm-water fish. Fatty fish include albacore tuna, salmon, and mackerel.

Leaner, warm-water fish, which include cod, catfish, halibut, sole, and snapper, do not appear to offer as great a positive effect on heart health as do their "fatter" counterparts.

Table 8-2 Omega-3 Fatty Acid Amounts Associated with Various Kinds of Cold-Water Fish

Per 3.5-oz. Serving (raw)	Omega-3s (grams)*
mackerel	2.3
albacore tuna	2.1
herring, Atlantic	1.6
anchovy	1.5
salmon, wild king (Chinook)	1.4
salmon, wild sockeye (red)	1.2
tuna, bluefin	1.2
salmon, wild pink	1.0
salmon, wild Coho (silver)	0.8
oysters, Pacific	0.7
salmon, farm-raised Atlantic	0.6
swordfish	0.6
trout, rainbow	0.6

*Omega-3 content of fish can vary depending on harvest location and time of year.

Fish do not make the omega-3 fatty acids they have within themselves. Rather, they obtain these fatty acids from the **algae** that they feed on. Genetic engineering experiments are underway in which the genes that allow algae to synthesize omega-3 fatty acids are incorporated into plants. In the future, plants may become sources for omega-3 fatty acids.

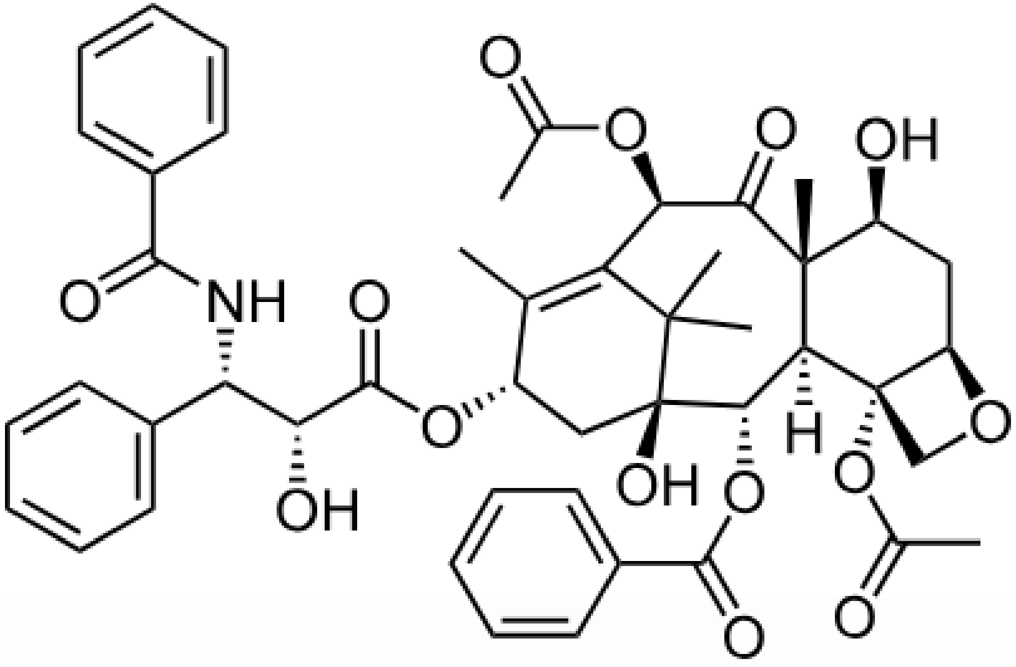
Fat and Fatty Acid Composition of Selected Nuts

	Total Fat (percentage of weight)	SFA	MUFA	PUFA	UFA/SFA Ratio
		(percentage of total fat)			
almonds	52	10	68	22	9.0
cashews	46	20	62	18	3.9
hazelnuts	63	8	82	10	11.9
macadamias	74	16	82	2	5.4
peanuts	49	15	51	34	5.7
pecans	68	8	66	26	10.9
pistachios	48	13	72	15	6.6
walnuts	62	10	24	66	9.0

Nuts also offer valuable antioxidant vitamins, minerals, plant fiber protein, and secondary metabolites.

Paclitaxel

- a highly lipophilic diterpenoid compound that was first discovered in theslow-growing and limited pacific yew tree Taxus brevifolia in 1963
- commercially known as the anti-cancer drug Taxol
- Was found in the more readily available hazelnuts in the year 2000



Hazelnuts and hazelnut shells. © Petr Gross/Getty

Dietary Considerations and Triacylglycerols

Essential Fatty Acids

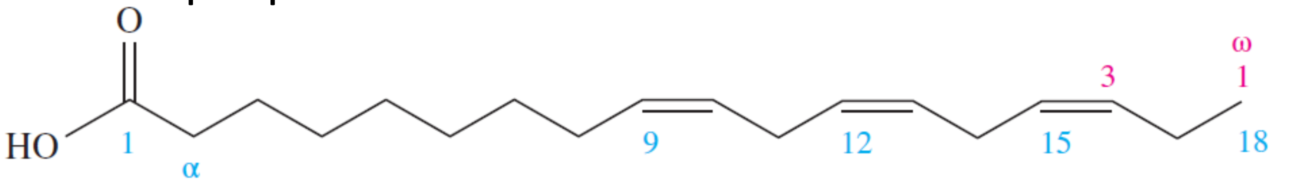
Table 8-3 Biochemically Important Omega-3 and Omega-6 Fatty Acids

Omega-3 Acids	Omega-6 Acids
linolenic acid (18:3) (lin-oh-LEN-ic)	linoleic acid (18:2) (lin-oh-LAY-ic)
eicosapentaenoic acid (20:5) (EYE-cossa-PENTA-ee-NO-ic)	arachidonic acid (20:4) (a-RACK-ih-DON-ic)
docosahexaenoic acid (20:6) (DOE-cossa-HEXA-ee-NO-ic)	

- Linoleic acid is the starting material for the biosynthesis of arachidonic acid.
- Linolenic acid is the starting material for the biosynthesis of two additional omega-3 fatty acids.

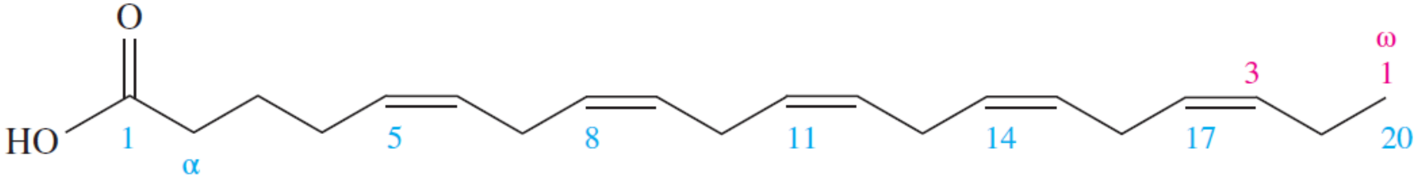
omega-3 fatty acids reduce the risk of cardiovascular disease by decreasing blood clot formation, blood triglyceride levels, and growth of atherosclerotic plaque.

- **Linolenic acid (ALA)** an essential fatty acid and must be acquired through the diet

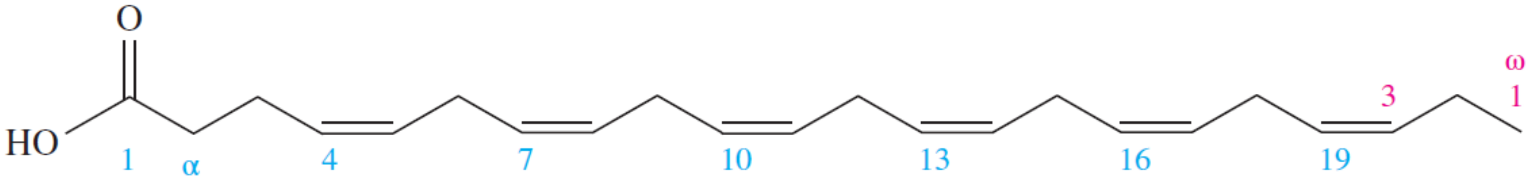


All *cis*-9,12,15-Octadecatrienoic acid
(α-linolenic acid or ALA)

- **EPA** is a precursor for the synthesis of prostacyclin, which inhibits clumping of platelets and thus reduces clot formation.

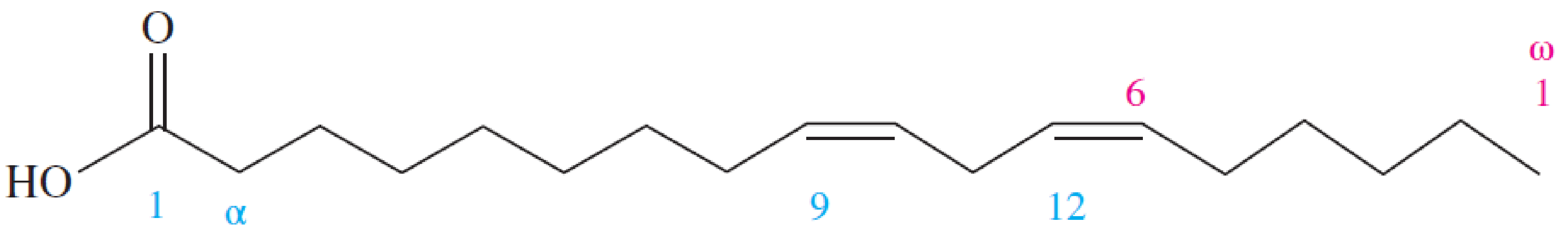


All *cis*-5,8,11,14,17-Eicosapentaenoic acid
(EPA)

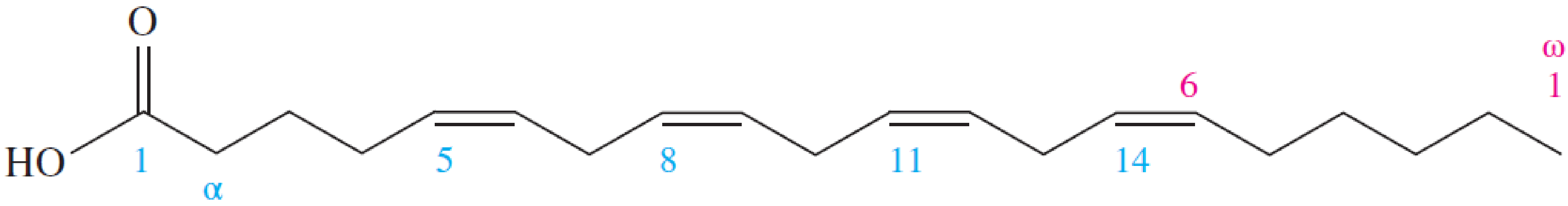


All *cis*-4,7,10,13,16,19-Docosahexaenoic acid
(DHA)

- **DHA** is one of the major fatty acids in the phospholipids of sperm and brain cells, as well as in the retina. It has also been shown to reduce triglyceride levels, although the mechanism is not understood.



cis,cis-9,12-Octadecadienoic acid
(linoleic acid)



All *cis*-5,8,11,14-Eicosatetraenoic acid
(arachidonic acid)

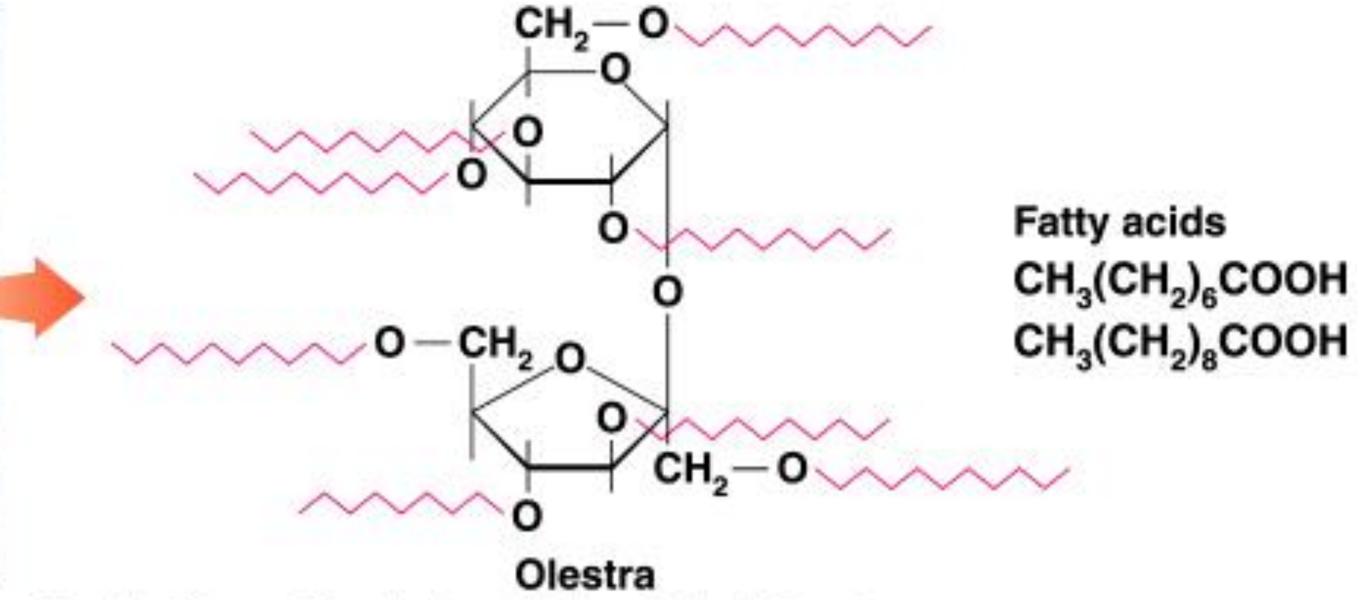
Linoleic acid is also an essential fatty acid, required for the synthesis of **arachidonic acid**, the precursor for many prostaglandins.

It is intriguing to note that the omega-3 fatty acids are precursors of prostaglandins that exhibit anti-inflammatory effects, and the omega-6 fatty acids are precursors of prostaglandins that have inflammatory effects. This has led researchers to suggest that the amount of omega-6 fatty acids in our diets should not exceed 2–4 times the amount of omega-3.

Dietary Considerations and Triacylglycerols

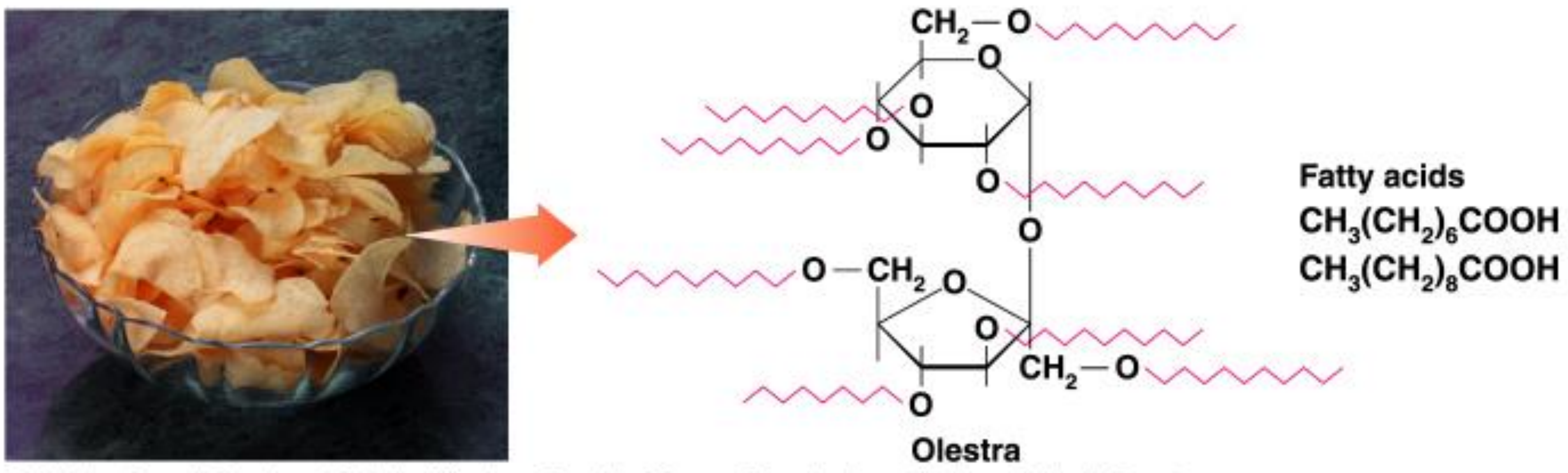
Fat Substitutes

- substances that create the sensations of "richness" of taste and "creaminess" of texture in food without the negative effects associated with dietary fats (heart disease and obesity).
- **Olestra:** Sucrose linked by ester bonds to several long-chain fatty chains; Not broken down in the intestinal tract.



Dietary Considerations and Triacylglycerols

- Olestra interferes with the absorption of both dietary and body-produced cholesterol; thus, it may lower total cholesterol levels. A problem with its use is that it also reduces the absorption of the fat-soluble vitamins A, D, E, and K.
- All products containing Olestra must carry the following label: ***"Olestra may cause abdominal cramping and loose stools. Olestra inhibits the absorption of some vitamins and other nutrients. Vitamins A, D, E, and K have been added."***



Section 8-5 Quick Quiz

1. In terms of human body response to dietary fat, which of the following is considered to be "good fat"?
   a. saturated fats
   b. monounsaturated fats
   c. polyunsaturated fats
   d. no correct response
2. Current dietary recommendations for Americans, relative to omega-3 and omega-6 fatty acids, include a recommended increase in
   a. omega-3 fatty acid intake
   b. omega-6 fatty acid intake
   c. both omega-3 and omega-6 fatty acid intake
   d. no correct response
3. Linolenic acid and linoleic acid, the *essential* fatty acids, are, respectively,
   a. 16:1 and 18:1 fatty acids
   b. 18:1 and 18:2 fatty acids
   c. 18:2 and 18:3 fatty acids
   d. no correct response

Chemical Reactions of Fatty Acids and Triacylglycerols

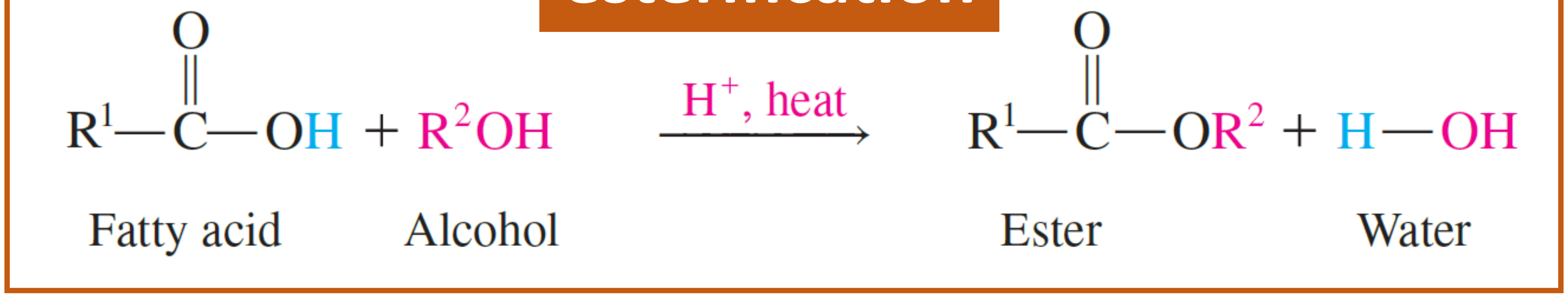
The reactions of fatty acids are identical to those of short-chain carboxylic acids. The major reactions of fatty acids include the following:

- Acid hydrolysis: Breaking the ester bond of a glyceride by the addition of a water molecule in the presence of a strong acid.
- Saponification: Breaking the ester bond of a glyceride by the addition of a water molecule in the presence of a strong base.
- Addition at the double bond: This generally involves the addition of hydrogen (H_2) to the double bond of an unsaturated fatty acid.
- Esterification: The reaction between the carboxyl group of a fatty acid and the hydroxyl group of an alcohol.

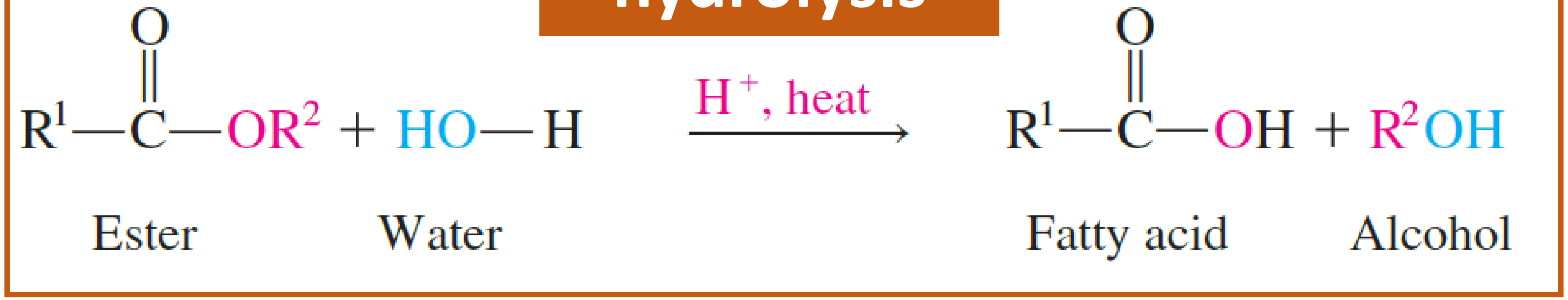
Chemical Reactions of FA and TAG: (1) HYDROLYSIS

- Hydrolysis of a triacylglycerol is the reverse of the esterification reaction by which it was formed

esterification

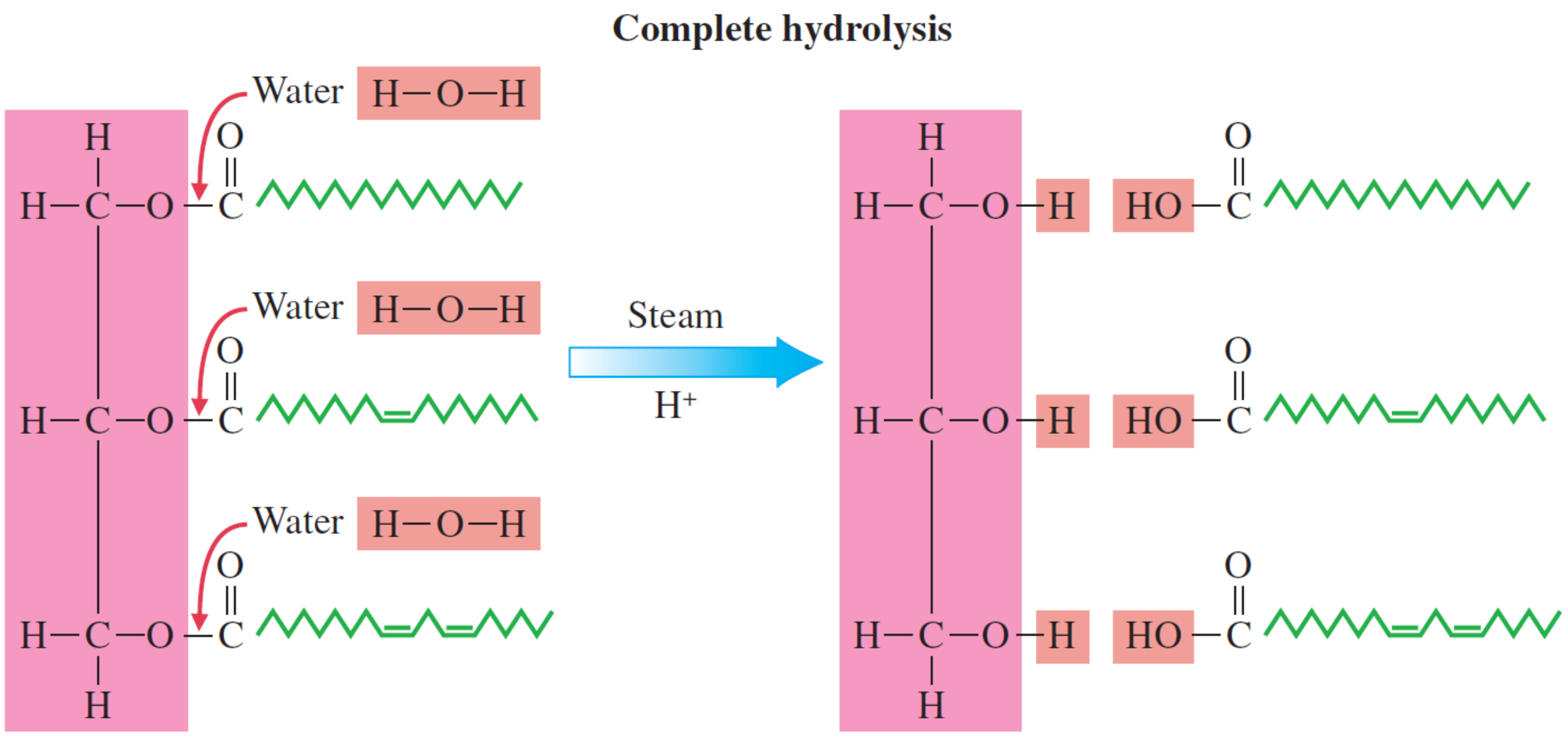


hydrolysis



Chemical Reactions of FA and TAG: (1) HYDROLYSIS

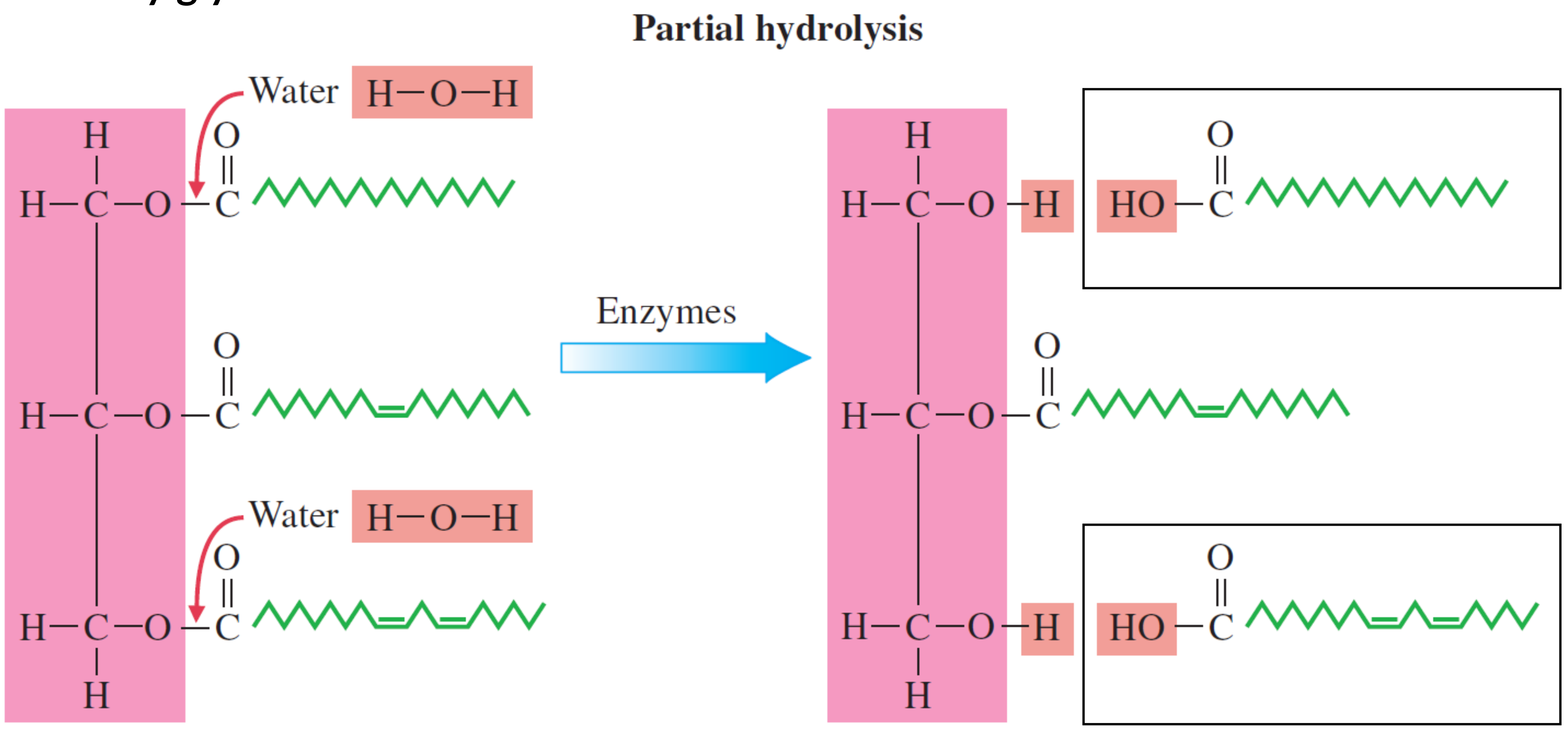
- Under acidic conditions, the hydrolysis products are glycerol and fatty acids.
- Under basic conditions, the hydrolysis products are glycerol and fatty acid salts (See **saponification**)



a Complete hydrolysis of a triacylglycerol produces glycerol and three fatty acid molecules.

