David L. Nelson and Michael M. Cox

Lehninger Principles of Biochemistry

Fourth Edition

Chapter 10:

Lipids

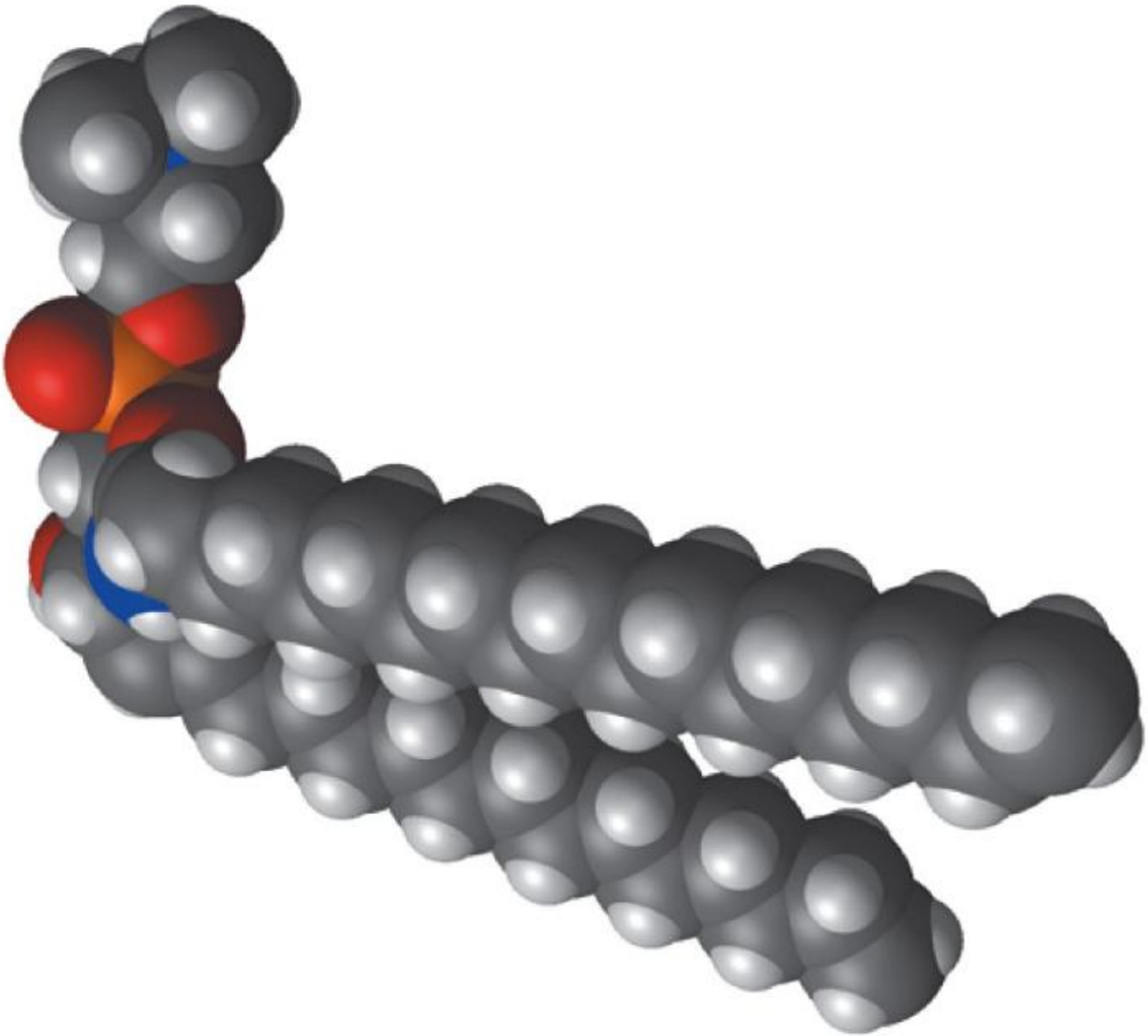
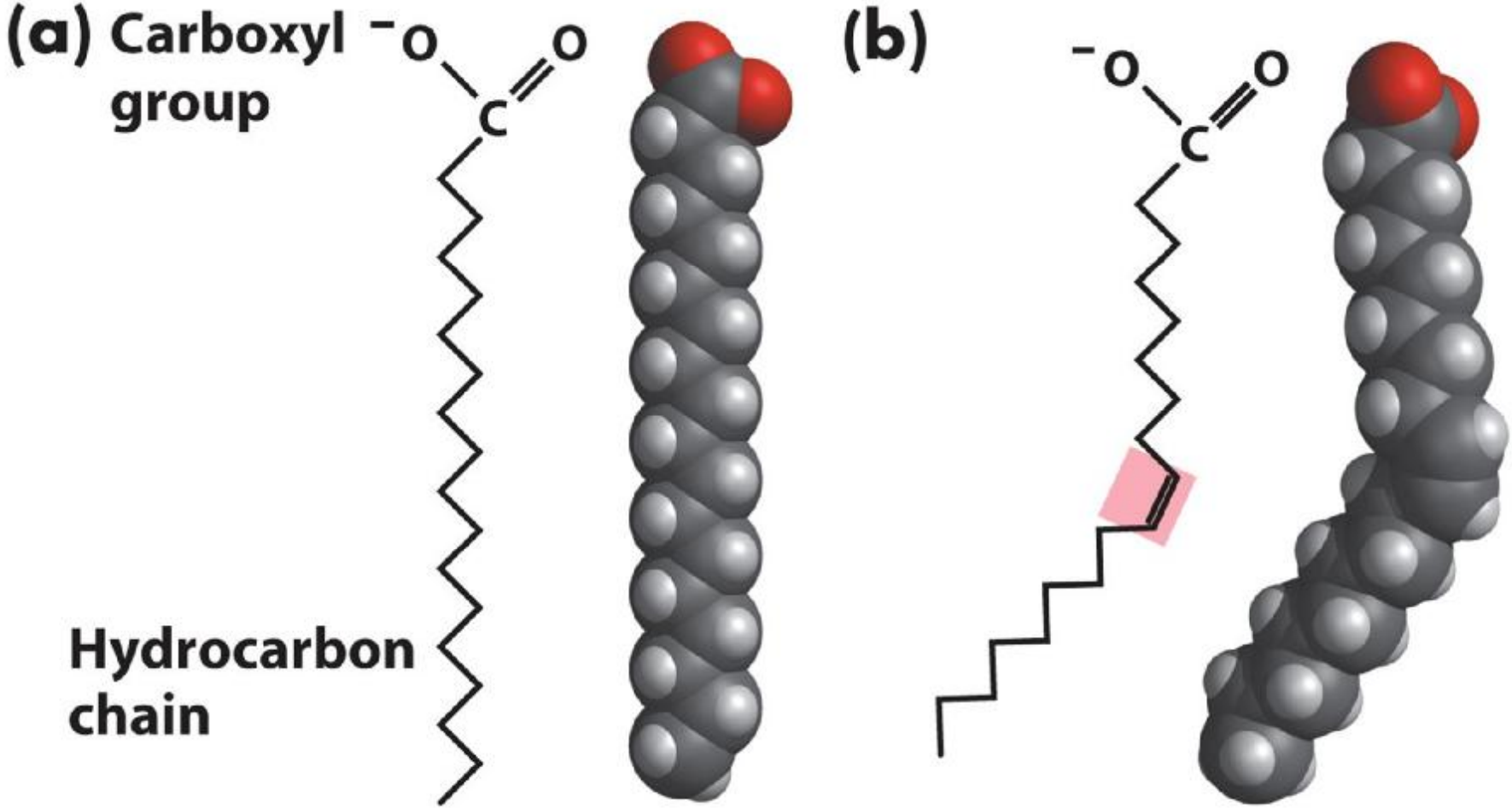


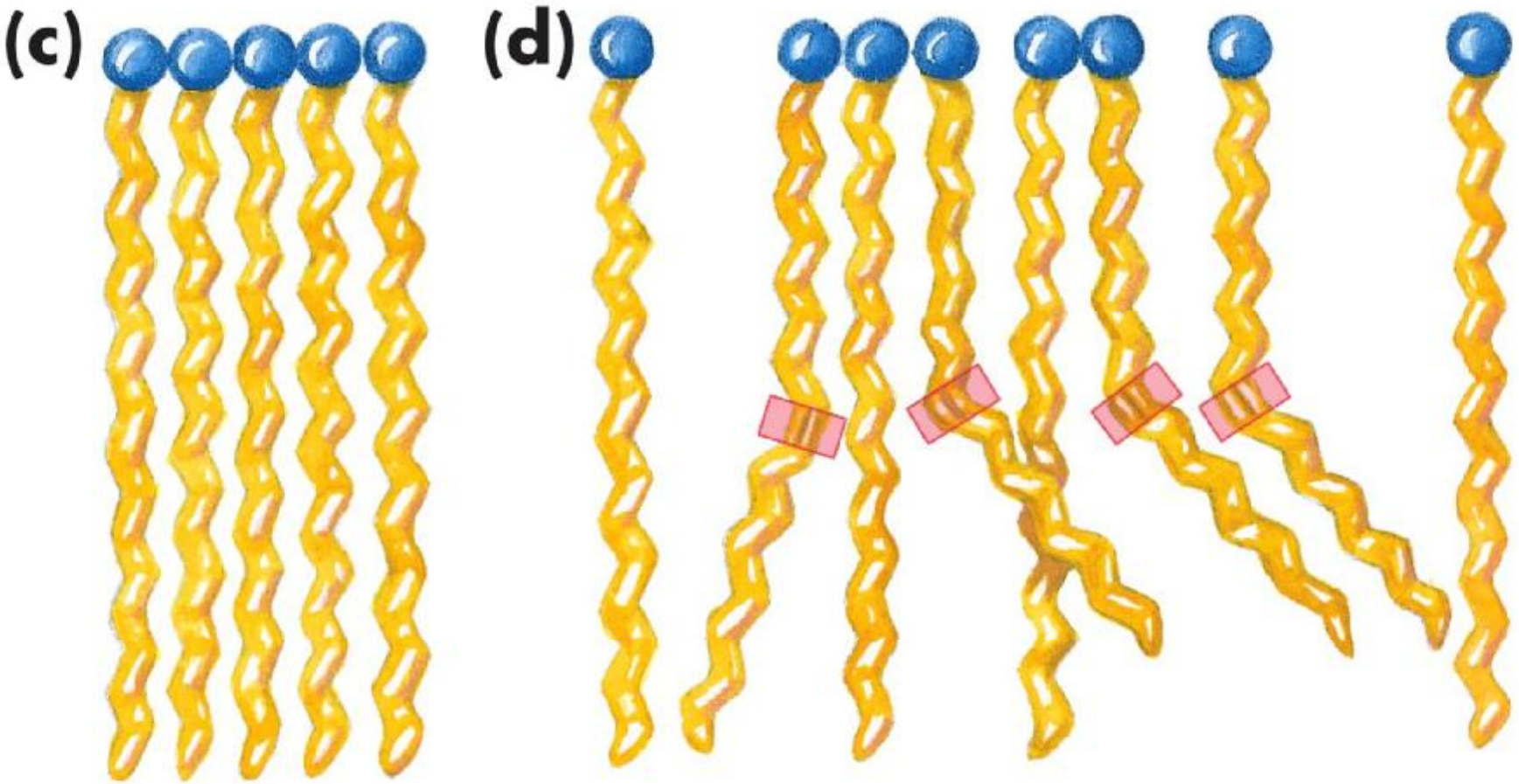
TABLE 10–1 Some Naturally Occurring Fatty Acids: Structure, Properties, and Nomenclature

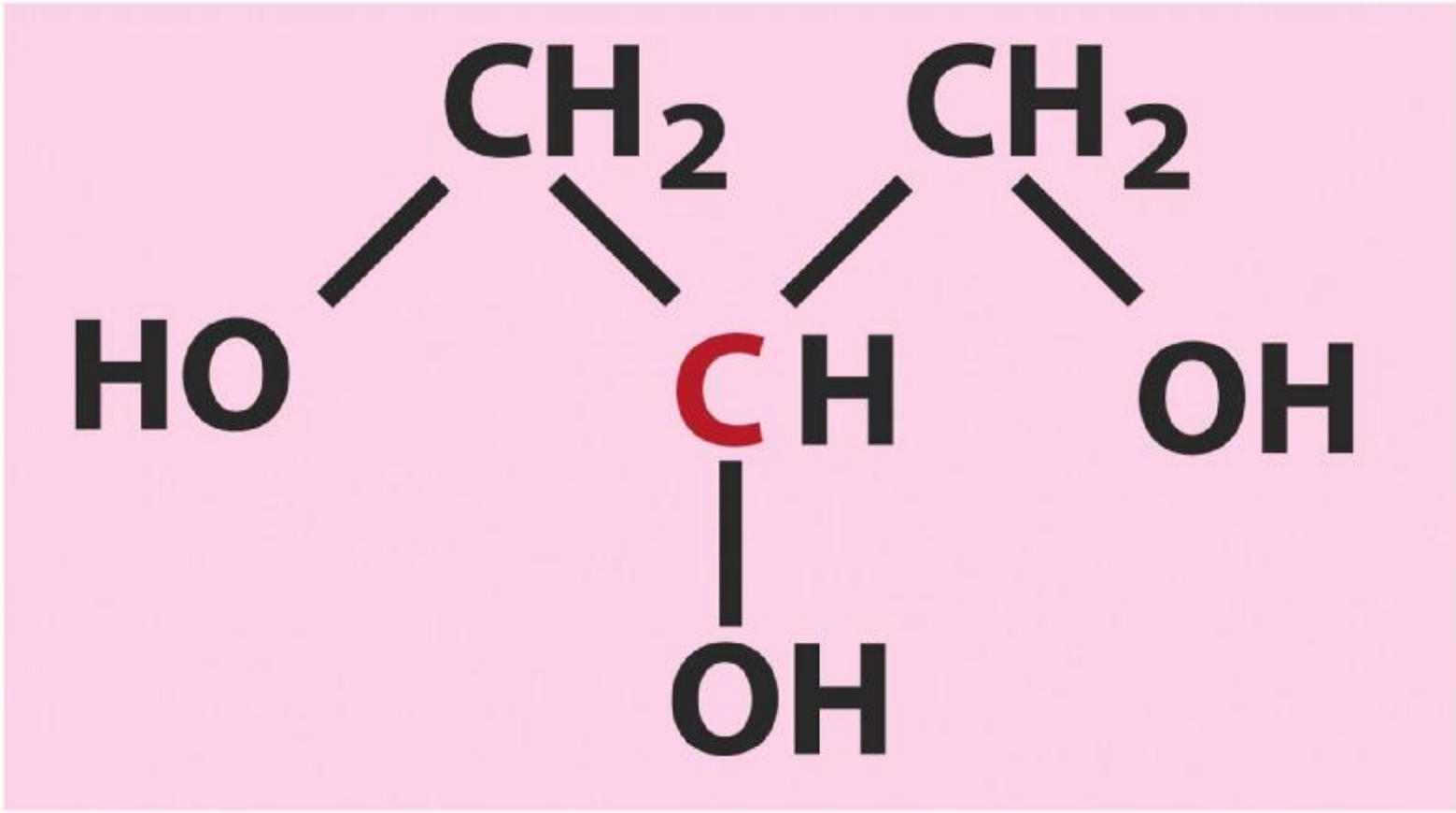
Carbon skeleton	Structure*	Systematic name†	Common name (derivation)	Melting point (°C)	Solubility at 30 °C (mg/g solvent)	
					Water	Benzene
12:0	$CH_3(CH_2)_{10}COOH$	*n*-Dodecanoic acid	Lauric acid (Latin *laurus*, "laurel plant")	44.2	0.063	2,600
14:0	$CH_3(CH_2)_{12}COOH$	*n*-Tetradecanoic acid	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		
16:1(Δ^9)	$CH_3(CH_2)_5CH{=}CH(CH_2)_7COOH$	*cis*-9-Hexadecenoic acid	Palmitoleic acid	1–0.5		
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	−11		
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		

*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.

