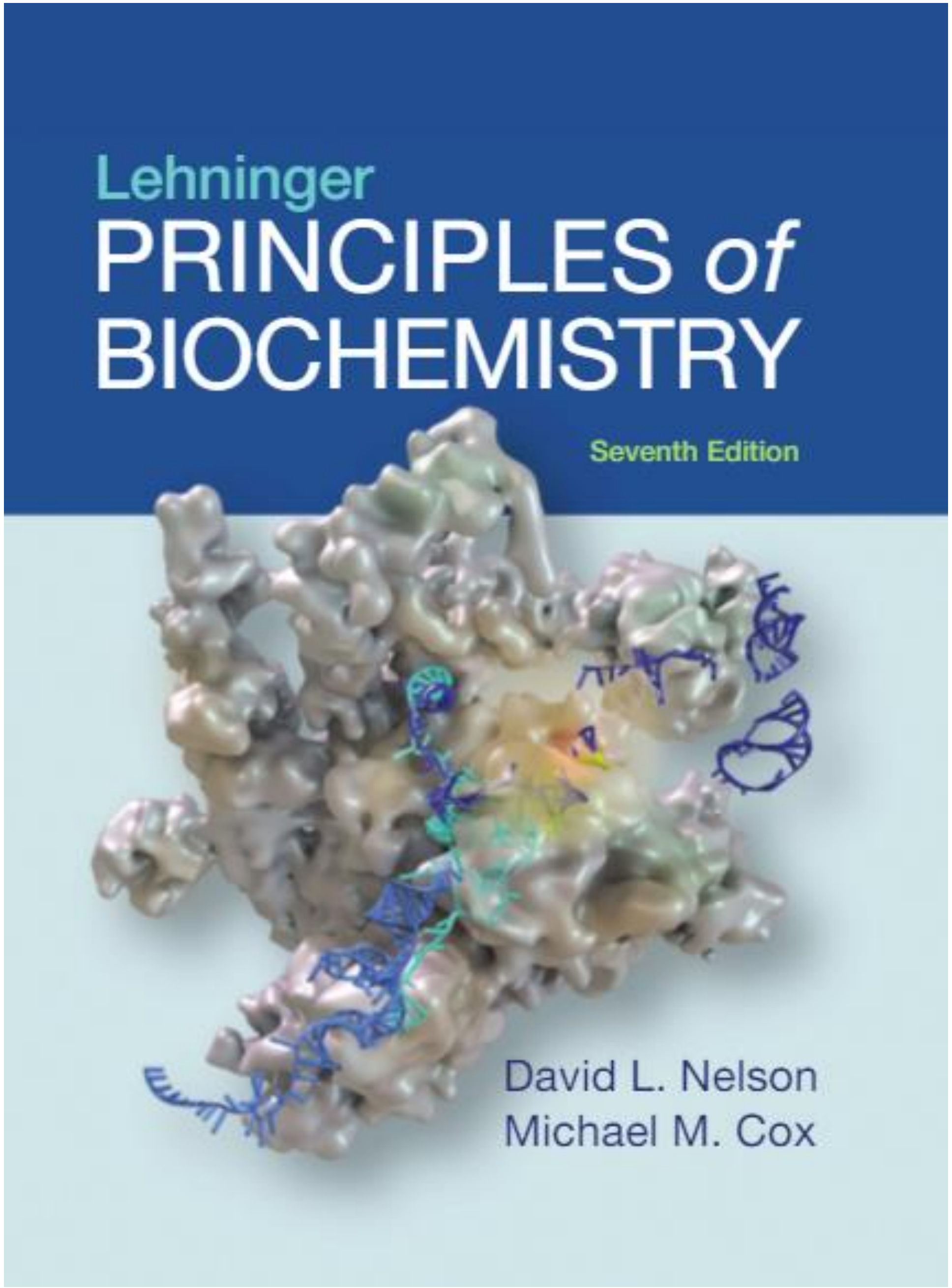
10| Lipids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PRINCIPLES of
BIOCHEMISTRY
Seventh Edition
David L. Nelson
Michael M. Cox

CHAPTER 10
Lipids

Learning goals:

- Biological roles of lipids
- Structure and properties of storage lipids
- Structure and properties of membrane lipids
- Structure and properties of signaling lipids

Lipids: Structurally Diverse Class

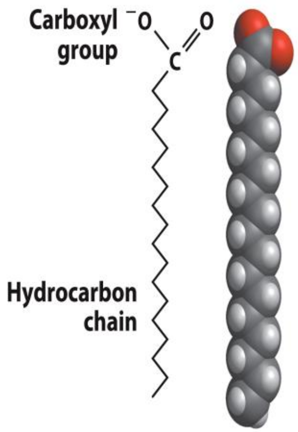

Figure 10-2a
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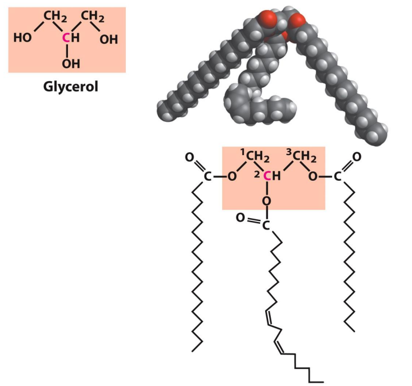

1-Stearoyl, 2-linoleoyl, 3-palmitoyl glycerol, a mixed triacylglycerol

Figure 10-3
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Figure 10-9
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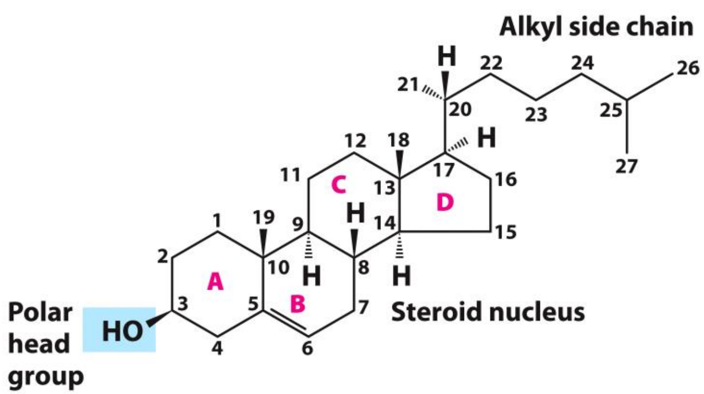

Figure 10-17
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(d)
Ubiquinone: a mitochondrial electron carrier (coenzyme Q)
(*n* = 4 to 8)

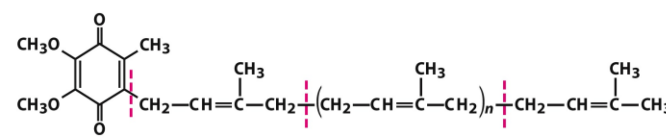

Figure 10-22d
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Organic molecules that are characterized by low solubility in water, that is, are relatively hydrophobic.

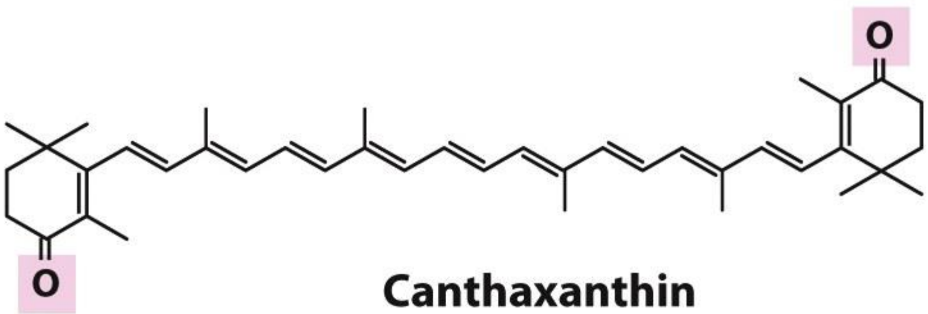
Biological Functions of Lipids

- Storage of energy
  - Reduced compounds: lots of available energy
  - Hydrophobic nature: good packing
- Insulation from environment
  - Low thermal conductivity
  - High heat capacity (can "absorb" heat)
  - Mechanical protection (can absorb shocks)
- Water repellant
  - Hydrophobic nature: keeps surface of the organism dry
    - Prevents excessive wetting (birds)
    - Prevents loss of water via evaporation
- Buoyancy control and acoustics in marine mammals
  - Increased density while diving deep helps sinking (just a hypothesis)
  - Spermaceti organ may focus sound energy: sound stun gun?

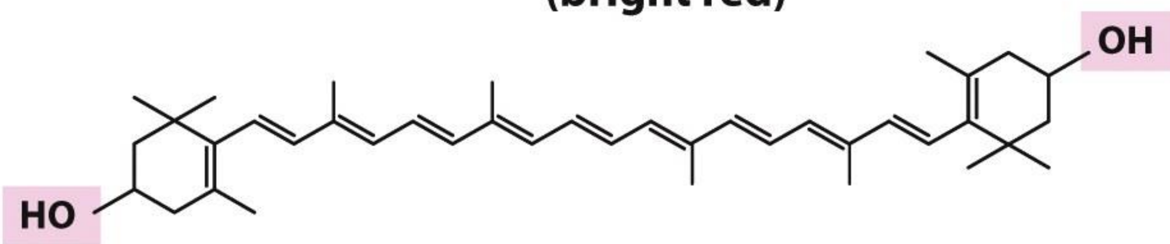
More Functions

- Membrane structure
  - Main structure of cell membranes
- Cofactors for enzymes
  - Vitamin K: blood clot formation
  - Coenzyme Q: ATP synthesis in mitochondria
- Signaling molecules
  - Paracrine hormones (act locally)
  - Steroid hormones (act body-wide)
  - Growth factors
  - Vitamins A and D (hormone precursors)
- Pigments
  - Color of tomatoes, carrots, pumpkins, some birds
- Antioxidants
  - Vitamin E

Lipids can provide pigment



Canthaxanthin
(bright red)



Zeaxanthin
(bright yellow)

✓ Minor differences in the chemistry of these compounds produce pigments of strikingly different colors

✓ Birds obtain the pigments that color their feathers red or yellow by eating plant materials that contain carotenoid pigments (e.g., canthaxanthin and zeaxanthin)

✓ The differences in pigmentation between male and female birds are the result of differences in intestinal uptake and processing of carotenoids.

Classification of Lipids

- Based on the structure and function
  - Lipids that do not contain fatty acids: cholesterol, pigments, vitamins
  - Lipids that contain fatty acids (complex lipids)
    - can be further separated into:
      - storage lipids and membrane lipids