Chemical Reactions of FA and TAG: (1) HYDROLYSIS

Within the human body, triacylglycerol hydrolysis occurs during the process of digestion. First, one of the outer fatty acids is removed, producing a **diacylglycerol**, then the other outer one is removed, to produce a **monoacylglycerol**.

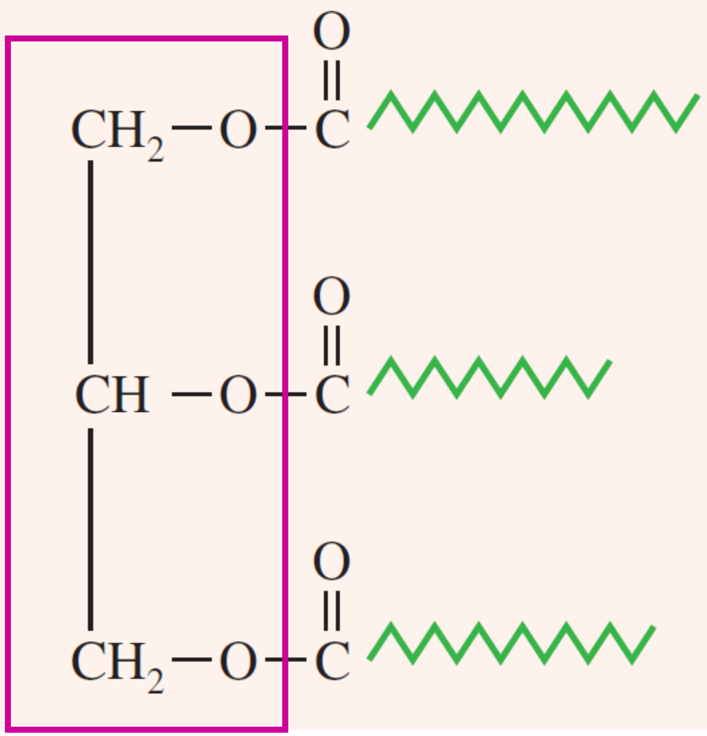


b Partial hydrolysis (during digestion) of a triacylglycerol produces a monoacylglycerol and two fatty acid molecules.

EXAMPLE 8-3

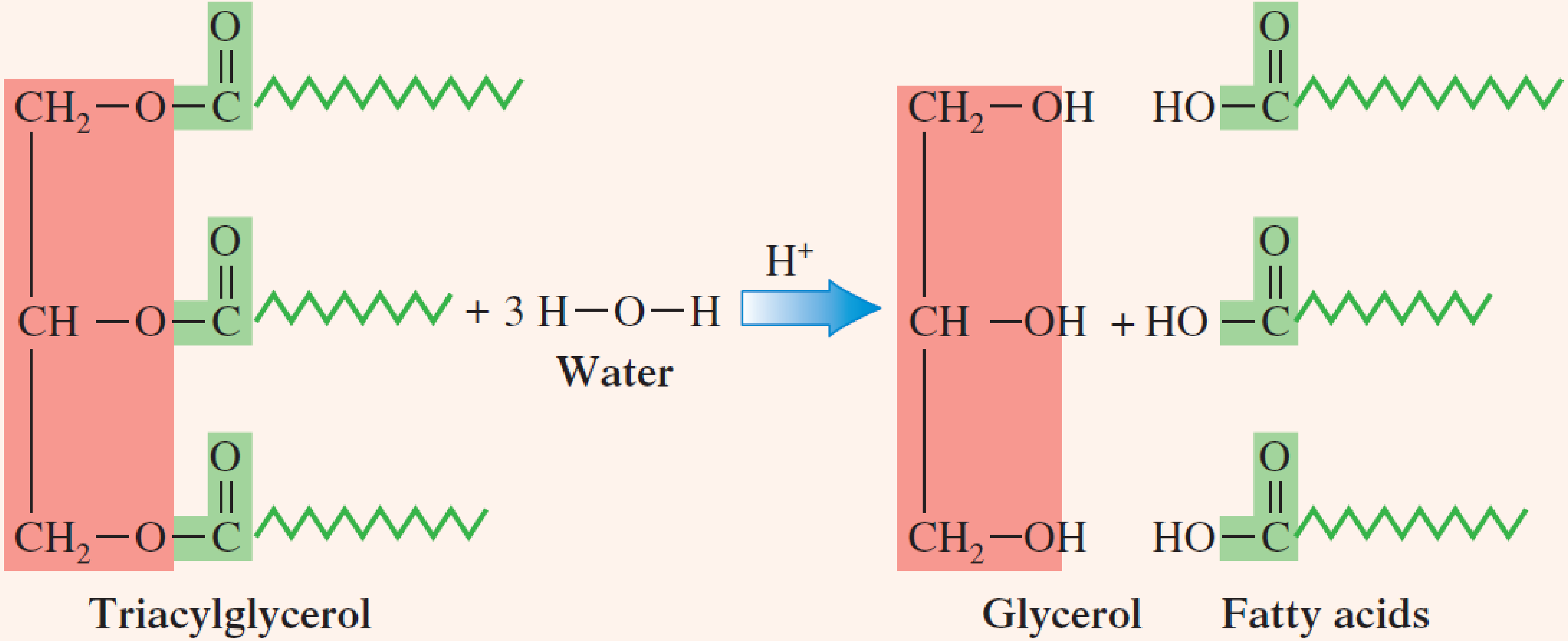
Writing a Structural Equation for the Acidic Hydrolysis of a Triacylglycerol

Write an equation for the acid-catalyzed hydrolysis of the following triacylglycerol:



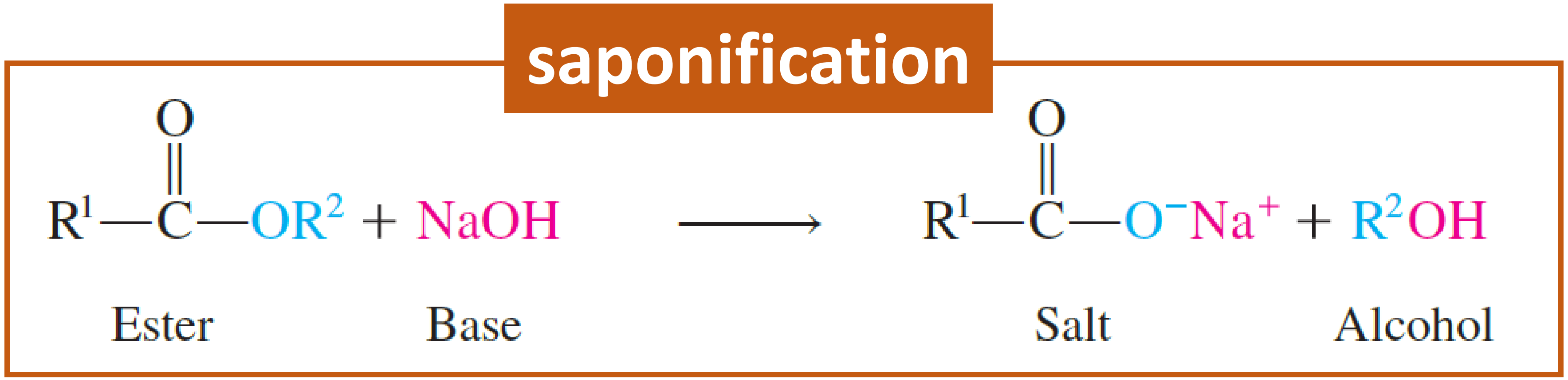
Solution

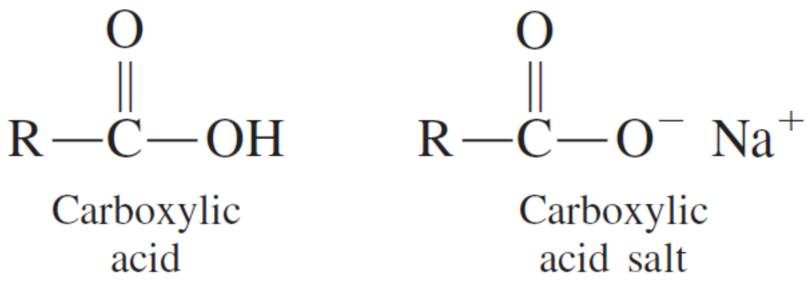
Three water molecules are required for complete hydrolysis, one to interact with each of the ester linkages present in the triacylglycerol. Breaking of the three ester linkages produces four product molecules: glycerol and three fatty acids.



Chemical Reactions of FA and TAG: (2) SAPONIFICATION

Saponification is a hydrolysis reaction carried out in an alkaline (basic) solution. For fats and oils (TAGs), the products of saponification are **glycerol** and **fatty acid salts**.





Chemical Reactions of FA and TAG: (2) SAPONIFICATION

The overall reaction of triacylglycerol saponification can be thought of as occurring in two steps.

Step 1: hydrolysis of the ester linkages to produce glycerol and three fatty acid molecules

$$\boxed{\text{Fat or oil} + 3H_2O \longrightarrow 3 \text{ fatty acids} + \text{glycerol}}$$

Step 2: acid–base reaction between FAs and base (NaOH) that produces water plus salts:

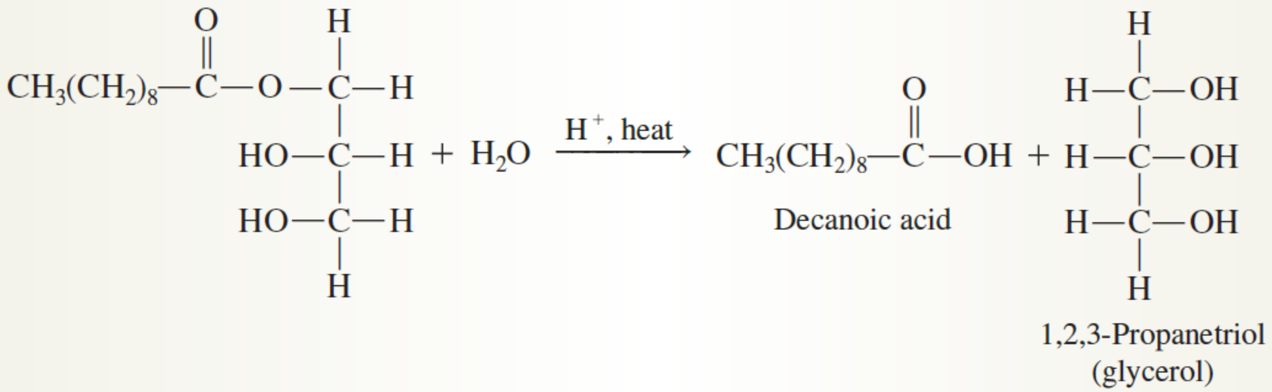
$$\boxed{3 \text{ fatty acids} + 3NaOH \longrightarrow 3 \text{ fatty acid salts} + 3H_2O}$$

soap

EXAMPLE 17.5 Writing Equations Representing the Acid Hydrolysis of a Monoglyceride

Write an equation representing the acid hydrolysis of a monoglyceride composed of one decanoic acid molecule esterified to glycerol.

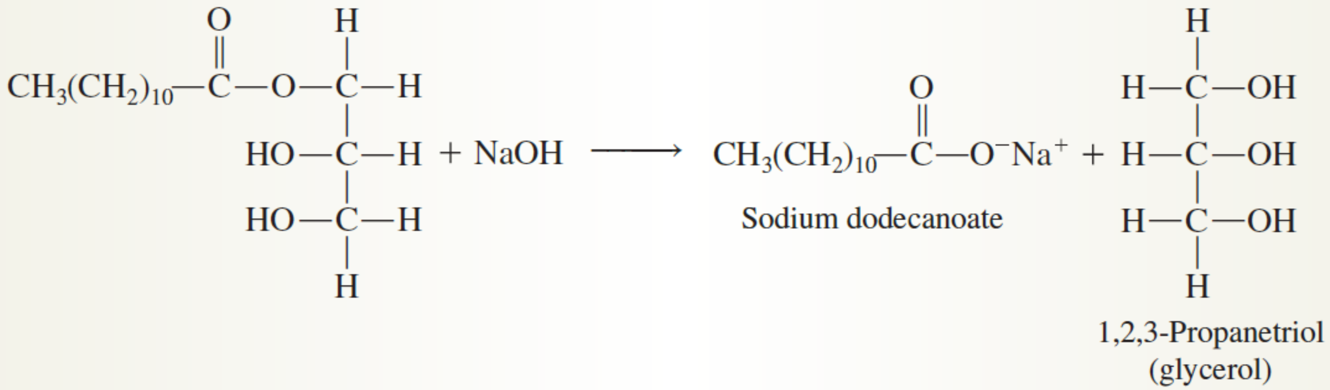
Solution



EXAMPLE 17.6 Writing Equations Representing the Base-Catalyzed Hydrolysis of a Monoglyceride

Write an equation representing the base-catalyzed hydrolysis of a monoglyceride composed of dodecanoic acid and glycerol.

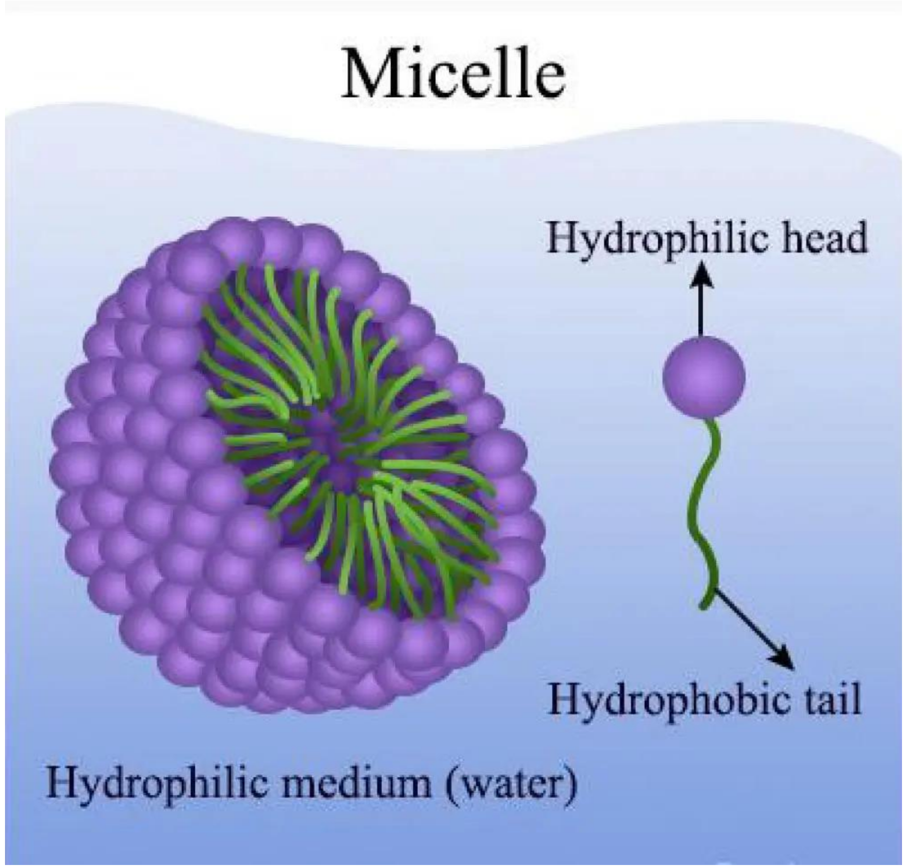
Solution



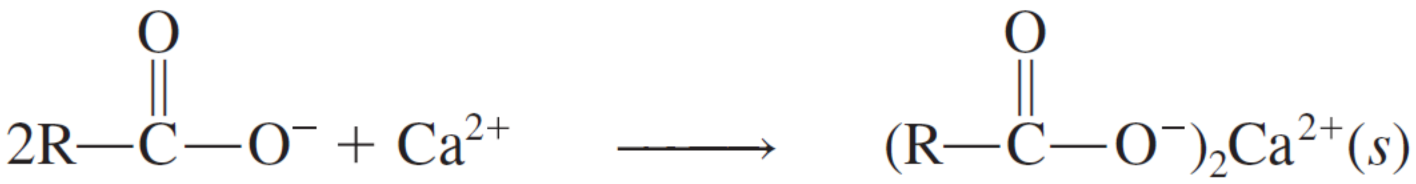
Chemical Reactions of FA and TAG: (2) SAPONIFICATION

The long-chain carboxylic acid salt or fatty acid salt that is the product of this reaction is a **soap**. Because soaps have a long uncharged hydrocarbon tail and a negatively charged terminus (the carboxylate group), they form **micelles**—***spherical cluster of molecules in which the polar portions of the molecules are on the surface, and the nonpolar portions are located in the interior***—that dissolve oil and dirt particles. Thus, the dirt is **emulsified** and broken into small particles, and can be rinsed away.

The micelles do not combine into larger drops because their surfaces are all negatively charged, and like charges repel each other.



https://www.sciencerendezvous.ca/resources/everyday-activities/milk-soap-rainbow-art-exploring-polarity-solutions-micelles/



Problems can arise when “hard” water is used for cleaning because the high concentrations of Ca^{2+} and Mg^{2+} in such water cause fatty acid salts to precipitate. Not only does this interfere with the emulsifying action of the soap, it also leaves a hard scum on the surface of sinks and tubs.

Soft water vs hard water

Chemical Reactions of FA and TAG: (3) HYDROGENATION

Hydrogenation: double bonds in unsaturated fatty acids react with H_2 in the presence of a Ni or Pt catalyst..

$$\text{---}CH_2\text{—}CH_2\text{—}\boxed{CH{=}CH}\text{—}CH_2\text{—}CH_2\text{---} + \boxed{H_2} \longrightarrow \text{---}CH_2\text{—}CH_2\text{—}\boxed{CH_2\text{—}CH_2}\text{—}CH_2\text{—}CH_2\text{---}$$

Portion of an unsaturated fatty acid residue in a triacylglycerol containing one double bond

The double bond has been converted to a single bond; the degree of saturation has increased

$$CH_3(CH_2)_7CH{=}CH(CH_2)_7\text{—}\overset{\overset{\displaystyle O}{\|}}{C}\text{—}OH \xrightarrow{H_2,\ Ni} CH_3(CH_2)_{16}\text{—}\overset{\overset{\displaystyle O}{\|}}{C}\text{—}OH$$

cis-9-Octadecenoic acid

Octadecanoic acid

$$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7COOH \xrightarrow{2H_2,\ Ni} CH_3(CH_2)_{16}COOH$$

Linoleic acid

Stearic acid

Chemical Reactions of FA and TAG: (3) HYDROGENATION

Hydrogenation is used in the food industry to convert polyunsaturated vegetable oils into saturated solid fats.

Partial hydrogenation is carried out to add hydrogen to some, but not all, double bonds in polyunsaturated oils. Margarine is produced by partial hydrogenation of vegetable oils, such as corn oil or soybean oil. The extent of hydrogenation is carefully controlled so that the solid fat will be spreadable and have the consistency of butter when eaten. If too many double bonds were hydrogenated, the resulting product would have the undesirable consistency of animal fat.

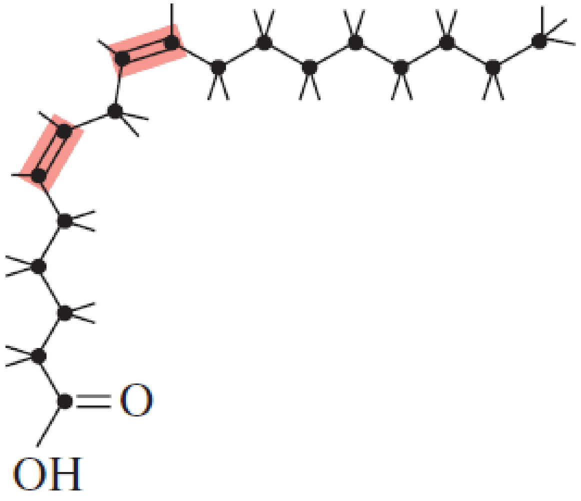
Concern has arisen about food products obtained from hydrogenation processes because the hydrogenation process itself converts some *cis* double bonds within fatty acid residues into *trans* double bonds, producing ***trans* unsaturated fatty acids.**

Trans Fatty Acid Content of Foods

Two types of changes, rather than just one (as was previously thought), occur in the fatty acid residues during partial hydrogenation:

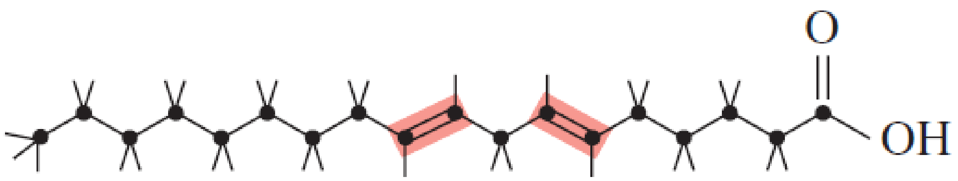
1. some of the cis double bonds present are converted to single bonds (the objective of the process)
2. **some of the remaining cis double bonds are converted to *trans* double bonds** (an unanticipated result of the process).

18:2 (*cis*, *cis*)



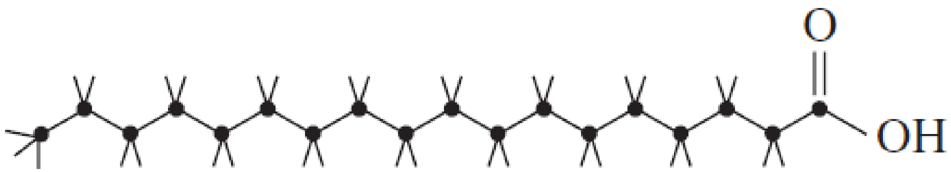
Trans fat raises bad (LDL) cholesterol, but it does not raise good (HDL) cholesterol

18:2 (*trans*–*trans*)



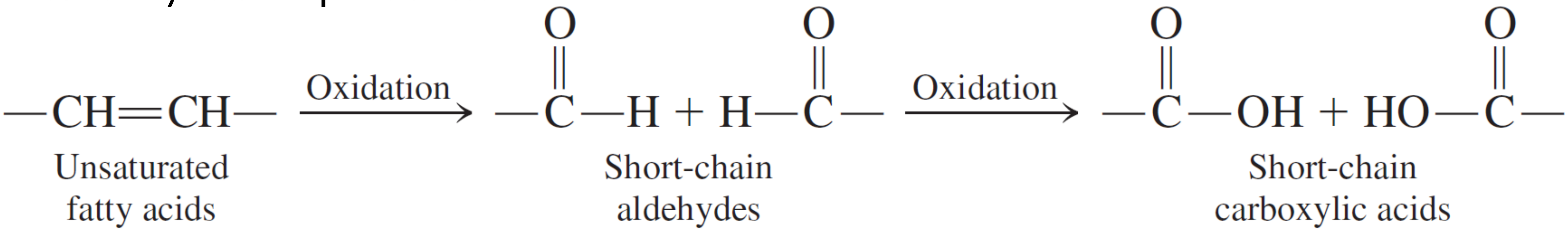
18:0

Saturated fat, on the other hand, raises both good and bad cholesterol.



Chemical Reactions of FA and TAG: (4) OXIDATION

The carbon–carbon double bonds present in the fatty acid residues of a triacyl-glycerol are subject to oxidation with **molecular oxygen (from air)** as the oxidizing agent. Such oxidation breaks these bonds, producing both aldehyde and carboxylic acid products.

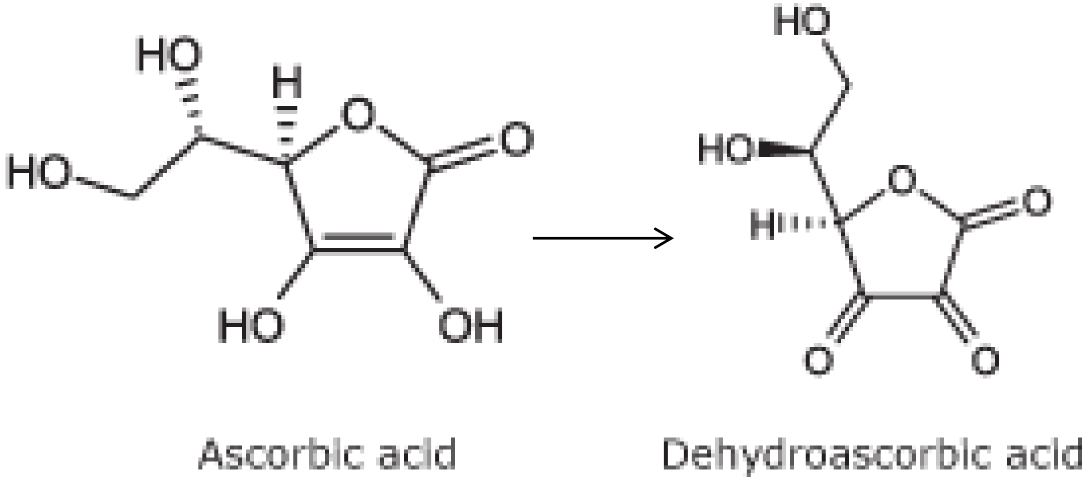


- The short-chain aldehydes and carboxylic acids so produced often have **objectionable odors**, and fats and oils containing them are said to have become ***rancid***.
- Perspiration generated by strenuous exercise or by “hot and muggy” climatic conditions contains numerous triacylglycerols (oils). Rapid oxidation of these oils, promoted by microorganisms on the skin, generates the **body odor** that accompanies most “sweaty” people.

Chemical Reactions of FA and TAG: (4) OXIDATION

Commercially prepared foods containing fats and oils nearly always contain **antioxidants**—substances that are more easily oxidized than the food. Two naturally occurring antioxidants are **vitamin C** and **vitamin E**.

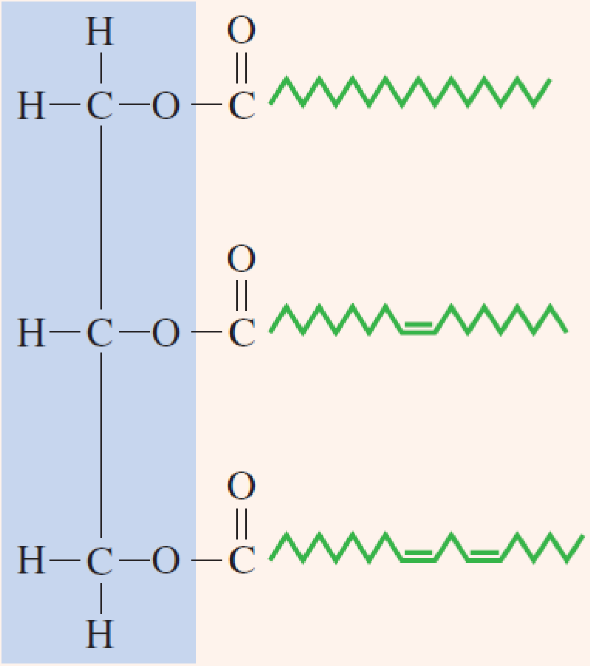
Two synthetic oxidation inhibitors are butylated hydroxyanisole **(BHA)** and butylated hydroxytoluene **(BHT)**. In the presence of air, antioxidants, rather than food, are oxidized.



EXAMPLE 8-4

Determining the Products for Reactions That Triacylglycerols Undergo

Using words rather than structural formulas, characterize the products formed when the following triacylglycerol undergoes the reactions listed.



(18:0 fatty acid residue)

(18:1 fatty acid residue)

(18:2 fatty acid residue)

a. Complete hydrolysis
b. Complete saponification using NaOH
c. Complete hydrogenation

Solution

a. When a triacylglycerol undergoes complete hydrolysis, there are four organic products: glycerol and three fatty acids. For the given triacylglycerol, the products are *glycerol, an* 18:0 *fatty acid, an* 18:1 *fatty acid,* and *an* 18:2 *fatty acid.* Three molecules of water are also consumed.

b. When a triacylglycerol undergoes complete saponification, there are four organic products: glycerol and three fatty acid salts. For the given triacylglycerol, with NaOH as the base involved in the saponification, the products are *glycerol, the sodium salt of the* 18:0 *fatty acid, the sodium salt of the* 18:1 *fatty acid,* and *the sodium salt of the* 18:2 *fatty acid.*

c. Complete hydrogenation will change the given triacylglycerol into a *triacylglycerol in which all three fatty acid residues are* 18:0 *fatty acid residues.* That is, all of the fatty acid residues are completely saturated (there are no carbon–carbon double bonds).