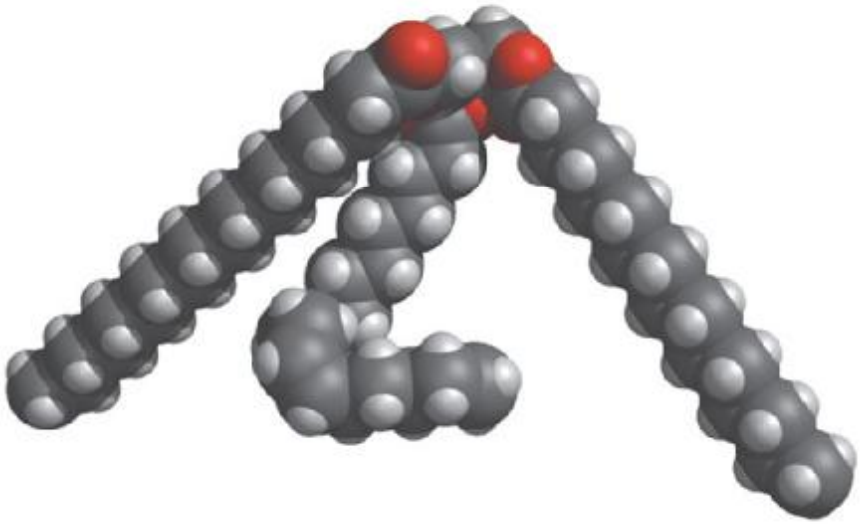
†The prefix *n*- indicates the "normal" unbranched structure. For instance, "dodecanoic" simply indicates 12 carbon atoms, which could be arranged in a variety of branched forms; "*n*-dodecanoic" specifies the linear, unbranched form. For unsaturated fatty acids, the configuration of each double bond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

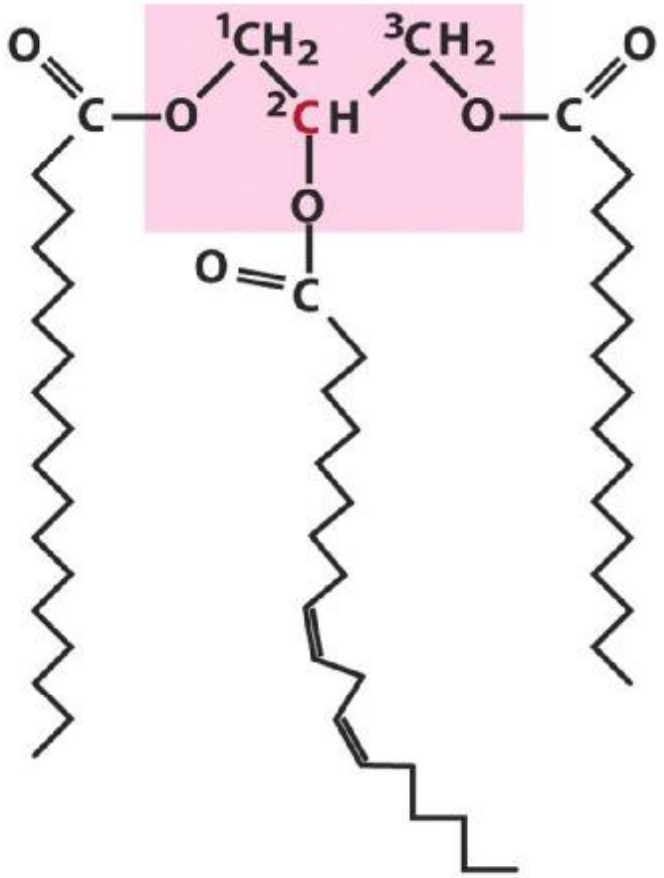

(a) Carboxyl group
Hydrocarbon chain
(b)