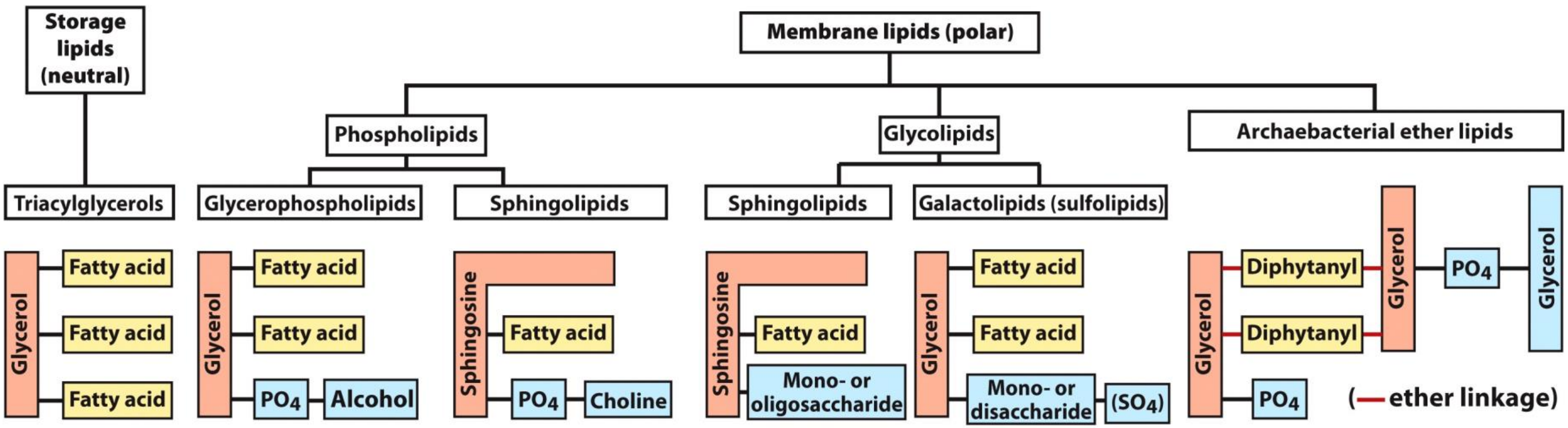


Figure 10-7
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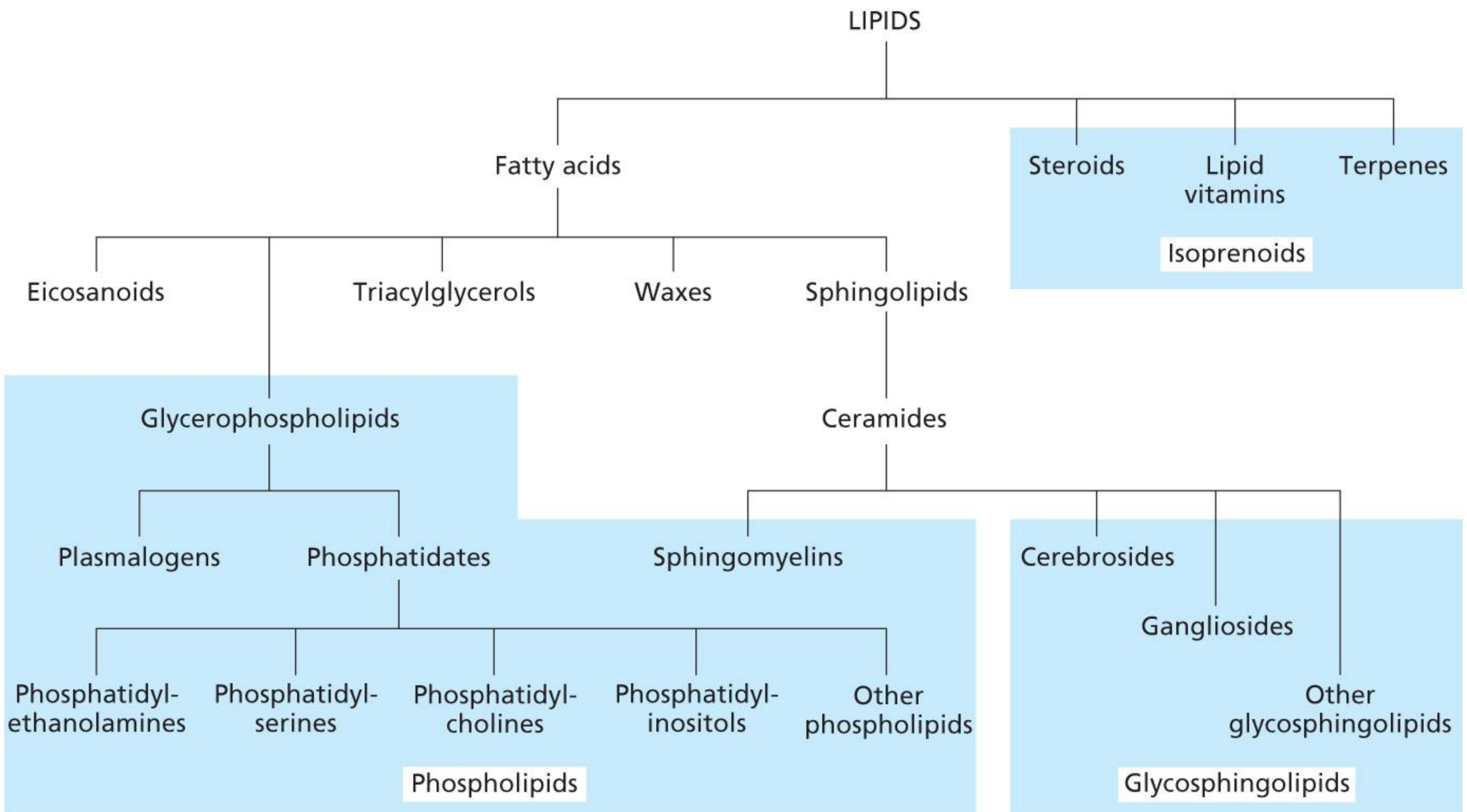
TABLE 10-2	Eight Major Categories of Biological Lipids	
Category	**Category code**	**Examples**
Fatty acids	FA	Oleate, stearoyl-CoA, palmitoylcarnitine
Glycerolipids	GL	Di- and triacylglycerols
Glycerophospholipids	GP	Phosphatidylcholine, phosphatidylserine, phosphatidyethanoloamine
Sphingolipids	SP	Sphingomyelin, ganglioside GM2
Sterol lipids	ST	Cholesterol, progesterone, bile acids
Prenol lipids	PR	Farnesol, geraniol, retinol, ubiquinone
Saccharolipids	SL	Lipopolysaccharide
Polyketides	PK	Tetracycline, erythromycin, aflatoxin B_1


LIPIDS
Fatty acids
Steroids
Lipid vitamins
Terpenes
Isoprenoids
Eicosanoids
Triacylglycerols
Waxes
Sphingolipids
Glycerophospholipids
Ceramides
Plasmalogens
Phosphatidates
Sphingomyelins
Cerebrosides
Gangliosides
Phosphatidyl-ethanolamines
Phosphatidyl-serines
Phosphatidyl-cholines
Phosphatidyl-inositols
Other phospholipids
Other glycosphingolipids
Phospholipids
Glycosphingolipids

10.1 Storage Lipids

- Derivatives of fatty acids
- Fatty acids are hydrocarbon derivatives
- Low oxidation state (highly reduced)
- Cellular oxidation is highly exergonic

Fatty Acids

- Carboxylic acids with hydrocarbon chains containing between 4 to 36 carbons
- Almost all natural fatty acids have an even number of carbons
- Most natural fatty acids are unbranched
- Saturated: no double bonds between carbons in the chain
- Monounsaturated: one double bond between carbons in the alkyl chain
- Polyunsaturated: more than one double bond in the alkyl chain

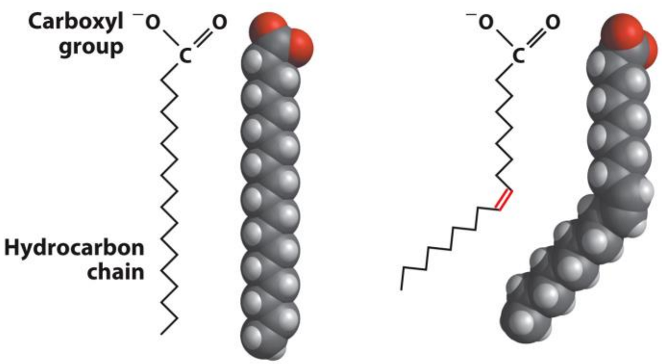


Figure 10-1ab
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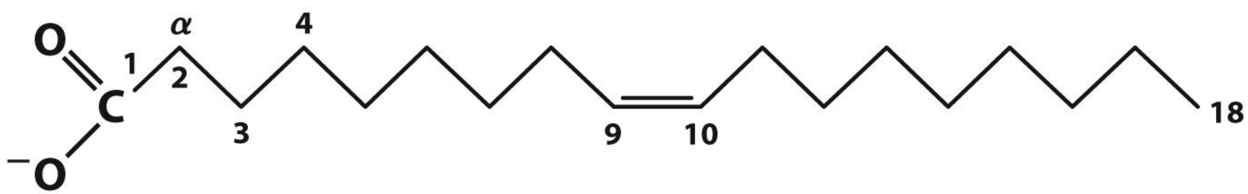
Fatty Acid Nomenclature

- Fatty acids can be described by (example):
  - systematic name: *cis*-9-octadecanoic acid
  - common name: oleic acid
  - delta numbering of carbon skeleton: 18:1(Δ^9)
    - describes location of the first carbon of the alkene in relationship to the carbonyl carbon
  - omega numbering of carbon skeleton: 18:1$^{\omega 9}$
    - describes location of the first carbon of the alkene in relationship to the terminal methyl



18:1(Δ^9) *cis*-9-Octadecenoic acid

Unnumbered 10 p361
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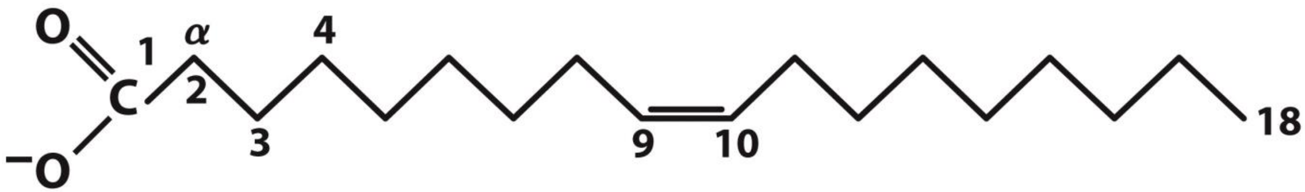
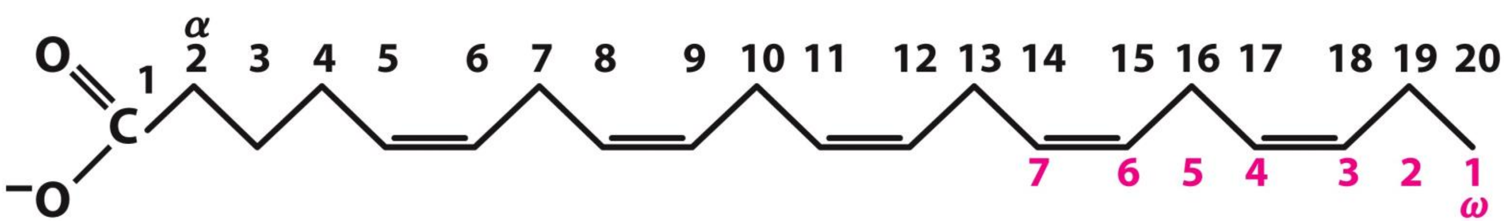
Fatty Acid Nomenclature



(a) 18:1(Δ^9) *cis*-9-Octadecenoic acid



(b) 20:5($\Delta^{5,8,11,14,17}$) Eicosapentaenoic acid (EPA), an omega-3 fatty acid

(a) **Standard nomenclature** – # 1 to the carboxyl carbon (C-1), and α to the carbon next to it. The position of any double bond(s) is indicated by Δ followed by a superscript number indicating the lower-numbered carbon in the double bond.

(b) **Polyunsaturated fatty acids (PUFAs) nomenclature** – # 1 to the methyl carbon at the other end of the chain (also designated ω; the last letter in the Greek alphabet). The positions of the double bonds are indicated relative to the ω carbon.

Fatty Acid Nomenclature

TABLE 10-1 Some Naturally Occurring Fatty Acids: Structure, Properties, and Nomenclature

Carbon skeleton	Structure[a]	Systematic name[b]	Common name (derivation)	Melting point (°C)	Solubility at 30 °C (mg/g solvent) Water	Benzene
12:0	$CH_3(CH_2)_{10}COOH$	*n*-Dodecanoic acid	Lauric acid (Latin *laurus*, "laurel plant")	44.2	0.063	2,600
14:0	$CH_3(CH_2)_{12}COOH$	*n*-Tetradecanoic acid	Myristic acid (Latin *Myristica*, nutmeg genus)	53.9	0.024	874
16:0	$CH_3(CH_2)_{14}COOH$	*n*-Hexadecanoic acid	Palmitic acid (Latin *palma* "palm tree")	63.1	0.0083	348
18:0	$CH_3(CH_2)_{16}COOH$	*n*-Octadecanoic acid	Stearic acid (Greek *stear*, "hard fat")	69.6	0.0034	124
20:0	$CH_3(CH_2)_{18}COOH$	*n*-Eicosanoic acid	Arachidic acid (Latin *Arachis*, legume genus)	76.5		
24:0	$CH_3(CH_2)_{22}COOH$	*n*-Tetracosanoic acid	Lignoceric acid (Latin *lignum*, "wood" + *cera*, "wax")	86.0		

[a]All acids are shown in their nonionized form. At pH 7, all free fatty acids have an ionized carboxylate. Note that numbering of carbon atoms begins at the carboxyl carbon.
[b]The prefix *n*- indicates the "normal" unbranched structure. For instance, "dodecanoic" simply indicates 12 carbon atoms, which could be arranged in a variety of branched forms; "*n*-dodecanic" specifies the linear, unbranched form. For unsaturated fatty acids, the configuration of each double bond is indicated; in biological fatty acids the configuration is almost always cis.

Fatty Acid Nomenclature

TABLE 10-1 **Some Naturally Occurring Fatty Acids: Structure, Properties, and Nomenclature**

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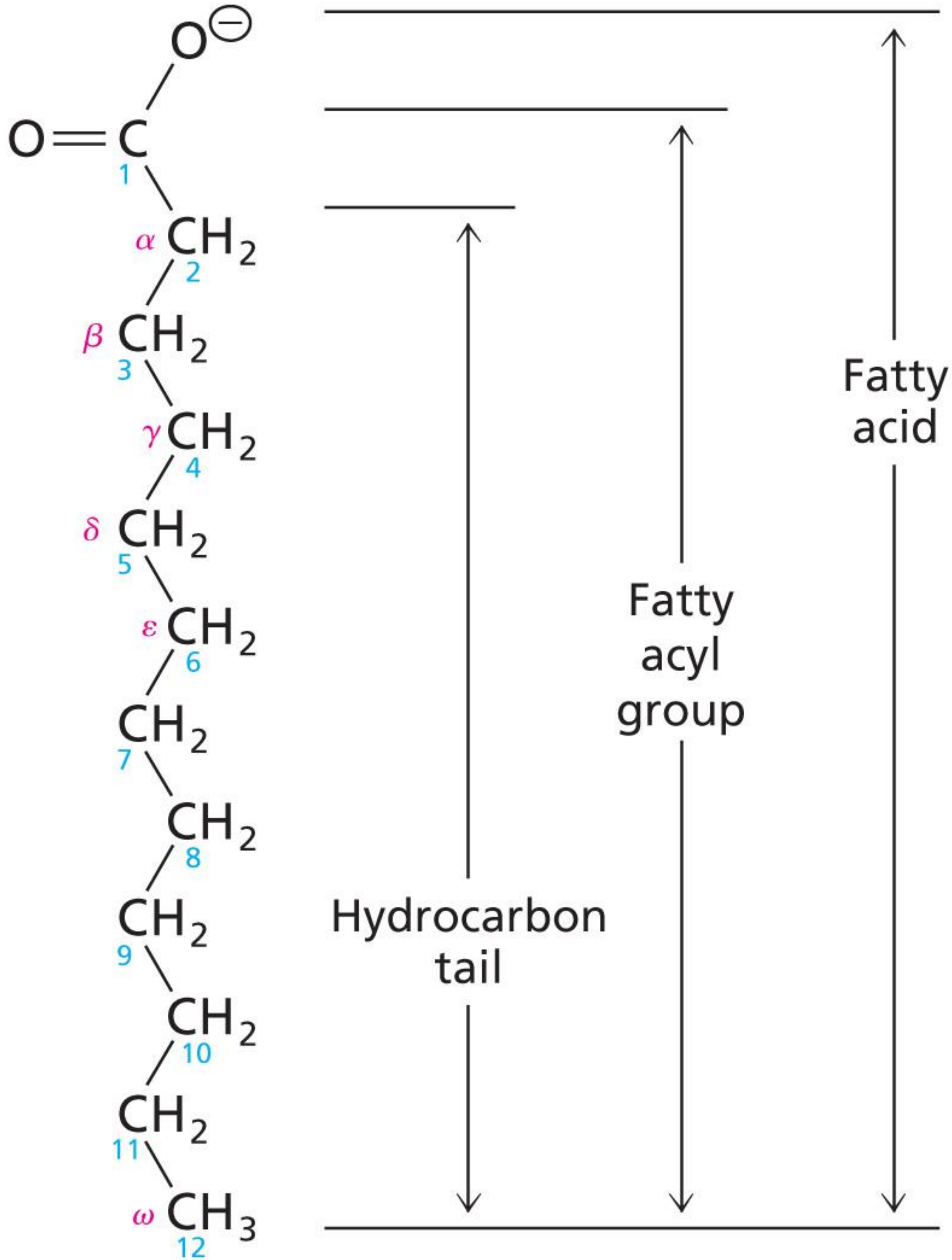
16:1(Δ^9)	$CH_3(CH_2)_5CH=CH(CH_2)_7COOH$	*cis*-9-Hexadecenoic acid	Palmitoleic acid	1 to –0.5		
18:1(Δ^9)	$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$	*cis*-9-Octadecenoic acid	Oleic acid (Latin *oleum*, "oil")	13.4		
18:2($\Delta^{9,12}$)	$CH_3(CH_2)_4CH=CHCH_2CH=CH(CH_2)_7COOH$	*cis*-,*cis*-9,12-Octadecadienoic acid	Linoleic acid (Greek *linon*, "flax")	1–5		
18:3($\Delta^{9,12,15}$)	$CH_3CH_2CH=CHCH_2CH=CHCH_2CH=CH(CH_2)_7COOH$	*cis*-,*cis*-,*cis*-9,12,15-Octadecatrienoic acid	*α*-Linolenic acid	211		
20:4($\Delta^{5,8,11,14}$)	$CH_3(CH_2)_4CH=CHCH_2CH=CHCH_2CH=CHCH_2CH=CH(CH_2)_3COOH$	*cis*-,*cis*-,*cis*-, *cis*-5,8,11,14-Icosatetraenoic acid	Arachidonic acid	–49.5		