Section 8-6 Quick Quiz

1. One molecule of a fat or oil, upon complete hydrolysis, produces how many product molecules?
   a. two
   b. three
   c. four
   d. no correct responses
2. Triacylglycerol hydrolysis associated with the human digestive process most often produces which of the following?
   a. a diacylglycerol
   b. a monoacylglycerol
   c. glycerol
   d. no correct response

3. Which of the following are the expected products when a fat undergoes saponification?
   a. glycerol and fatty acids
   b. glycerol and fatty acid salts
   c. fatty acids and fatty acid salts
   d. no correct response

4. Unwanted production of *trans* fats is associated with which of the following types of triacylglycerol reactions?
   a. saponification
   b. hydrogenation
   c. oxidation
   d. no correct response
5. The effect of *partial* hydrogenation of a fat or oil is which of the following?
   a. decrease in the degree of fatty acid unsaturation
   b. decrease in melting point of the fat or oil
   c. increase in the number of fatty acid residues present in a molecule
   d. no correct response
6. In the oxidation of fats and oils, which structural part of the molecule is attacked by the oxidizing agent?
   a. carbon–carbon double bonds
   b. carbon–carbon single bonds
   c. ester linkages
   d. no correct response

CHEMISTRY AT A GLANCE

Classification Schemes for Fatty Acid Residues Present in Triacylglycerols

FATTY ACIDS

- Most contain an even number of carbon atoms.
- Carbon chain length is up to 24 carbon atoms.

Classification Based on Degree of Unsaturation

SATURATED

- No double bonds are present in the carbon chain.
- Dietary effect is an increase in heart disease risk.

MONOUNSATURATED

- One double bond is present in the carbon chain.
- Dietary effect is a decrease in heart disease risk.

POLYUNSATURATED

- Two or more double bonds are present in the carbon chain.
- Dietary effect is “mixed”; there have been several conflicting studies relative to heart disease risk.

Classification Based on Configuration of Double Bond

CIS

- Naturally occurring fatty acids generally contain *cis* double bonds.

TRANS

- Hydrogenation converts some *cis* double bonds to *trans* double bonds.
- *Trans* fatty acids have effects on blood chemistry similar to those of saturated fatty acids.

Classification Based on Location of Double Bond

OMEGA-3

- First double bond is three carbons away from the CH_3 end of the carbon chain.
- Linolenic acid (18:3) is the primary member of this family.

OMEGA-6

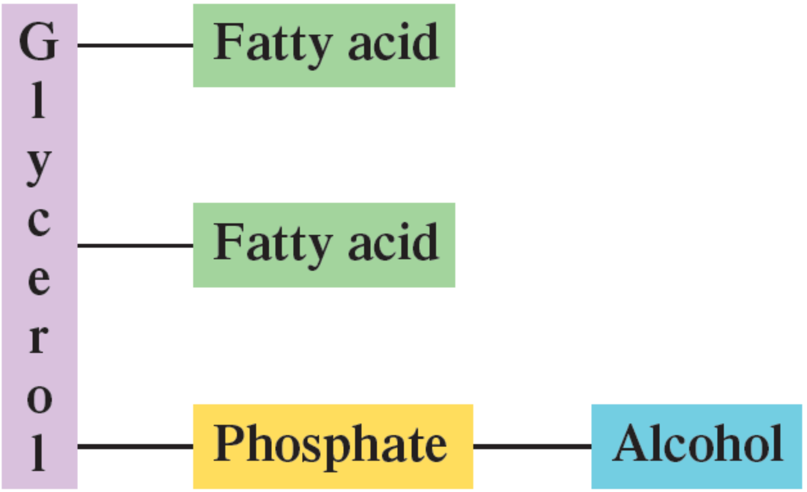
- First double bond is six carbons away from the CH_3 end of the carbon chain.
- Linoleic acid (18:2) is the primary member of this family.

Membrane Lipids: (1) Phospholipids

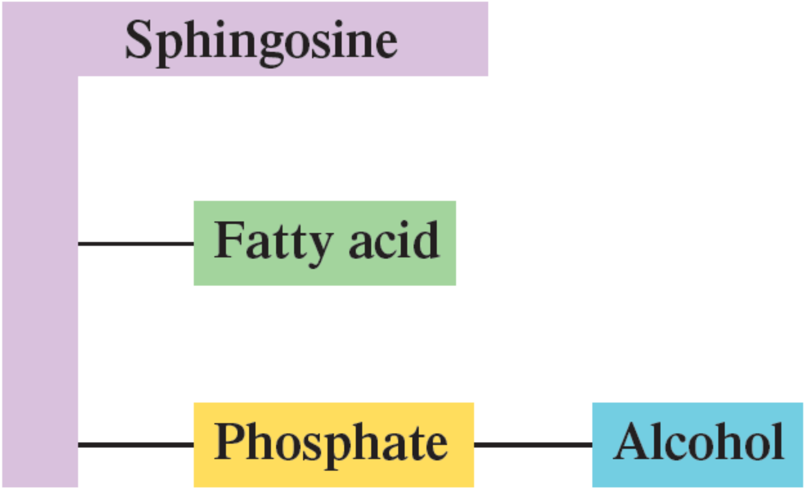
There are three common types of membrane lipids: **phospholipids**, sphingoglycolipids, and cholesterol.

Phospholipids are the most abundant type of membrane lipid. A phospholipid is a lipid that contains

- one or more fatty acids
- a phosphate group
- a platform molecule to which the fatty acid(s) and the phosphate group are attached and
- an alcohol that is attached to the phosphate group.



Glycerophospholipid (or phosphoglycerols)

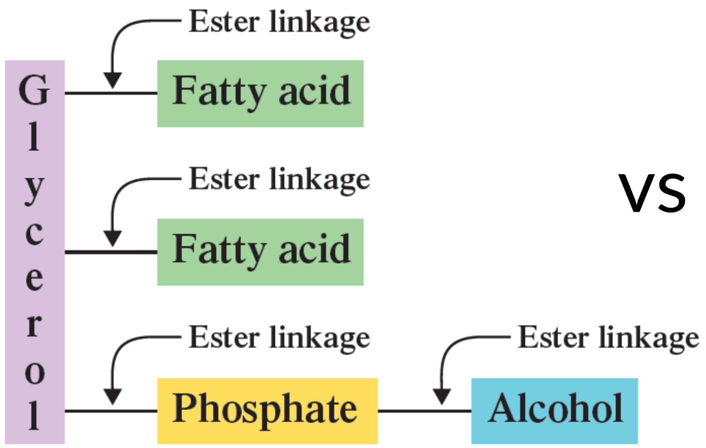


Sphingophospholipid

Membrane Lipids: (1) Phospholipids *(Glycerophospholipids)*

A **glycerophospholipid** is a lipid that contains two fatty acids and a phosphate group esterified to a glycerol molecule and an alcohol esterified to the phosphate group.

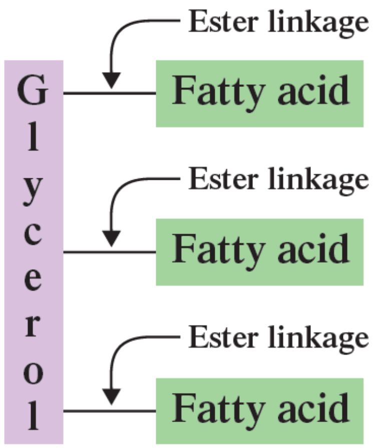
The presence of the phosphoryl group results in a molecule with a **polar head** (the phosphoryl group) and a **nonpolar tail** (the alkyl chain of the fatty acid). Because the phosphoryl group ionizes in solution, a charged lipid results.



Glycerophospholipid
(four ester linkages)

polar

vs



Triacylglycerol
(three ester linkages)

nonpolar

Membrane Lipids: (1) Phospholipids *(Glycerophospholipids)*

The alcohol attached to the phosphate group in a glycerophospholipid is usually one of three amino alcohols: choline, ethanolamine, or serine.

$$HO{-}CH_2{-}CH_2{-}\overset{+}{N}(CH_3)_3$$

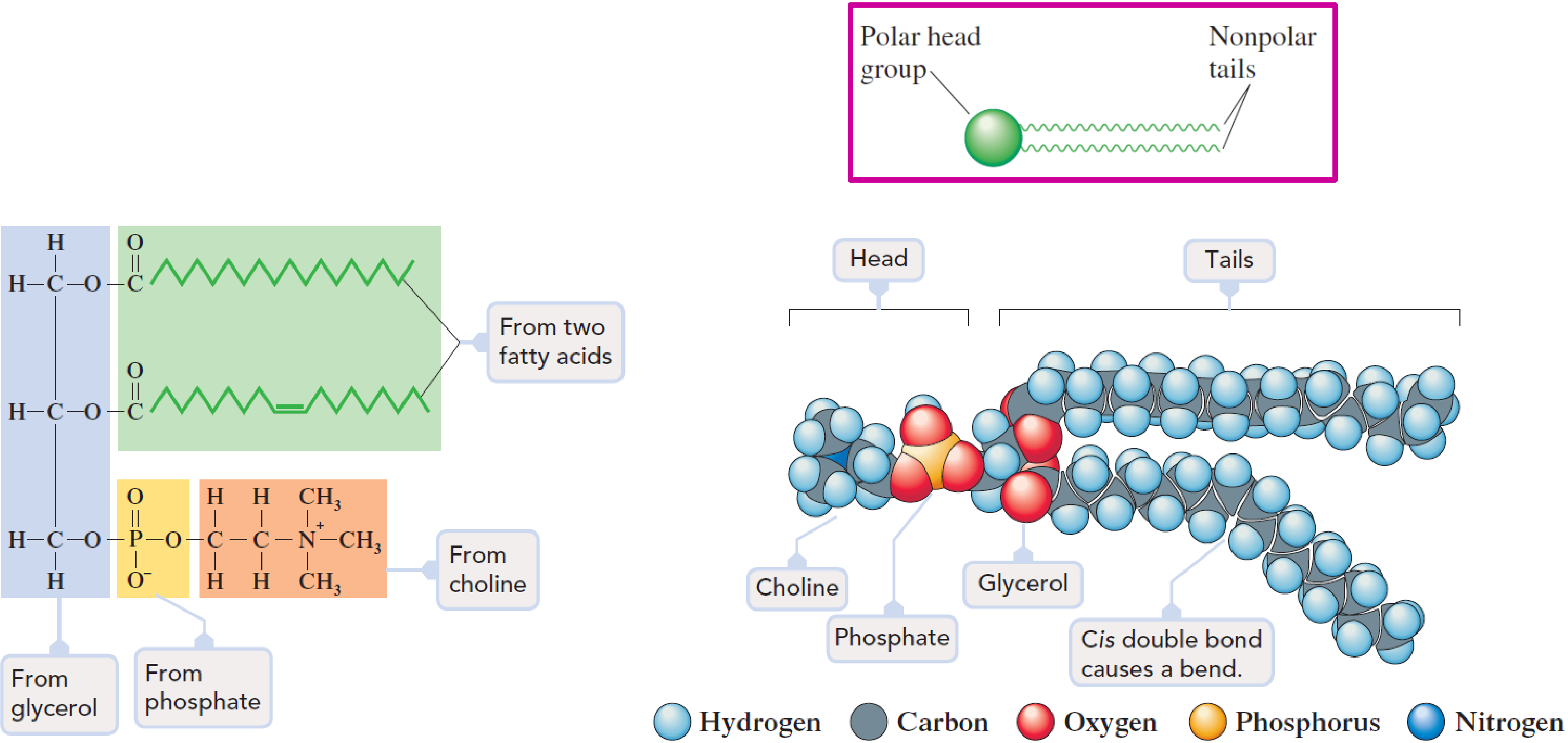
Choline
(a quaternary ammonium ion)

$$HO{-}CH_2{-}CH_2{-}\overset{+}{N}H_3$$

Ethanolamine
(positive-ion form)

$$\begin{array}{l} HO{-}CH_2{-}\underset{\displaystyle COO^-}{\underset{|}{CH}}{-}\overset{+}{N}H_3 \end{array}$$

Serine
(two ionic groups present)

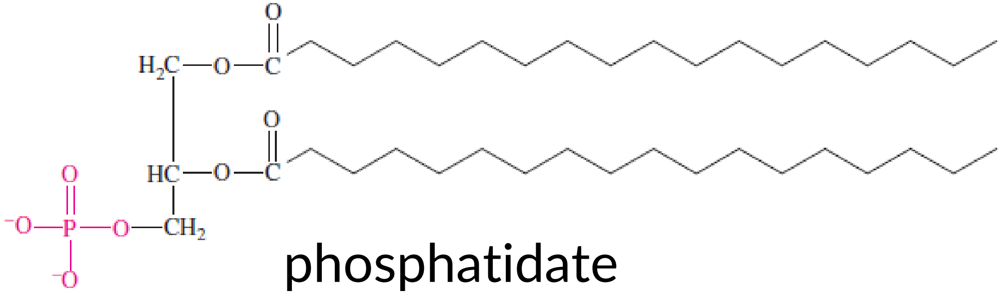


a Structural formula

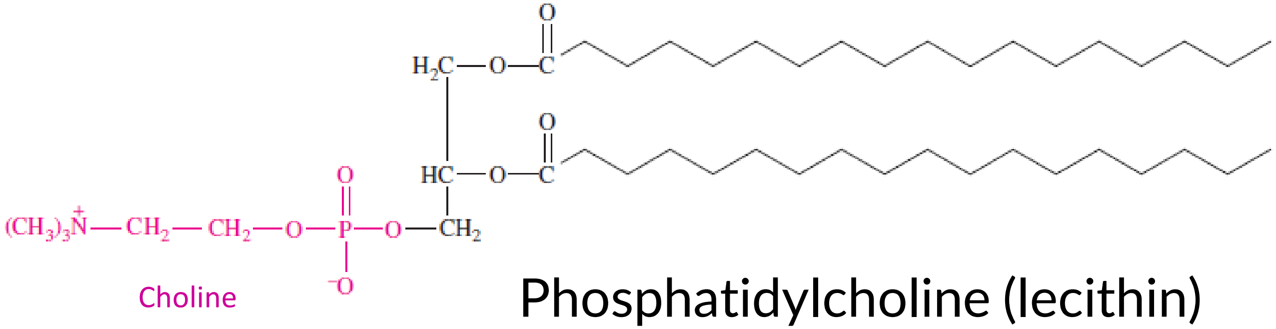
b Molecular model showing the “head and two tails” structure of a phosphatidylcholine molecule containing stearic acid (18:0) and oleic acid (18:1)

Figure 8-13 Models showing the "head and two tails" arrangement of structural subunits in a phosphatidylcholine molecule.

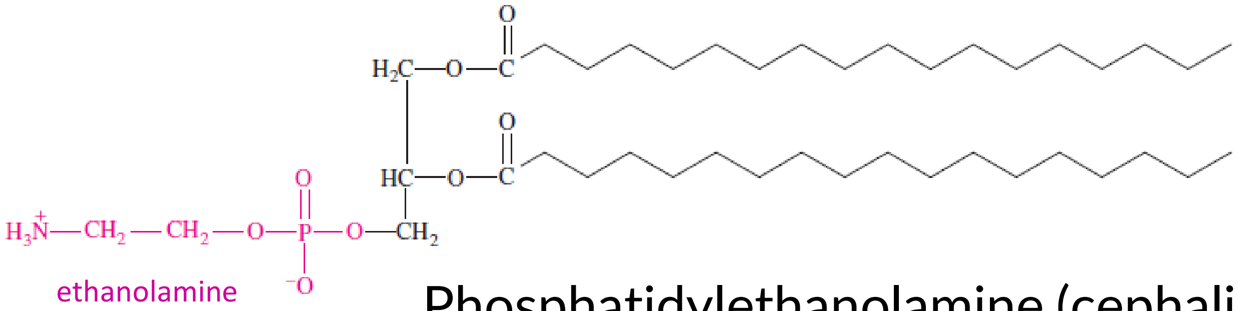
The presence of the phosphoryl group results in a molecule with a **polar head** (the phosphoryl group) and a **nonpolar tail** (the alkyl chain of the fatty acid). Because the phosphoryl group ionizes in solution, a charged lipid results.



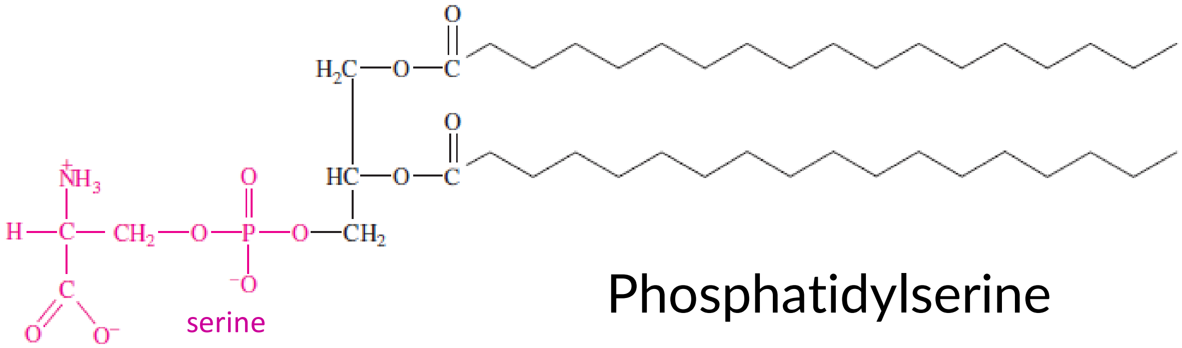
phosphatidate



Phosphatidylcholine (lecithin)

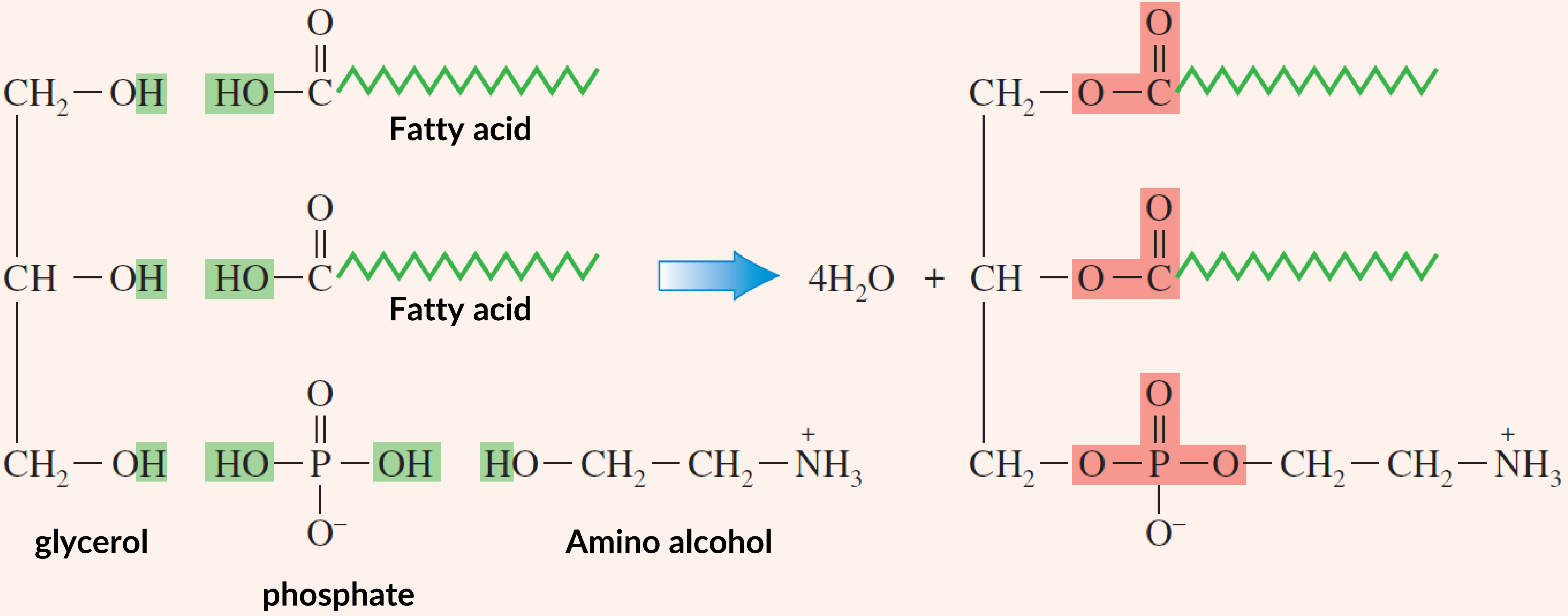


Phosphatidylethanolamine (cephalin)



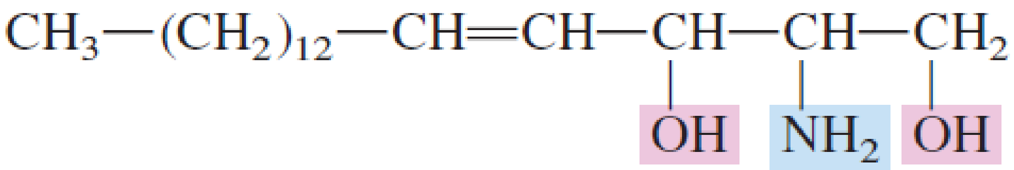
Phosphatidylserine

The atoms involved in this water formation are highlighted in color in the structures at the left and the ester linkages formed are highlighted in color in the structure at the right.



Membrane Lipids: (1) Phospholipids *(Sphingophospholipids)*

Sphingophospholipids have structures based on the 18-carbon monounsaturated aminodialcohol **sphingosine**.

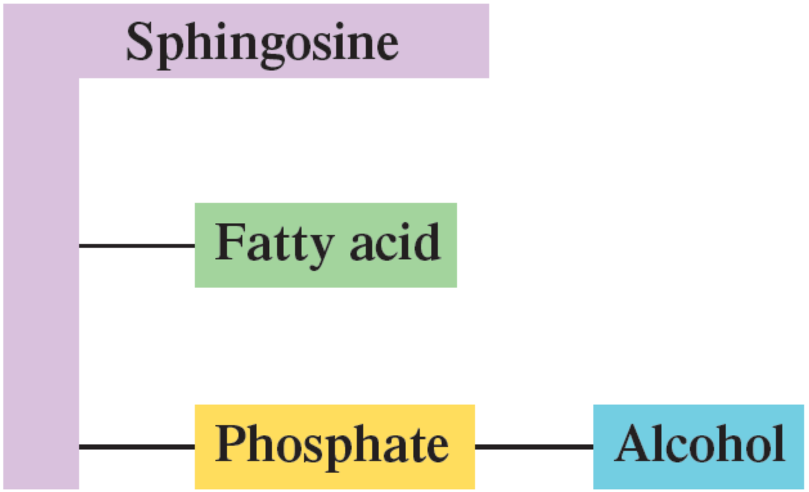


Sphingosine

A **sphingophospholipid** is a lipid that contains

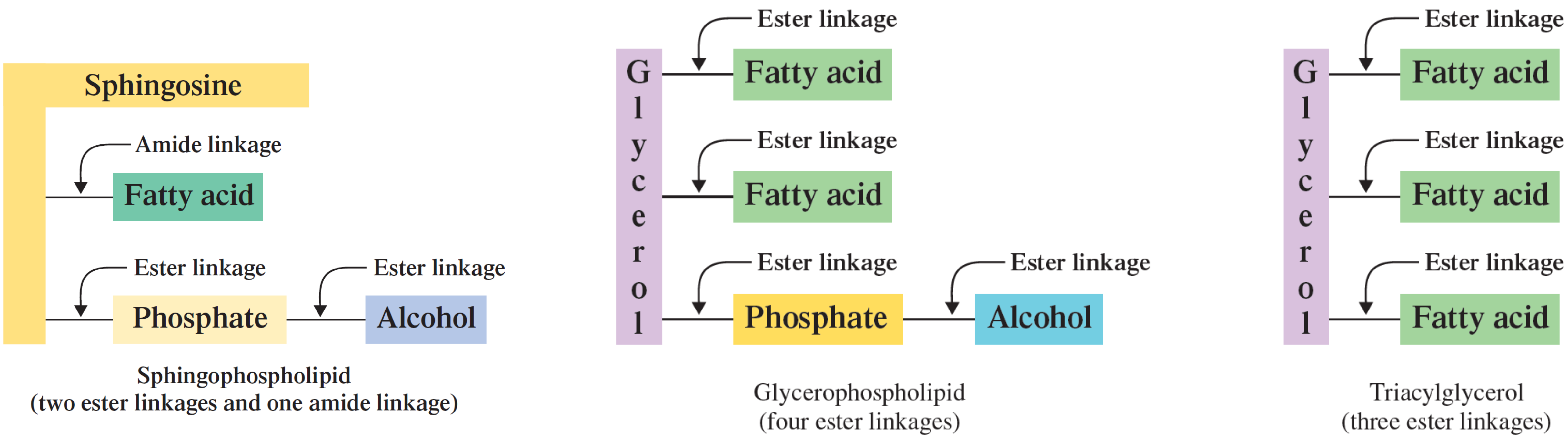
- **one fatty acid**
- **one phosphate group**
- **a sphingosine** molecule and
- **an alcohol** attached to

the phosphate group.



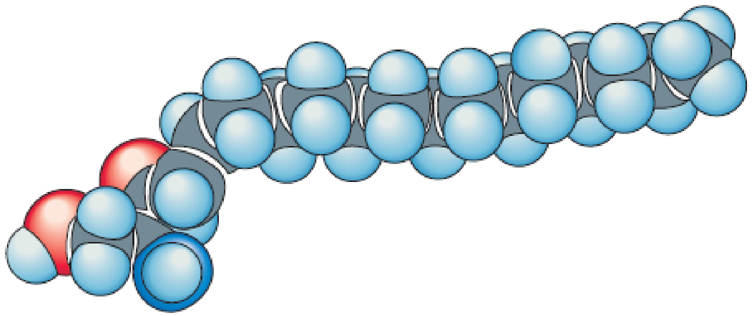
Sphingophospholipid

Membrane Lipids: (1) Phospholipids *(Sphingophospholipids)*

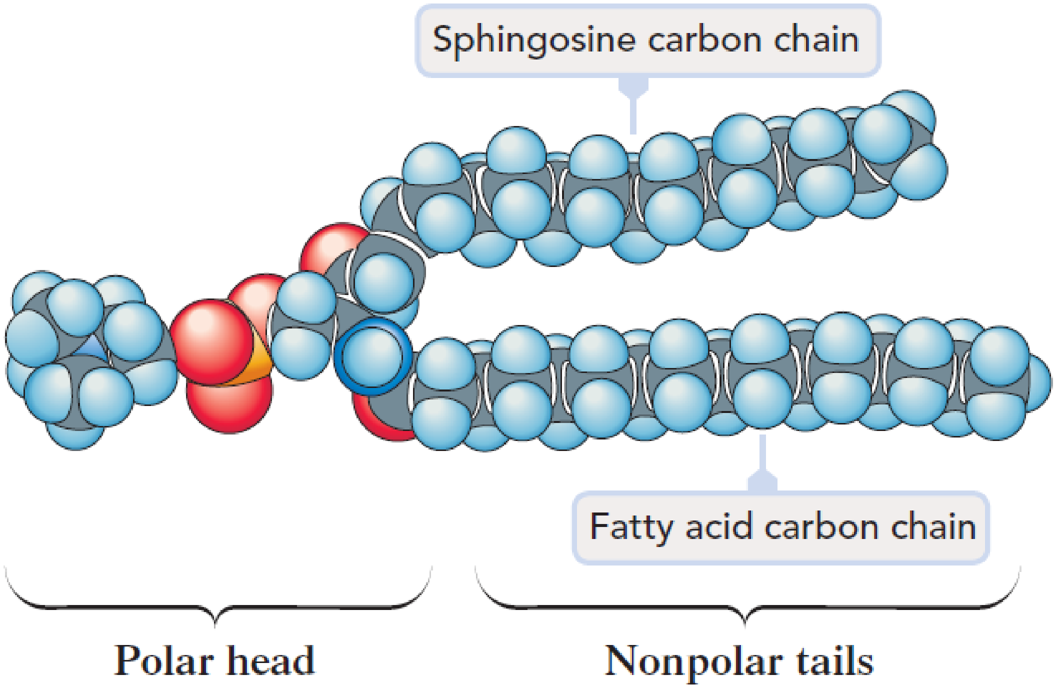


Like glycerophospholipids, sphingophospholipid participate in hydrolysis and saponification reactions. Amide linkages behave much as ester linkages do in this type of reaction.