(c)
(d)
Saturated fatty acids
Mixture of saturated and unsaturated fatty acids

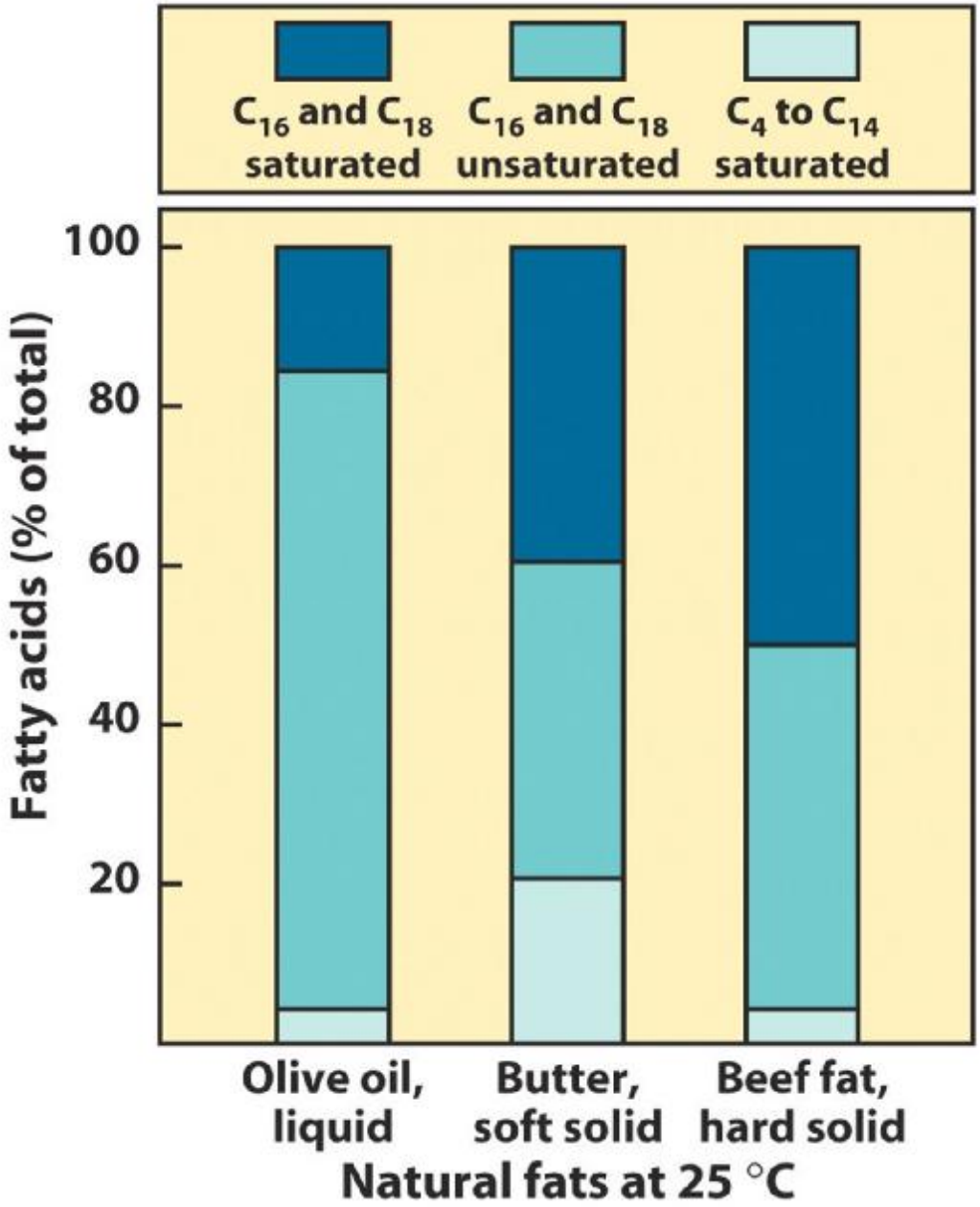


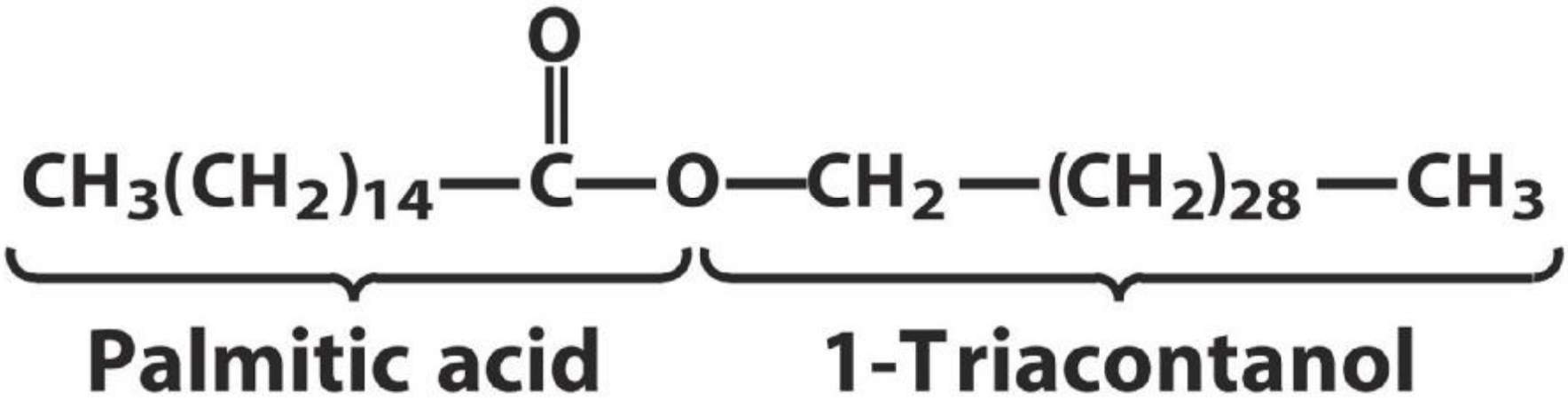
Glycerol

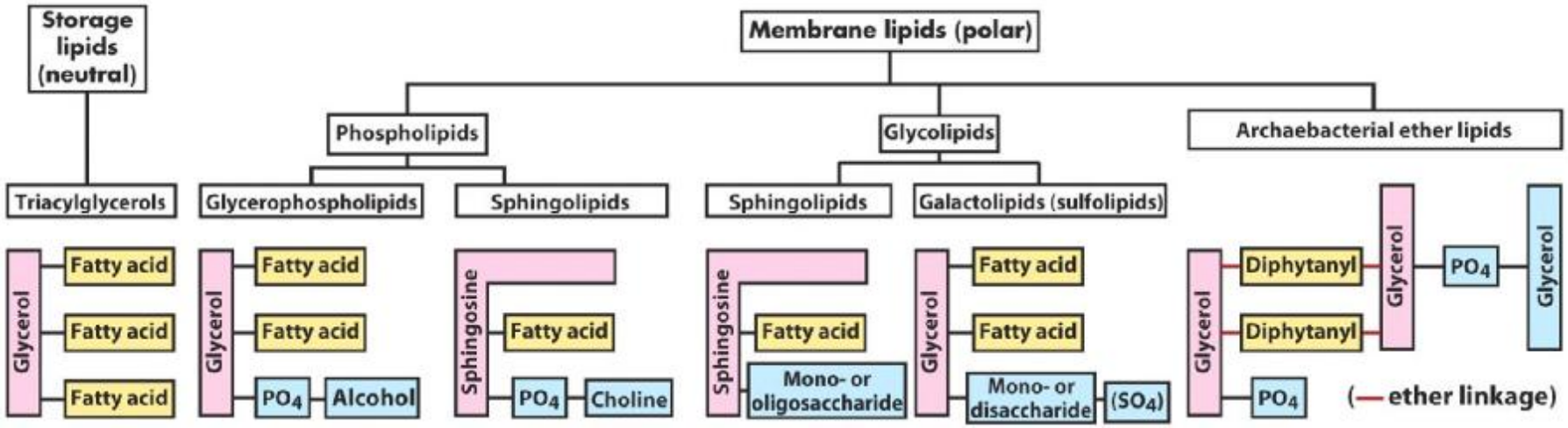


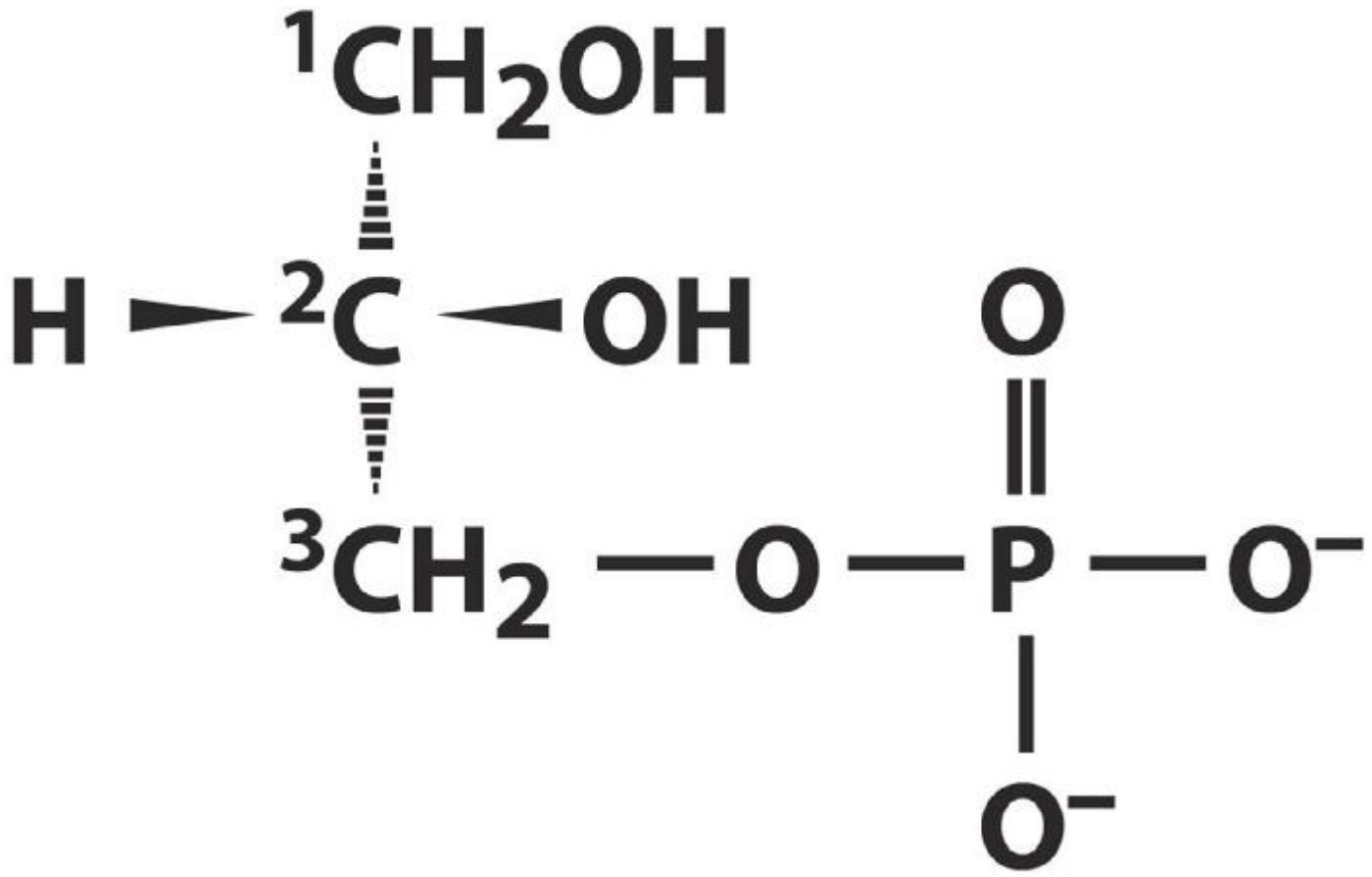


1-Stearoyl, 2-linoleoyl, 3-palmitoyl glycerol, a mixed triacylglycerol

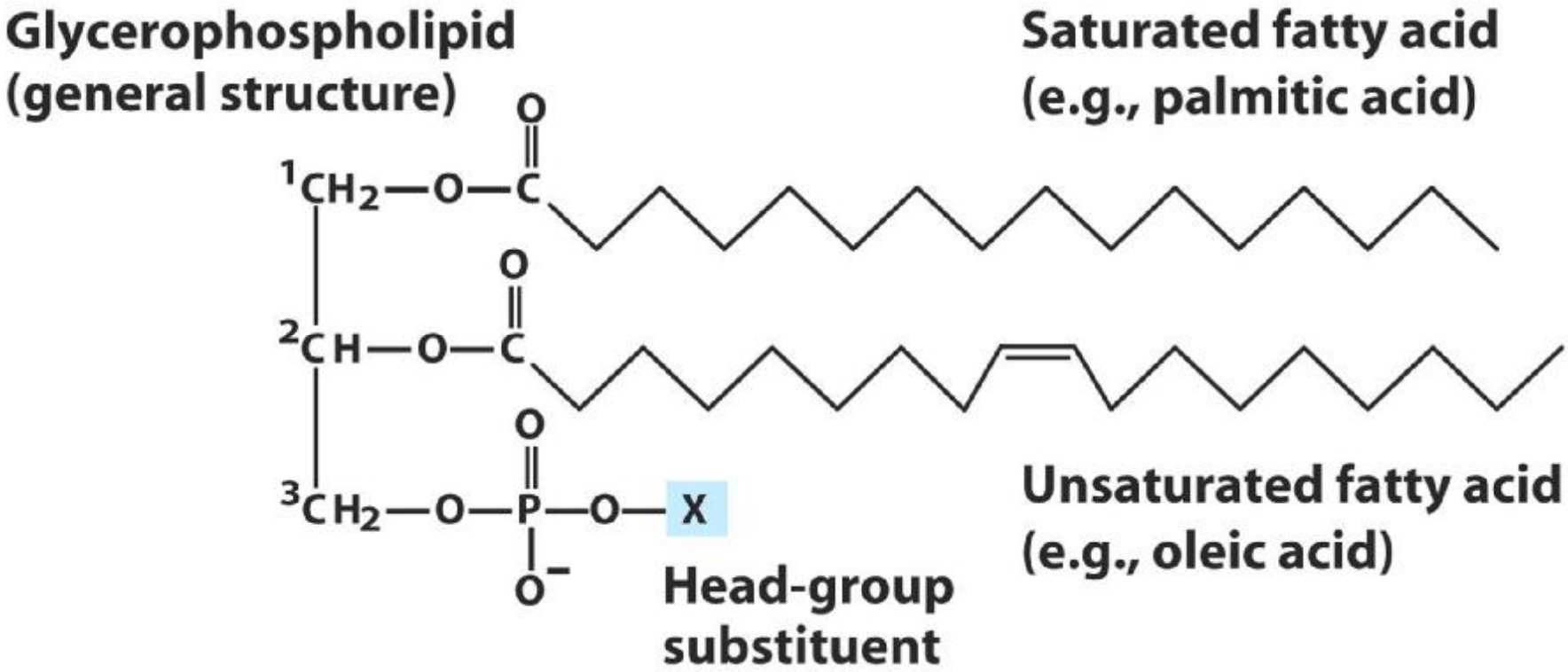

C_{16} and C_{18} saturated
C_{16} and C_{18} unsaturated
C_4 to C_{14} saturated
Fatty acids (% of total)
100
80
60
40
20
Olive oil, liquid
Butter, soft solid
Beef fat, hard solid
Natural fats at 25 °C

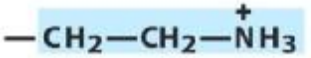
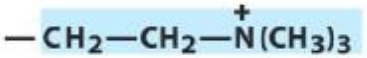
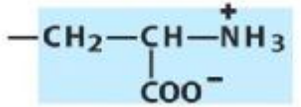
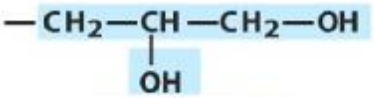
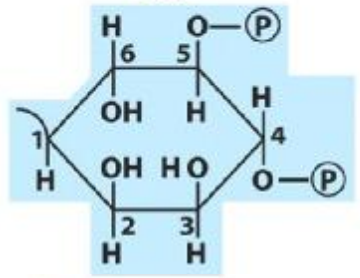
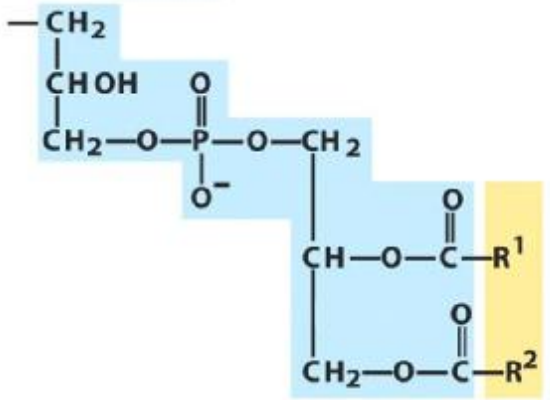

O
CH3(CH2)14—C—O—CH2—(CH2)28—CH3
Palmitic acid
1-Triacontanol

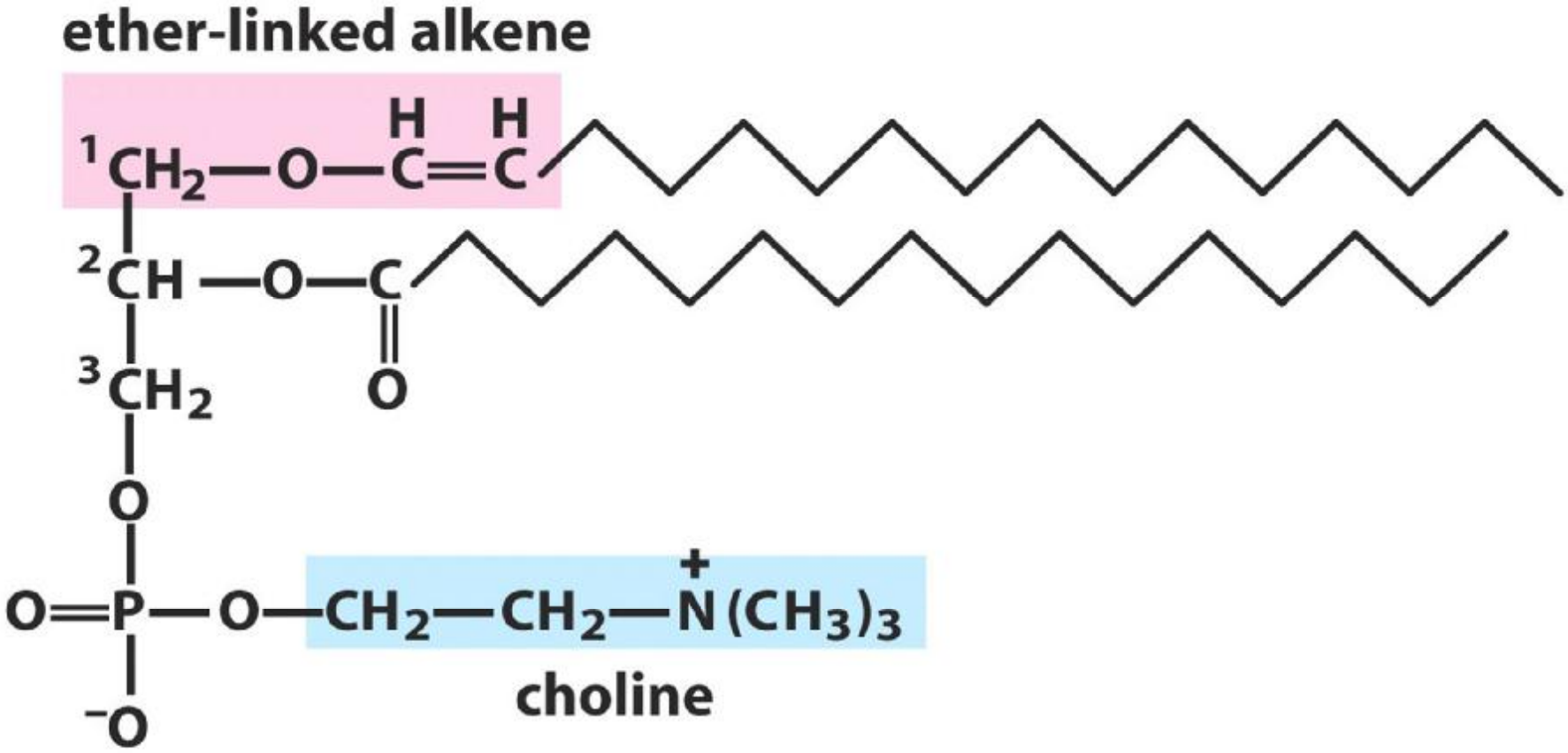

Storage lipids (neutral)
Membrane lipids (polar)
Phospholipids
Glycolipids
Archaebacterial ether lipids
Triacylglycerols
Glycerophospholipids
Sphingolipids
Sphingolipids
Galactolipids (sulfolipids)
Glycerol
Fatty acid
Fatty acid
Fatty acid
Glycerol
Fatty acid
Fatty acid
PO4
Alcohol
Sphingosine
Fatty acid
PO4
Choline
Sphingosine
Fatty acid
Mono- or oligosaccharide
Glycerol
Fatty acid
Fatty acid
Mono- or disaccharide
(SO4)
Glycerol
Diphytanyl
Diphytanyl
PO4
Glycerol
PO4
Glycerol
(— ether linkage)



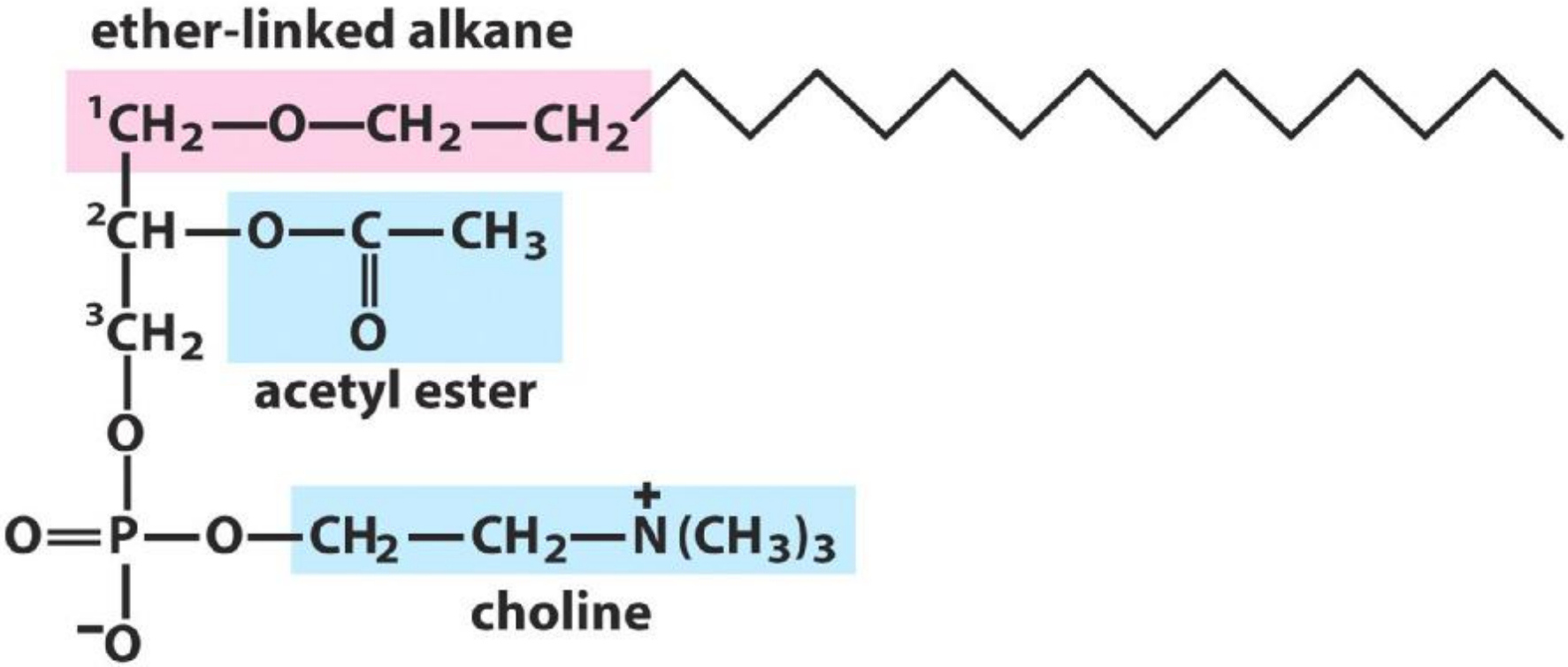
L-Glycerol 3-phosphate
(*sn*-glycerol 3-phosphate)