[a]All acids are shown in their nonionized form. At pH 7, all free fatty acids have an ionized carboxylate. Note that numbering of carbon atoms begins at the carboxyl carbon.

[b]The prefix *n*- indicates the "normal" unbranched structure. For instance, "dodecanoic" simply indicates 12 carbon atoms, which could be arranged in a variety of branched forms; "*n*-dodecanic" specifies the linear, unbranched form. For unsaturated fatty acids, the configuration of each double bond is indicated; in biological fatty acids the configuration is almost always cis.


O
O
C
1
α CH2
2
β CH2
3
γ CH2
4
δ CH2
5
ε CH2
6
CH2
7
CH2
8
CH2
9
CH2
10
CH2
11
ω CH3
12
Hydrocarbon tail
Fatty acyl group
Fatty acid

Omega-3 PUFA

- Omega-3 fatty acids are essential nutrients
  - Humans need them but cannot synthesize one
  - No synthetic pathway in humans to make the ω-3 PUFA α-linolenic acid; 18:3($\Delta^{9,12,15}$) ALA

- Must be obtained in the diet
  - Including ALA, DHA, and EPA
    - Although DHA and EPA can be synthesized from ALA

- Imbalance in ω-6 and ω-3 leads to an increased risk of cardiovascular disease

Solubility and Melting Point of Fatty Acids

- Solubility
  - decreases as the chain length increases
- Melting Point
  - decreases as the chain length decreases
  - decreases as the number of double bonds increases

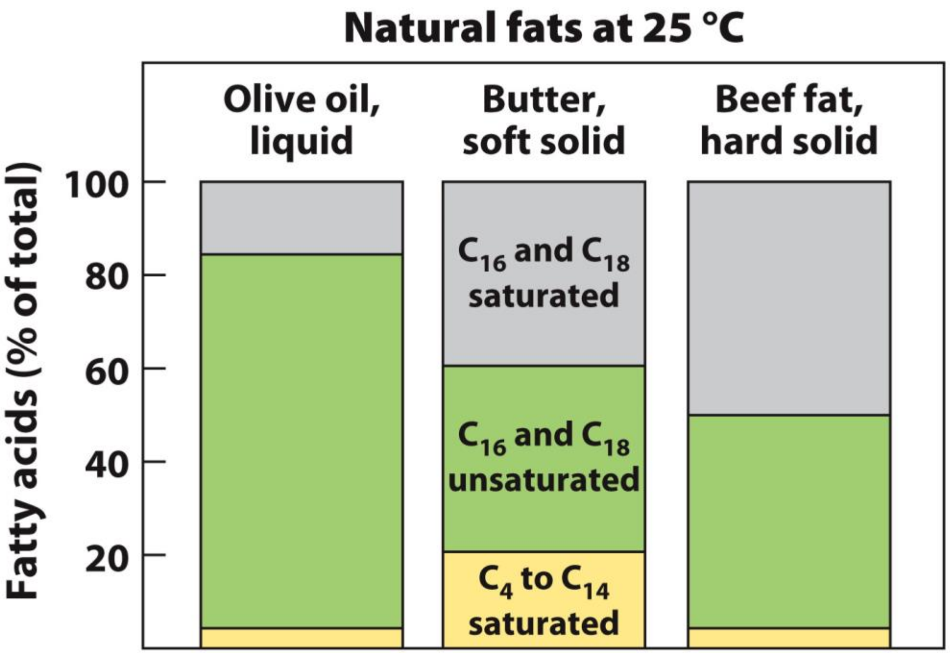


Figure 10-4
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Conformation of Fatty Acids

- The saturated chain tends to adopt extended conformations
- The double bonds in natural unsaturated fatty acids are commonly in cis configuration, which kinks the chain

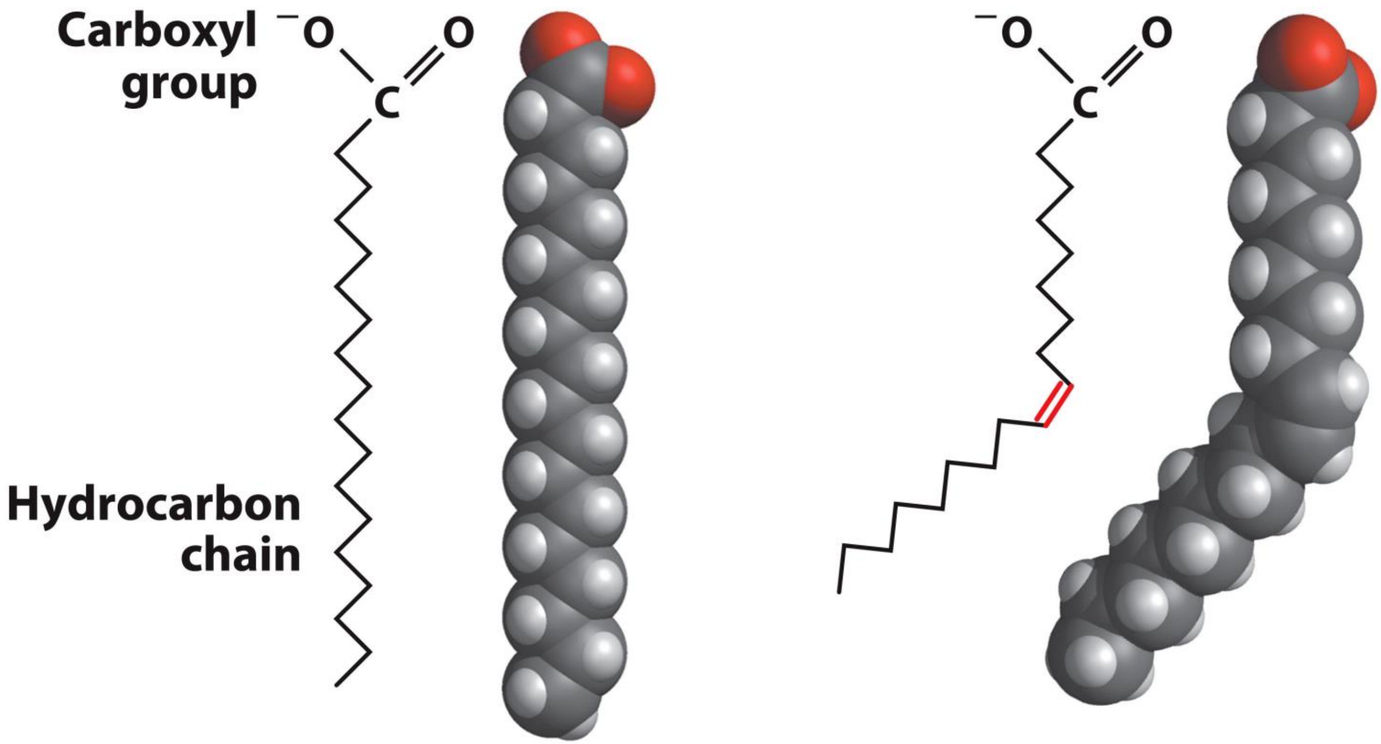

Figure 10-2ab
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Melting Point and Double Bonds

- Saturated fatty acids pack in a fairly orderly way
  - extensive favorable interactions
- Unsaturated cis fatty acid pack less orderly due to the kink
  - less-extensive favorable interactions
- It takes less thermal energy to disrupt disordered packing of unsaturated fatty acids:
  - unsaturated cis fatty acids have a lower melting point

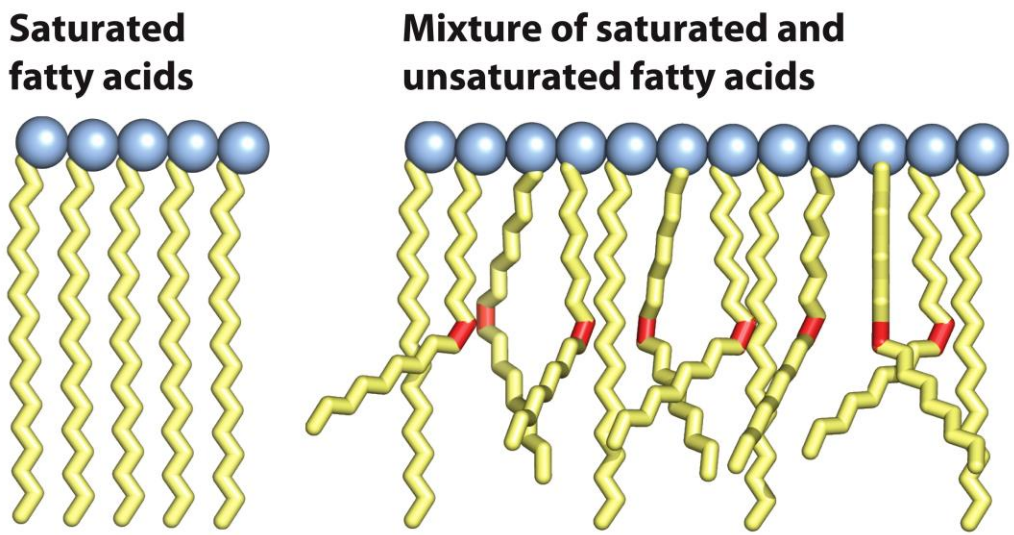

Figure 10-2cd
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Trans Fatty Acids

- Trans fatty acids form by partial dehydrogenation of unsaturated fatty acids
  - Done to increase shelf life or stability at high temperature of oils used in cooking (especially deep frying)
- A trans double bond allows a given fatty acid to adopt an extended conformation
- Trans fatty acids can pack more regularly and show higher melting points than cis forms
- Consuming trans fats increases risk of cardiovascular disease
  - Avoid deep-frying partially hydrogenated vegetable oils
  - Current trend: reduce trans fats in foods (Wendy's, KFC)

TABLE 10–2 Trans Fatty Acids in Some Typical Fast Foods and Snacks

	Trans fatty acid content	
	In a typical serving (g)	As % of total fatty acids
French fries	4.7–6.1	28–36
Breaded fish burger	5.6	28
Breaded chicken nuggets	5.0	25
Pizza	1.1	9
Corn tortilla chips	1.6	22
Doughnut	2.7	25
Muffin	0.7	14
Chocolate bar	0.2	2

Source: Adapted from Table 1 in Mozaffarian, D., Katan, M.B., Ascherio, P.H., Stampfer, M.J., & Willet, W.C. (2006). Trans fatty acids and cardiovascular disease. *N. Engl. J. Med.* **354**, 1604–1605.

Note: All data for foods prepared with partially hydrogenated vegetable oil in the United States in 2002.