Figure 8-14 Molecular models for (a) sphingosine and (b) a sphingophospholipid. The particular sphingophospholipid shown has choline as the alcohol esterified to the phosphate group. Note the "head and two tails" structure for the sphingophospholipid.



a Sphingosine

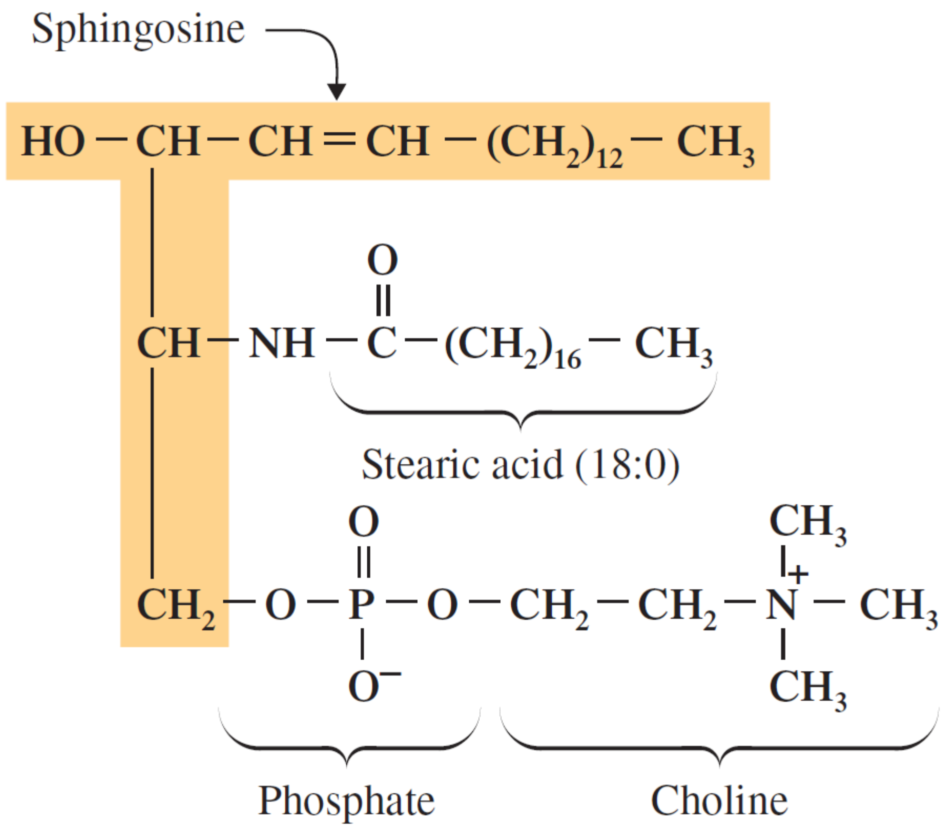


b A sphingophospholipid

Membrane Lipids: (1) Phospholipids *(Sphingophospholipids)*

Sphingomyelins

- Sphingophospholipids in which the alcohol esterified to the phosphate group is **choline**
- found in all cell membranes and are important structural components of the ***myelin sheath***, the protective and insulating coating that surrounds nerves.
- the only class of sphingolipids (sphingosine-containing) that are also phospholipids (phosphate-containing)



Section 8-7 Quick Quiz

1. Based on biological function, phospholipids are classified as
   - **a.** energy-storage lipids
   - **b.** membrane lipids
   - **c.** messenger lipids
   - **d.** no correct response
2. Which of the following types of lipids contain both ester and amide linkages?
   - **a.** triacylglycerols
   - **b.** sphingophospholipids
   - **c.** glycerophospholipids
   - **d.** no correct response
3. Which of the following statements about the molecule sphingosine is *correct*?
   - **a.** Two amino groups and one hydroxyl group are present.
   - **b.** Two hydroxyl groups and one amino group are present.
   - **c.** Two hydroxyl groups and two amino groups are present.
   - **d.** no correct response

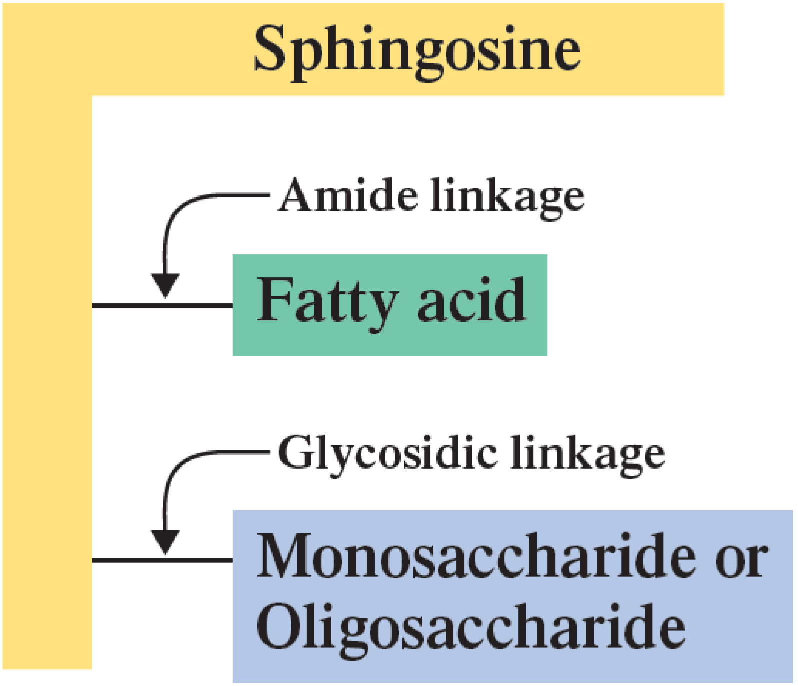
4. When the “head and two tails” structural model is applied to a glycerophospholipid, the two tails are
   a. both fatty acid residues
   b. a fatty acid residue and a phosphate group
   c. the phosphate group and the glycerol backbone
   d. no correct response
5. When the “head and two tails” structural model is applied to a sphingophospholipid, the two tails are
   a. the fatty acid residue and the phosphate group
   b. the fatty acid residue and part of the sphingosine molecule
   c. the phosphate group and part of the sphingosine molecule
   d. no correct response
6. In terms of the “head and two tails” model for phospholipids
   a. both tails are hydrophobic.
   b. both tails are hydrophilic.
   c. one tail is hydrophilic and the other hydrophobic.
   d. no correct response

Membrane Lipids: (2) Sphingoglycolipids (or Glycosphingolipids)

The second of the three major types of membrane lipids is sphingoglycolipids.

Sphingoglycolipid is a lipid that contains

- a fatty acid
- a carbohydrate component
- a sphingosine molecule

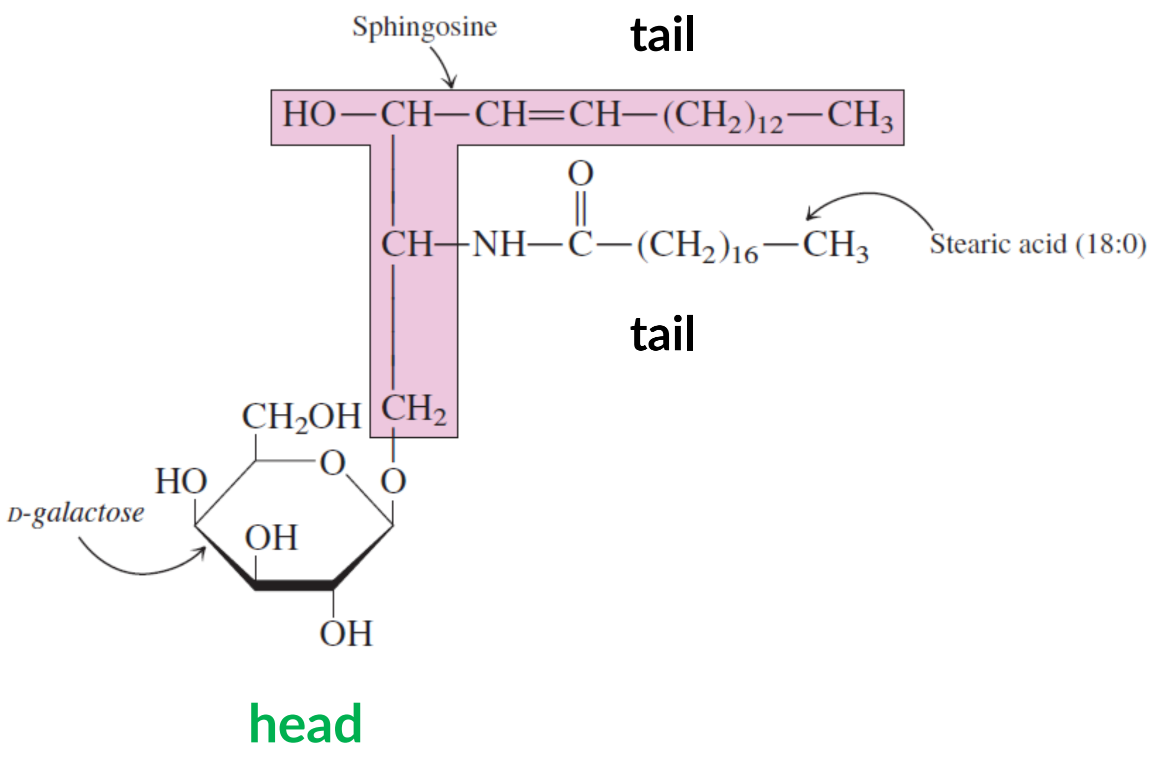


Sphingoglycolipid
(one amide linkage and one or more glycosidic linkages)

Membrane Lipids: (2) Sphingoglycolipids (or Glycosphingolipids)

Like the phospholipids (glycerophospholipids and sphingophospholipids), sphingoglycolipids have a "head and two tails" structure.

Sphingoglycolipids and sphingophospholipids have similar "tails," but their polar "heads" differ in the constituents present (**mono- or oligosaccharide** versus phosphate-alcohol).



A cerebroside

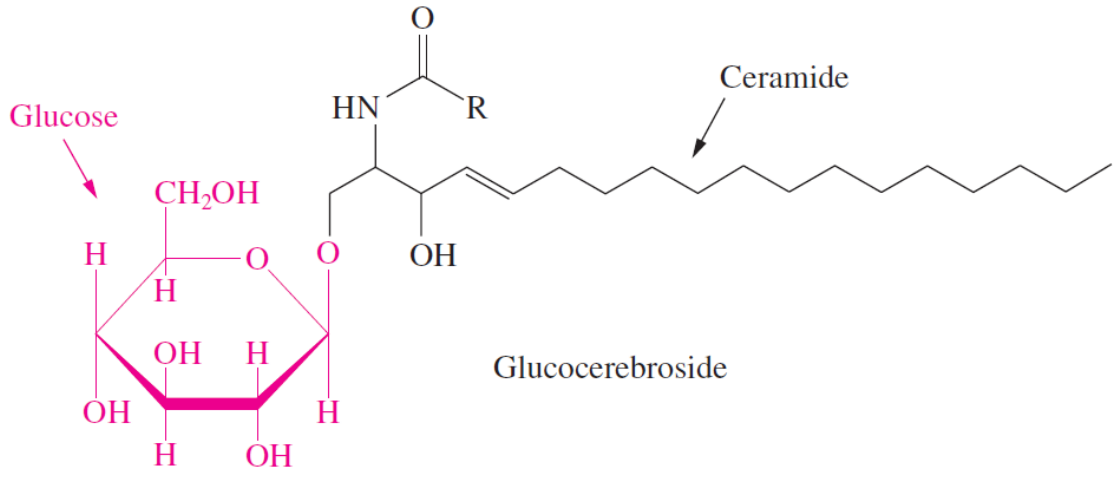
Membrane Lipids: (2) Sphingoglycolipids (or Glycosphingolipids)

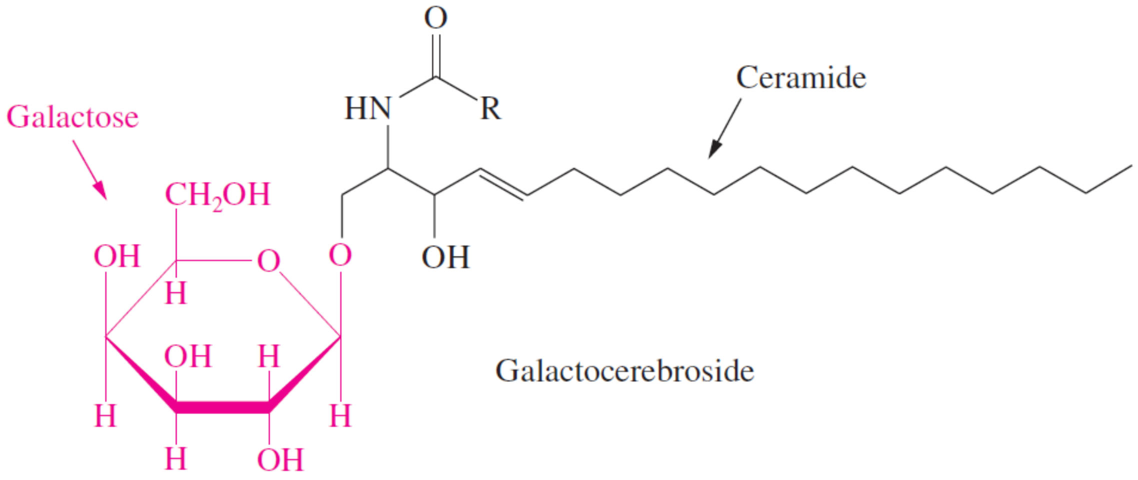
The simplest sphingoglycolipids, which are called **cerebrosides**, contain a single monosaccharide unit—either ***glucose or galactose.***

Common cerebrosides:

Glucocerebroside – found in the membranes of macrophages (cells that protect the body by ingesting and destroying foreign microorganisms)

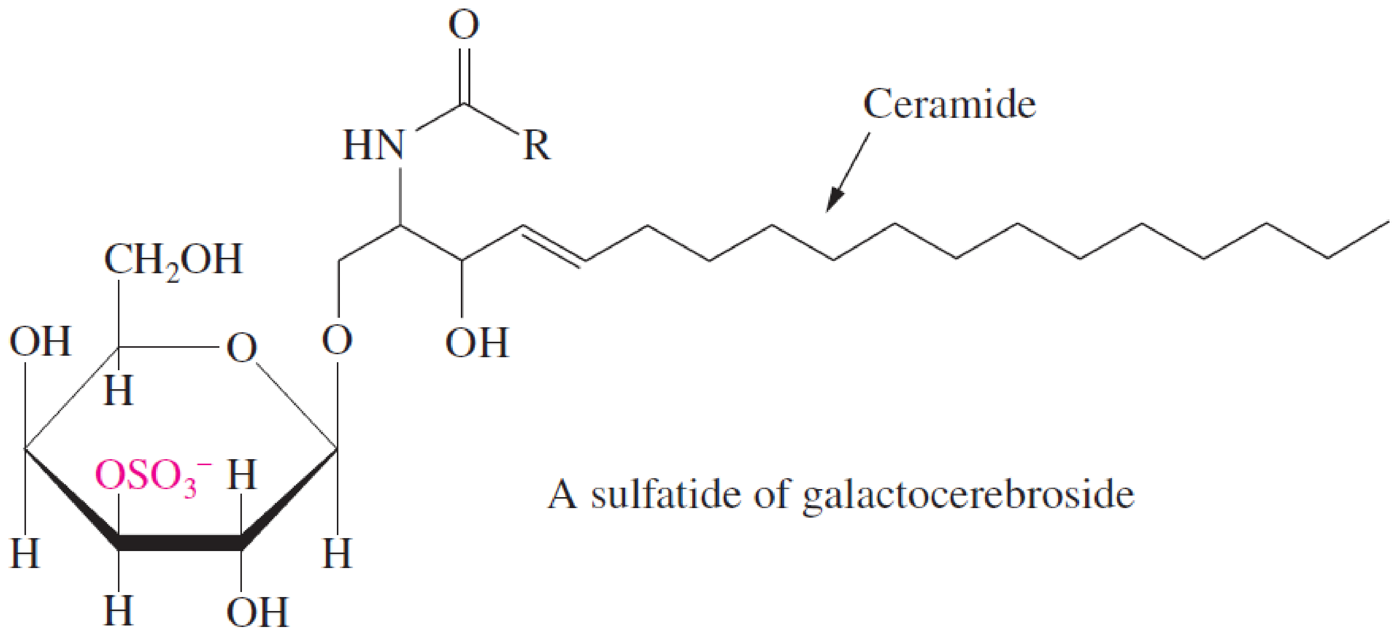
Galactocerebroside – found almost exclusively in the membranes of brain cells (7% dry weight of the brain)





Membrane Lipids: (2) Sphingoglycolipids (or Glycosphingolipids)

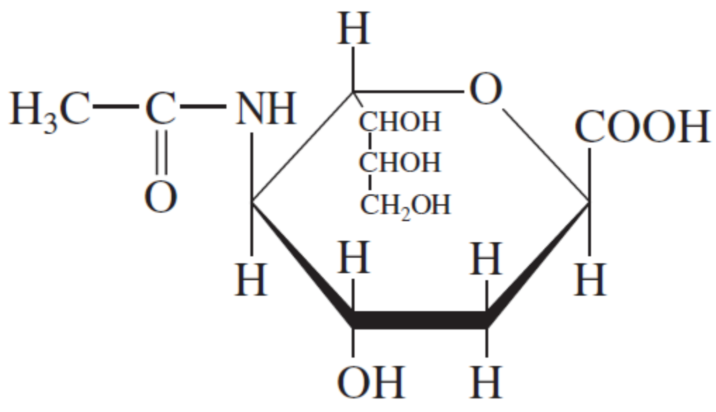
Sulfatides are derivatives of galactocerebroside that contain a sulfate group. Notice that they carry a negative charge at physiological pH.



A sulfatide of galactocerebroside

Membrane Lipids: (2) Sphingoglycolipids (or Glycosphingolipids)

Gangliosides are glycolipids that possess oligosaccharide groups (up to 7 monosaccharide residues) rather than a single monosaccharide. These oligosaccharide groups always contain one or more molecules of ***N-acetylneuraminic acid (sialic acid).*** First isolated from membranes of nerve tissue, gangliosides are found in most tissues of the body. These substances occur in the gray matter of the brain as well as in the myelin sheath.



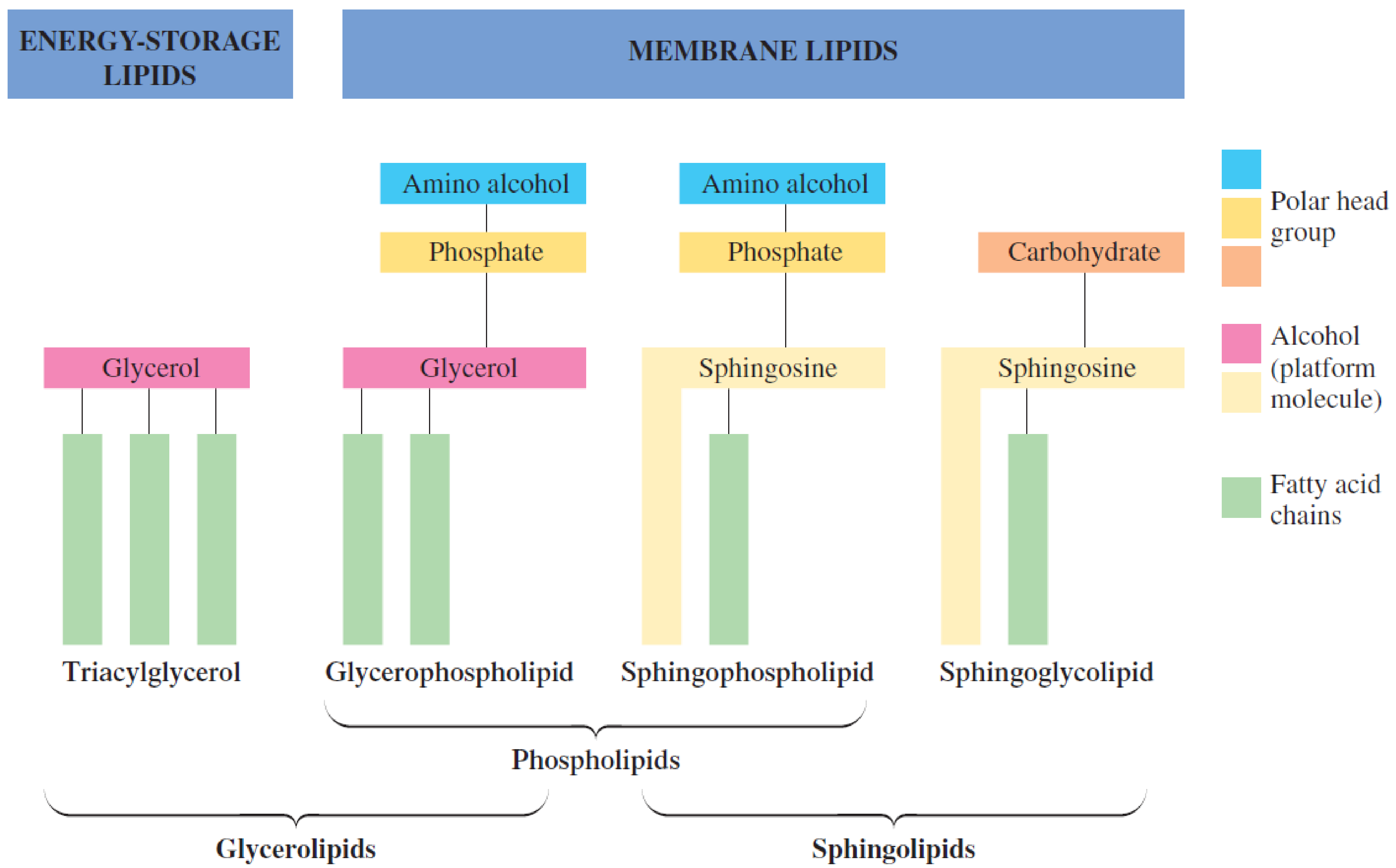
N-Acetylneuraminic acid (sialic acid)

Section 8-8 Quick Quiz

1. The number of structural building blocks present in a sphingoglycolipid in which a single monosaccharide unit is present is
   - **a.** two
   - **b.** three
   - **c.** four
   - **d.** no correct response
2. Which of the following types of linkages are always present in a sphingoglycolipid?
   - **a.** ester linkage and amide linkage
   - **b.** ester linkage and glycosidic linkage
   - **c.** amide linkage and glycosidic linkage
   - **d.** no correct response

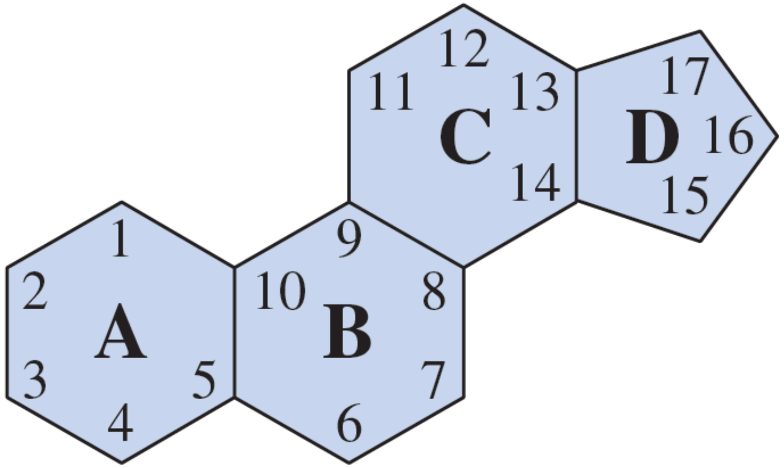
CHEMISTRY AT A GLANCE

Terminology for and Structural Relationships Among Various Types of Fatty-Acid-Containing Lipids



Membrane Lipids: (3) Cholesterol

Cholesterol, the third of the three major types of membrane lipids, is a specific compound rather than a family of compounds like the phospholipids and sphingoglycolipids; (1) there are no fatty acid residues present and (2) neither glycerol nor sphingosine is present as the platform molecule. Cholesterol is a ***steroid***.



Steroid nucleus

Membrane Lipids: (3) Cholesterol

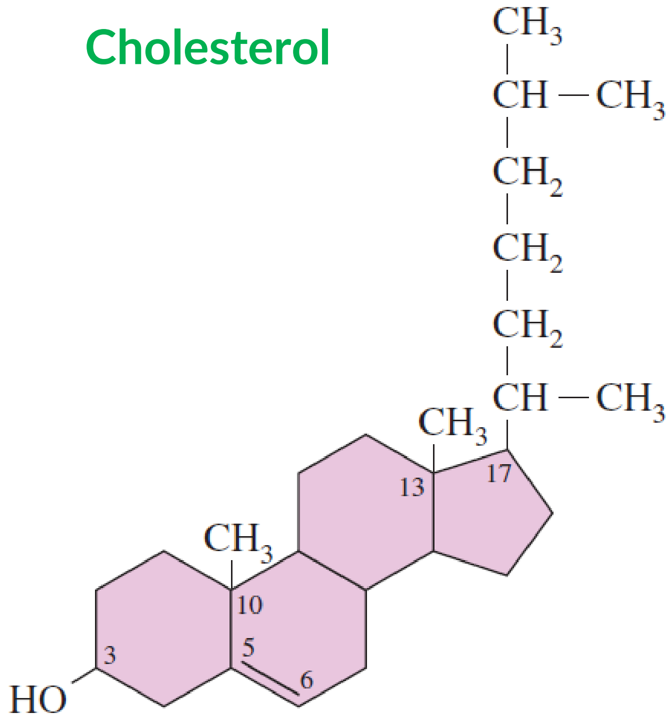
Cholesterol is ***a C_{27} steroid molecule that is a component of cell membranes and a precursor for other steroid-based lipids***.

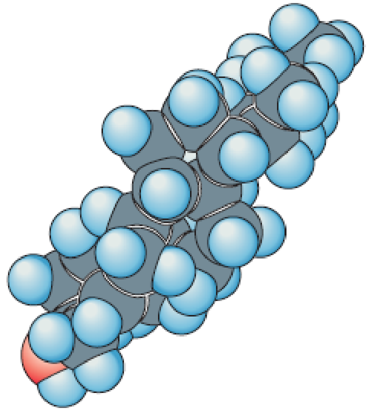
The “head and two tails” arrangement found in other membrane lipids is not present. The lack of a *large* polar head group causes cholesterol to have **limited water solubility**. The **-OH group on carbon 3 is considered the head of the molecule.**

Cholesterol is found in cell membranes (up to 25% by mass), in nerve tissue, in brain tissue (about 10% by dry mass), and in virtually all fluids. 100 ml of blood contains 50 mg of free cholesterol and about 170 mg of cholesterol esterified with various fatty acids.

most of it is biosynthesized by the liver and (to a lesser extent) the intestine (800-1000 mg)

Cholesterol





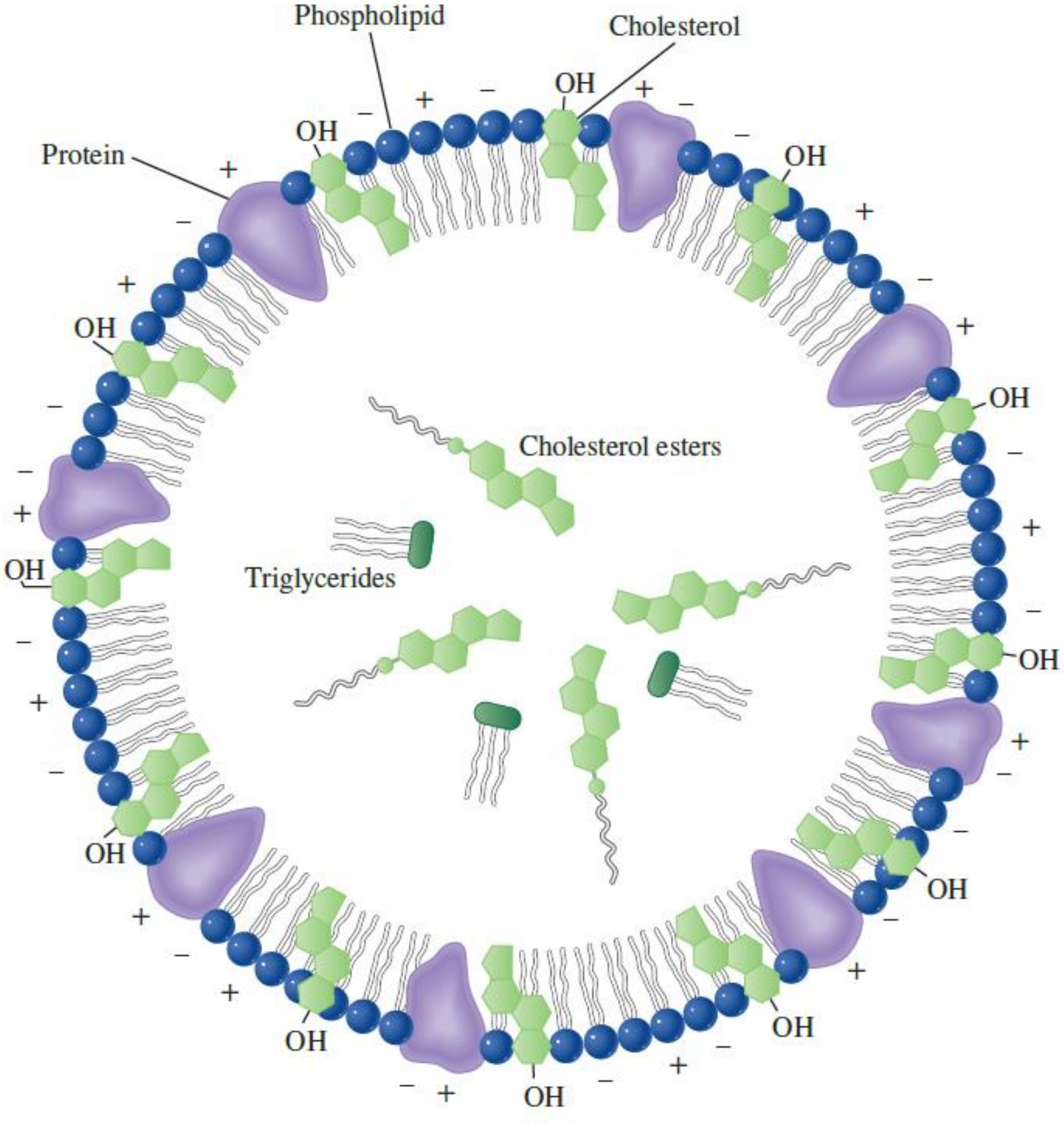
Complex Lipids: Plasma Lipoproteins

Lipoproteins

Because cholesterol and other lipids are only sparingly soluble in water (blood), a protein carrier system is used for their distribution. These cholesterol–protein combinations are called ***lipoproteins.***

Lipoprotein particles are spheres that consist of a ***core of hydrophobic lipids*** surrounded by an ***outer layer or shell of amphipathic proteins, phospholipids, and cholesterol***.