Glycerophospholipid
(general structure)
Saturated fatty acid
(e.g., palmitic acid)
Unsaturated fatty acid
(e.g., oleic acid)
Head-group
substituent
X

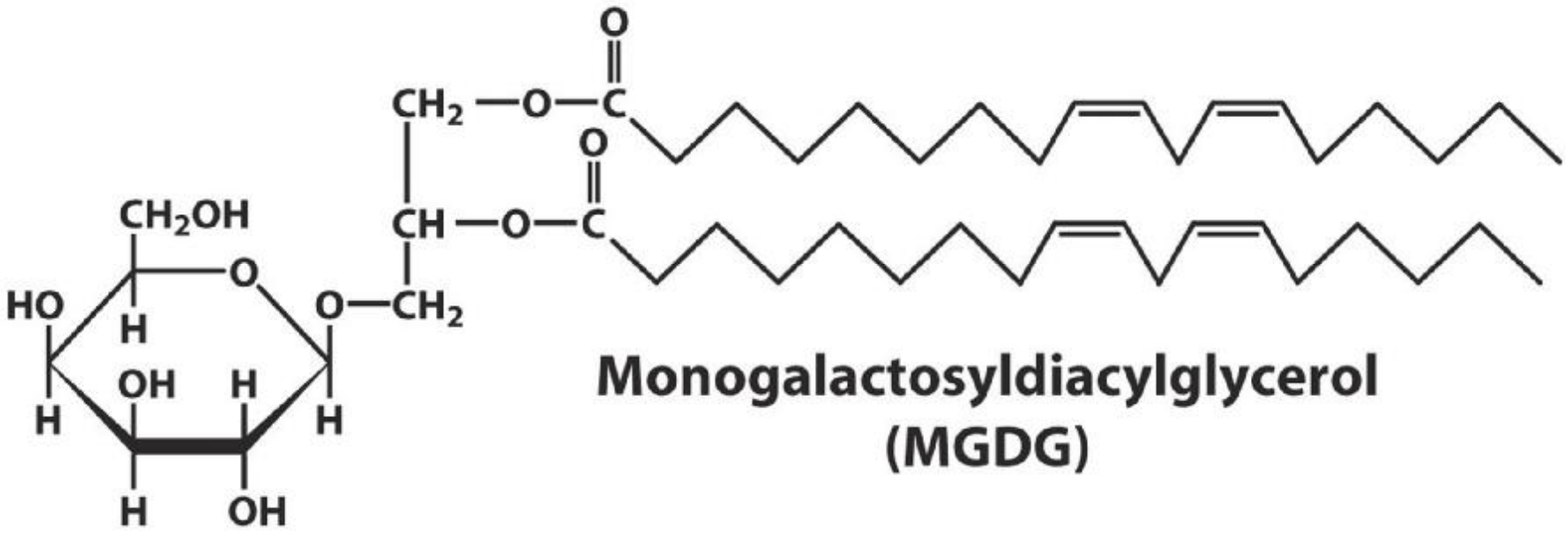
Name of glycerophospholipid	Name of X	Formula of X	Net charge (at pH 7)
Phosphatidic acid	—		−1
Phosphatidylethanolamine	Ethanolamine		0
Phosphatidylcholine	Choline		0
Phosphatidylserine	Serine		−1
Phosphatidylglycerol	Glycerol		−1
Phosphatidylinositol 4,5-bisphosphate	*myo*-Inositol 4,5-bisphosphate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



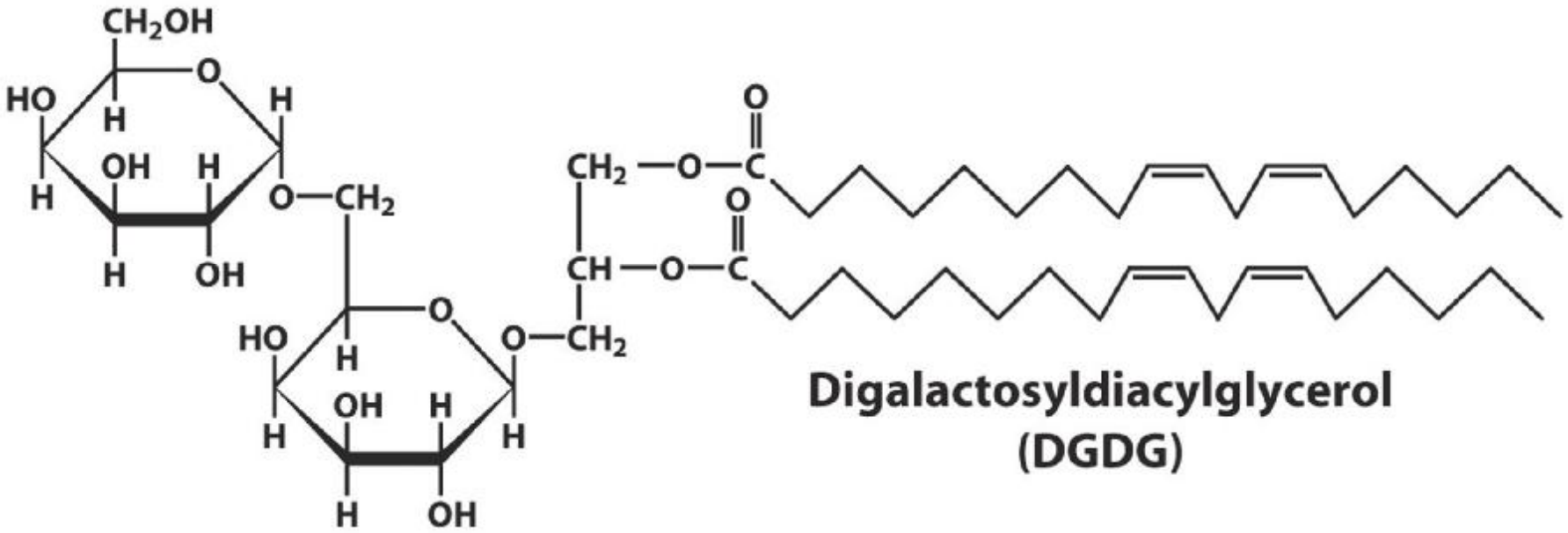
Plasmalogen



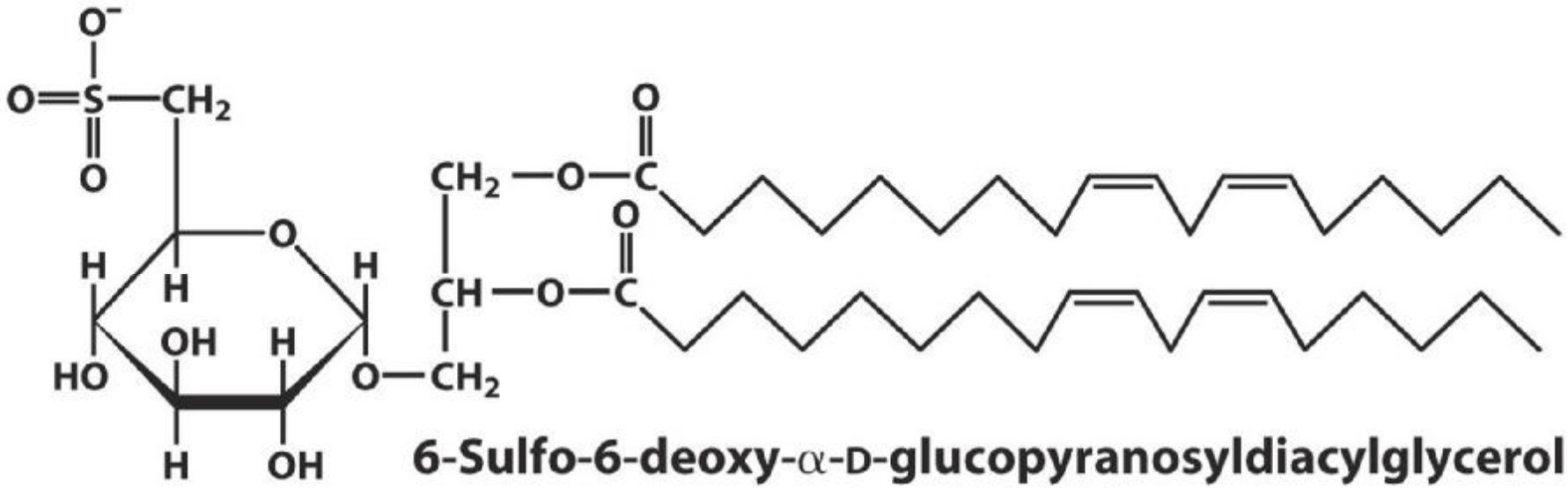
Platelet-activating factor



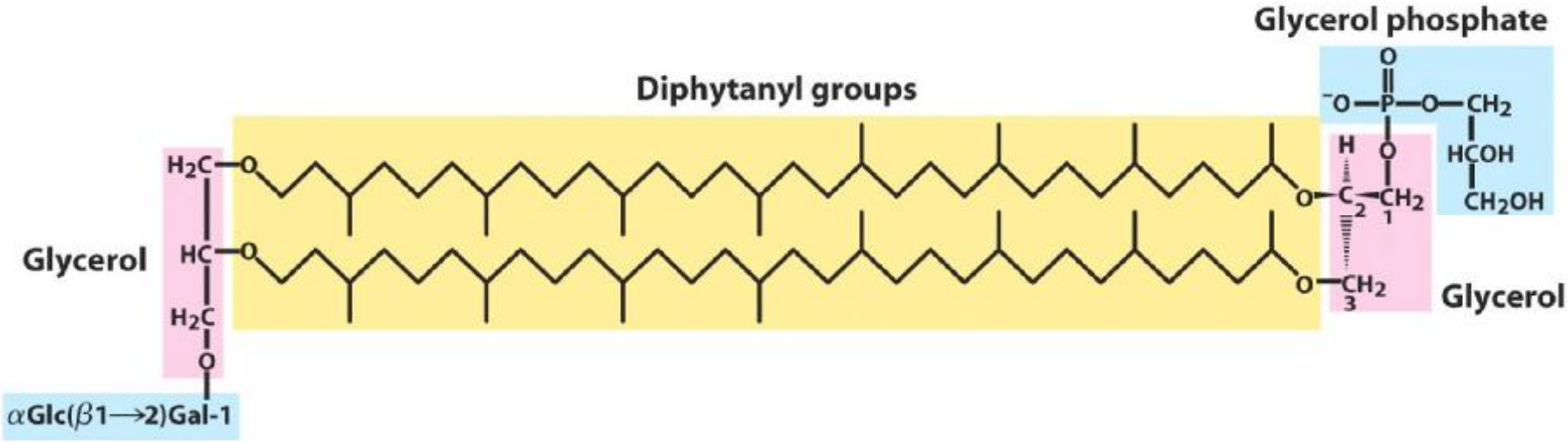
Monogalactosyldiacylglycerol (MGDG)

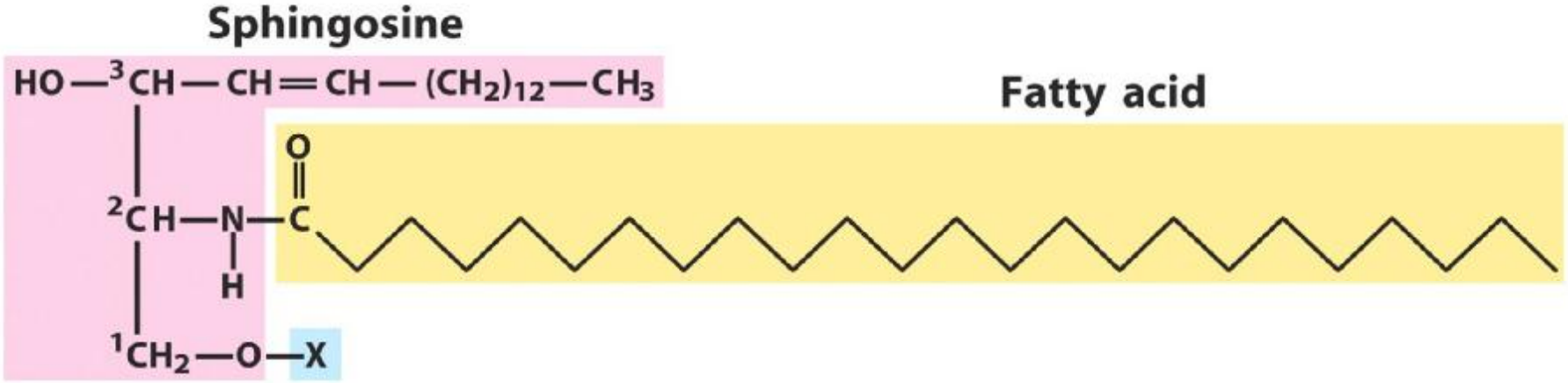


Digalactosyldiacylglycerol (DGDG)