Table 10-2
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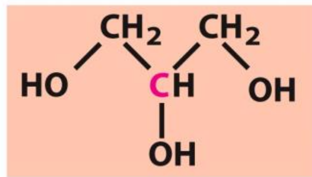
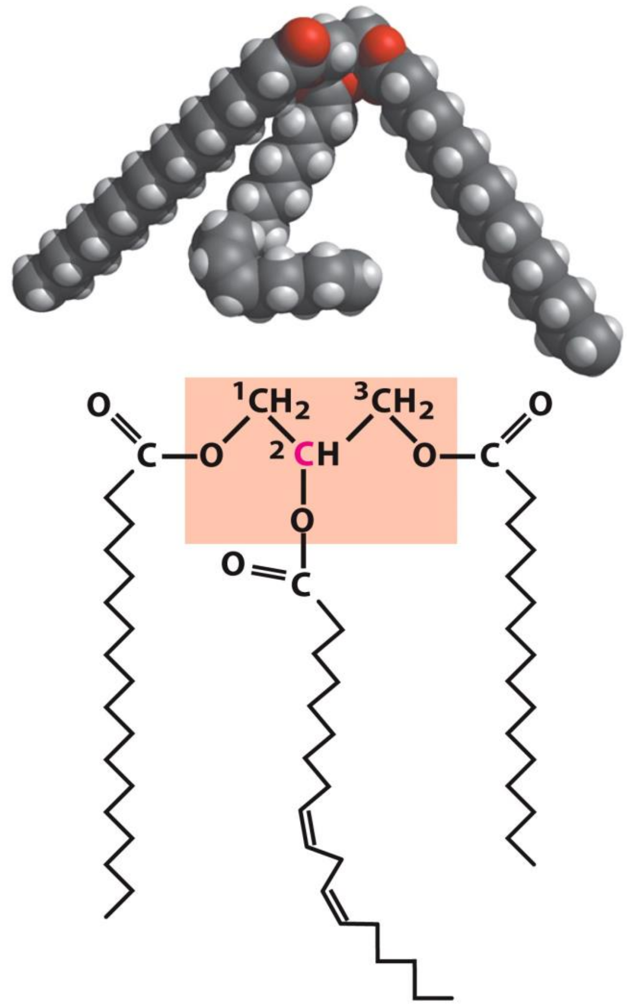
Triacylglycerols (Nonpolar)

- Majority of fatty acids in biological systems are found in the form of triacylglycerols
- Solid ones are called fats
- Liquid ones are called oils
- The primary storage form of lipids (body fat)
- Less soluble in water than fatty acids due to the lack of charged carboxylate group
- Less dense than water: fats and oils float

Triacylglycerols



Glycerol



1-Stearoyl, 2-linoleoyl, 3-palmitoyl glycerol, a mixed triacylglycerol

Figure 10-3
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Fats Provide Efficient Fuel Storage

- The advantage of fats over polysaccharides:
  - Fatty acids carry more energy per carbon because they are more reduced
  - Fatty acids carry less water per gram because they are nonpolar

- Glucose and glycogen are for short-term energy needs, quick delivery
- Fats are for long-term (months) energy needs, good storage, slow delivery

Fats Provide Efficient Fuel Storage

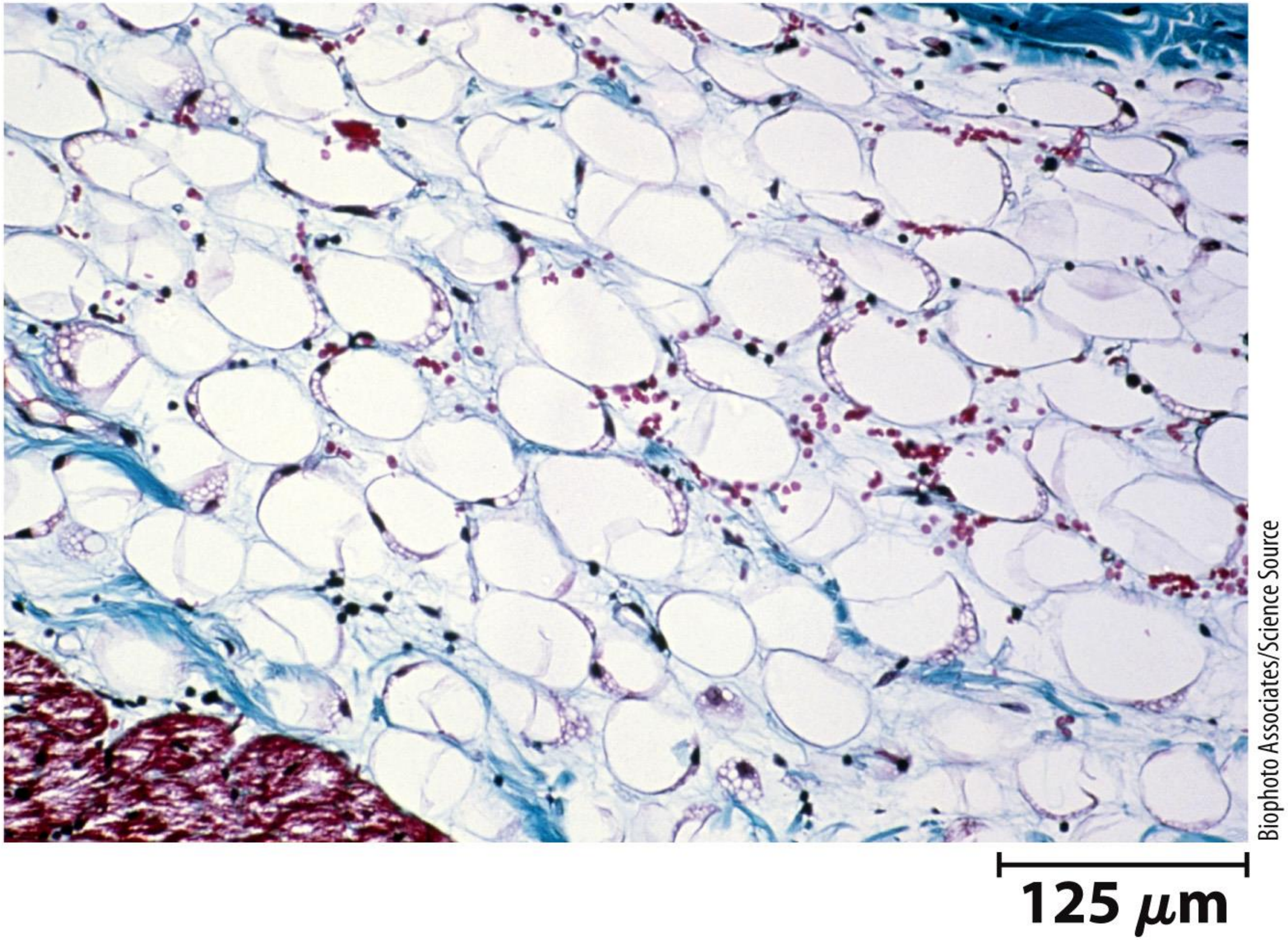

Figure 10-3a
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Waxes

- Waxes are esters of long-chain saturated and unsaturated fatty acids with long-chain alcohols
- Insoluble and have high melting points ~ 60 – 100 ^{o}C
- Variety of functions:
  - Storage of metabolic fuel in plankton
  - Protection and pliability for hair and skin in vertebrates
  - Waterproofing of feathers in birds
  - Protection from evaporation in tropical plants and ivy
  - Used by people in lotions, ointments, and polishes

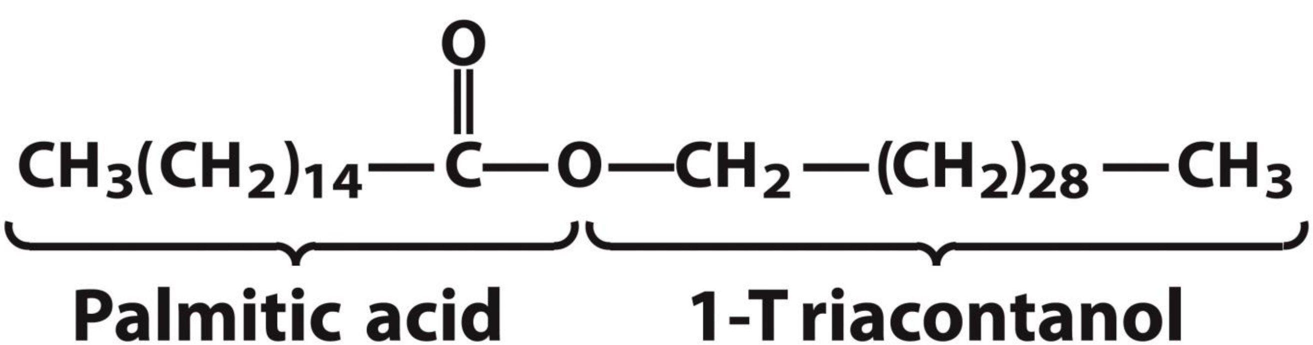

Figure 10-6a
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Wax: The Material of the Honeycomb

Beeswax is a mixture of a large number of lipids, including esters of triacontanol, and a long-chain alkane hentiacontane

Figure 10-6b
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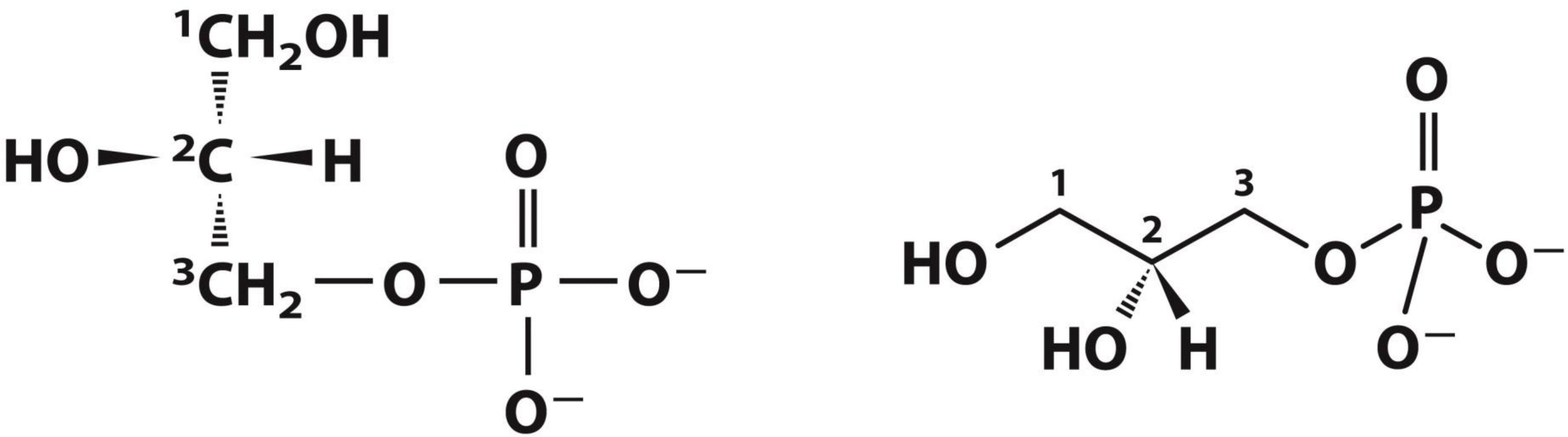
Structural Lipids in Membranes (Polar)

- Contain polar head groups and nonpolar tails (usually attached fatty acids)
- Diversification can come from:
  - modifying a different backbone
  - changing the fatty acids
  - modifying the head groups
- The properties of head groups determine the surface properties of membranes
- Different organisms have different membrane lipid head group compositions
- Different tissues have different membrane lipid head group compositions

Glycerophospholipids

- Primary constituents of cell membranes
- Two fatty acids form ester linkages with the first and second hydroxyl groups of L-glycerol-3-phosphate
- The phosphate head group is charged at physiological pH



L-Glycerol 3-phosphate (*sn*-glycerol 3-phosphate)

Figure 10-8
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Glycerol itself is not chiral.
*However, glycerol is **prochiral** – it can be converted to a chiral compound by adding a substituent such as phosphate to either of the —CH_2OH groups.*

General Structure of Glycerophospholipids

- Unsaturated fatty acids are commonly found connected to C2
- The highly polar phosphate group may be further esterified by an alcohol; such substituent groups are called the head groups

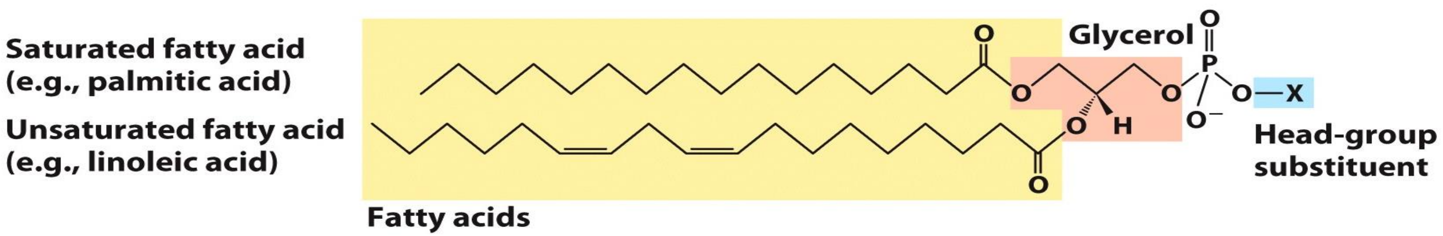

Figure 10-9
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Examples of Glycerophospholipids

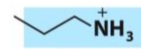
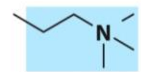
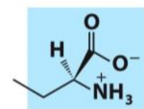
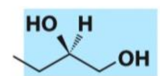
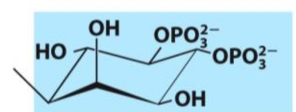
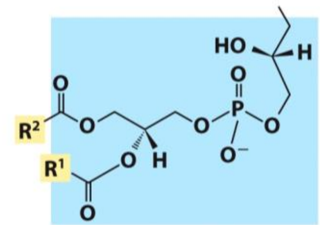
Name of glycerophospholipid	Name of X—O	Formula of X	Net charge (at pH 7)
Phosphatidic acid	—	—H	−2
Phosphatidylethanolamine	Ethanolamine		0
Phosphatidylcholine	Choline		0
Phosphatidylserine	Serine		−1
Phosphatidylglycerol	Glycerol		−1
Phosphatidylinositol 4,5-bisphosphate	*myo*-Inositol 4,5-bisphosphate		−4*
Cardiolipin	Phosphatidyl-glycerol		−2