The amphipathic molecules of the outer surface are able to interact with the aqueous environment of the bloodstream and the hydrophobic molecules in the interior of the lipoprotein particle.



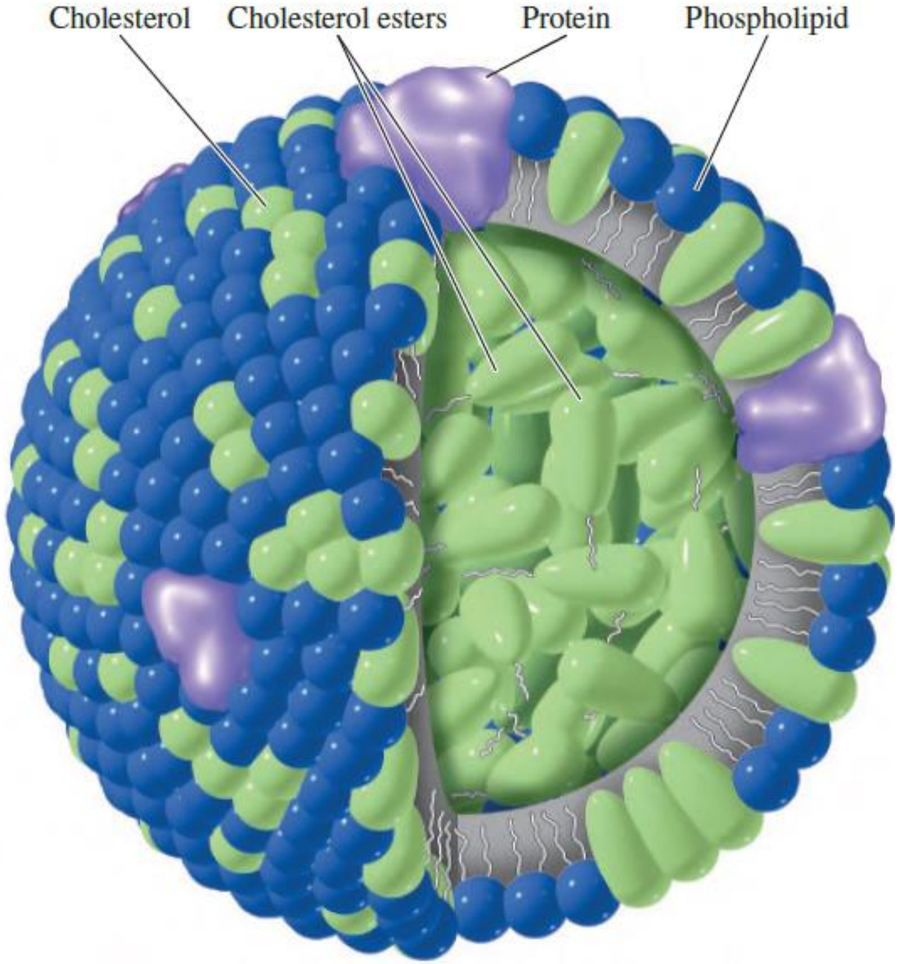
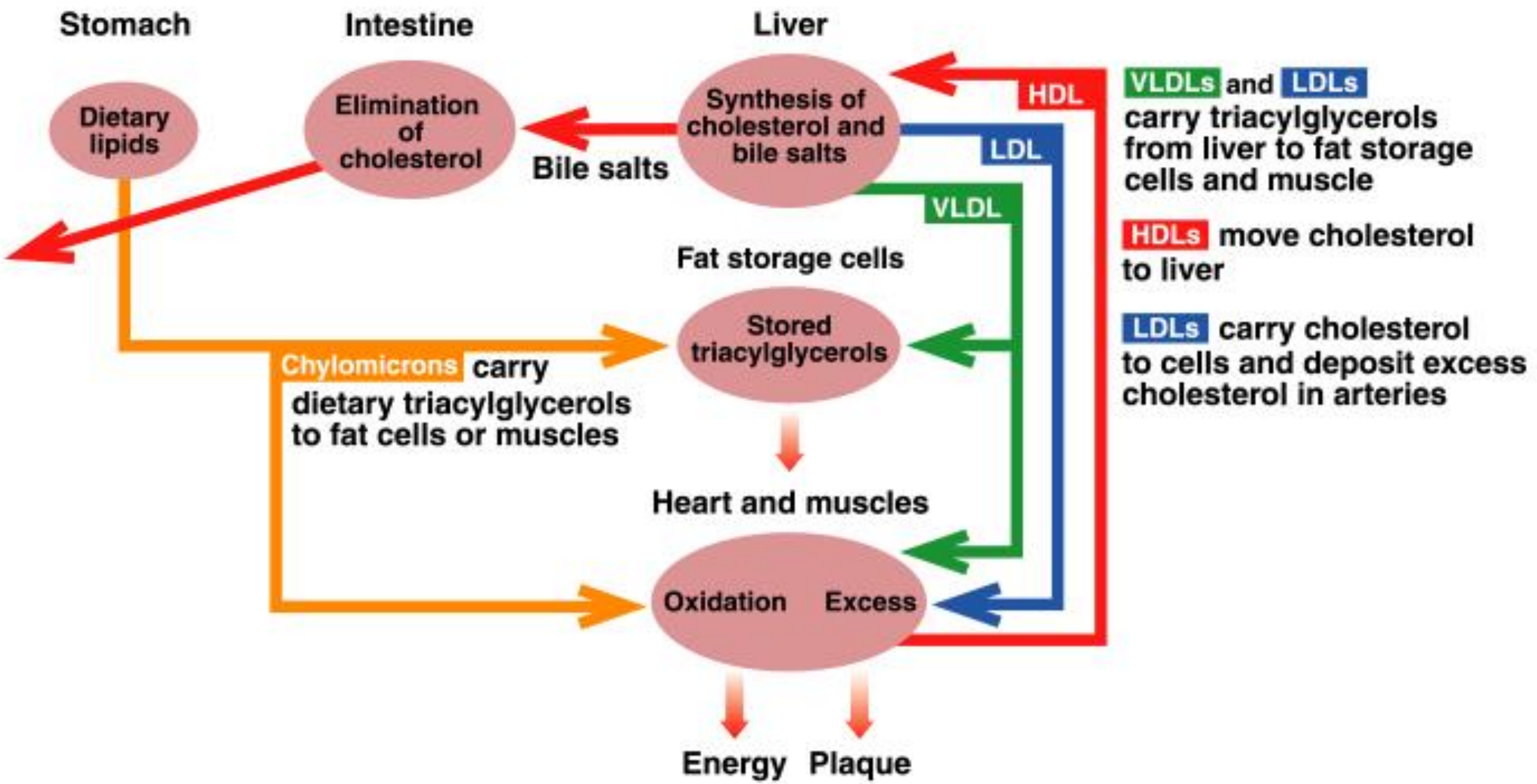


Figure 17.8 A model for the structure of a plasma lipoprotein. The various lipoproteins are composed of a shell of protein, cholesterol, and phospholipids surrounding more hydrophobic molecules such as triglycerides or cholesterol esters (cholesterol esterified to fatty acids). (a) Cross section, (b) three-dimensional view.

Complex Lipids: Plasma Lipoproteins

Four major classes of human plasma lipoproteins:

- **Chylomicrons** carry dietary triglycerides from the intestine to other tissues; Not all lipids in the blood are derived directly from the diet.
- **Very low density lipoproteins (VLDL)** bind **triglycerides** synthesized in the liver and carry them to adipose and other tissues for storage (and energy)
- **Low-density lipoproteins (LDL)** carry **cholesterol** synthesized in the liver to peripheral tissues and help regulate cholesterol levels in those tissues. These are richest in cholesterol, frequently carrying 40% of the plasma cholesterol.
- **High-density lipoproteins (HDL)** are bound to plasma cholesterol; however, they transport cholesterol from peripheral tissues to the liver.

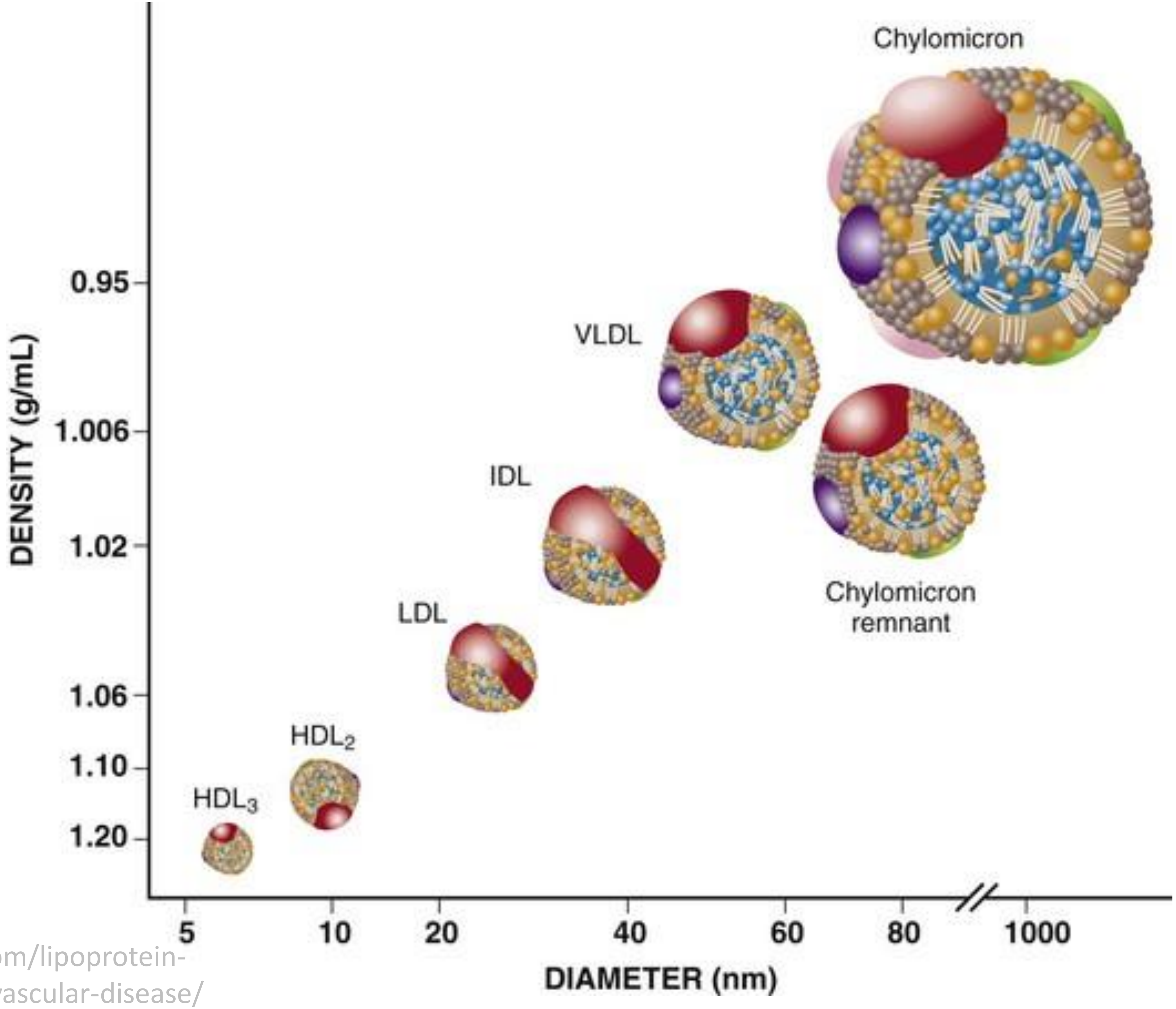


Stomach
Intestine
Liver
Dietary lipids
Elimination of cholesterol
Bile salts
Synthesis of cholesterol and bile salts
HDL
LDL
VLDL
Fat storage cells
Stored triacylglycerols
Chylomicrons carry dietary triacylglycerols to fat cells or muscles
Heart and muscles
Oxidation
Excess
Energy
Plaque
VLDLs and LDLs carry triacylglycerols from liver to fat storage cells and muscle
HDLs move cholesterol to liver
LDLs carry cholesterol to cells and deposit excess cholesterol in arteries

Complex Lipids: Plasma Lipoproteins

Table 18.5 Composition and Properties of Plasma Lipoproteins

	Chylomicron	VLDL	LDL	HDL
Density (g/mL)	0.94	0.950–1.006	1.006–1.063	1.063–1.210
Composition (% by mass)				
Triacylglycerol	86	55	6	4
Phospholipids	7	18	22	24
Cholesterol	2	7	8	2
Cholesteryl esters	3	12	42	15
Protein	2	8	22	55



https://thoracickey.com/lipoprotein-disorders-and-cardiovascular-disease/

Complex Lipids: Plasma Lipoproteins

Receptor-mediated endocytosis

- Entry of LDL particles into the cell is dependent on a specific recognition event and binding between the LDL particle and a protein receptor embedded within the membrane. The molecules on the surface of the LDL that binds to the LDL receptor is the protein apolipoprotein B (apoB). **There is one apoB molecule on each LDL particle.** Low-density lipoprotein receptors (LDL receptors) are found in the membranes of cells outside the liver and are responsible for the uptake of cholesterol by the cells of various tissues.

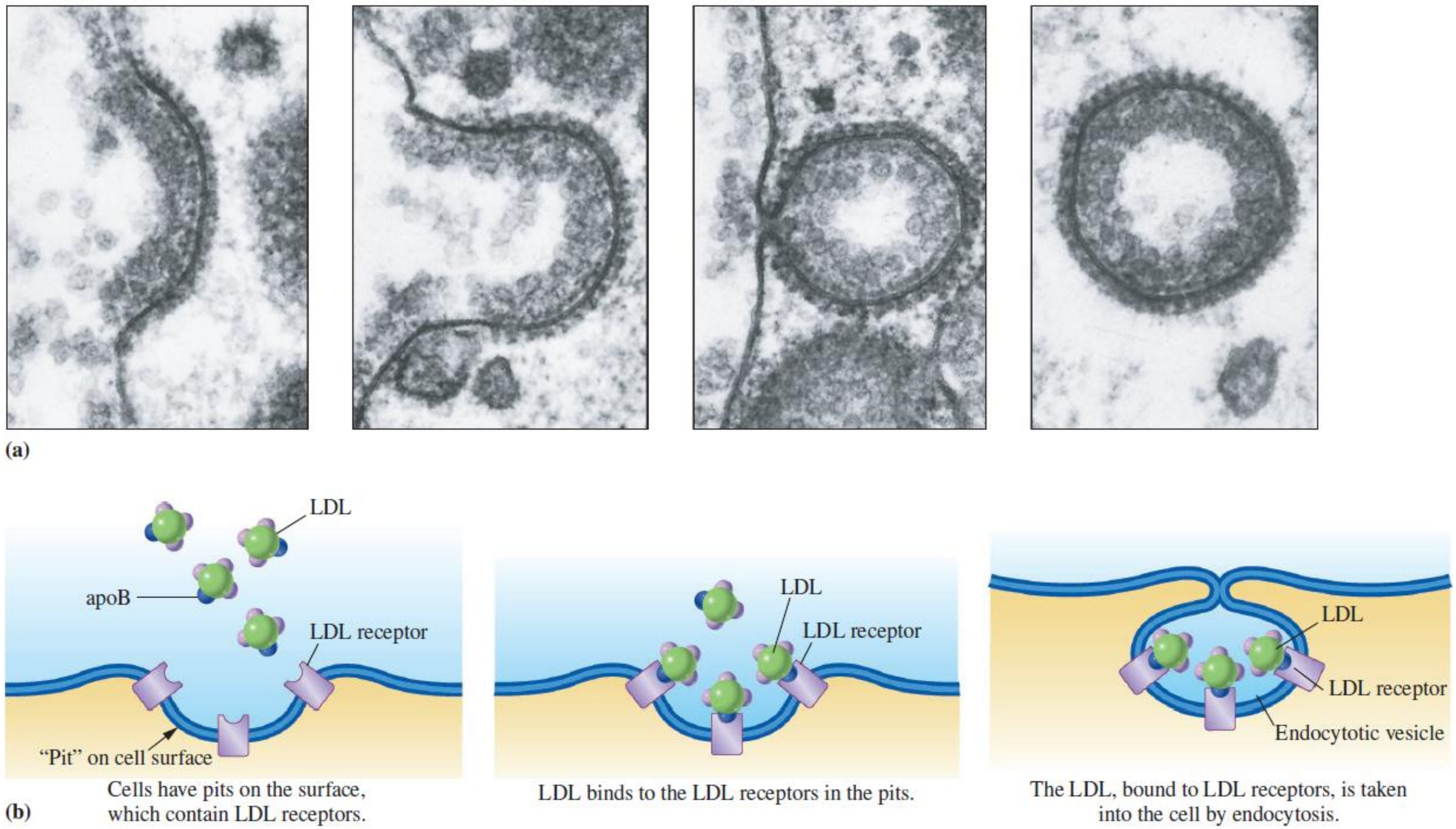
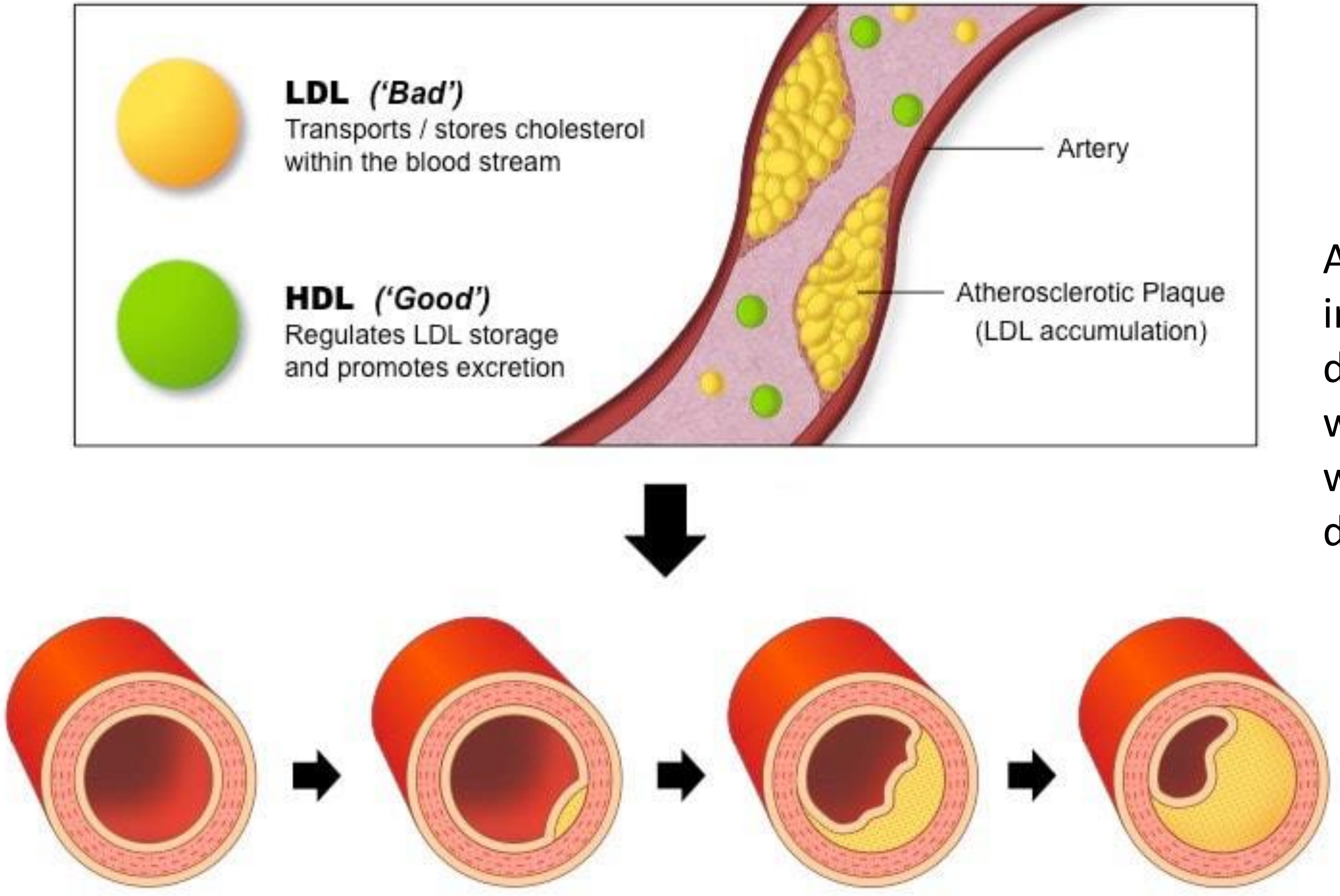


Figure 17.9 Receptor-mediated endocytosis. (a) Electron micrographs of the process of receptor-mediated endocytosis. (b) Summary of the events of receptor-mediated endocytosis of LDL.

Complex Lipids: Plasma Lipoproteins



Also, people who have a genetic defect in the gene coding for the LDL receptor do not take up as much cholesterol which gets deposited on the artery walls, causing atherosclerosis. This disease is called *hypercholesterolemia.*

https://mysciencesquad.weebly.com/ib-hl-d3nos.html

Complex Lipids: Plasma Lipoproteins

A person's *total* blood cholesterol level does not necessarily correlate with that individual's real risk for heart and blood vessel disease. A better measure is the ***cholesterol ratio***

$$\text{Cholesterol ratio} = \frac{\text{total cholesterol}}{\text{HDL cholesterol}}$$

What Cholesterol Ratio Means

Ratio	Heart Disease Risk
6.0	high
5.0	above average
4.5	average
4.0	below average
3.0	low

Table 8-4 The Amount of Cholesterol Found in Various Foods

Food	Cholesterol (mg)
liver (3 oz)	410
egg (1 large)	213
shrimp (3 oz)	166
pork chop (3 oz)	83
chicken (3 oz)	75
beef steak (3 oz)	70
fish fillet (3 oz)	54
whole milk (1 cup)	33
cheddar cheese (1 oz)	30
Swiss cheese (1 oz)	26
low-fat milk (1 cup)	22

Section 8-9 Quick Quiz

1. The "steroid nucleus" common to all steroid structures involves a fused-ring system that contains
   a. four 6-membered rings
   b. four 5-membered rings
   c. three 6-membered rings and one 5-membered ring
   d. no correct response
2. Which of the following types of membrane lipids has a steroid structure?
   a. cholesterol
   b. sphingoglycolipids
   c. sphingophospholipids
   d. no correct response
3. Which of the following statements concerning cholesterol is *correct*?
   a. An alcohol functional group is present in its structure.
   b. The lipoprotein HDL distributes cholesterol to various parts of the human body.
   c. The cholesterol associated with LDL is often called "good cholesterol."
   d. no correct response

Complex Lipids: Plasma Lipoproteins

A person's *total* blood cholesterol level does not necessarily correlate with that individual's real risk for heart and blood vessel disease. A better measure is the ***cholesterol ratio***

$$\text{Cholesterol ratio} = \frac{\text{total cholesterol}}{\text{HDL cholesterol}}$$

What Cholesterol Ratio Means

Ratio	Heart Disease Risk
6.0	high
5.0	above average
4.5	average
4.0	below average
3.0	low

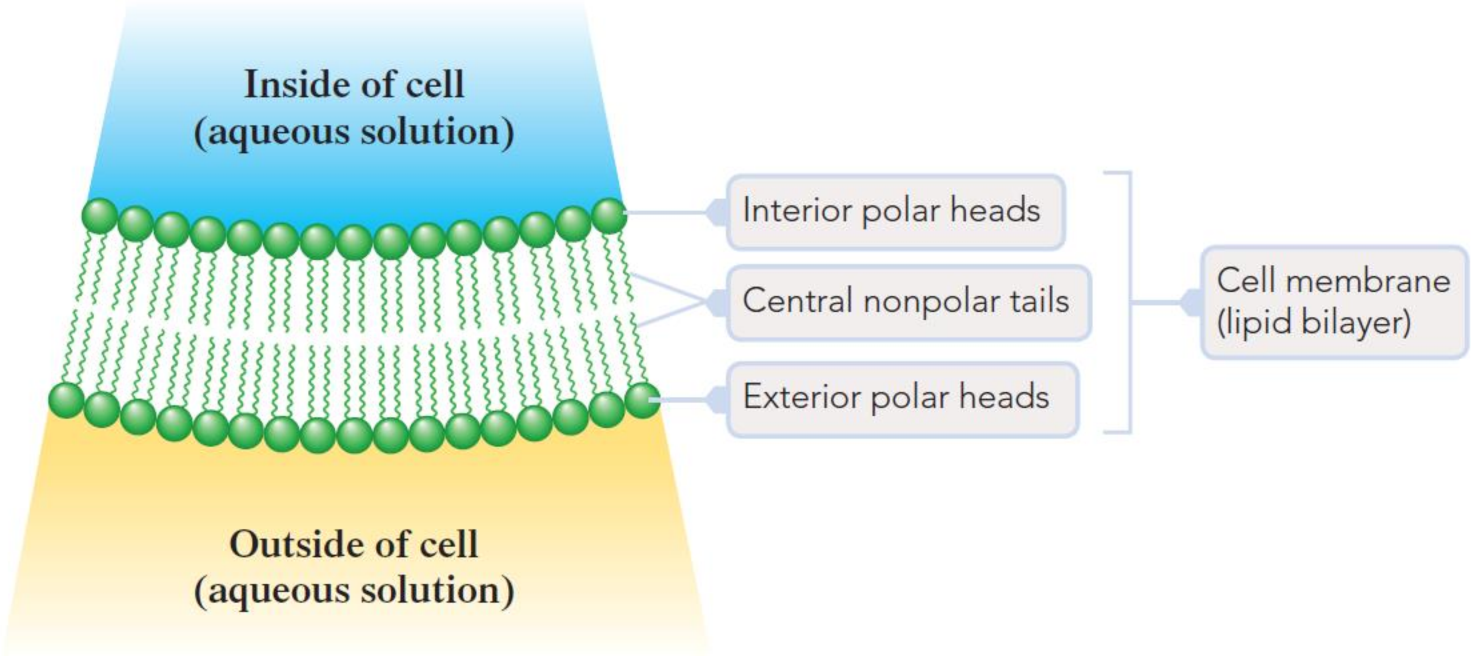
Table 8-4 The Amount of Cholesterol Found in Various Foods

Food	Cholesterol (mg)
liver (3 oz)	410
egg (1 large)	213
shrimp (3 oz)	166
pork chop (3 oz)	83
chicken (3 oz)	75
beef steak (3 oz)	70
fish fillet (3 oz)	54
whole milk (1 cup)	33
cheddar cheese (1 oz)	30
Swiss cheese (1 oz)	26
low-fat milk (1 cup)	22

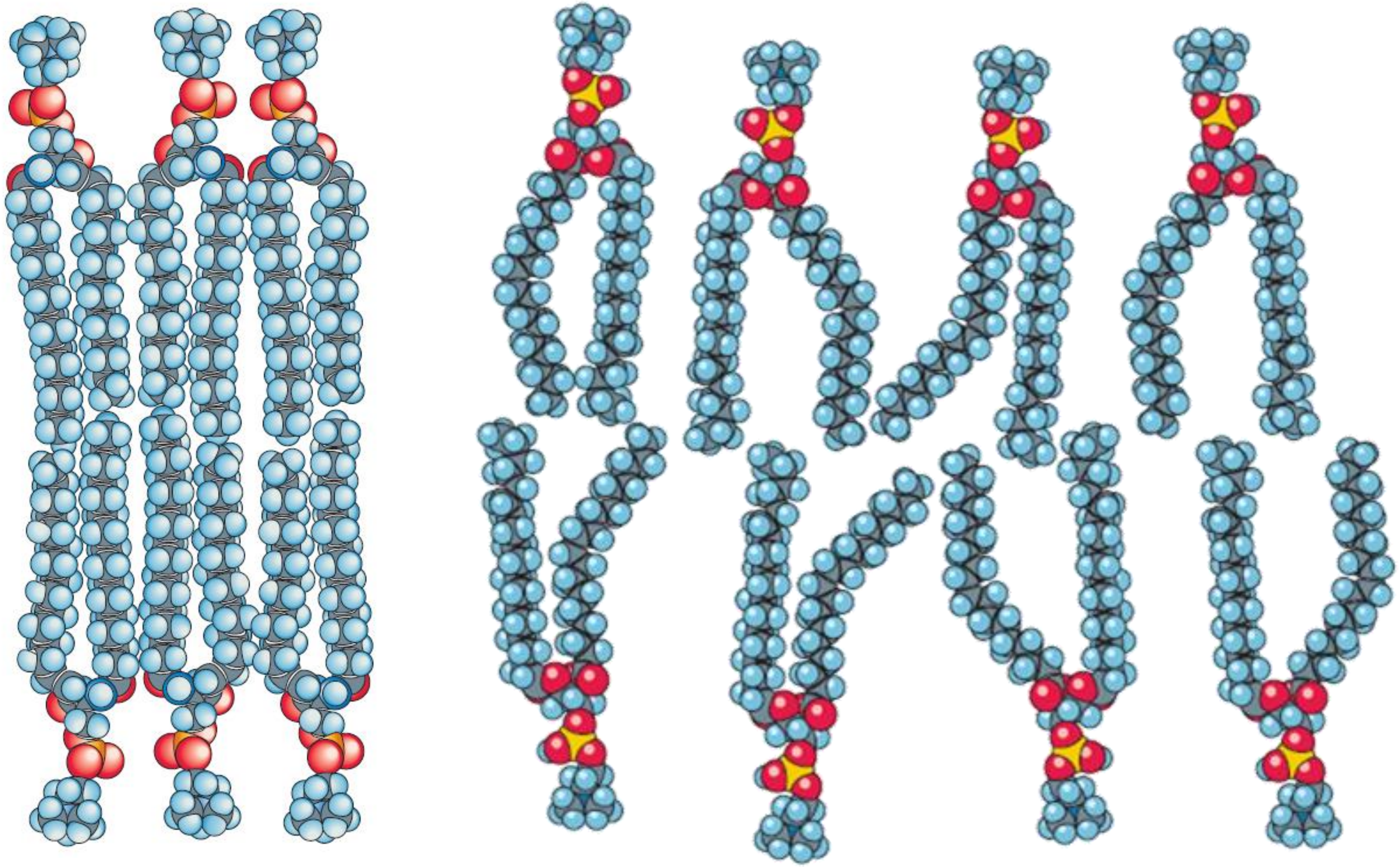
The Structure of Biological Membranes

Cell membrane

- a lipid-based structure that separates a cell's aqueous-based interior from the aqueous environment surrounding the cell
- A lipid bilayer made of phospholipids and glycolipids in which the ***nonpolar tails*** of the lipids are in the ***middle*** of the structure and the ***polar heads*** are on the ***outside surfaces*** of the structure.