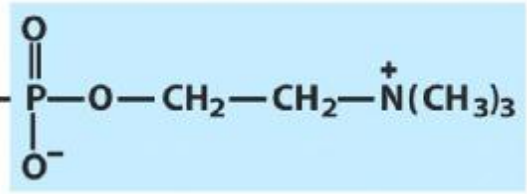
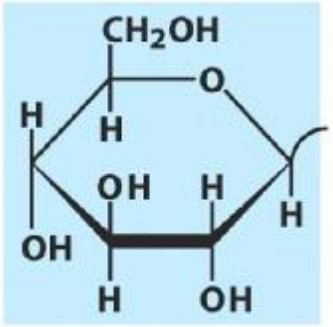
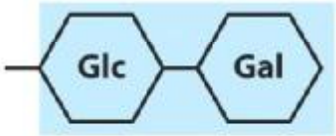
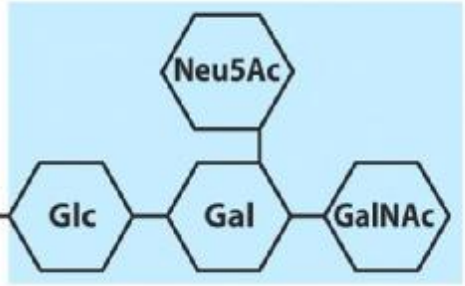


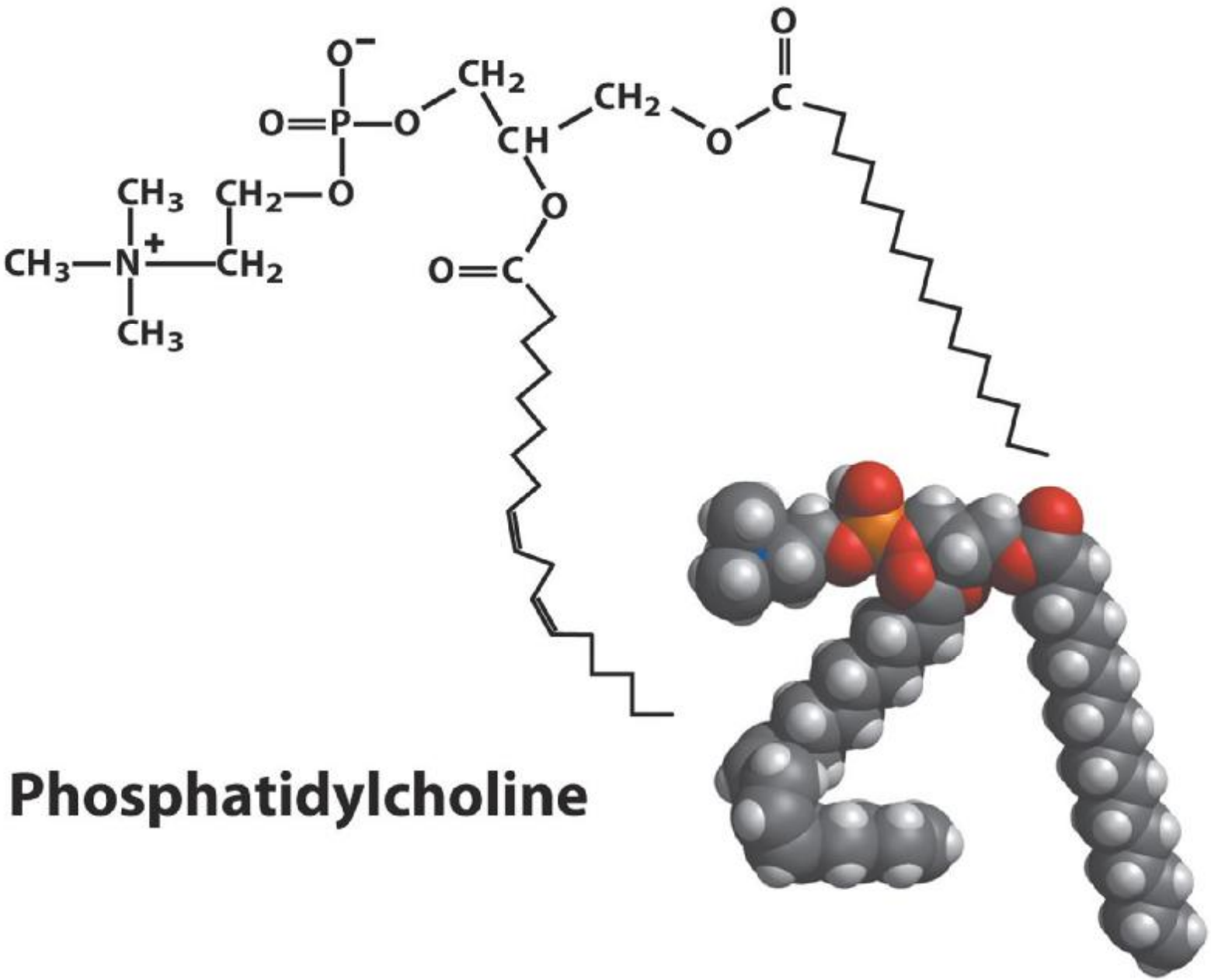
6-Sulfo-6-deoxy-α-D-glucopyranosyldiacylglycerol
(a sulfolipid)


Glycerol phosphate
Diphytanyl groups
Glycerol
Glycerol
αGlc(β1⟶2)Gal-1

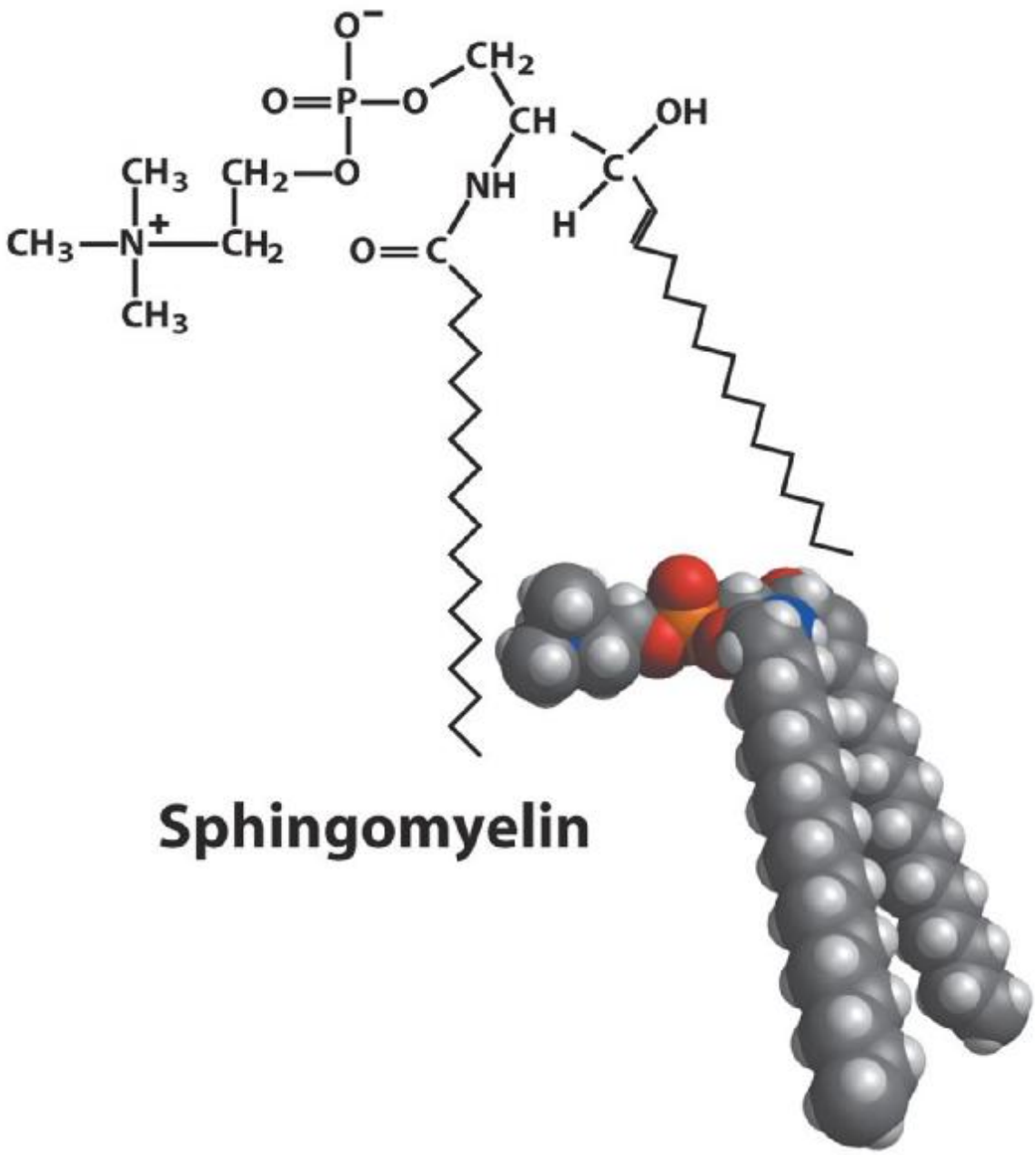


Sphingolipid (general structure)

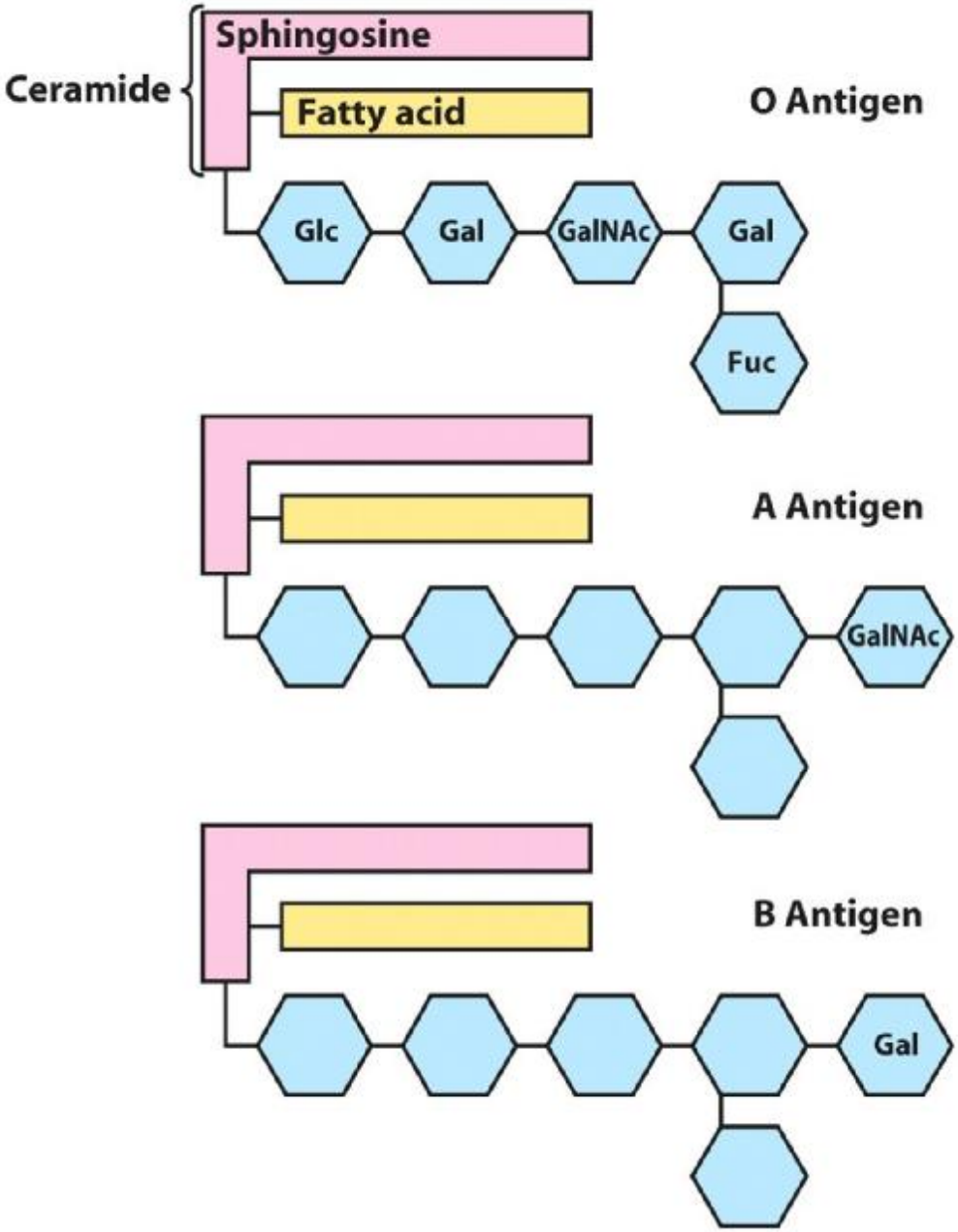
Name of sphingolipid	Name of X	Formula of X
Ceramide	—	— H
Sphingomyelin	Phosphocholine	
Neutral glycolipids Glucosylcerebroside	Glucose	
Lactosylceramide (a globoside)	Di-, tri-, or tetrasaccharide	
Ganglioside GM2	Complex oligosaccharide	