Figure 10-9
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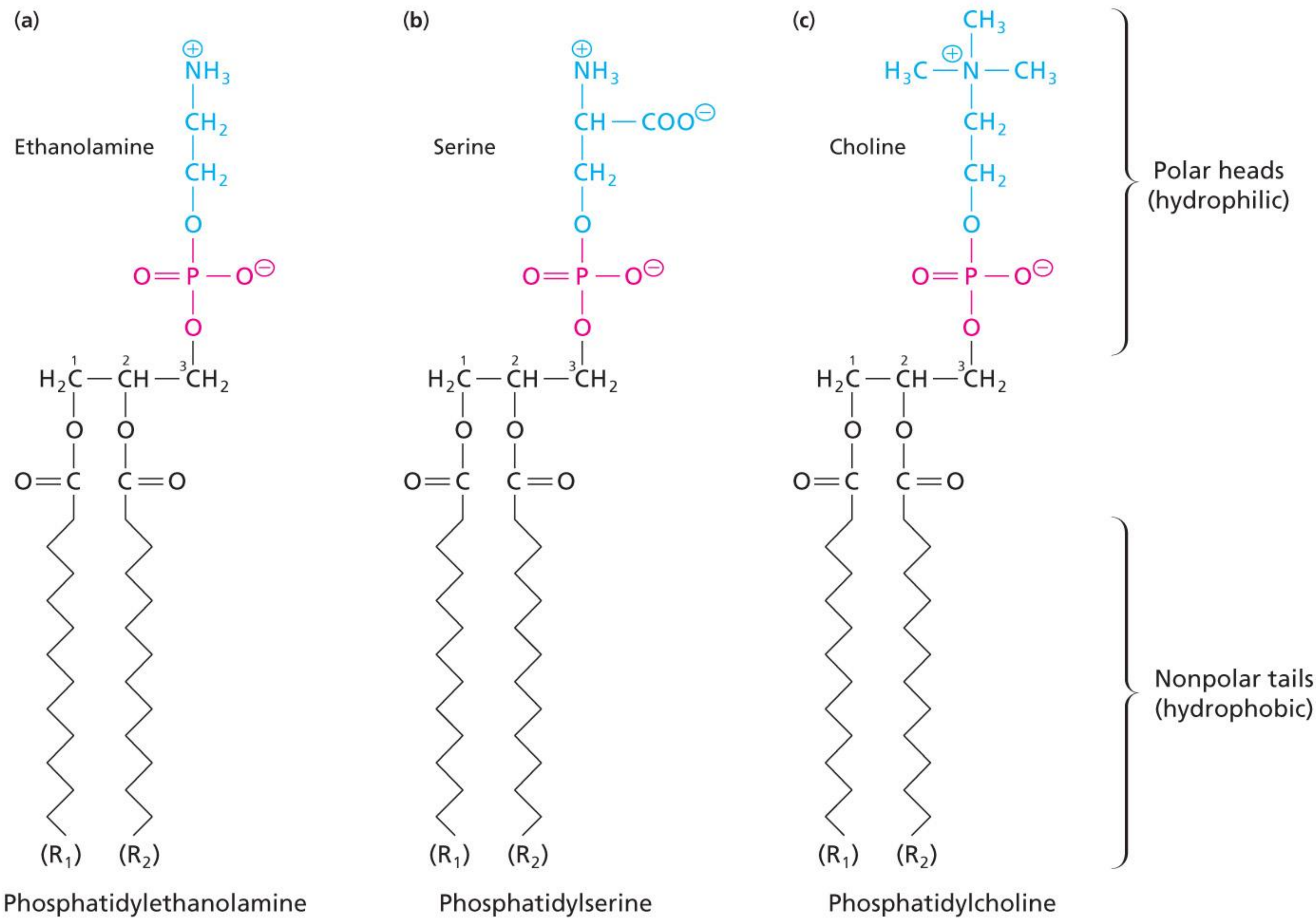
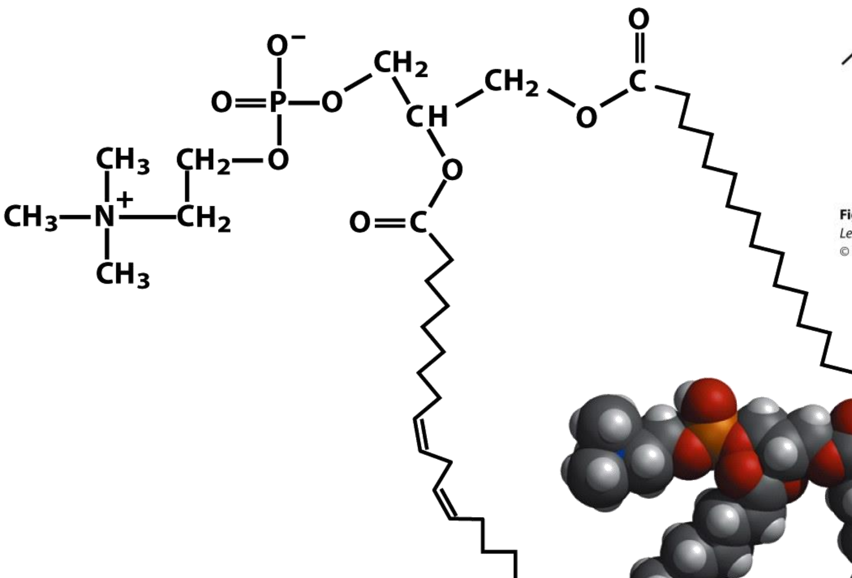
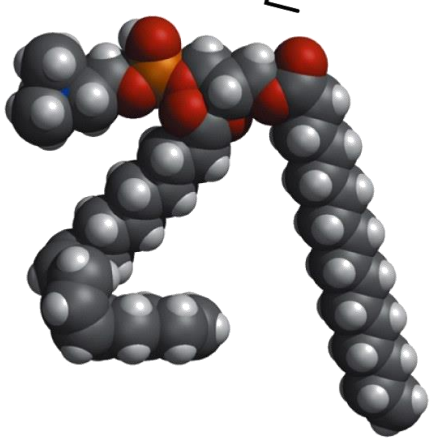


(a)
Ethanolamine
(b)
Serine
(c)
Choline
Polar heads (hydrophilic)
Nonpolar tails (hydrophobic)
Phosphatidylethanolamine
Phosphatidylserine
Phosphatidylcholine

Phosphatidylcholine

- Phosphatidylcholine is the major component of most eukaryotic cell membranes
- Many prokaryotes, including *E. coli,* cannot synthesize this lipid; their membranes do not contain phosphatidylcholine





Phosphatidylcholine

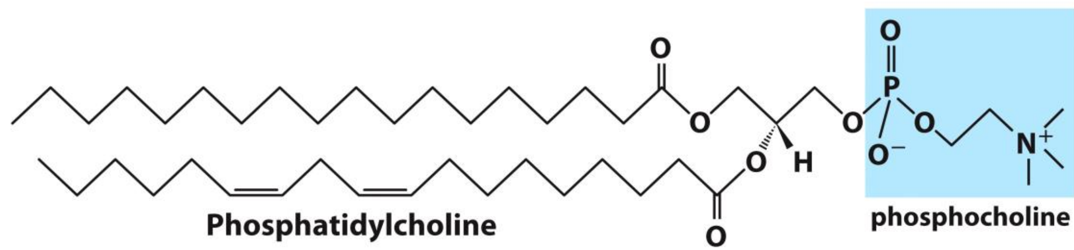


Figure 10-14
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Ether Lipids: Plasmalogen

- Vinyl ether analog of phosphatidylethanolamine
- Common in vertebrate heart tissue
- Also found in some protozoa and anaerobic bacteria
- Function is not well understood
  - Resistant to cleavage by common lipases but cleaved by few specific lipases
  - Increase membrane rigidity?
  - Sources of signaling lipids?
  - May be antioxidants?

Ether Lipids: Plasmalogen

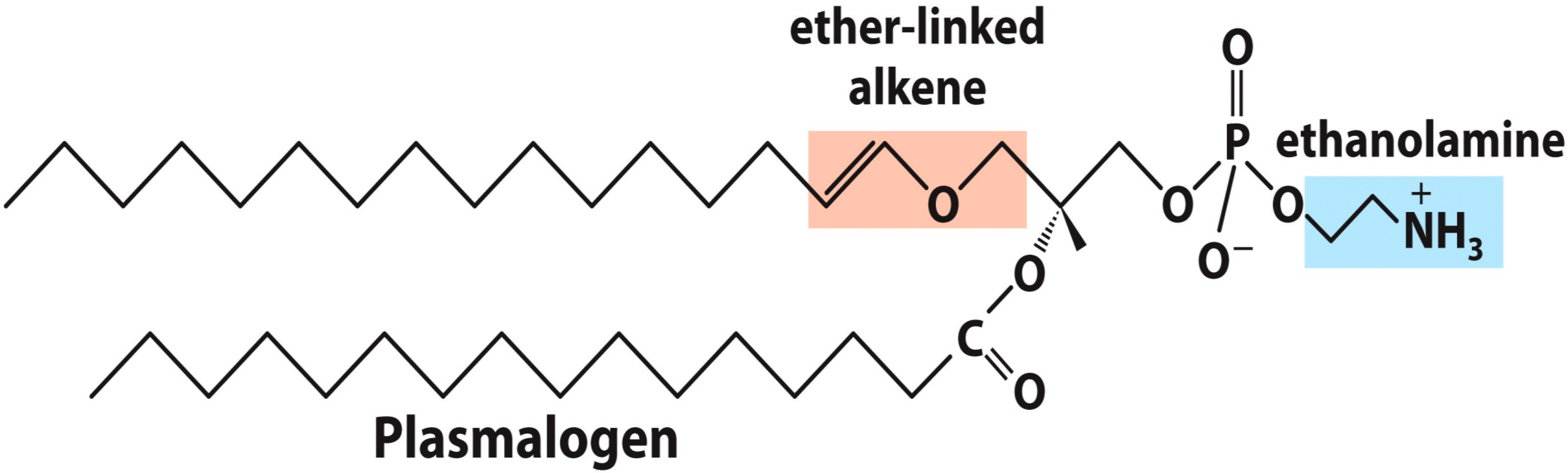

Figure 10-10
Lehninger Principles of Biochemistry, Sixth Edition

Ether Lipids: Platelet-Activating Factor

- Aliphatic ether analog of phosphatidylcholine
- Acetic acid has esterified position C2
- First signaling lipid to be identified
- Stimulates aggregation of blood platelets
- Plays role in mediation of inflammation

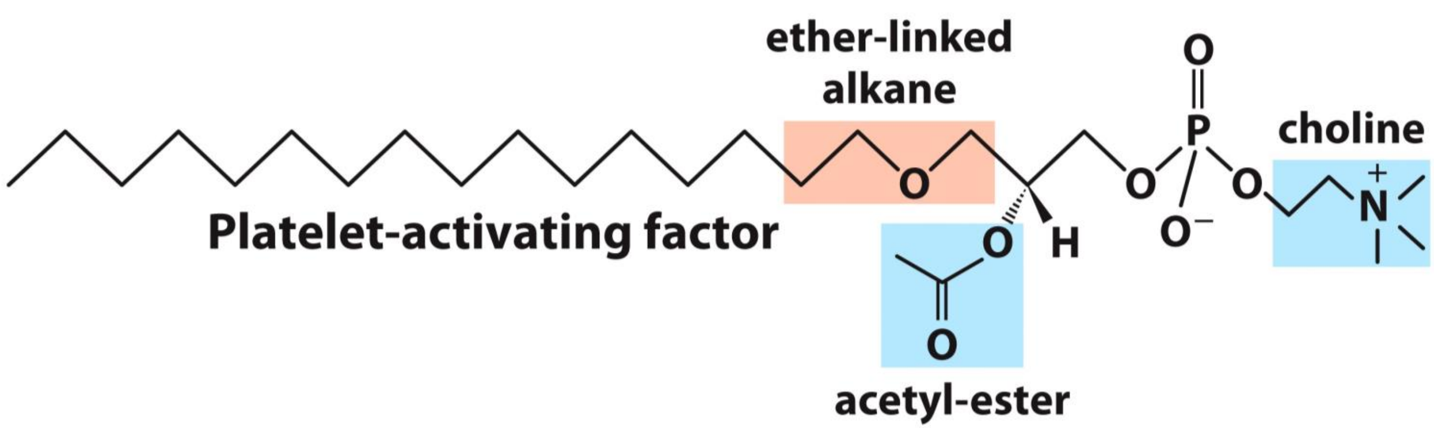

Figure 10-10
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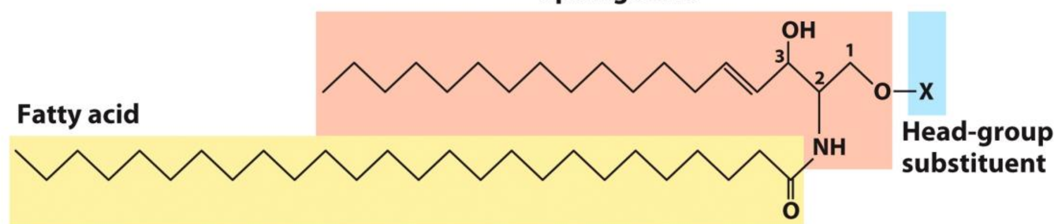
Sphingolipids

- The backbone of sphingolipids is NOT glycerol
- The backbone of sphingolipids is a long-chain amino alcohol sphingosine
- A fatty acid is joined to sphingosine via an amide linkage rather than an ester linkage as usually seen in lipids
- A polar head group is connected to sphingosine by a glycosidic or phosphodiester linkage
- The sugar-containing glycosphingolipids are found largely in the outer face of plasma membranes

Sphingolipids

Ceramide is the parent compound for this group (structurally similar to diacylglycerol).



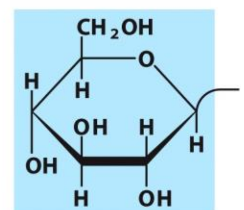
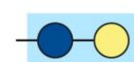
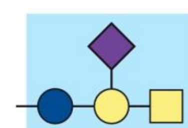
Name of sphingolipid	Name of X—O	Formula of X
Ceramide	—	—H
Sphingomyelin	Phosphocholine	$-\overset{O}{\overset{\Vert}{P}}(O^-)-O-CH_2-CH_2-\overset{+}{N}(CH_3)_3$
Neutral glycolipids Glucosylcerebroside	Glucose	
Lactosylceramide (a globoside)	Di-, tri-, or tetrasaccharide	
Ganglioside GM2	Complex oligosaccharide	

Figure 10-13
Lehninger Principles of Biochemistry, Sixth Edition

1. *J. Stiban*, *D. Fistere and M. Colombini* (2006) Dihydroceramide hinders **ceramide** channel formation: Implications on apoptosis. *Apoptosis. 11(5): 773-780.*

2. *J. Stiban, L. Caputo and M. Colombini* (2008) **Ceramide** synthesis in the endoplasmic reticulum can permeabilize mitochondria to proapoptotic proteins. *J. Lipid Res. 49(3): 625-634.*

3. *J. Stiban, L.C. Silva and A.H. Futerman* (2008) **Ceramide**-containing membranes: the interface between biophysics and biology. *Trends Glycosci. Glycotech. 20(116):* 297–313.