The Structure of Biological Membranes



The kinks associated with *cis* double bonds in fatty acid chains prevent tight packing of the lipid molecules in a lipid bilayer.

The open packing imparts a flexible or fluid character to the membrane—a necessity because ***numerous types of biochemicals must pass into and out of a cell***.

The Structure of Biological Membranes

Cholesterol molecules regulate membrane rigidity. Because of their compact shape cholesterol molecules fit between the fatty acid chains of the lipid bilayer restricting movement of the fatty acid chains.

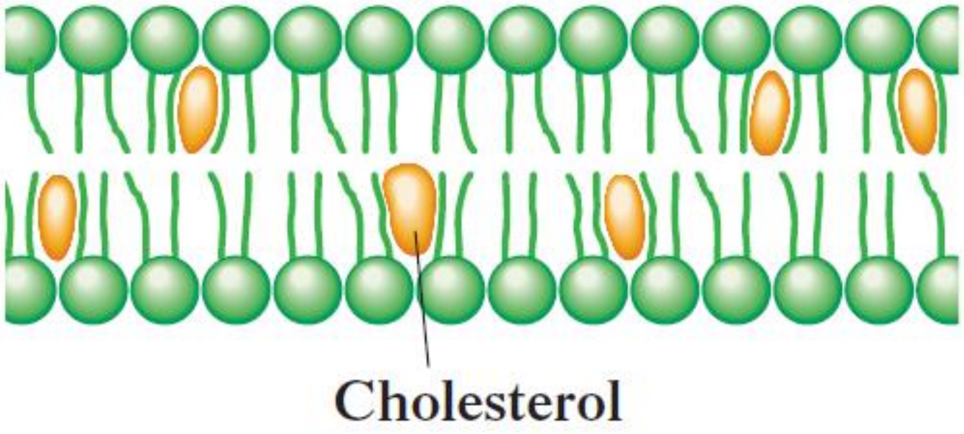
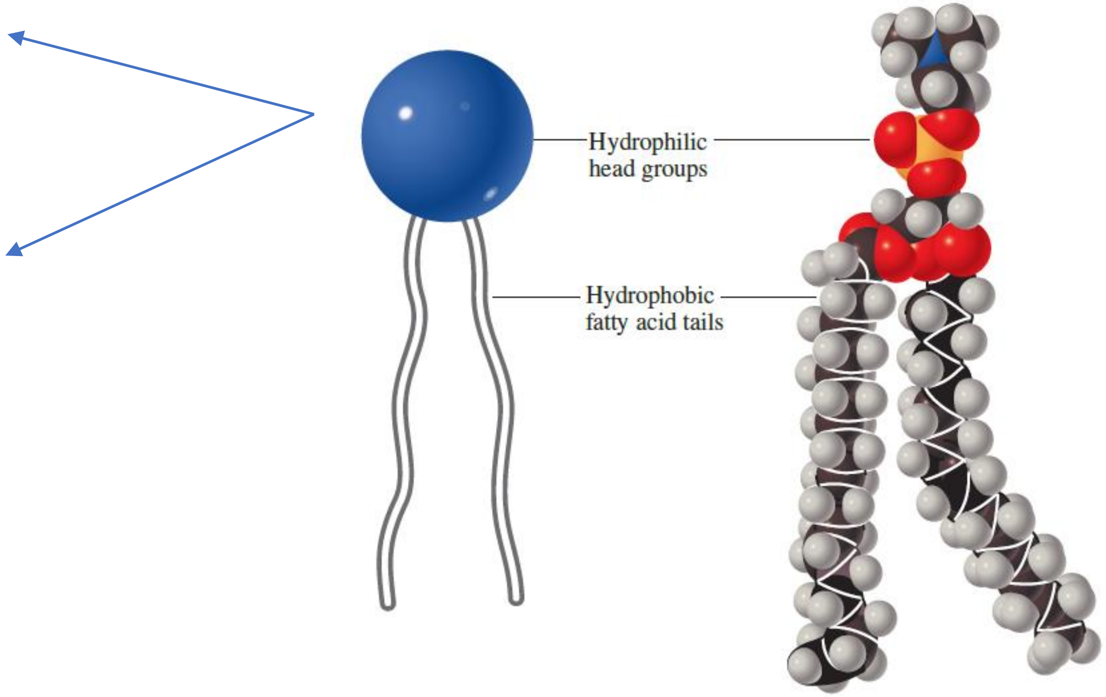
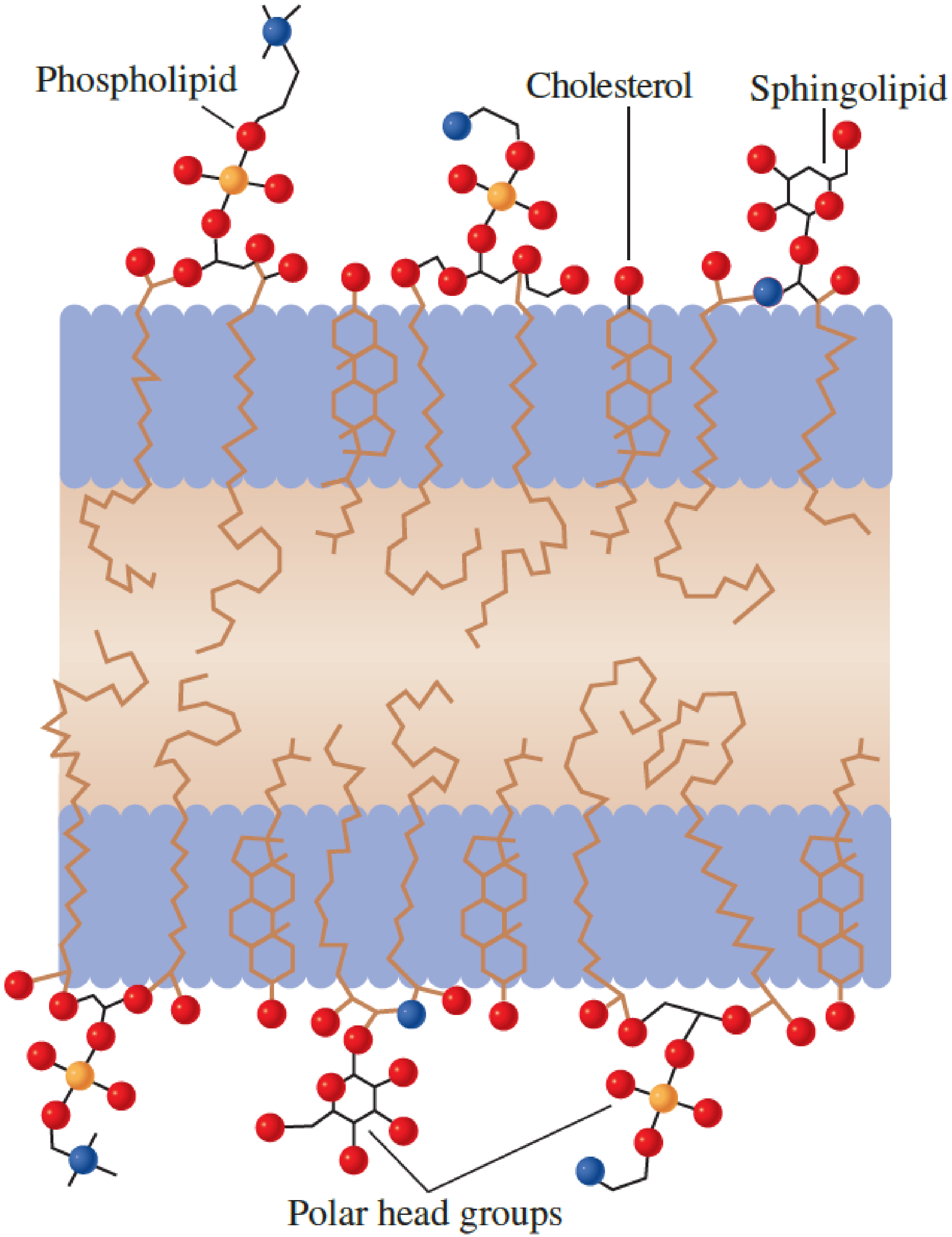


Figure 8-20 Cholesterol molecules fit between fatty acid chains in a lipid bilayer.



Line formula structure of a bilayer membrane composed of phospholipids, cholesterol, and sphingolipids.

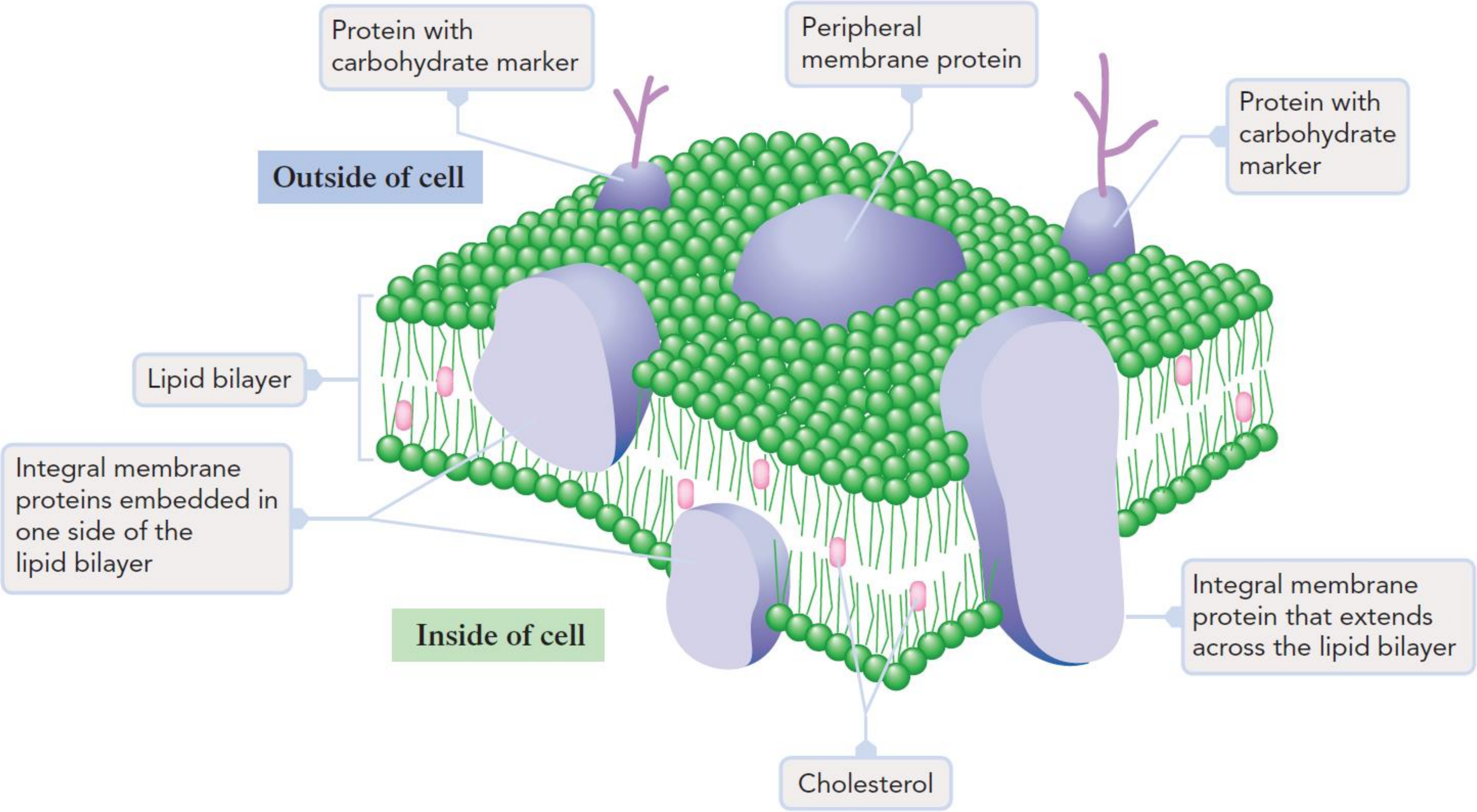


The Structure of Biological Membranes

Proteins are also components of lipid bilayers.

- move substances such as nutrients and electrolytes across the membrane
- also act as receptors that bind hormones and neurotransmitters
    a. **integral membrane protein** *is a membrane protein that penetrates the cell membrane*
    b. **peripheral membrane protein** *is a nonpenetrating membrane protein located on the surface of the cell membrane*; bound only to one of the surfaces of the membrane by interactions between ionic head groups of the membrane lipids and ionic amino acids on the surface of the peripheral protein.

Small carbohydrate molecules, usually oligosaccharides, are covalently bonded to protein molecules ***(glycoprotein)*** or lipid molecules ***(glycolipid)*** and extend outward from the membrane into the surrounding aqueous environment.

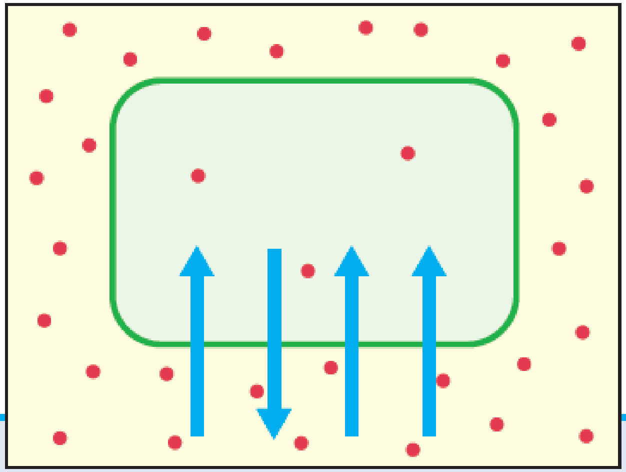

Protein with carbohydrate marker
Peripheral membrane protein
Protein with carbohydrate marker
Outside of cell
Lipid bilayer
Integral membrane proteins embedded in one side of the lipid bilayer
Inside of cell
Integral membrane protein that extends across the lipid bilayer
Cholesterol

The Structure of Biological Membranes

- Intermolecular forces rather than covalent bonds govern the interactions among the lipid and protein components of a lipid bilayer. Thus, the various lipids and proteins present are free to move about within the bilayer structure but their *orientations are unchanged*.
- Interior and exterior surfaces of a lipid bilayer do not have exactly the same lipid/protein composition; different mixtures of lipid and proteins are present.

The Structure of Biological Membranes

Transport Across Cell Membranes

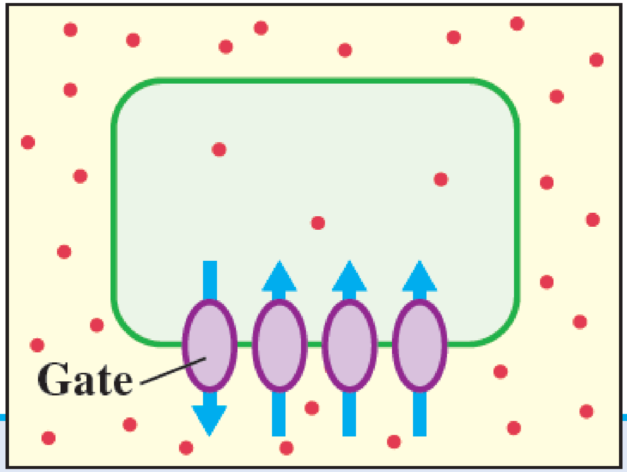


Concentration gradient: movement with the gradient; from high to low concentration

Cellular energy expenditure: none required

Protein help: none required

a Passive transport

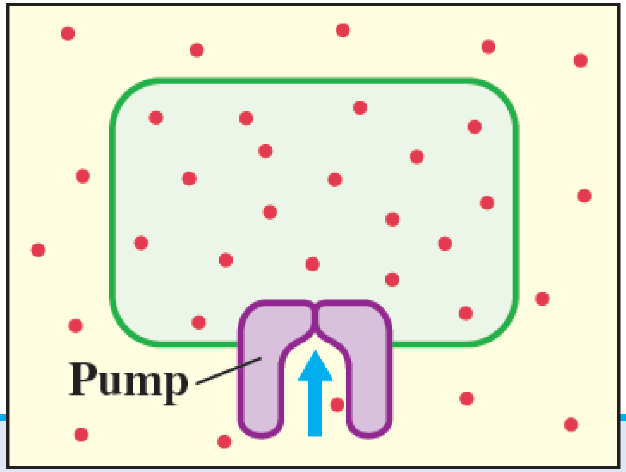


Concentration gradient: movement with the gradient; from high to low concentration

Cellular energy expenditure: none required

Protein help: proteins serve as “gates”

b Facilitated transport



Concentration gradient: movement against the gradient; from low to high concentration

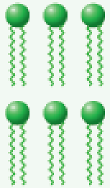
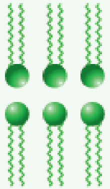
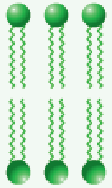
Cellular energy expenditure: energy input required

Protein help: proteins serve as “pumps”

c Active transport

Section 8-10 Quick Quiz

1. Which of the following is a correct representation for the structure of a lipid bilayer?

   a. 
   b. 
   c. 
   d. no correct response

2. The exterior surface positions in a lipid bilayer are occupied by
   a. hydrophilic entities
   b. hydrophobic entities
   c. nonpolar entities
   d. no correct response

3. Which of the following polarity-based descriptions is correct for the interior of a lipid bilayer?
   a. contains "polar heads"
   b. contains "nonpolar heads"
   c. contains "nonpolar tails"
   d. no correct response

4. The biochemical function for the cholesterol present in cell membranes is
   a. impart polarity to the interior membrane
   b. prevent other membrane components from reacting with each other
   c. regulate membrane fluidity
   d. no correct response

5. Which of the following membrane transport mechanisms requires both the aid of proteins and the expenditure of cellular energy?
   a. facilitated transport
   b. active transport
   c. passive transport
   d. no correct response

Emulsification Lipids: Bile Acids

Emulsifier

a substance that can disperse and stabilize water-insoluble substances as colloidal particles in an aqueous solution

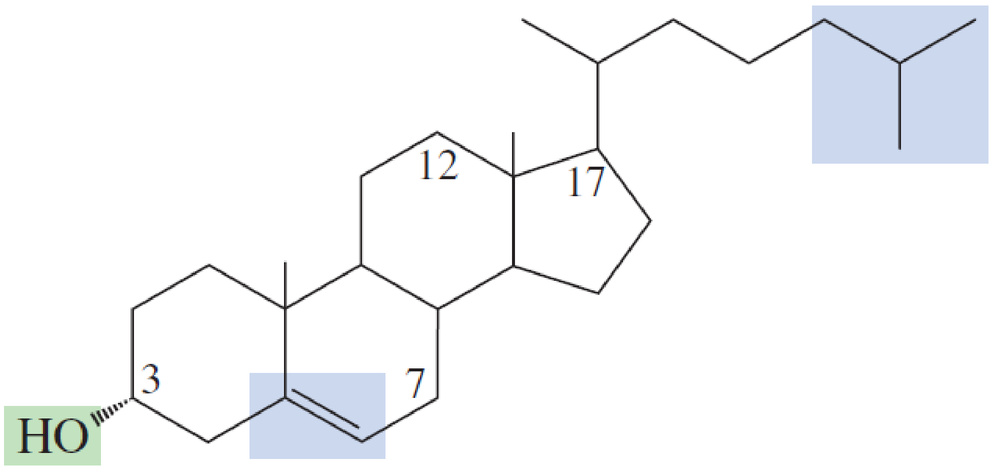
Bile acid

a cholesterol derivative that functions as a lipid-emulsifying agent in the aqueous environment of the digestive tract

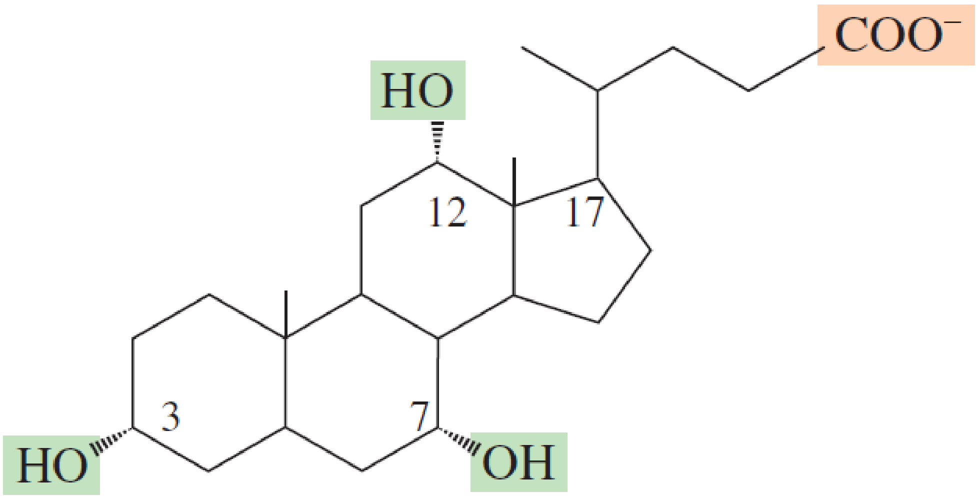
Bile

a fluid containing emulsifying agents that is secreted by the liver, stored in the gallbladder, and released into the small intestine during digestion.

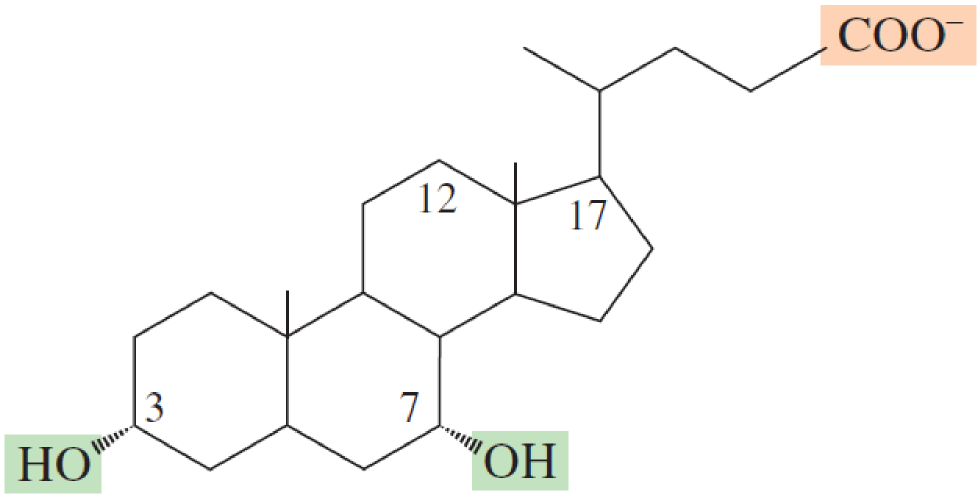
Figure 8-25 A large percentage of gallstones, the causative agent for many "gallbladder attacks," are almost pure crystallized cholesterol that has precipitated from bile solution.



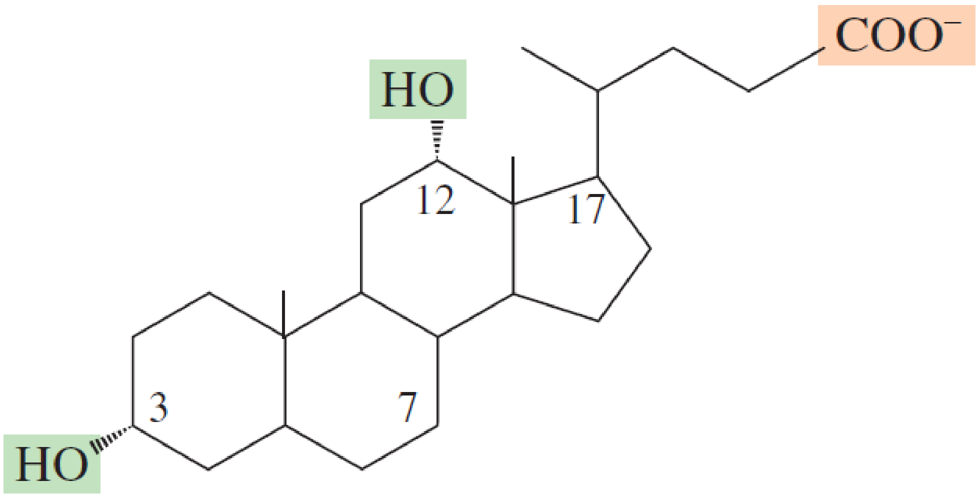
Cholesterol (C_{27})



Cholic acid (C_{24})

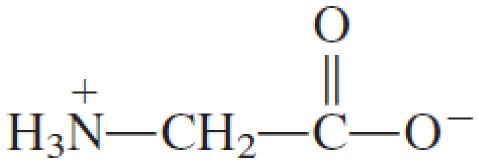


12-Deoxycholic acid (C_{24})

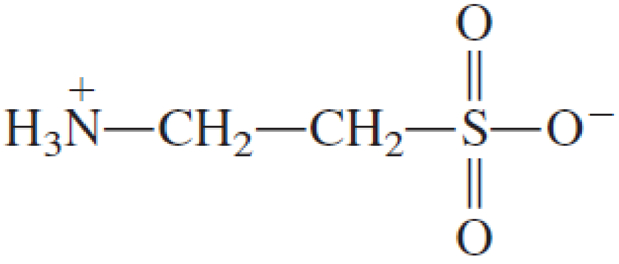


7-Deoxycholic acid (C_{24})

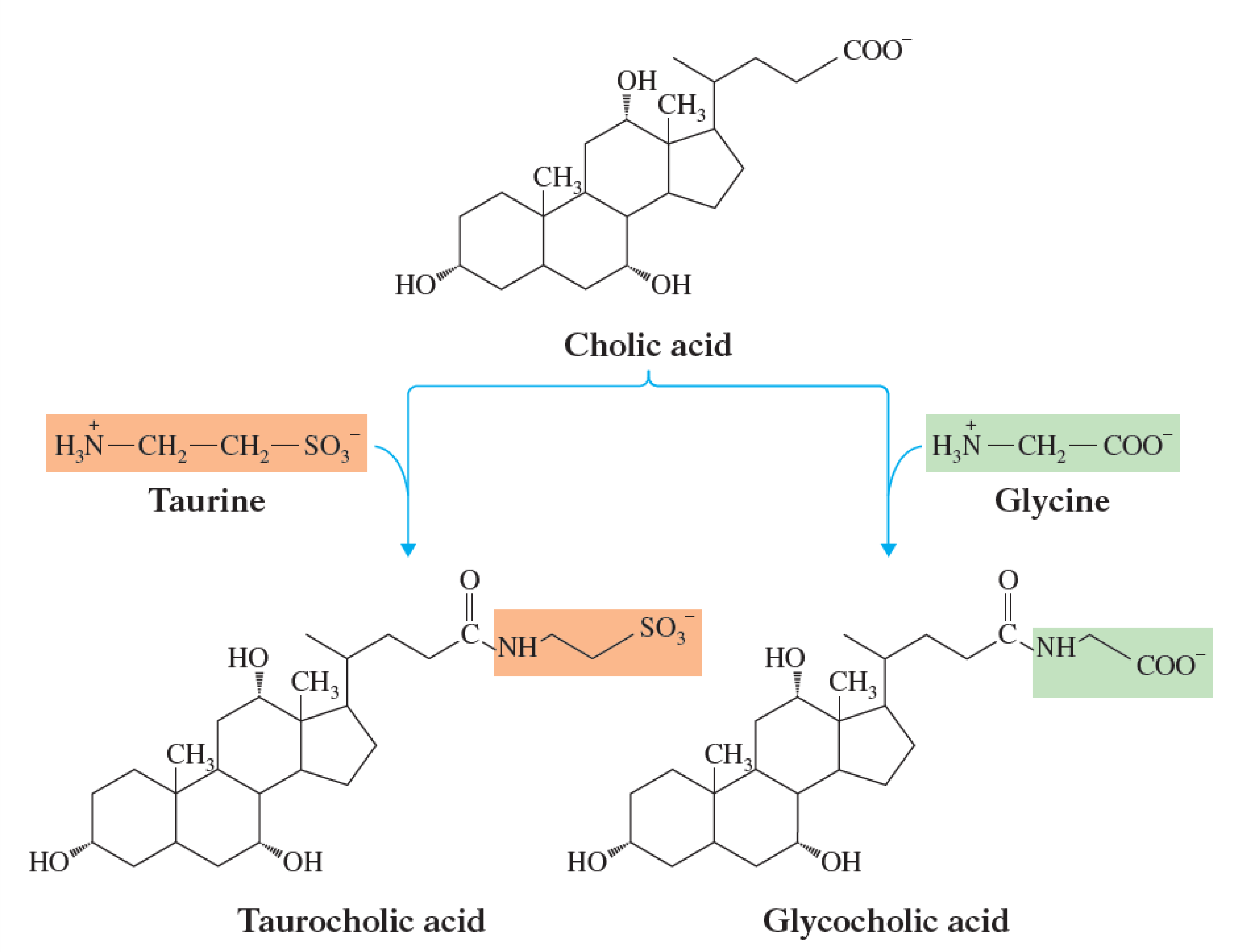
The free bile acids are converted to more complex bile acids by attachment of a small amino acid to the carbon 17 side chain carboxyl group via an amide linkage.