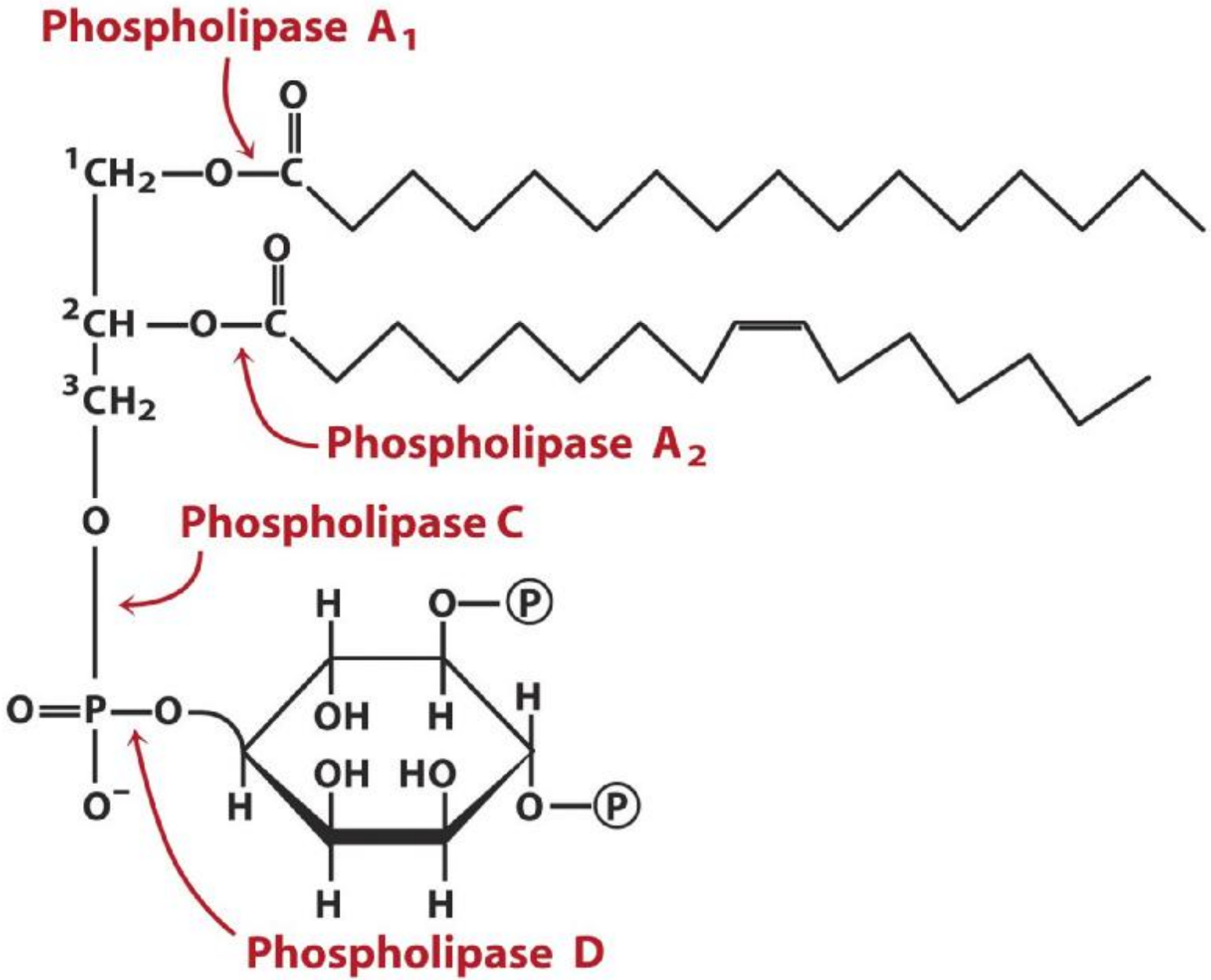


Phosphatidylcholine

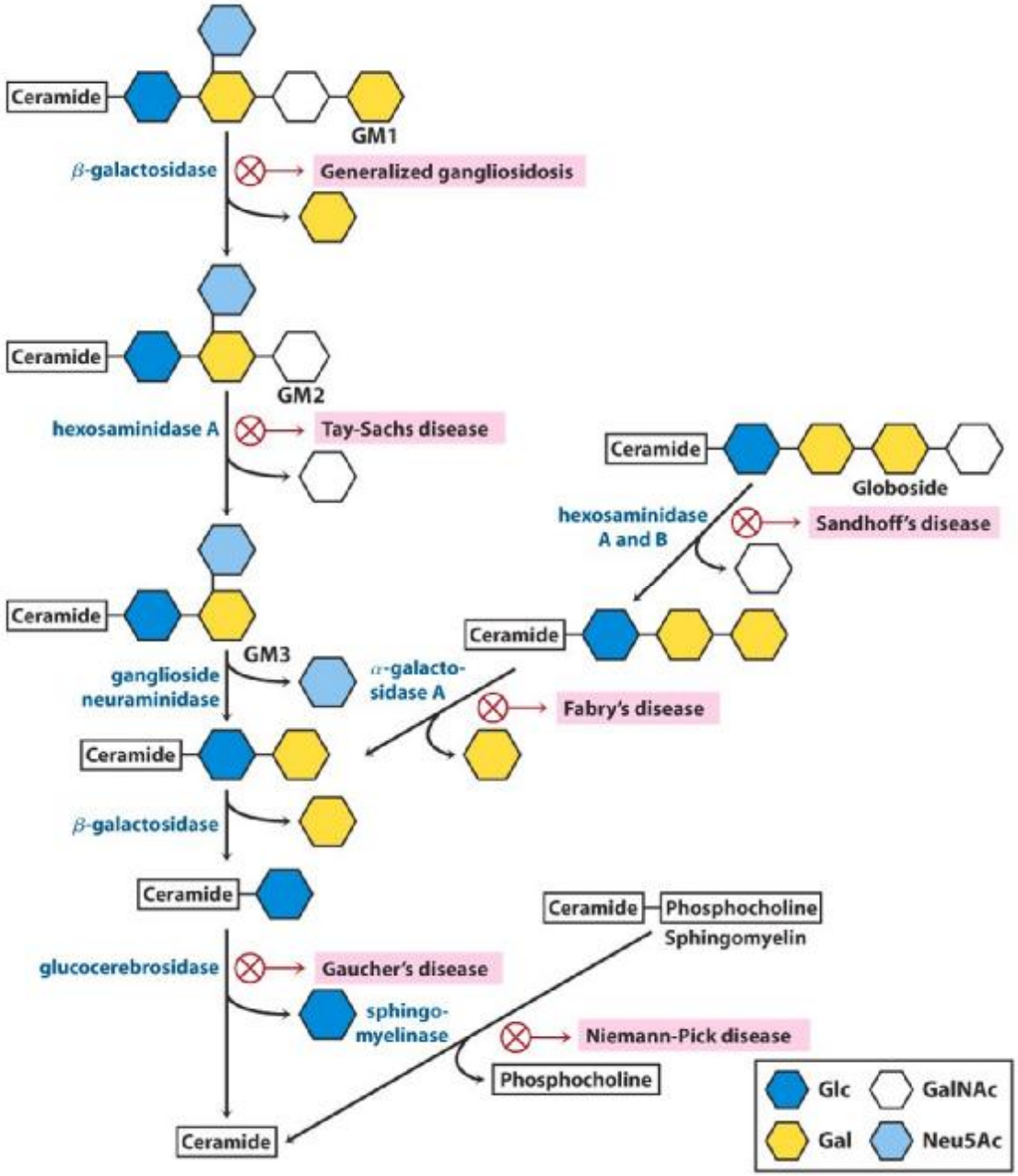


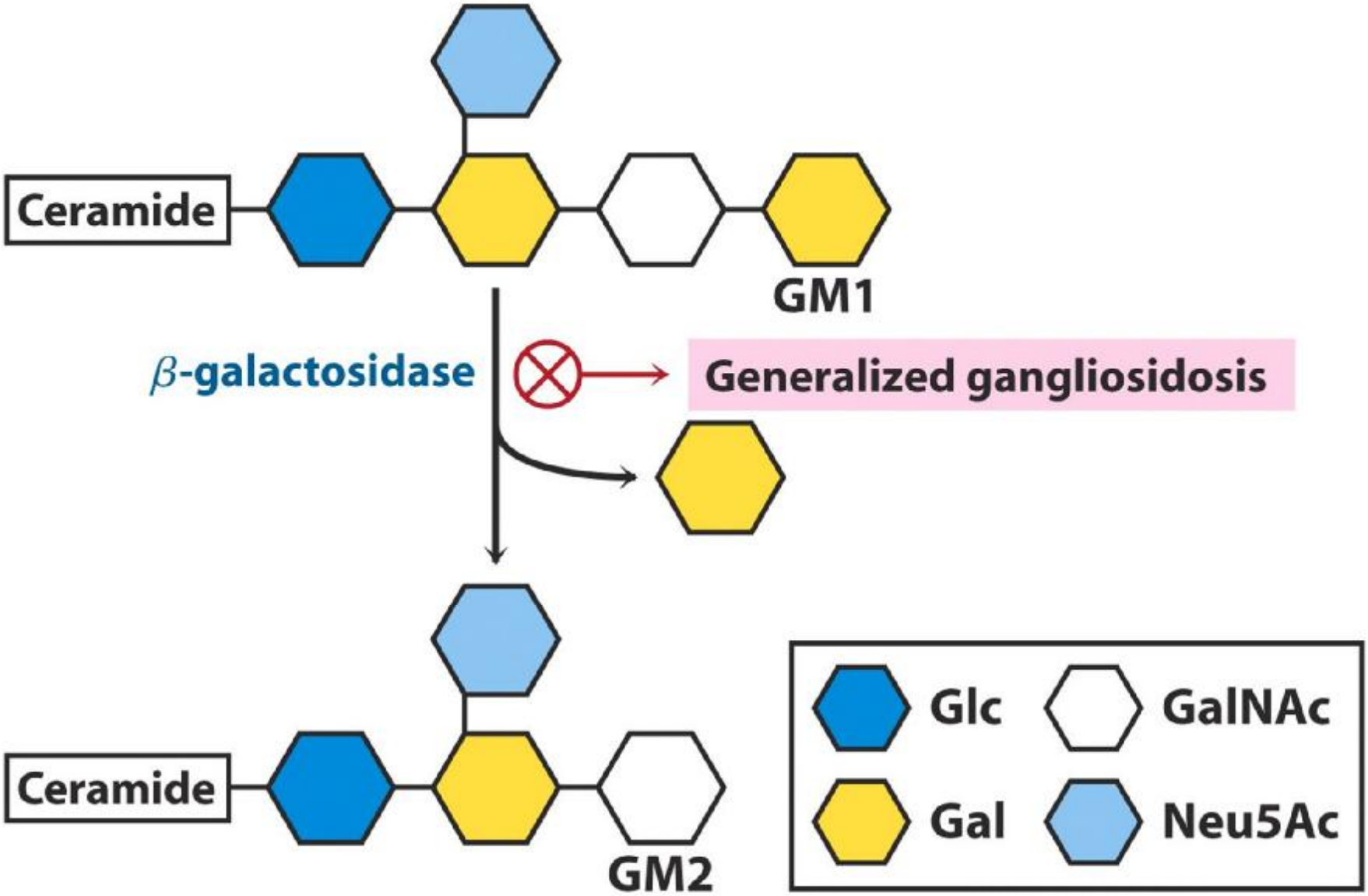
Sphingomyelin

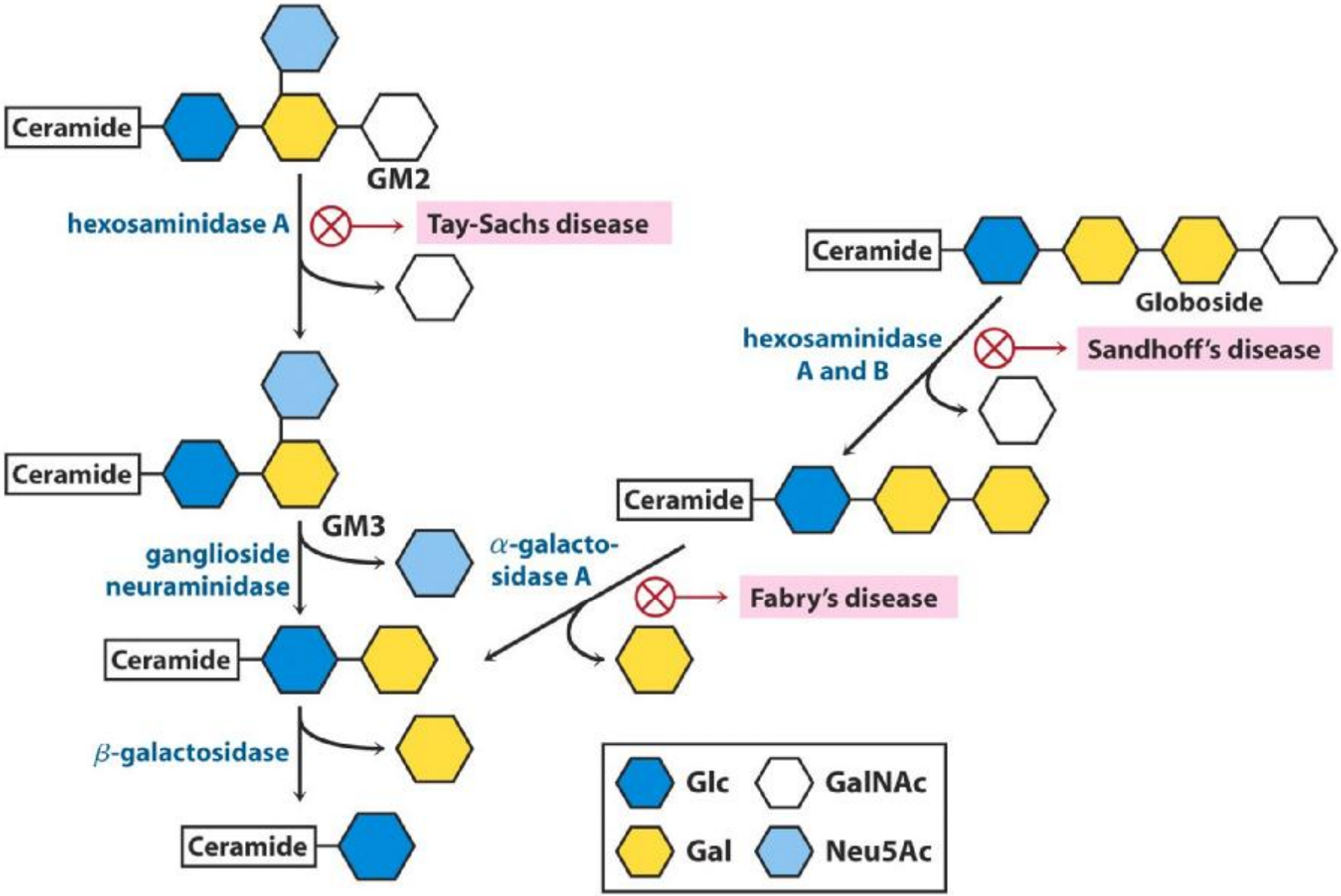

Ceramide
Sphingosine
Fatty acid
O Antigen
Glc
Gal
GalNAc
Gal
Fuc
A Antigen
GalNAc
B Antigen
Gal