4. *J. Stiban*, *R. Tidhar and A.H. Futerman* (2009) ***Ceramide*** Synthases: Roles in Cell Physiology and Signaling, *In: 'Sphingolipids as Signaling and Regulatory Molecules' Landes Bioscience*

5. *Y. Pewzner-Jung Y, H. Park, E.L. Laviad, L.C. Silva, S. Lahiri, J. Stiban*, *et. al.* A critical role for **ceramide** synthase 2 in liver homeostasis: I. alterations in lipid metabolic pathways (2010) *J. Biol. Chem. 285(14):10902-10910.*

6. *S. Samanta, J. Stiban*, *T.K. Maugel and M. Colombini* (2011) Visualization of **ceramide** channels by transmission electron microscopy. *Biochim. Biophys. Acta - Biomembranes 1808(4):1196-1201*.

7. *J. Stiban and M. Perera* (2015) Very long chain **ceramides** interfere with C16-ceramide channel formation: A plausible mechanism for regulating the initiation of intrinsic apoptosis. *Biochim. Biophys. Acta 1848(2): 561-567.*

8. *M. Abou-Ghali and J. Stiban* (2015) Regulation of **ceramide** channel formation and disassembly: Insights on the initiation of apoptosis. *Saudi J. Biol. Sci.* 22(6): 760-772

Sphingomyelin

- Ceramide (sphingosine + amide-linked fatty acid) + phosphocholine attached to the alcohol
- Sphingomyelin is abundant in myelin sheath that surrounds some nerve cells in animals

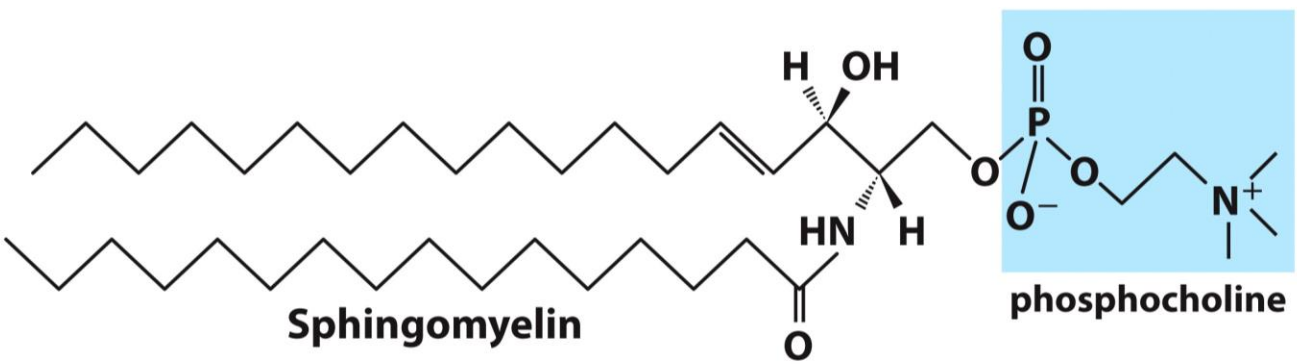


Figure 10-14
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Sphingomyelin is structurally similar to phosphatidylcholine

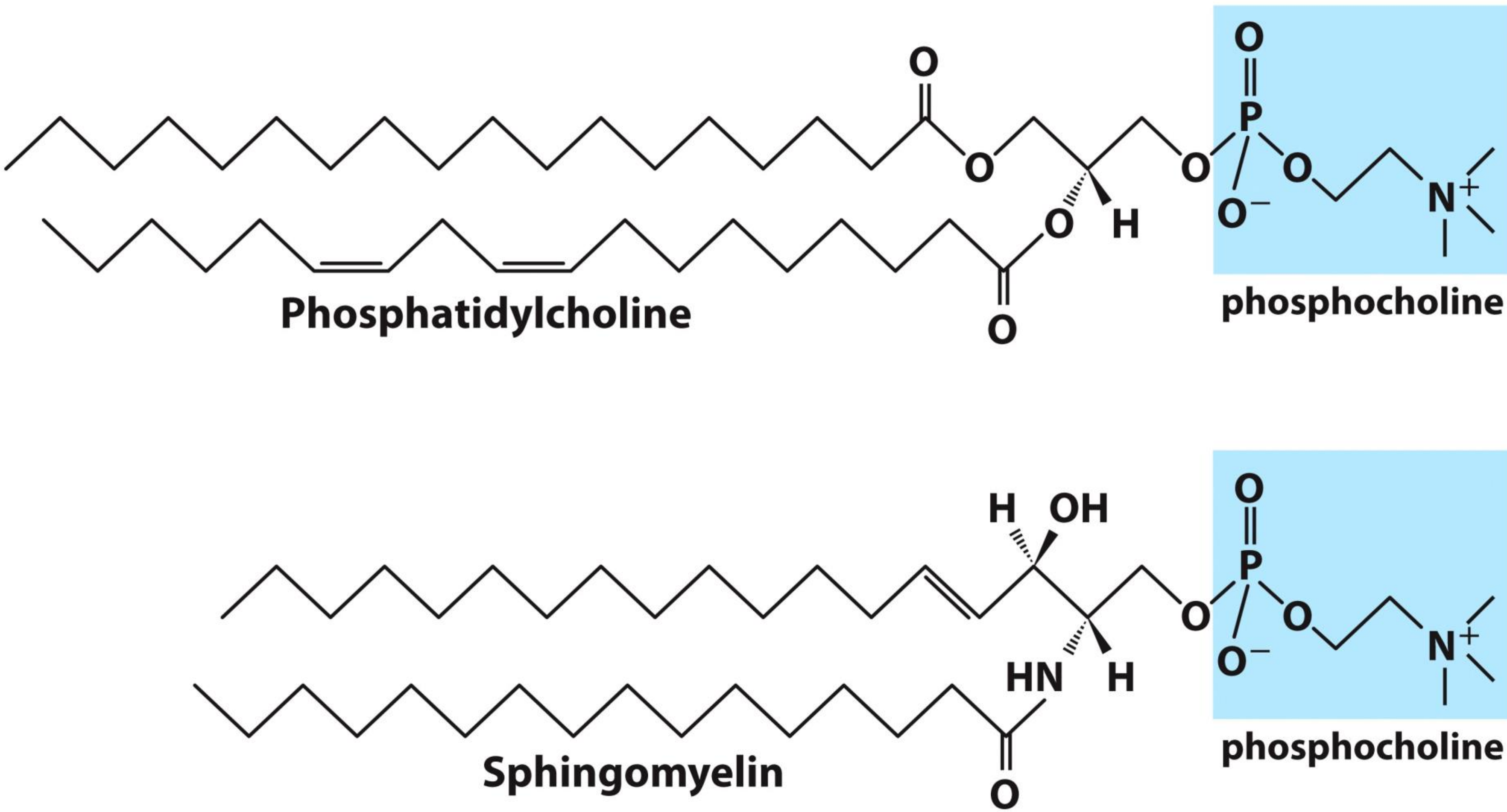

Figure 10-14
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Glycosphingolipids and Blood Groups

- The blood groups are determined in part by the type of sugars located on the head groups in glycosphingolipids.
- The structure of sugar is determined by an expression of specific glycosyltransferases
  - Individuals with no active glycosyltransferase will have the **O antigen**
  - Individuals with a glycosyltransferase that transfers an N-acetylgalactosamine group have **A blood group**
  - Individuals with a glycosyltransferase that transfers a galactose group have **B blood group**

Glycosphingolipids Determine Blood Groups

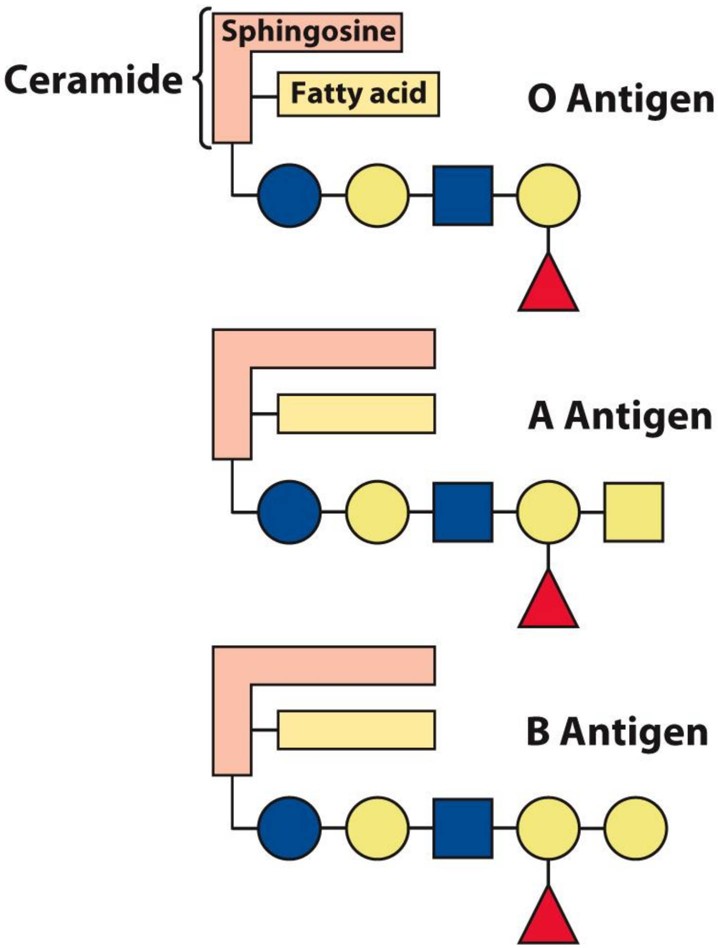

Figure 10-14
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TABLE 7-1 Symbols and Abbreviations for Common Monosaccharides and Some of Their Derivatives

Abequose	Abe	Glucuronic acid	GlcA
Arabinose	Ara	Galactosamine	GalN
Fructose	Fru	Glucosamine	GlcN
Fucose	Fuc	*N*-Acetylgalactosamine	GalNAc
Galactose	Gal	*N*-Acetylglucosamine	GlcNAc
Glucose	Glc	Iduronic acid	IdoA
Mannose	Man	Muramic acid	Mur
Rhamnose	Rha	*N*-Acetylmuramic acid	Mur2Ac
Ribose	Rib	*N*-Acetylneuraminic acid (a sialic acid)	Neu5Ac
Xylose	Xyl		

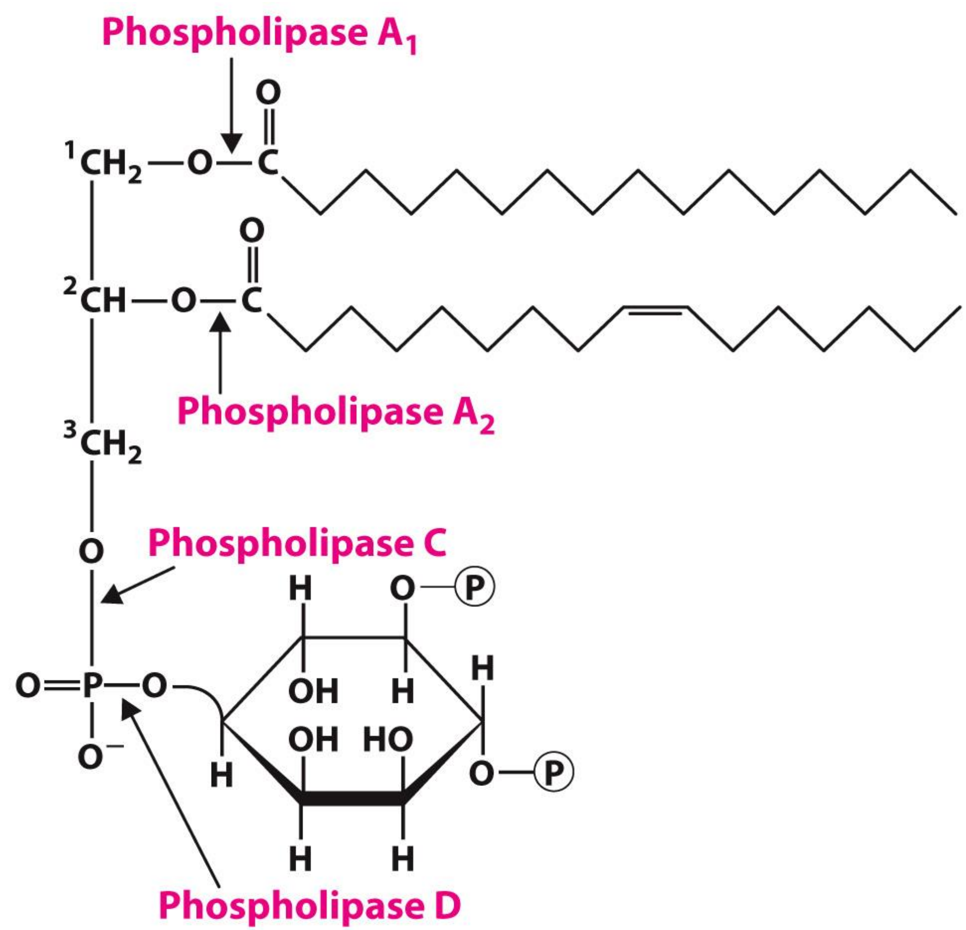
Note: In a commonly used convention, hexoses are represented as circles, *N*-acetylhexosamines as squares, and hexosamines as squares divided diagonally. All sugars with the "gluco" configuration are blue, those with the "galacto" configuration are yellow, and "manno" sugars are green. Other substituents can be added as needed: sulfate (S), phosphate (P), *O*-acetyl (OAc), or *O*-methyl (OMe).