Glycine

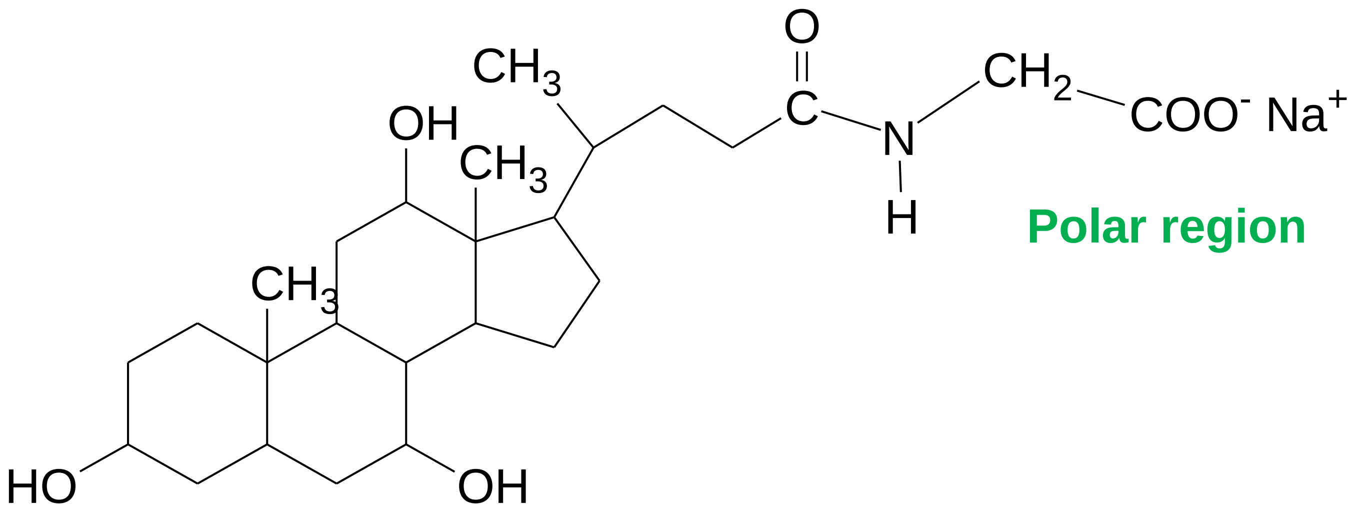


Taurine



cholic acid, a bile acid

glycine, an amino acid



Polar region

Nonpolar region

sodium glycocholate, a bile salt

The “solubilizing” of lipids from bile acid action is similar to the action of soap in the washing process

Section 8-11 Quick Quiz

1. Which of the following statements concerning bile acids is *incorrect*?
   a. They are cholesterol derivatives.
   b. They are emulsifying agents.
   c. They are insoluble in water.
   d. no correct response
2. Which of the following statements concerning structural characteristics of bile acids is *correct*?
   a. No hydroxyl groups are present.
   b. Fewer hydroxyl groups are present than in cholesterol.
   c. More hydroxyl groups are present than in cholesterol.
   d. no correct response

Messenger Lipids: (1) Steroid Hormones

Steroid hormones and **eicosanoids** (fatty acid derivatives) are two large families of lipids that have messenger functions.

A **hormone** *is a biochemical substance, produced by a ductless gland, that has a messenger function*. Hormones serve as a means of communication *between* various tissues. Some hormones, though not all, are lipids.

A **steroid hormone** *is a hormone that is a cholesterol derivative*. There are two major classes of steroid hormones:

(1) ***sex hormones***, which control reproduction and secondary sex characteristics and

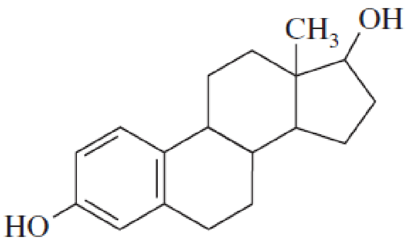
(2) ***adrenocorticoid hormones***, which regulate numerous biochemical processes in the body.

Messenger Lipids: (1) Steroid Hormones (Sex Hormones)

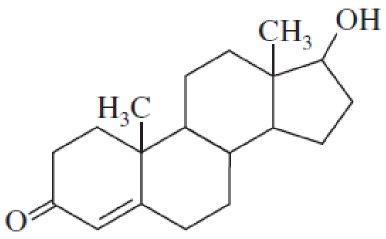
Subclass	Site of biosynthesis	Function
Estrogens—the female sex hormones	ovaries and adrenal cortex (the outer part of the adrenal glands, which are located on the top of each kidney)	development of female secondary sex characteristics at the onset of puberty, regulation of the menstrual cycle; stimulate the development of the mammary glands during pregnancy and induce estrus (heat) in animals.
Androgens—the male sex hormones	testes and adrenal cortex	promote the development of male secondary sex characteristics; promote muscle growth
Progestins—the pregnancy hormones	ovaries and the placenta	prepare the lining of the uterus for implantation of the fertilized ovum; suppress ovulation

Figure 8-26 Structures of selected sex hormones and synthetic compounds that have similar actions.

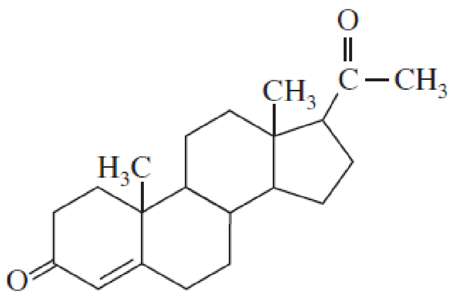
Increased knowledge of the structures and functions of sex hormones has led to the development of a number of *synthetic* steroids whose actions often mimic those of the natural steroid hormones.



Estradiol
(the primary estrogen; responsible for secondary female characteristics)

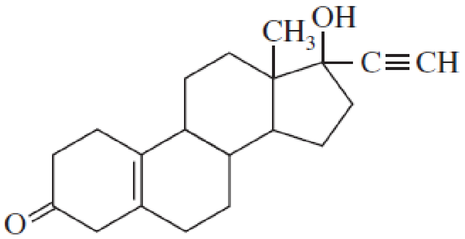


Testosterone
(the primary androgen; responsible for secondary male characteristics)

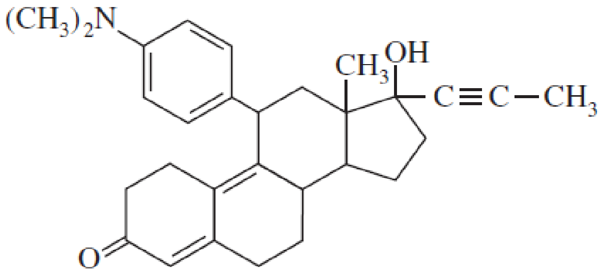


Progesterone
(the primary progestin; prepares the uterus for pregnancy)

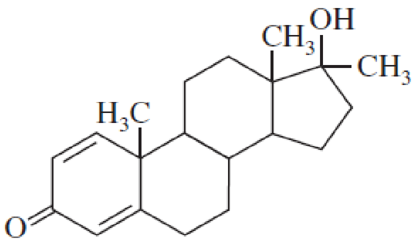
a Natural hormones



Norethynodrel
(a synthetic progestin)



RU-486
(mifepristone; a synthetic abortion drug)



Methandrostenolone
(a synthetic tissue-building steroid)

b Synthetic steroids

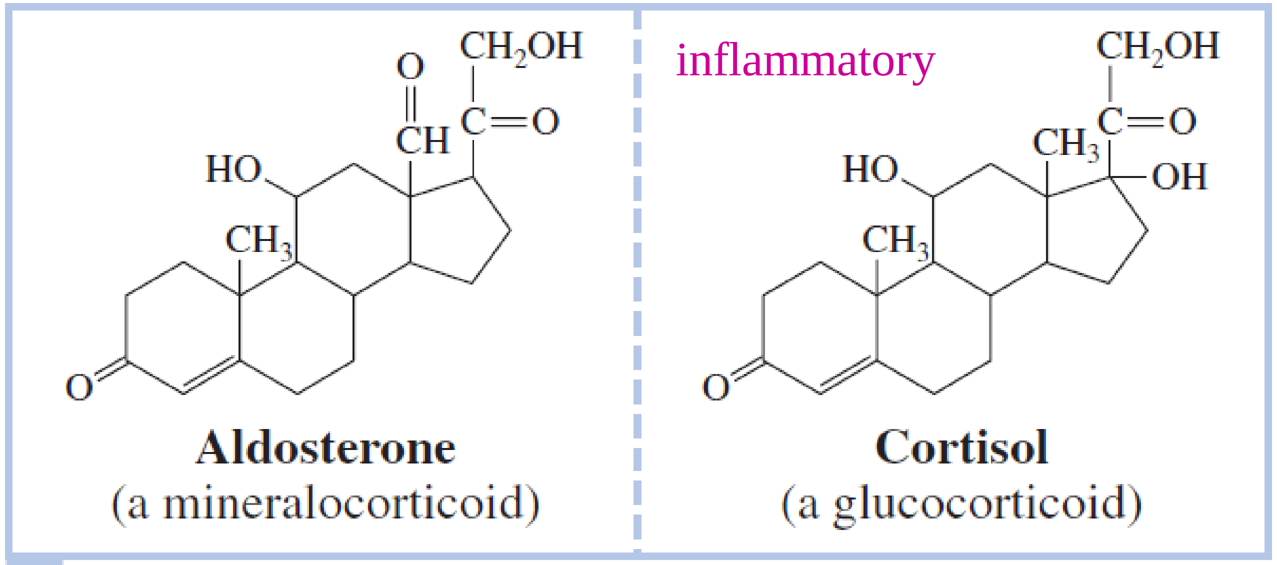
The fact that seemingly minor changes in structure effect great changes in biofunction points out, again, the extreme specificity of the enzymes that control biochemical reactions.

Messenger Lipids: (1) Steroid Hormones (Adrenocorticoid Hormones)

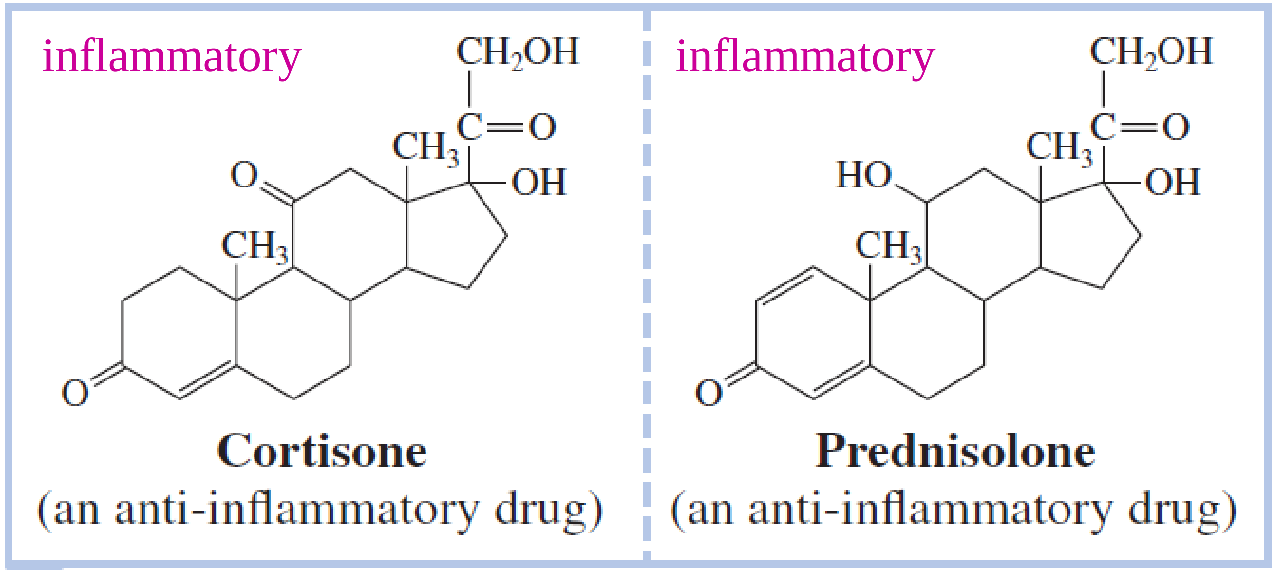
There are two subclasses of adrenocorticoid hormones.

1. ***Mineralocorticoids*** control the balance of Na+ and K+ ions in cells and body fluids.
2. ***Glucocorticoids*** control glucose metabolism and counteract inflammation.

Figure 8-27 Structures of selected adrenocorticoid hormones and related synthetic compounds.



a Natural hormones



b Synthetic steroids

Upon reaching its target tissues in the kidney, **aldosterone** activates a set of reactions that cause sodium ions and water to be returned to the blood. If sodium levels are elevated, aldosterone is not secreted from the adrenal cortex and the sodium ions filtered out of the blood by the kidney will be excreted.

Treatment with **cortisone** is not without risk. Some of the possible side effects of cortisone therapy include fluid retention, sodium retention, and potassium loss that can lead to congestive heart failure. Other side effects include muscle weakness, osteoporosis, gastrointestinal upsets including peptic ulcers, and neurological symptoms, including vertigo, headaches, and convulsions.

Section 8-12 Quick Quiz

1. Which of the following statements concerning steroid hormones is *correct*?
   a. Some, but not all of them, are cholesterol derivatives.
   b. Some, but not all of them, are glucose derivatives.
   c. All of them are cholesterol derivatives.
   d. no correct response
2. Which of the following is a correct pairing of concepts?
   a. pregnancy hormones and estrogens
   b. female sex hormones and progestins
   c. male sex hormones and androgens
   d. no correct response
3. Which of the following substances is associated with Na^+/K^+ balance in the human body?
   a. aldosterone
   b. cortisol
   c. prednisolone
   d. no correct response

Messenger Lipids: (2) Eicosanoids

An eicosanoid *is an oxygenated C_{20}-fatty-acid derivative that functions as a messenger lipid* (Greek word *eikos* means "twenty")

- Almost all cells, *except red blood cells*, produce eicosanoids
- like hormones, have profound physiological effects at extremely low concentrations
- ***hormone-like*** molecules rather than true hormones because they are ***not transported in the bloodstream*** to their site of action as true hormones are; Instead, they exert their effects in the tissues where they are synthesized
- usually have a very short "life," being broken down, often within seconds of their synthesis, to inactive residues (which are eliminated in urine)

Messenger Lipids: (2) Eicosanoids

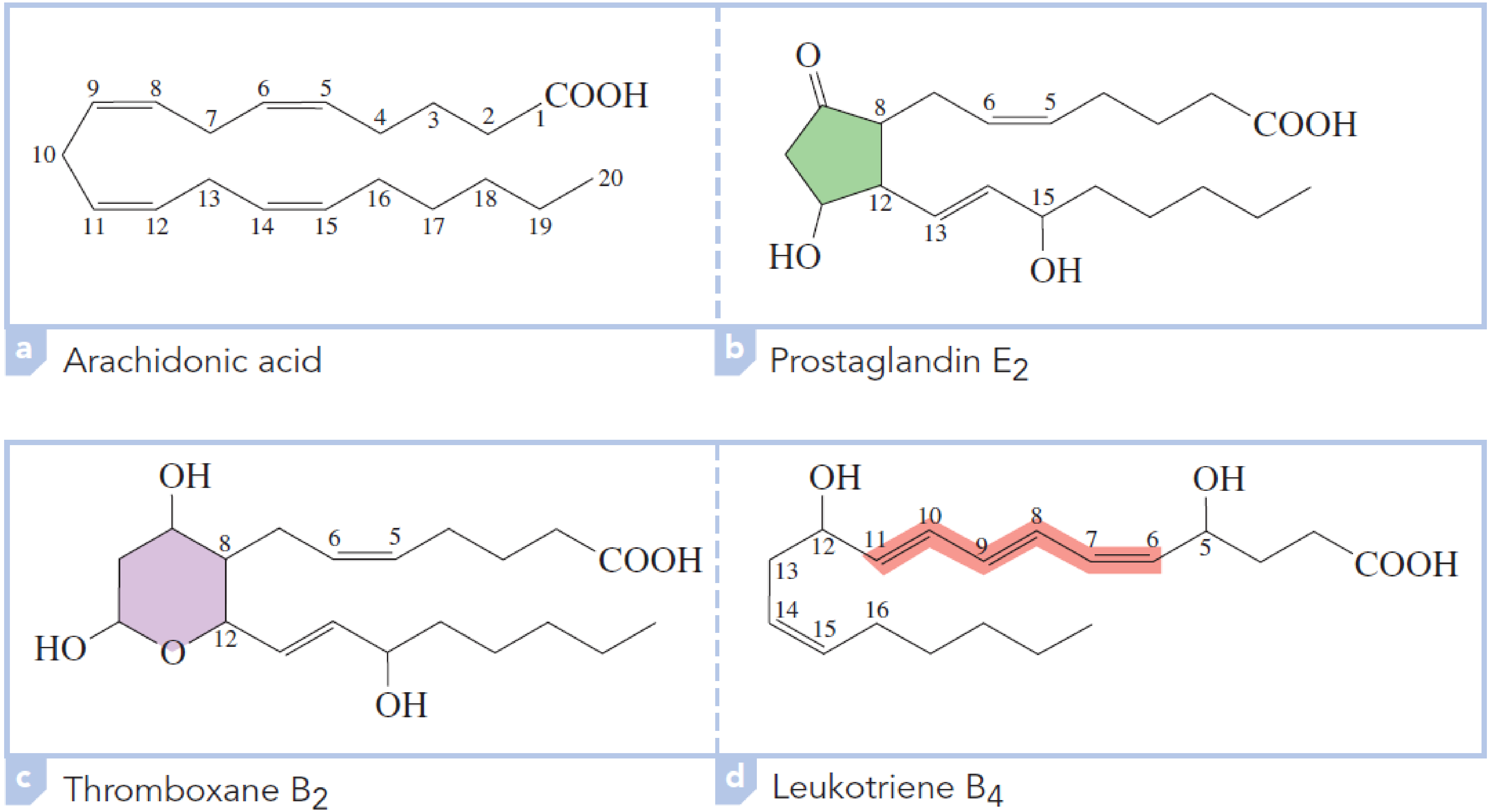
The physiological effects of eicosanoids include mediation of

1. The inflammatory response, a normal response to tissue damage
2. The production of pain and fever
3. The regulation of blood pressure
4. The induction of blood clotting
5. The control of reproductive functions, such as induction of labor
6. The regulation of the sleep/wake cycle

Three principal types of eicosanoids: prostaglandins, thromboxanes, and leukotrienes.

Figure 8-28 Relationship of the structures of various eicosanoids to their precursor, arachidonic acid. ◀

▶ *The capital letter–numerical subscript designations for individual eicosanoids is based on selected structural characteristics of the molecules. The numerical subscript indicates the number of carbon–carbon double bonds present. The letters denote subgroups of molecules. The prostaglandin E group, for example, has a carbonyl group on carbon 9.*



a Arachidonic acid

b Prostaglandin E_2

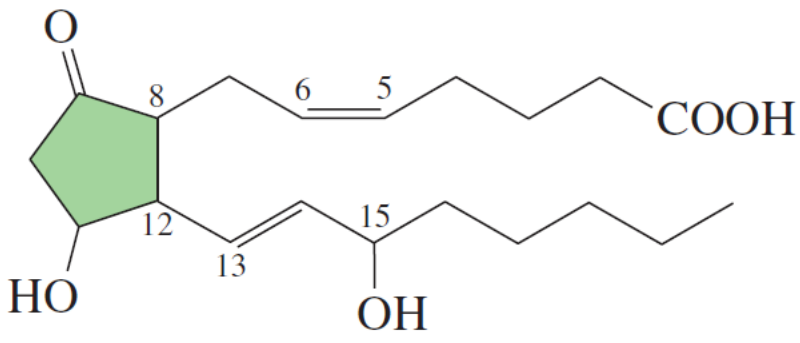
c Thromboxane B_2

d Leukotriene B_4

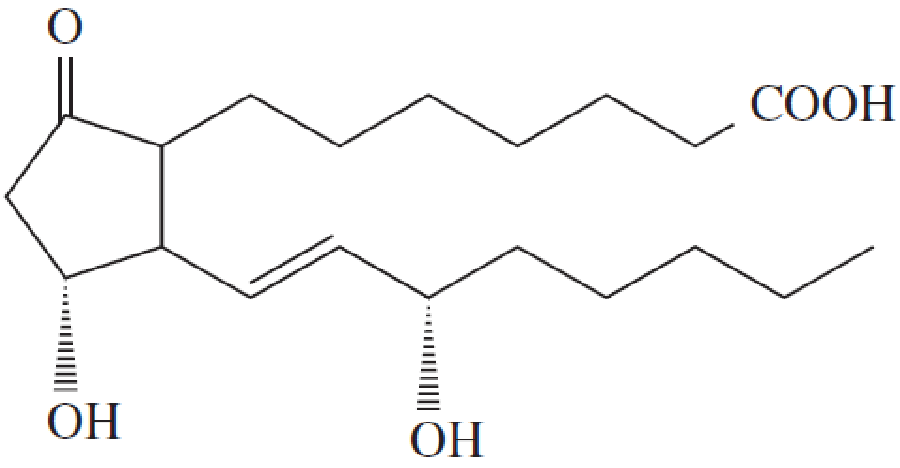
Messenger Lipids: (2) Eicosanoids

A prostaglandin *is a messenger lipid that is a C_{20}-fatty-acid derivative that contains a* ***cyclopentane ring*** *and oxygen-containing functional groups.*

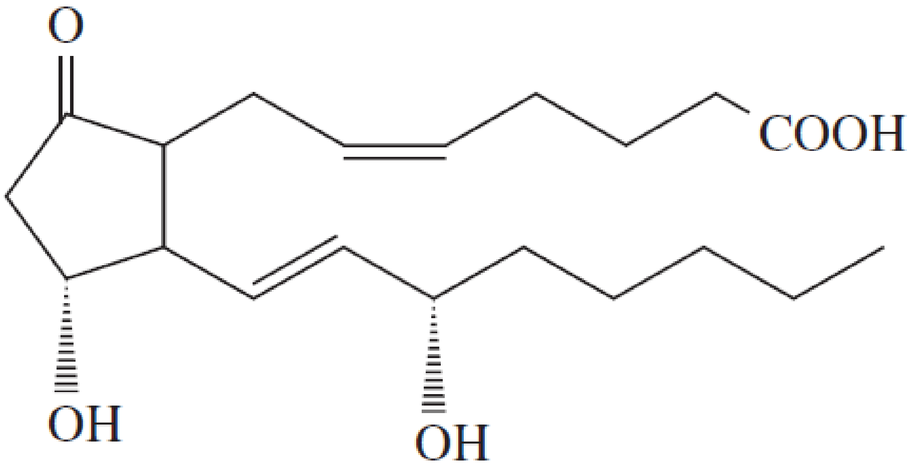
- named after the ***prostate gland***, which was first thought to be their only source. Today, more than 20 prostaglandins have been discovered in a ***variety of tissues*** in both males and females.
- involved in many ***regulatory functions*** including raising body temperature, inhibiting the secretion of gastric juices, increasing the secretion of a protective mucus layer into the stomach, relaxing and contracting smooth muscle, directing water and electrolyte balance, intensifying pain, and enhancing inflammation responses.



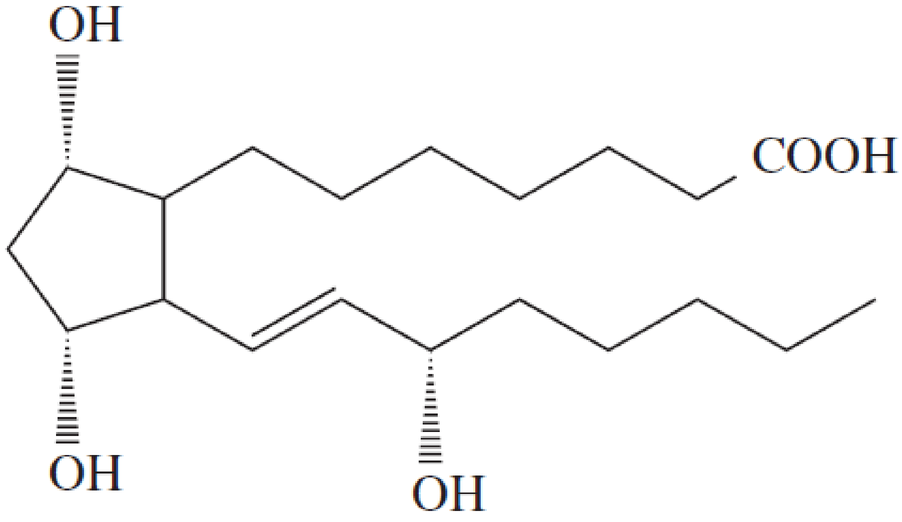
b Prostaglandin E_2



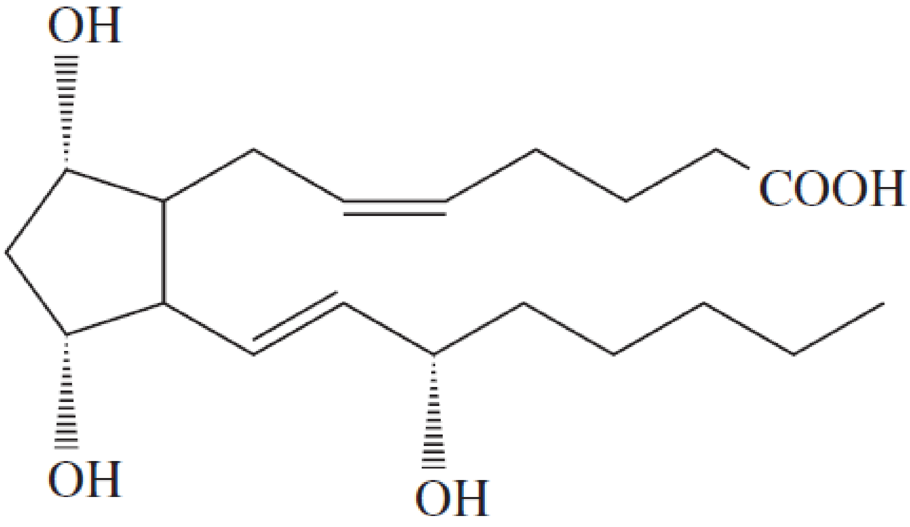
Prostaglandin E_1



Prostaglandin E_2



Prostaglandin F_1



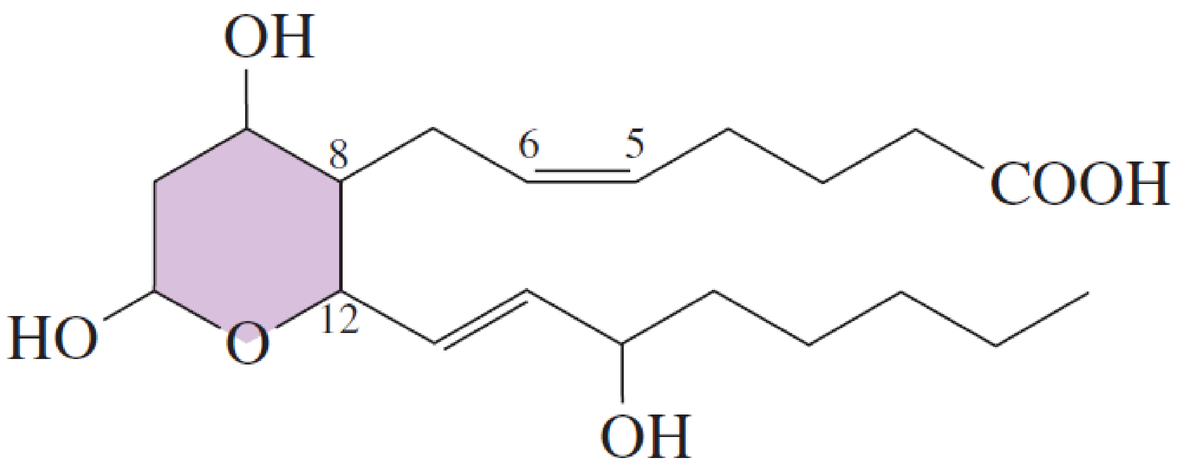
Prostaglandin F_2

Figure 17.3 The structures of four prostaglandins.