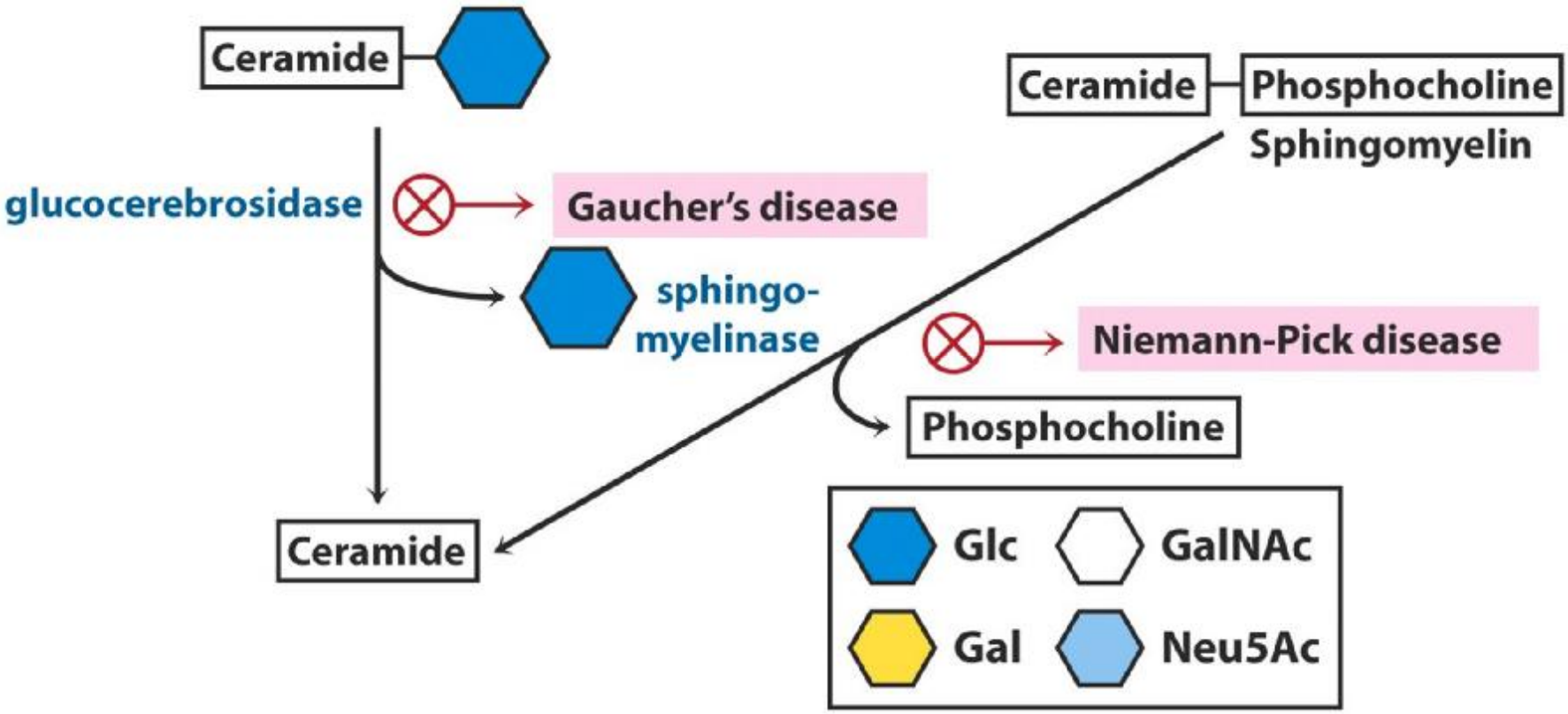

Phospholipase A1
Phospholipase A2
Phospholipase C
Phospholipase D

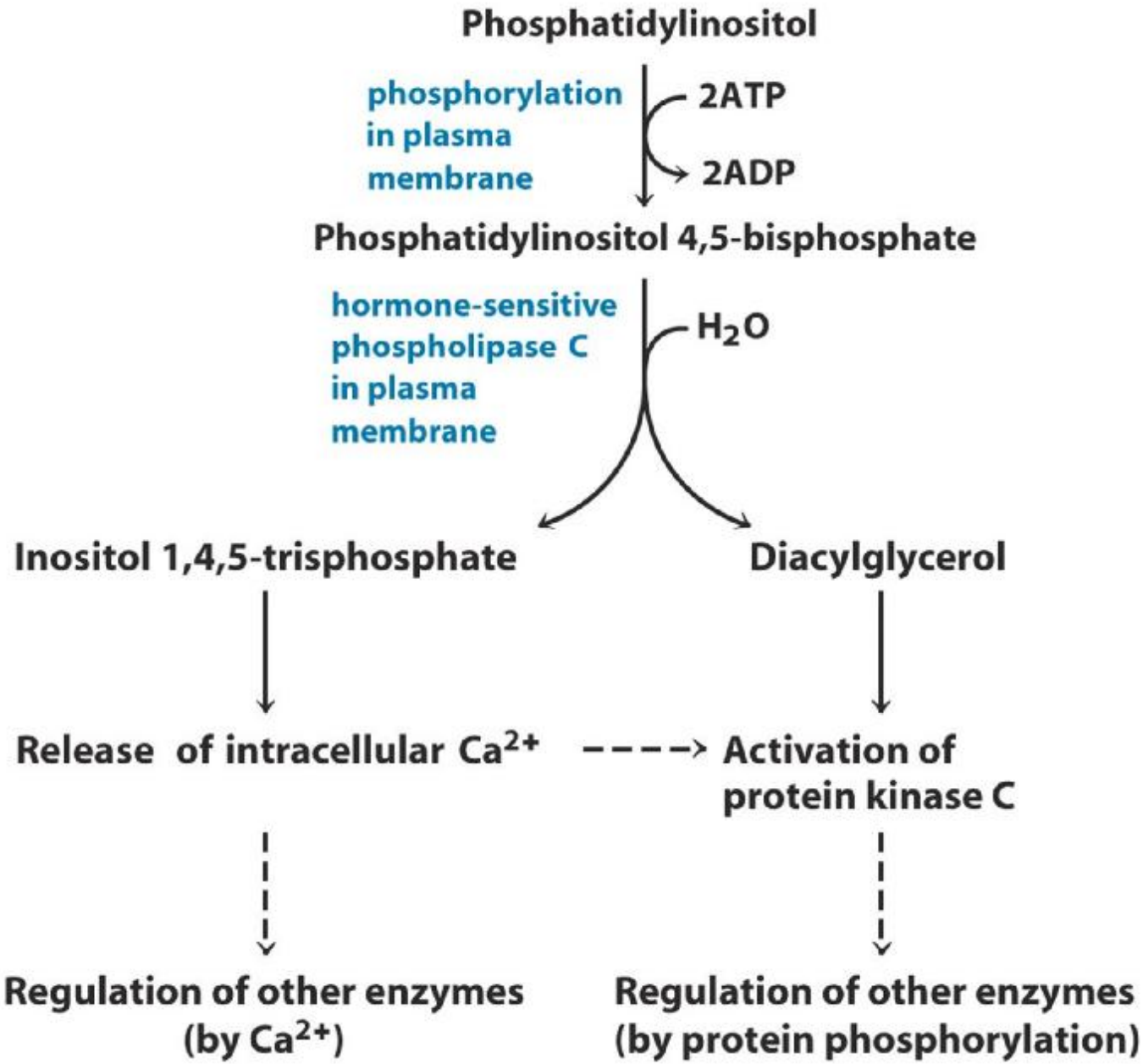

26CH3
25CH —27CH3
24CH2
23CH2
22CH2
20CH —21CH3
Alkyl side chain
18CH3
19CH3
A
B
C
D
HO
Polar head
Steroid nucleus

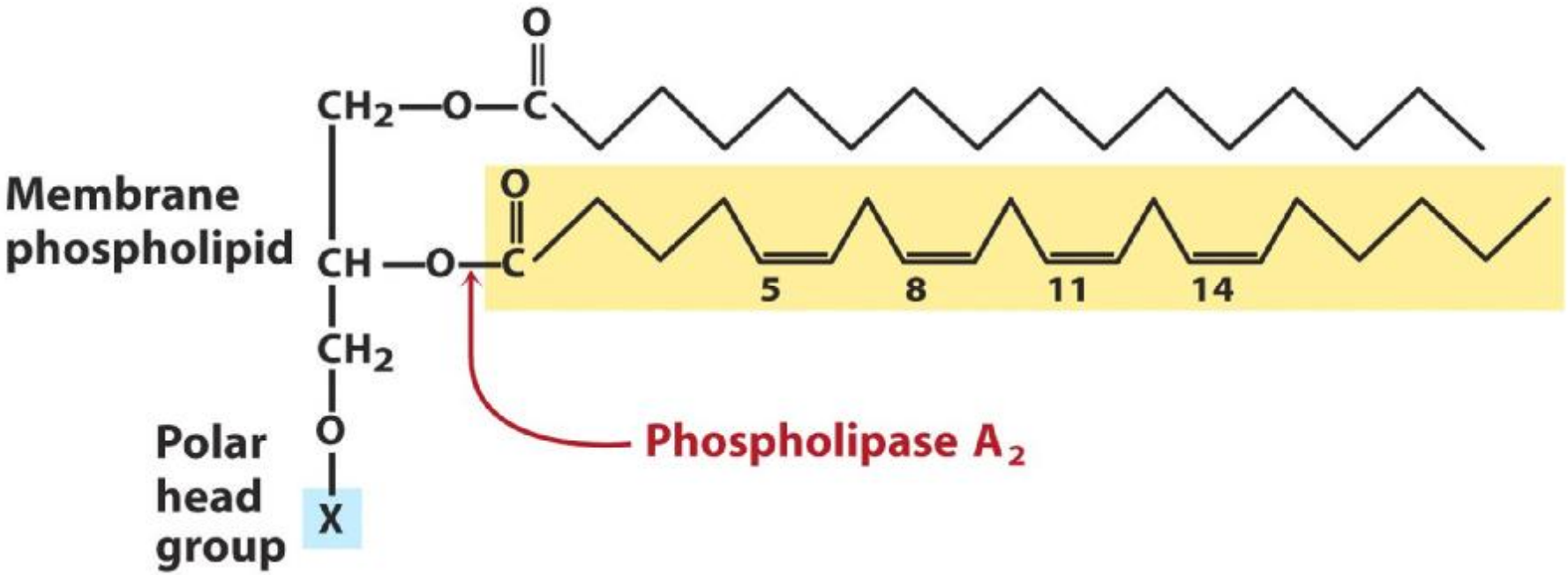

Ceramide
GM1
β-galactosidase
Generalized gangliosidosis
Ceramide
GM2
hexosaminidase A
Tay-Sachs disease
Ceramide
Globoside
hexosaminidase A and B
Sandhoff's disease
Ceramide
GM3
ganglioside neuraminidase
α-galacto-sidase A
Fabry's disease
Ceramide
β-galactosidase
Ceramide
Ceramide
Phosphocholine
Sphingomyelin
glucocerebrosidase
Gaucher's disease
sphingo-myelinase
Niemann-Pick disease
Phosphocholine
Ceramide
Glc
GalNAc
Gal
Neu5Ac

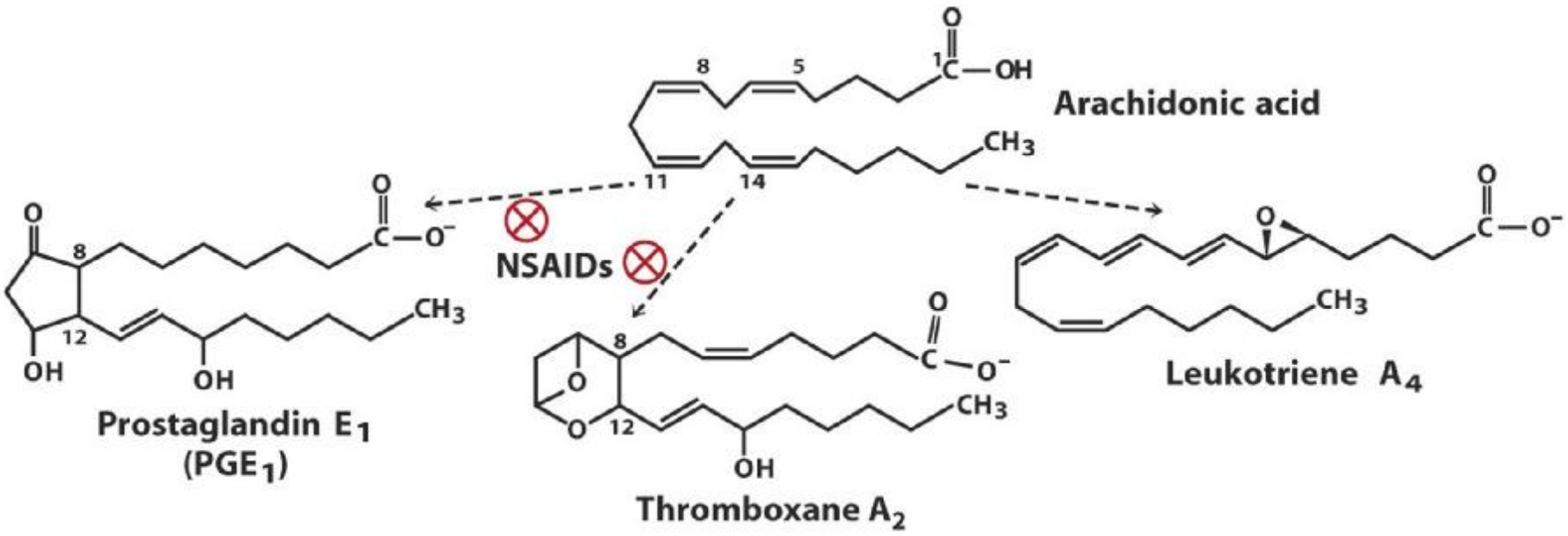

Ceramide
GM1
β-galactosidase
Generalized gangliosidosis
Ceramide
GM2
Glc
GalNAc
Gal
Neu5Ac


Ceramide
GM2
hexosaminidase A
Tay-Sachs disease
Ceramide
GM3
ganglioside neuraminidase
Ceramide
β-galactosidase
Ceramide
Ceramide
Globoside
hexosaminidase A and B
Sandhoff's disease
Ceramide
α-galacto-sidase A
Fabry's disease
Glc
GalNAc
Gal
Neu5Ac

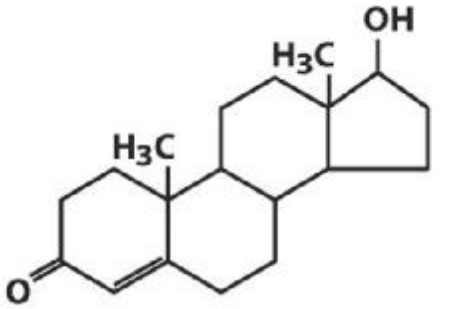

Ceramide
glucocerebrosidase
Gaucher's disease
sphingo-
myelinase
Ceramide
Ceramide
Phosphocholine
Sphingomyelin
Niemann-Pick disease
Phosphocholine
Glc
GalNAc
Gal
Neu5Ac


Phosphatidylinositol
phosphorylation in plasma membrane
2ATP
2ADP
Phosphatidylinositol 4,5-bisphosphate
hormone-sensitive phospholipase C in plasma membrane
H_2O
Inositol 1,4,5-trisphosphate
Diacylglycerol
Release of intracellular Ca^{2+}
Activation of protein kinase C
Regulation of other enzymes (by Ca^{2+})
Regulation of other enzymes (by protein phosphorylation)