Table 7-1
Lehninger Principles of Biochemistry, Seventh Edition

Structural and Signaling Lipids Are Degraded in the Lysosome

- Most cells continually degrade and replace their membrane lipids.
- Phospholipids are degraded by phospholipases A–D.
    - Each phospholipase cleaves a specific bond.

- Gangliosides are degraded via a series of enzymatic cleavages.
    - Failure to correctly degrade gangliosides results in build-up of lipids in lysosomes, a dysfunction categorized as “lysosomal storage disorders.”



Phosphatidylinositol 4,5-bisphosphate

Figure 10-15
Lehninger Principles of Biochemistry, Seventh Edition

Sterols and Cholesterol

- Sterol
  - Steroid nucleus: four fused rings
  - Hydroxyl group (polar head) in the A-ring
  - Various nonpolar side chains
- The steroid nucleus is almost planar

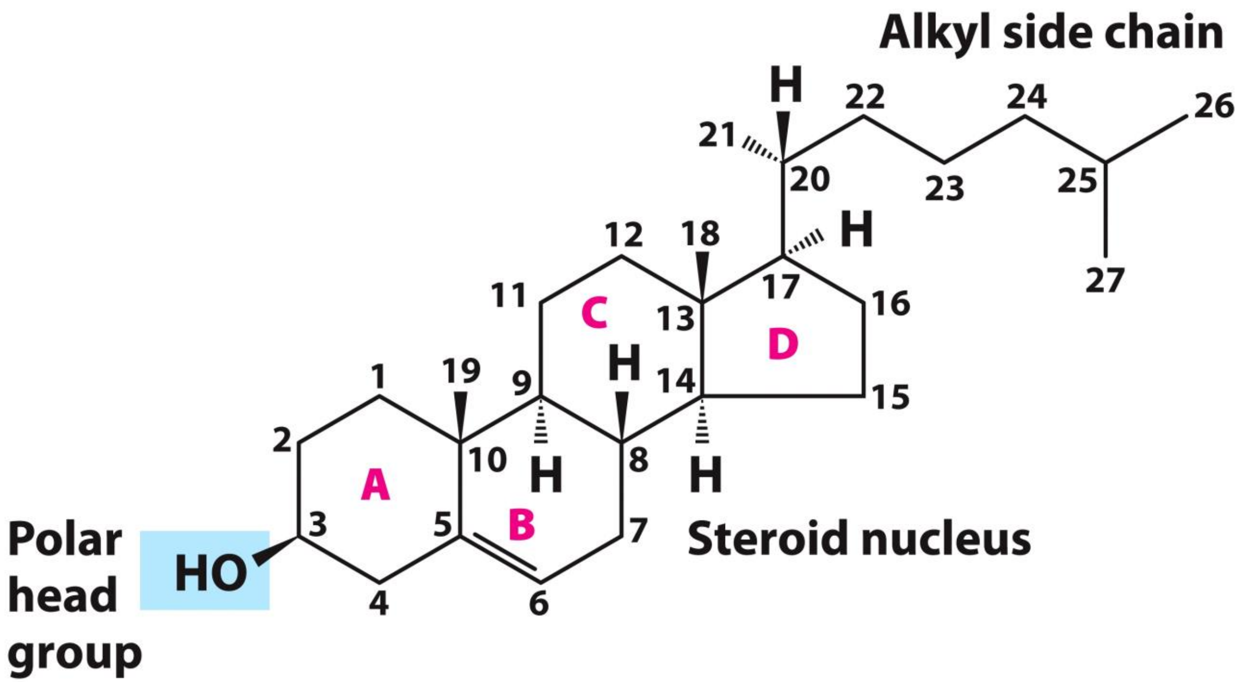


Figure 10-17
Lehninger Principles of Biochemistry, Sixth Edition

Physiological Role of Sterols

- Cholesterol and related sterols are present in the membranes of most eukaryotic cells
  - Modulate fluidity and permeability
  - Thicken the plasma membrane
  - Most bacteria lack sterols
- Mammals obtain cholesterol from food or synthesize it *de novo* in the liver
- Cholesterol, bound to proteins, is transported to tissues via blood vessels
  - Cholesterol in low-density lipoproteins tends to deposit and clog arteries
- Many hormones are derivatives of sterols

Membrane microdomains (rafts)

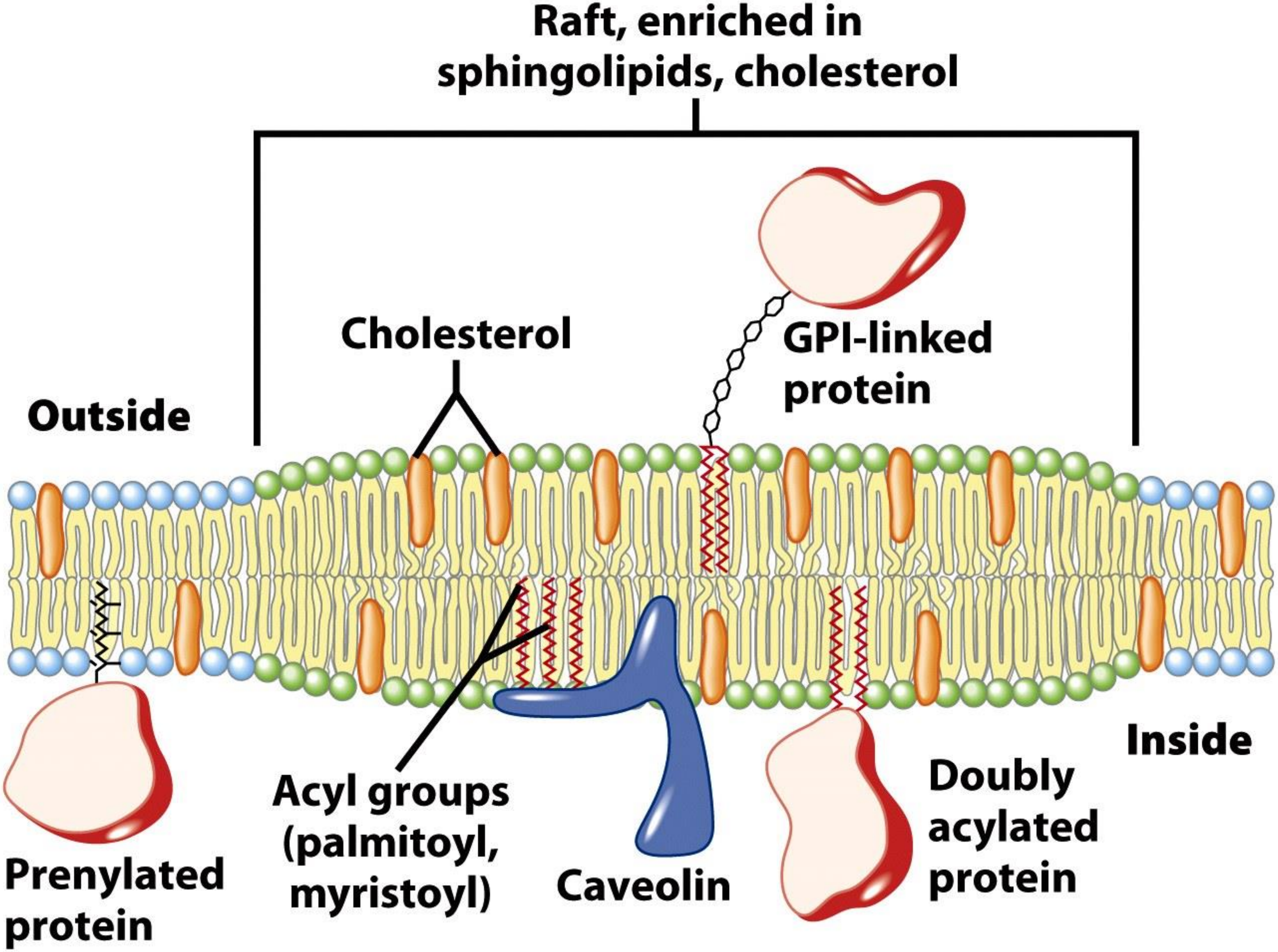
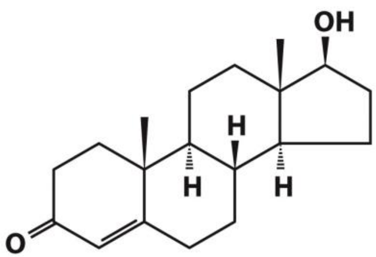


Figure 11-20a
Lehninger Principles of Biochemistry, Fifth Edition

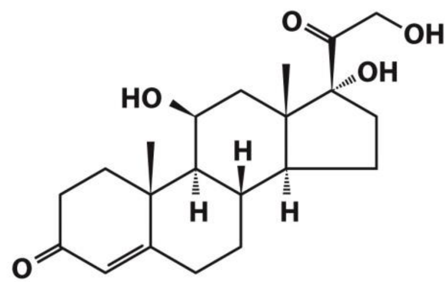
Steroid Hormones

- Steroids are oxidized derivatives of sterols
- Steroids have the sterol nucleus, but lack the alkyl chain found in cholesterol
- More polar than cholesterol
- Steroid hormones are synthesized from cholesterol in gonads and adrenal glands
- They are carried through the body in the bloodstream, usually attached to carrier proteins
- Many of the steroid hormones are male and female sex hormones

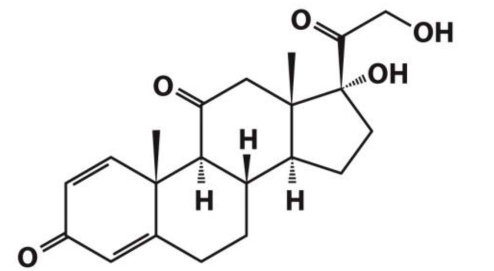
Steroid Hormones



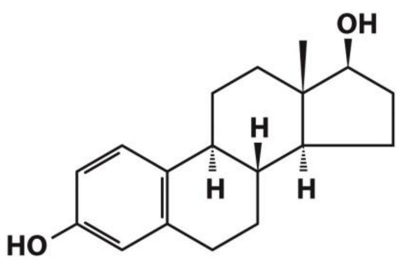
Testosterone



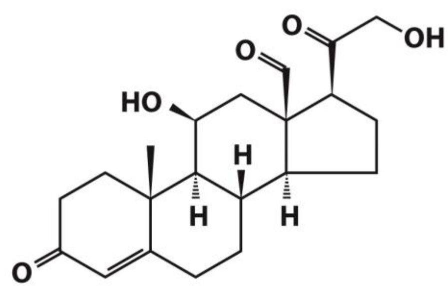
Cortisol



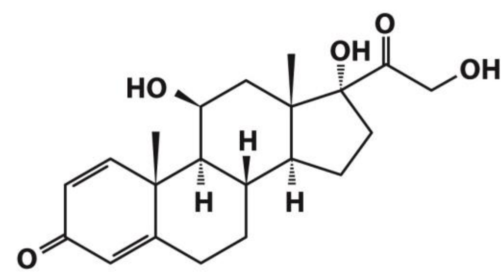
Prednisone



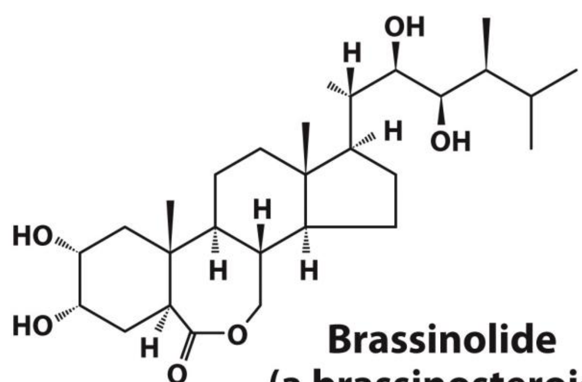
β-Estradiol



Aldosterone



Prednisolone



Brassinolide
(a brassinosteroid)

Figure 10-19
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Biologically Active Lipids

- Are present in much smaller amounts than storage or structural lipids
- Play vital roles as signaling molecules between nearby cells
- Lipid soluble vitamins (A, D, E, and K)

Signaling Lipids

- Paracrine lipid hormones are present in small amounts but play vital roles as signaling molecules between nearby cells
- Enzymatic oxidation of arachidonic acid yields
  - prostaglandins,
  - thromboxanes,
  - leukotrienes
- Arachidonic acid: $20{:}4(\Delta^{5,8,11,14})$

Arachidonic Acid Derivatives as Signaling Lipids

- Variety of functions:
  - Inflammation and fever, increase in body temperature (prostaglandins)
  - Formation of blood clots (thromboxanes)
  - Smooth muscle contraction in lungs; overproduction causes asthmatic attacks (leukotrienes)
  - Smooth muscle contraction in uterus during labor and menstruation (prostaglandins)

Nonsteroidal antiinflammatory drugs (NSAIDs) such as **aspirin** and **ibuprofen** block the formation of prostaglandins and thromboxanes from arachidonate by inhibiting the enzyme cyclooxygenase (prostaglandin H2 synthase).