Messenger Lipids: (2) Eicosanoids

A **thromboxane** *is a messenger lipid that is a* C_{20}*-fatty-acid derivative that contains a* ***cyclic ether ring*** *and oxygen-containing functional groups.*

- promote the formation of blood clots
- produced by blood platelets and promote platelet aggregation

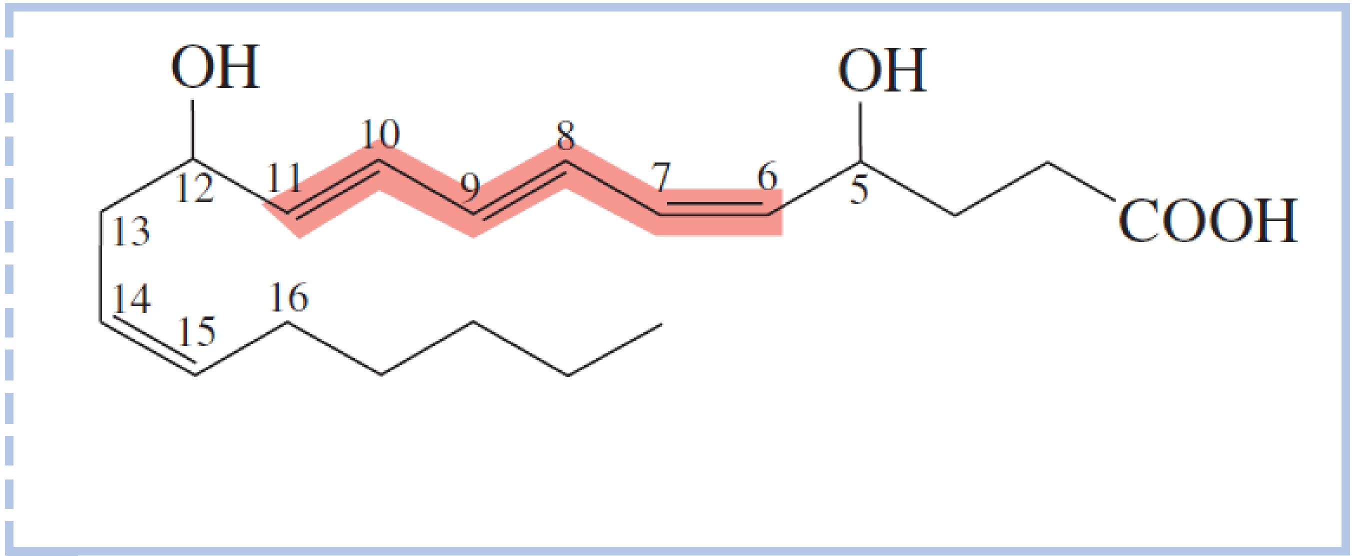


Thromboxane B_2

Messenger Lipids: (2) Eicosanoids

A **leukotriene** *is a messenger lipid that is a C_{20}-fatty-acid derivative that contains three conjugated double bonds and hydroxy groups.*

- found in leukocytes (white blood cells)
- Various inflammatory and hypersensitivity (allergy) responses are associated with elevated levels of leukotrienes.



d Leukotriene B_4

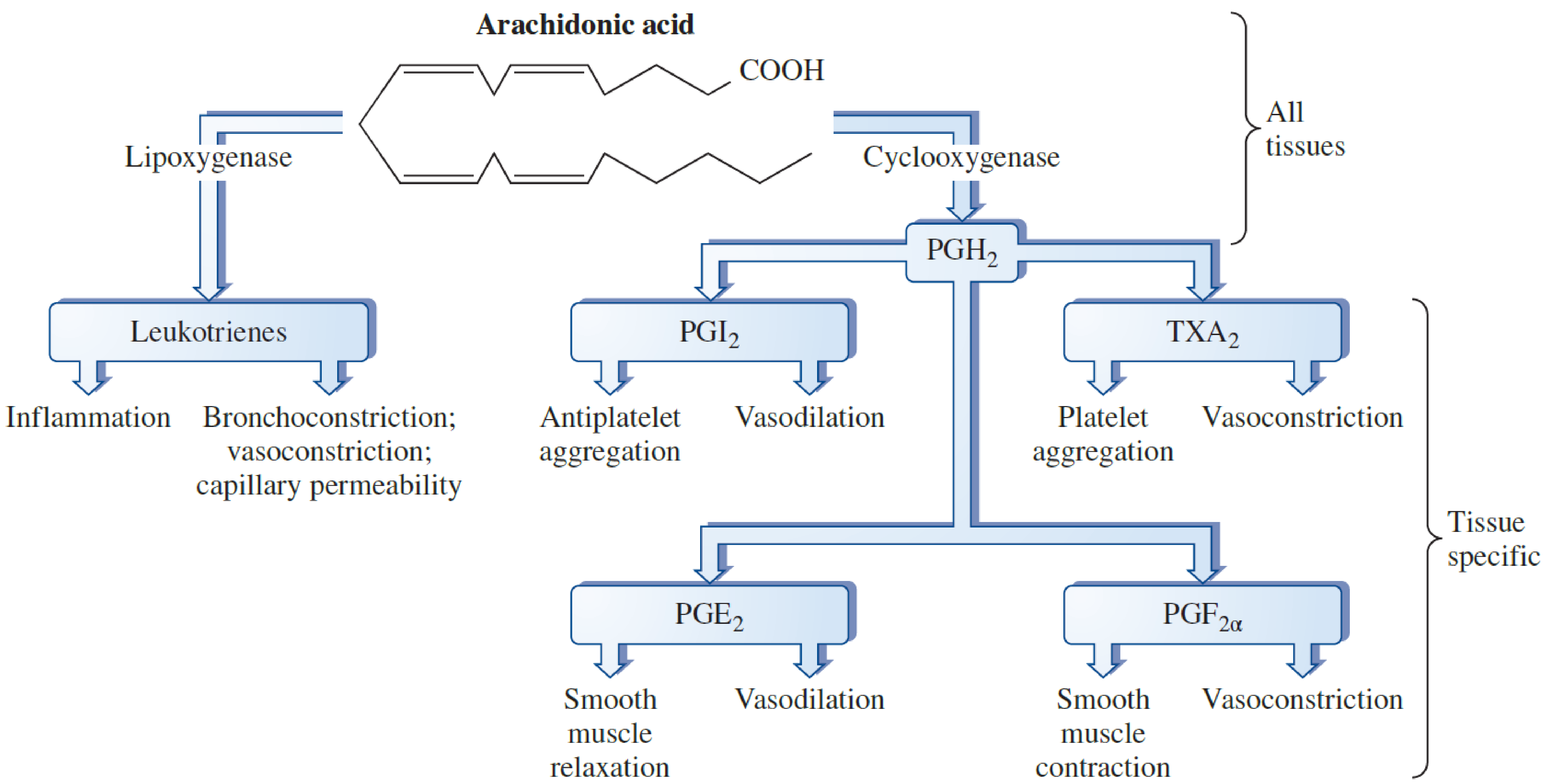


Figure 17.6 A summary of the synthesis of several prostaglandins from arachidonic acid.

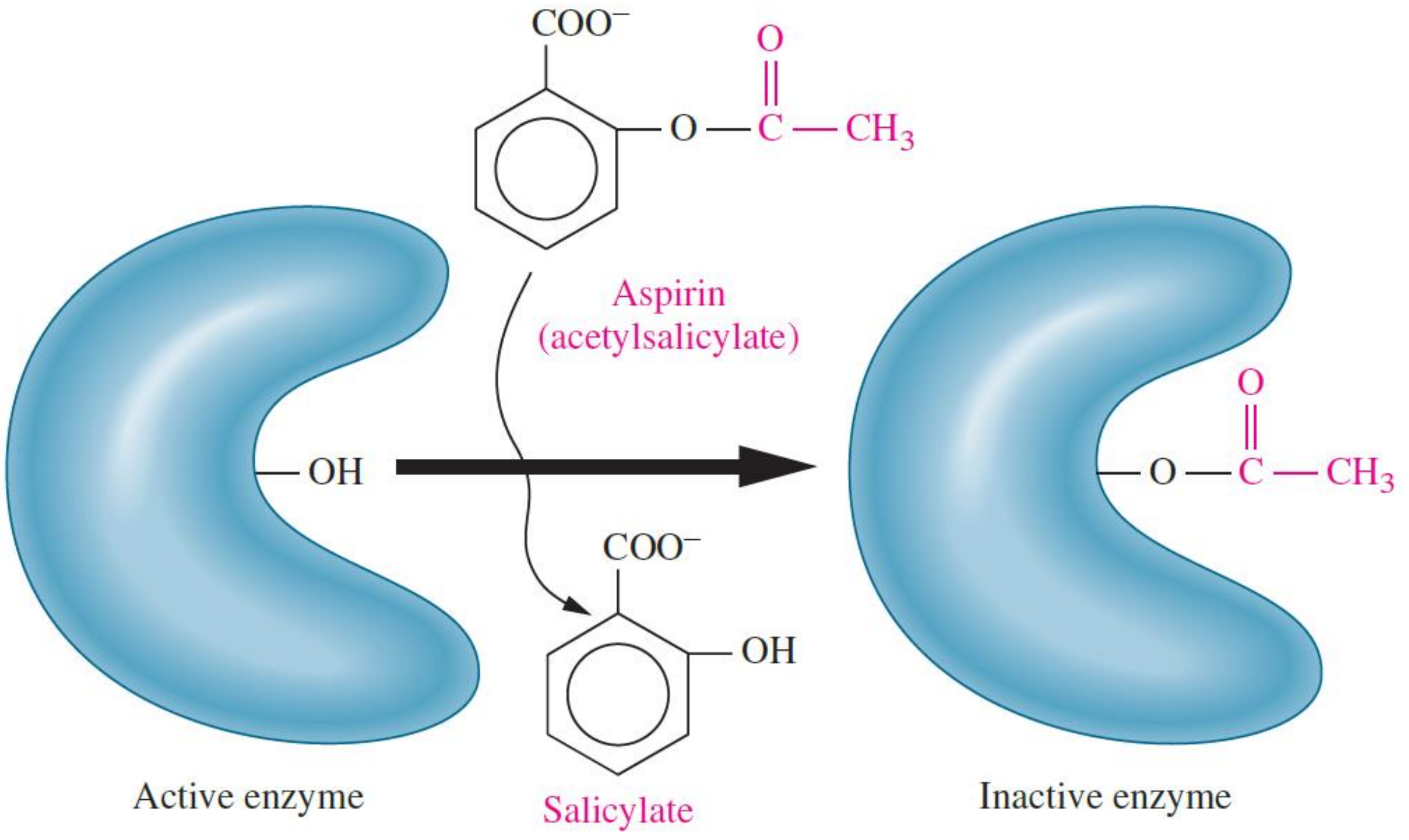
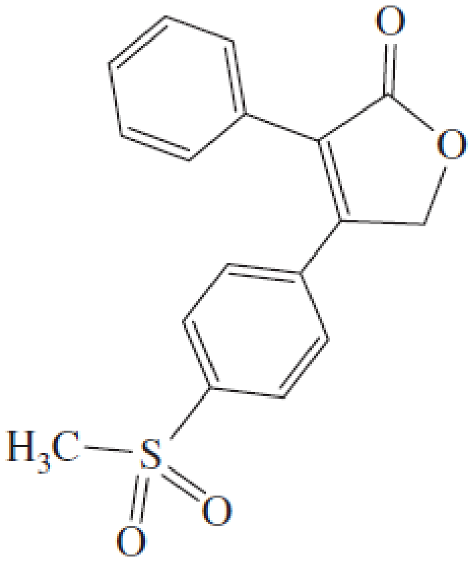


Figure 17.5 Aspirin inhibits the synthesis of prostaglandins by acetylating the enzyme cyclooxygenase. The acetylated enzyme is no longer functional.

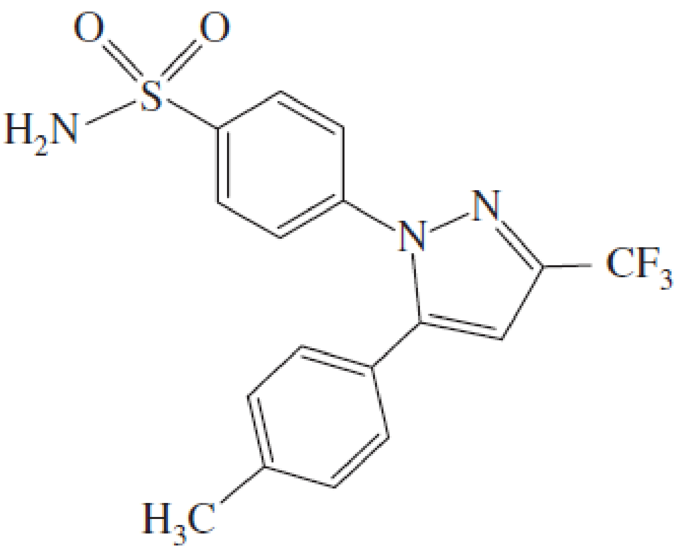
Aspirin works by inhibiting cyclooxygenase, which catalyzes the first step in the pathway leading from arachidonic acid to PGH_2. The acetyl group of aspirin becomes covalently bound to the enzyme, thereby inactivating it. Because the reaction catalyzed by cyclooxygenase occurs in all cells, **aspirin effectively inhibits synthesis of all of the prostaglandins**.

Use of these NSAIDs (Aspirin, ibuprofen, naproxen, and diclofenac) thus decreases inflammation but also makes an individual more susceptible to stomach irritation and ulcer formation, as protective mucous secretions are decreased when COX-1 is inhibited.

A new generation of prescription anti-inflammatory agents, developed in the 1990s, is now in use. These drugs are COX-2 inhibitors but not COX-1 inhibitors. The best known of these COX-2 inhibitors are Vioxx and Celebrex.



Vioxx



Celebrex

Section 8-13 Quick Quiz

1. The metabolic precursor for the production of most eicosanoids is
   a. cholesterol
   b. arachidonic acid
   c. sphingosine
   d. no correct response
2. Aspirin reduces inflammation and fever by inhibiting the formation of which of the following types of messenger lipids?
   a. prostaglandins
   b. thromboxanes
   c. leukotrienes
   d. no correct response
3. Which of the following types of eicosanoids has a cyclopentane ring as a structural component?
   a. prostaglandins
   b. thromboxanes
   c. leukotrienes
   d. no correct response

Protective-Coating Lipids: Biological Waxes

A **biological wax** *is a lipid that is a monoester of a long-chain fatty acid and a long-chain alcohol.* Biological waxes are *monoesters*, unlike fats and oils (triacylglycerols), which are *triesters*.

Long-chain fatty acid — Long-chain alcohol

Fatty acid residue

Ester linkage

Alcohol residue

$$CH_3-(CH_2)_{14}-\overset{\overset{\displaystyle O}{\|}}{C}-O-(CH_2)_{29}-CH_3$$

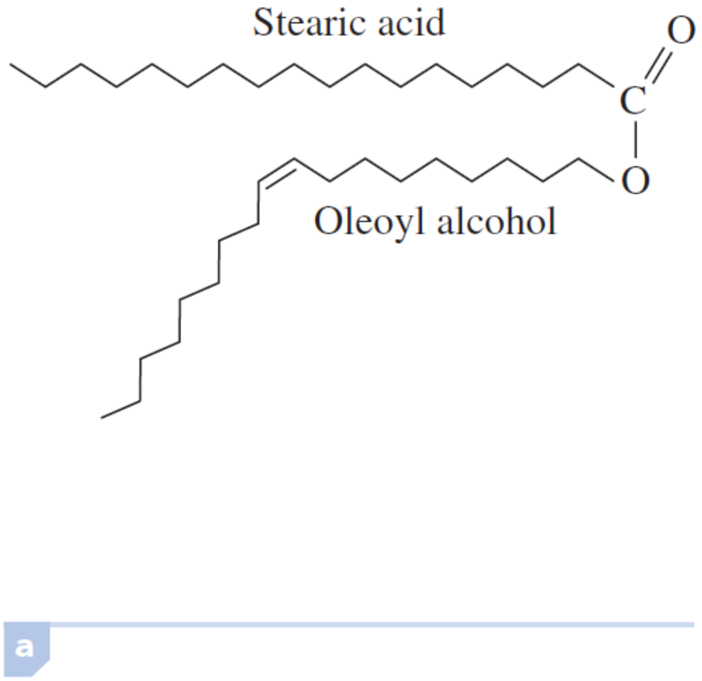
A component of beeswax

$$R-\overset{\overset{\displaystyle O}{\|}}{C}-O-R'$$

General structural formula

both R and R’ are long carbon chains (usually 20–30 carbon atoms)

Protective-Coating Lipids: Biological Waxes



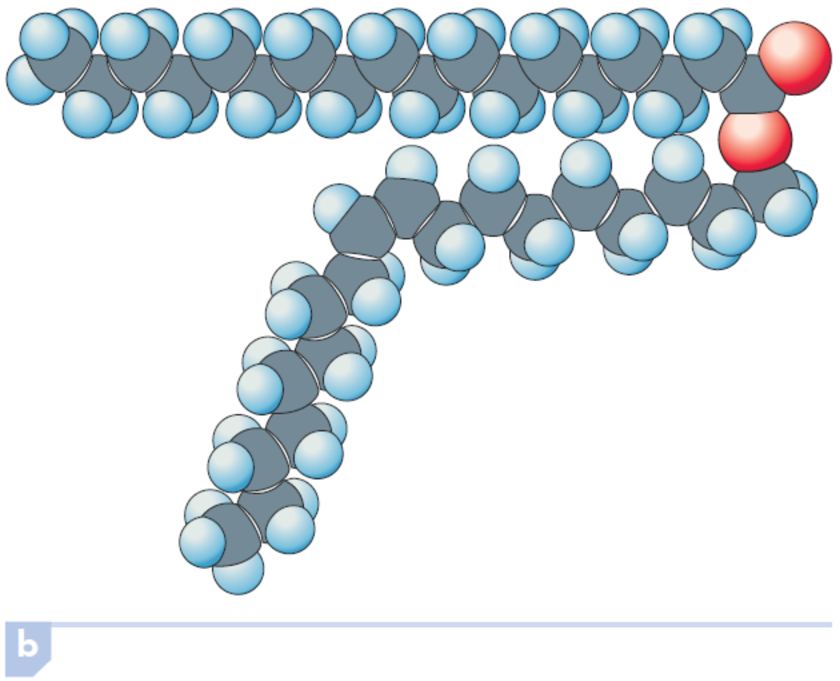


Figure 8-29 A biological wax has a structure with a small, weakly polar "head" and two long, nonpolar "tails." The polarity of the small "head" is not sufficient to impart any degree of water solubility to the molecule.

Waxes are water-insoluble, water-repellent lipids. Both humans and animals possess skin glands that secrete biological waxes to protect hair and skin and to keep it pliable and lubricated. Waxes impart water repellency to the fur and feathers of animals. In plants, biological waxes prevent excessive evaporation of water and to protect against parasite attack.

Protective-Coating Lipids: Biological Waxes

In general discussions, a **wax** *is a pliable, water-repelling substance used particularly in protecting surfaces and producing polished surfaces.* This broadened definition for waxes includes not only *biological waxes* but also *mineral waxes.*

A **mineral wax (or paraffin waxes)** *is a mixture of long-chain alkanes obtained from the processing of petroleum.*

Some "wax products" are a **blend of biological and mineral waxes**. For example, beeswax is sometimes a component of candle wax.

▶ *Human ear wax, which acts as a protective barrier against infection by capturing airborne particles, is not a true biological wax—that is, it is not a mixture of simple esters. Human ear wax is a yellow waxy secretion that is a mixture of triacylglycerols, phospholipids, and esters of cholesterol. Its medical name is* cerumen.

CHEMISTRY AT A GLANCE

Types of Lipids in Terms of How They Function

ENERGY-STORAGE LIPIDS

Lipids stored for use when energy demand is high

- **Triacylglycerols**
  - Fats
  - Oils

MEMBRANE LIPIDS

Lipids that are structural components of cell membranes

- **Phospholipids**
  - Glycerophospholipids
    - Lecithins
    - Cephalins
  - Sphingophospholipids
    - Sphingomyelins
- **Cholesterol**
- **Sphingoglycolipids**
  - Cerebrosides
  - Gangliosides

EMULSIFICATION LIPIDS

Lipids that stabilize and disperse water-insoluble materials in aqueous solution

- **Bile acids**
  - Cholic acid
  - Deoxycholic acids

CHEMISTRY AT A GLANCE

Types of Lipids in Terms of How They Function

MESSENGER LIPIDS

Regulatory lipids that act in the tissue where they are synthesized or at other locations after transport via the bloodstream

- **Steroid hormones**
  - **Sex hormones**
    - Estrogens
    - Androgens
    - Progestins
  - **Adrenocorticoids**
    - Mineralocorticoids
    - Glucocorticoids
- **Eicosanoids**
  - **Prostaglandins**
  - **Thromboxanes**
  - **Leukotrienes**

PROTECTIVE-COATING LIPIDS

Water-insoluble, water-repellent lipids with protective-coating and lubricant functions

- **Biological waxes**

Saponifiable and Nonsaponifiable Lipids

The chemical reaction (saponification) classification system for lipids is very simple. There are only two categories of lipids in this system: saponifiable lipids and nonsaponifiable lipids. A saponification reaction, the basis for this classification system, is ***a hydrolysis reaction that is carried out in basic solution***.

A **saponifiable lipid** *is a lipid that undergoes hydrolysis in basic solution to yield two or more smaller product molecules.* As a result of hydrolysis, a saponifiable lipid is ***broken up into smaller component parts***.

A **nonsaponifiable lipid** *does not undergo hydrolysis in basic solution.* Such lipids ***cannot be broken up into smaller component parts using hydrolysis***.

Saponifiable and Nonsaponifiable Lipids

LIPIDS

Saponifiable Lipids

- Triacylglycerols
- Glycerophospholipids
- Sphingophospholipids
- Sphingoglycolipids
- Biological Waxes

Nonsaponifiable Lipids

- Cholesterol
- Bile Acids
- Steroid Hormones
- Eicosanoids

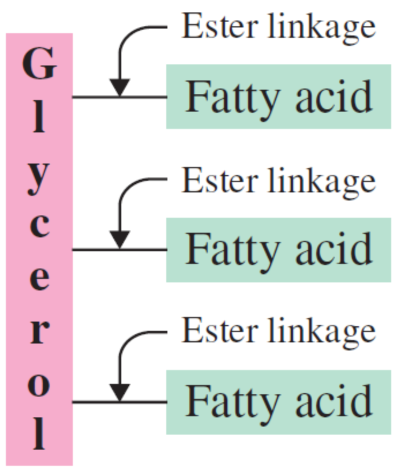
Saponifiable and Nonsaponifiable Lipids

What determines whether or not a lipid is saponifiable?

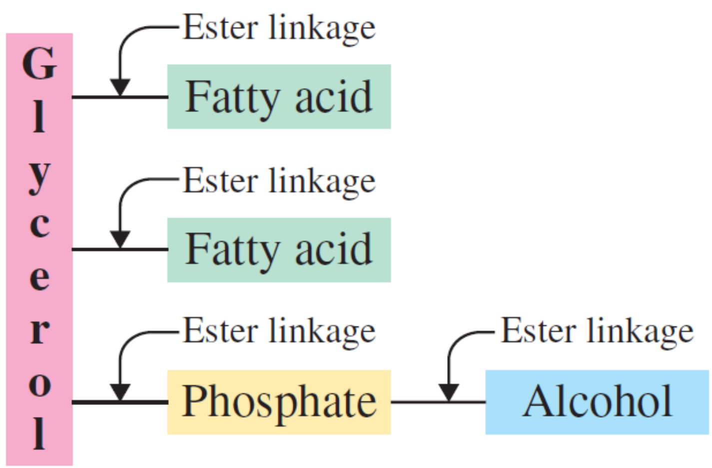
It is the types of linkages (bonds) that hold its component parts (building blocks) together.

Three types of linkages, all of which have been previously considered, can be hydrolyzed (broken) by reaction with water.

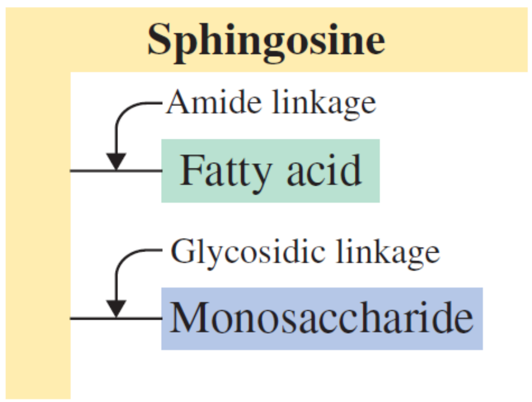
(1) ester linkages
(2) amide linkages, and
(3) glycosidic linkages



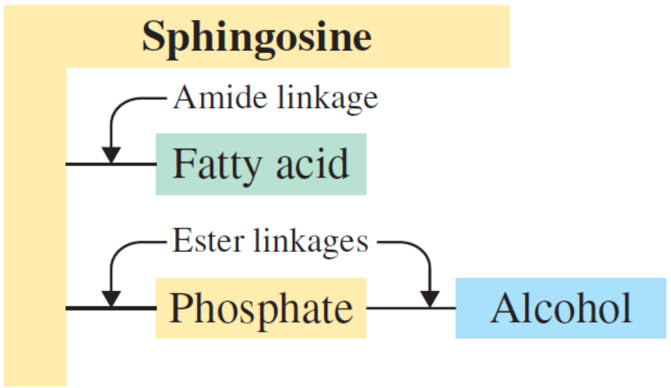
Triacylglycerol
(three ester linkages)



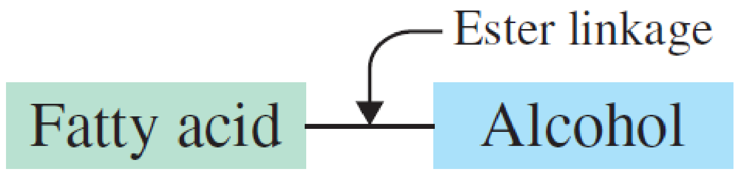
Glycerophospholipid
(four ester linkages)



Sphingoglycolipid
(one amide linkage and
one glycosidic linkage)



Sphingophospholipid
(two ester linkages and
one amide linkage)



Biological wax
(one ester linkage)

References

- Stoker, H. Stephen, *Organic, and Biological Chemistry*, 7th ed., Brooks/Cole, Cengage Learning, Belmont, CA, 2016.
- Denniston, K., Topping, J., Quirk Dorr, D., & Caret, R. *General, organic, and biochemistry* (10th ed). McGraw-Hill, 2020.
- Timberlake, K. C. *Chemistry: An Introduction to General, Organic and Biological Chemistry*, 10th ed.; Pearson Prentice Hall, 2009