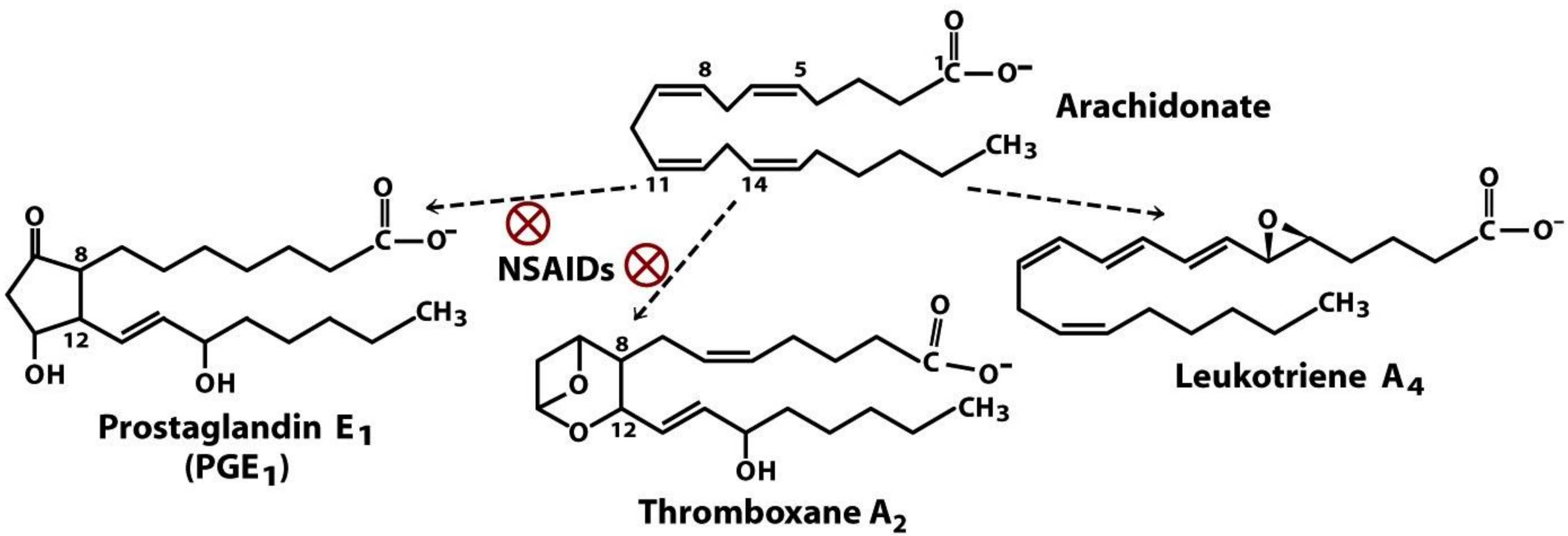

Figure 10-18
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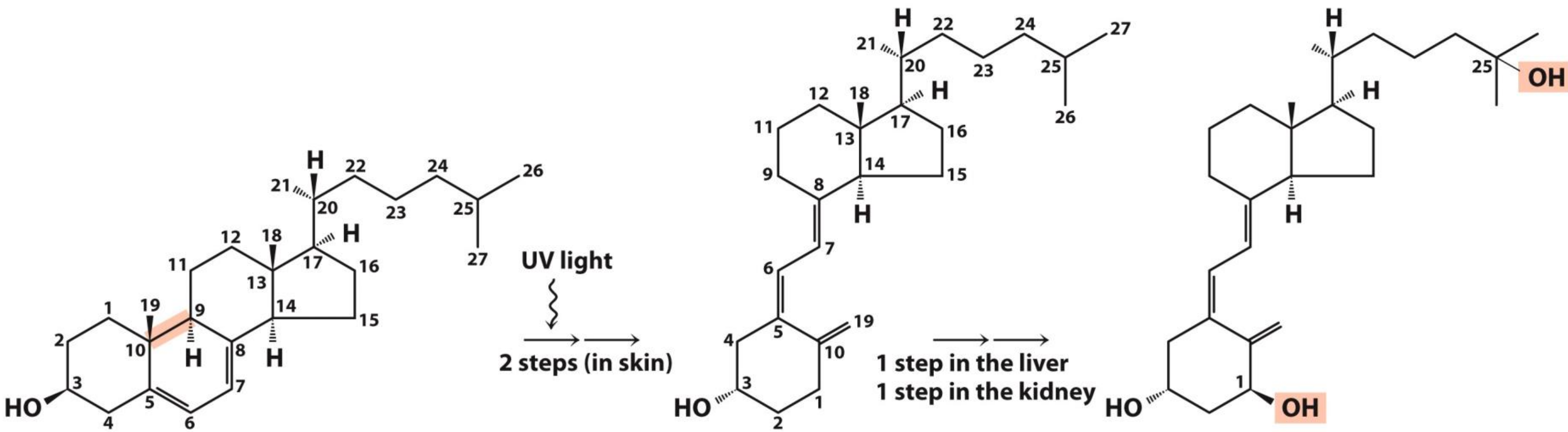
Vitamin D regulates calcium uptake



7-Dehydrocholesterol

Cholecalciferol (vitamin D_3)

1α,25-Dihydroxyvitamin D_3 (calcitriol)

Figure 10-20a
Lehninger Principles of Biochemistry, Sixth Edition

Vitamin A (Retinol)

- Involved in visual pigment
- Precursor for other hormones involved in signaling

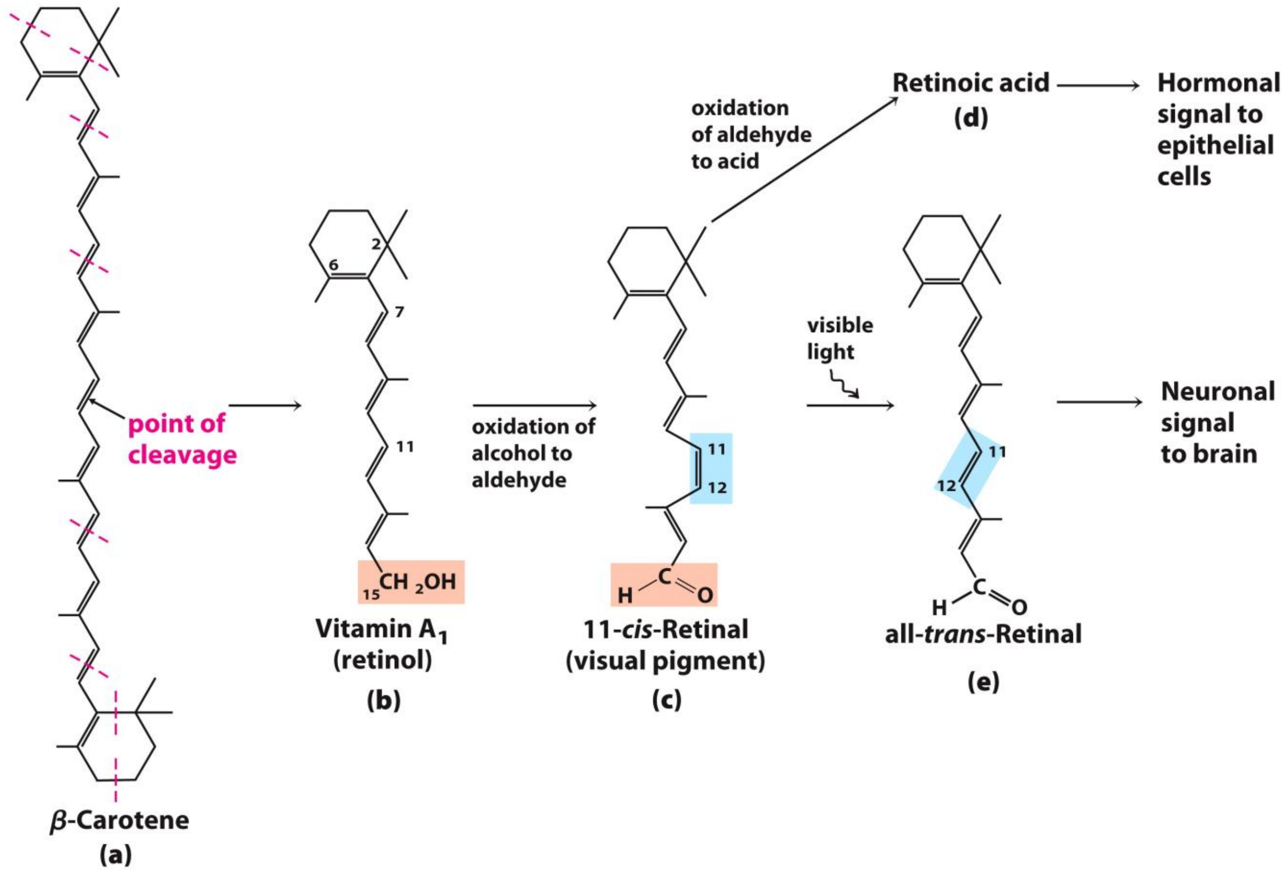
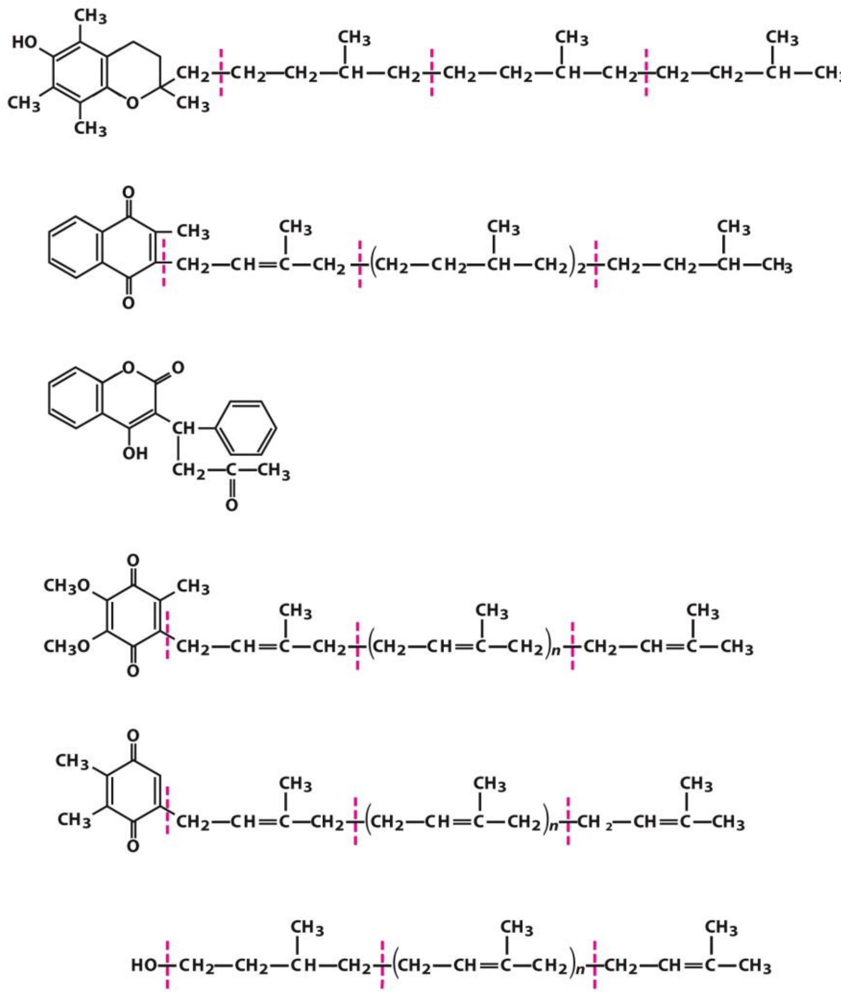


Figure 10-21
Lehninger Principles of Biochemistry, Sixth Edition

Vitamin E, K, and other lipid quinones are antioxidants



(a) Vitamin E: an antioxidant

(b) Vitamin K_1: a blood-clotting cofactor (phylloquinone)

(c) Warfarin: a blood anticoagulant

(d) Ubiquinone: a mitochondrial electron carrier (coenzyme Q) (n = 4 to 8)

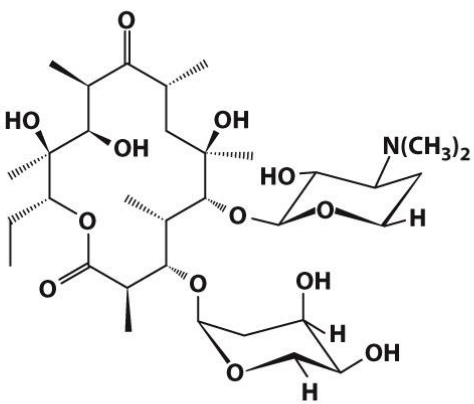
(e) Plastoquinone: a chloroplast electron carrier (n = 4 to 8)

(f) Dolichol: a sugar carrier (n = 9 to 22)

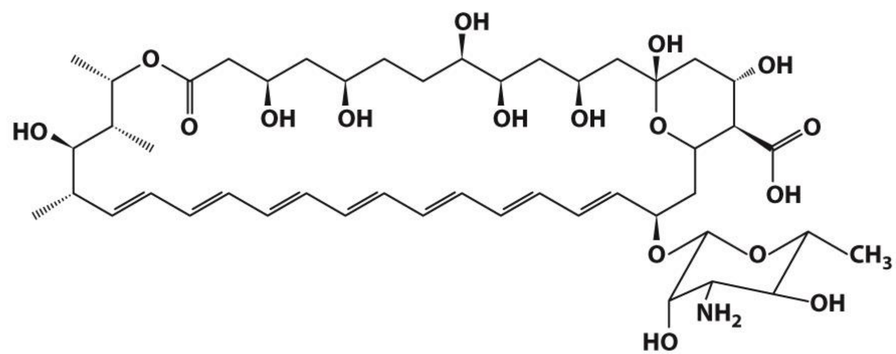
Figure 10-22
Lehninger Principles of Biochemistry, Sixth Edition

Polyketides Are Biologically Active Lipids with Medicinal Uses

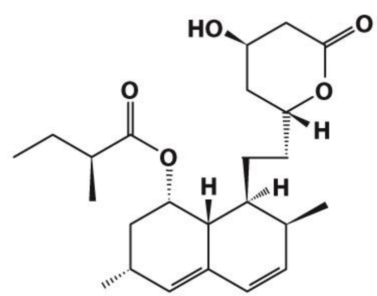
- Polyketides are a diverse family of compounds synthesized similarly to fatty acid biosynthesis.
    - commonly secondary metabolites with specialized function



Erythromycin (antibiotic)



Amphotericin B (antifungal)



Lovastatin (statin)

Figure 10-24
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