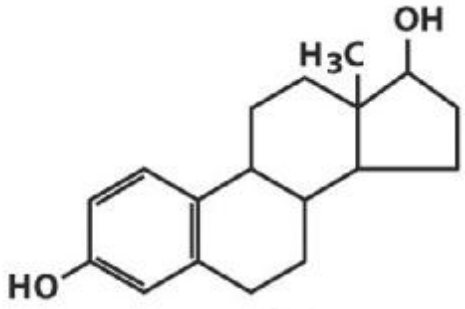

Membrane phospholipid
O
CH2—O—C
O
CH—O—C
5
8
11
14
CH2
O
X
Polar head group
Phospholipase A2



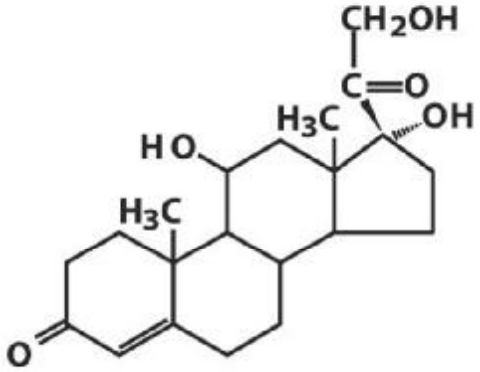
Eicosanoids



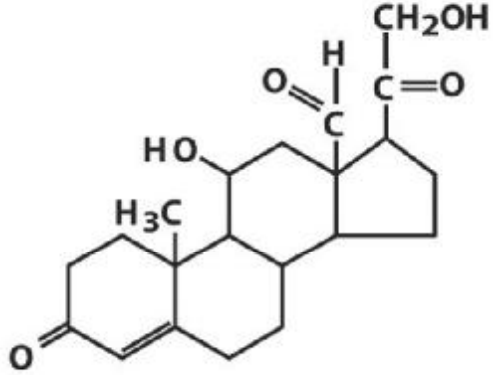
Testosterone



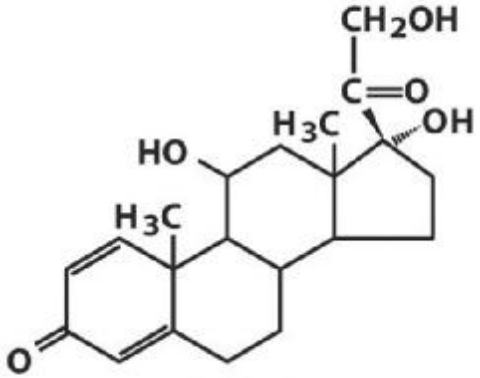
Estradiol



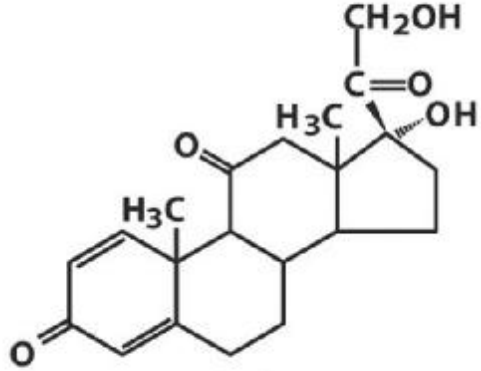
Cortisol



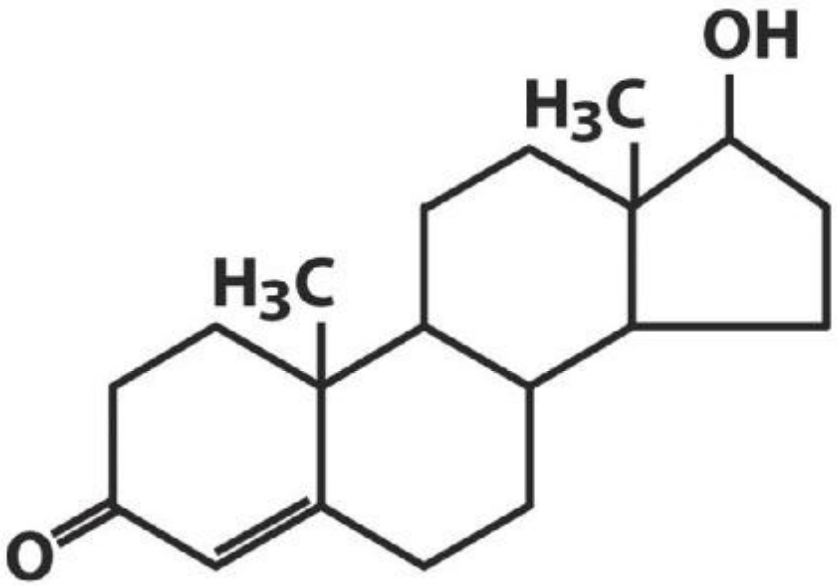
Aldosterone



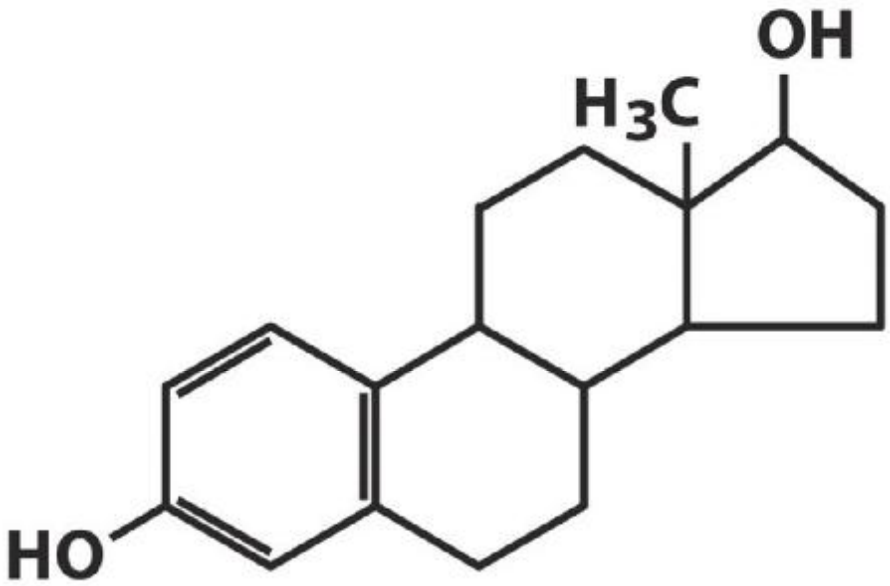
Prednisolone



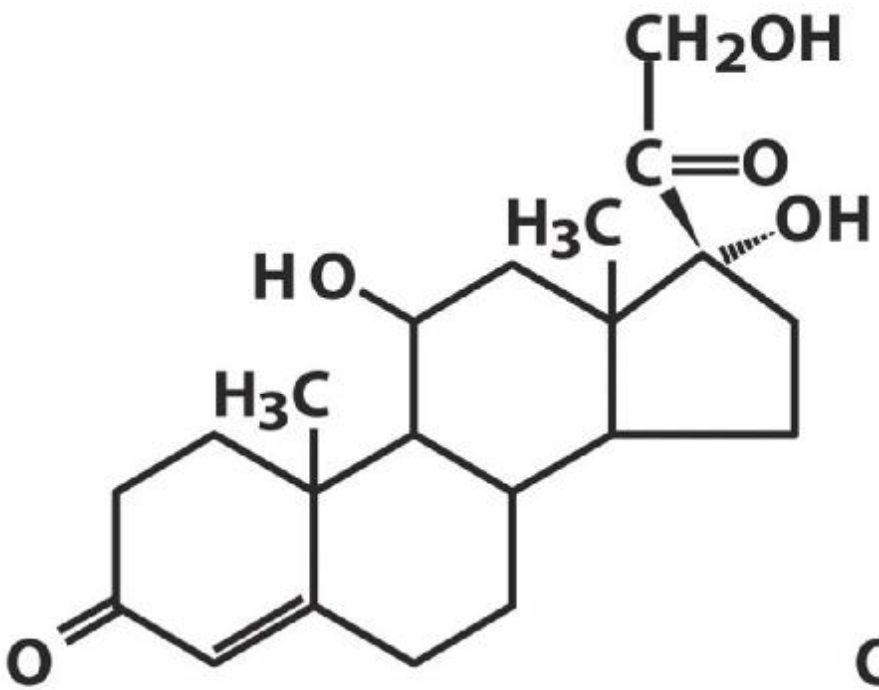
Prednisone



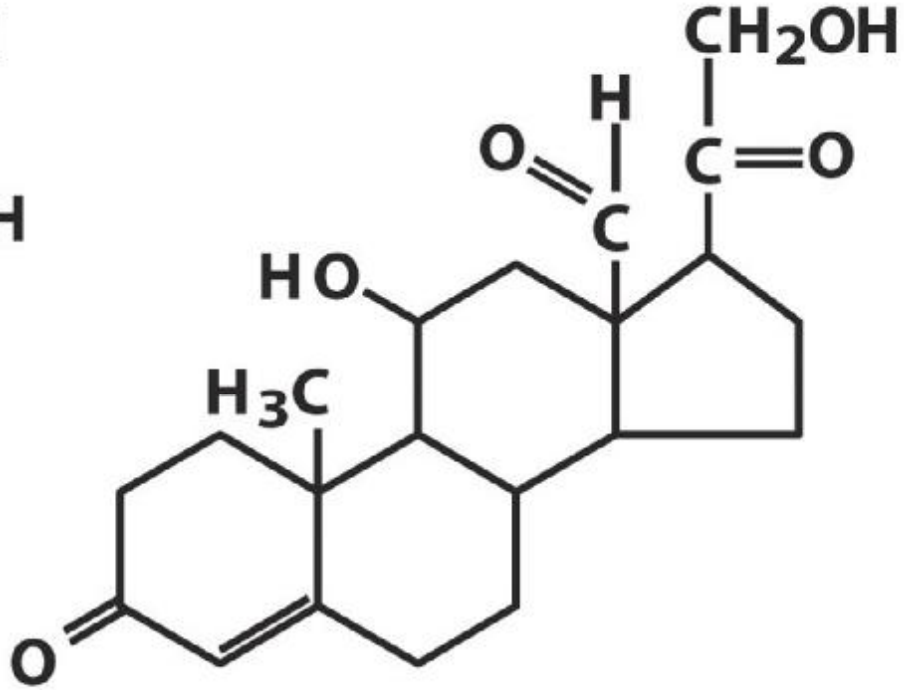
Testosterone



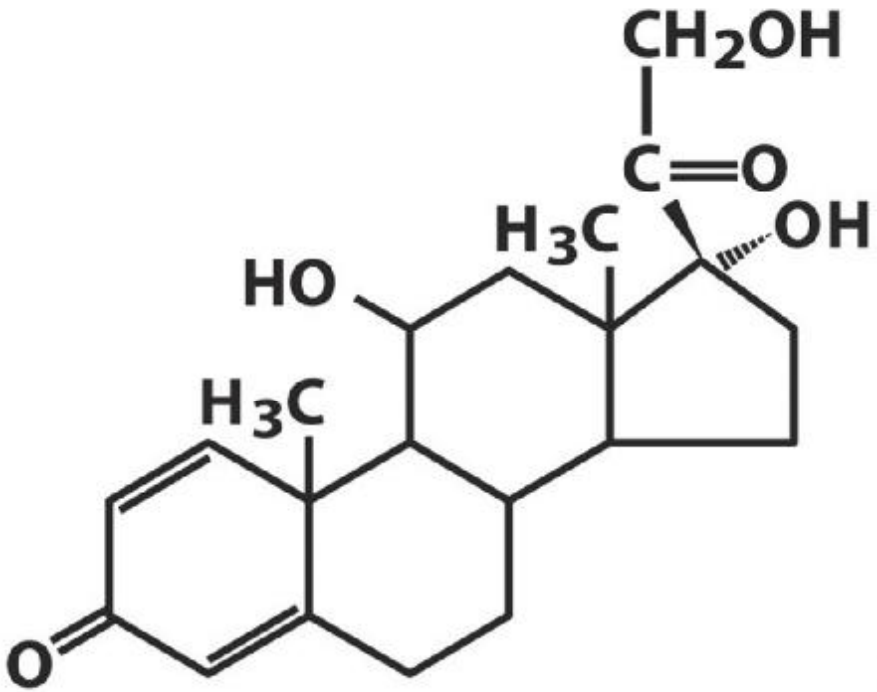
Estradiol



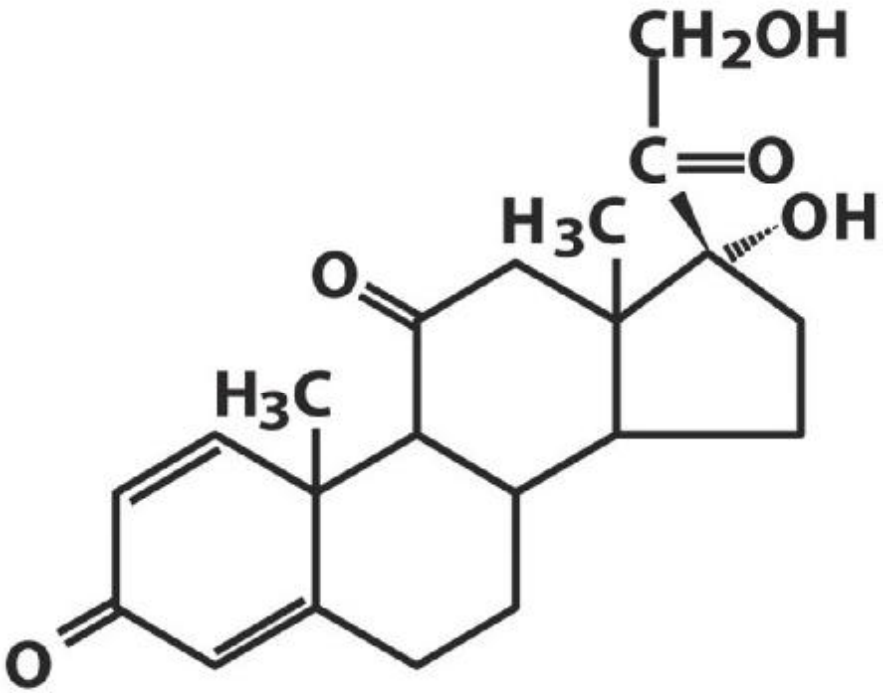
Cortisol



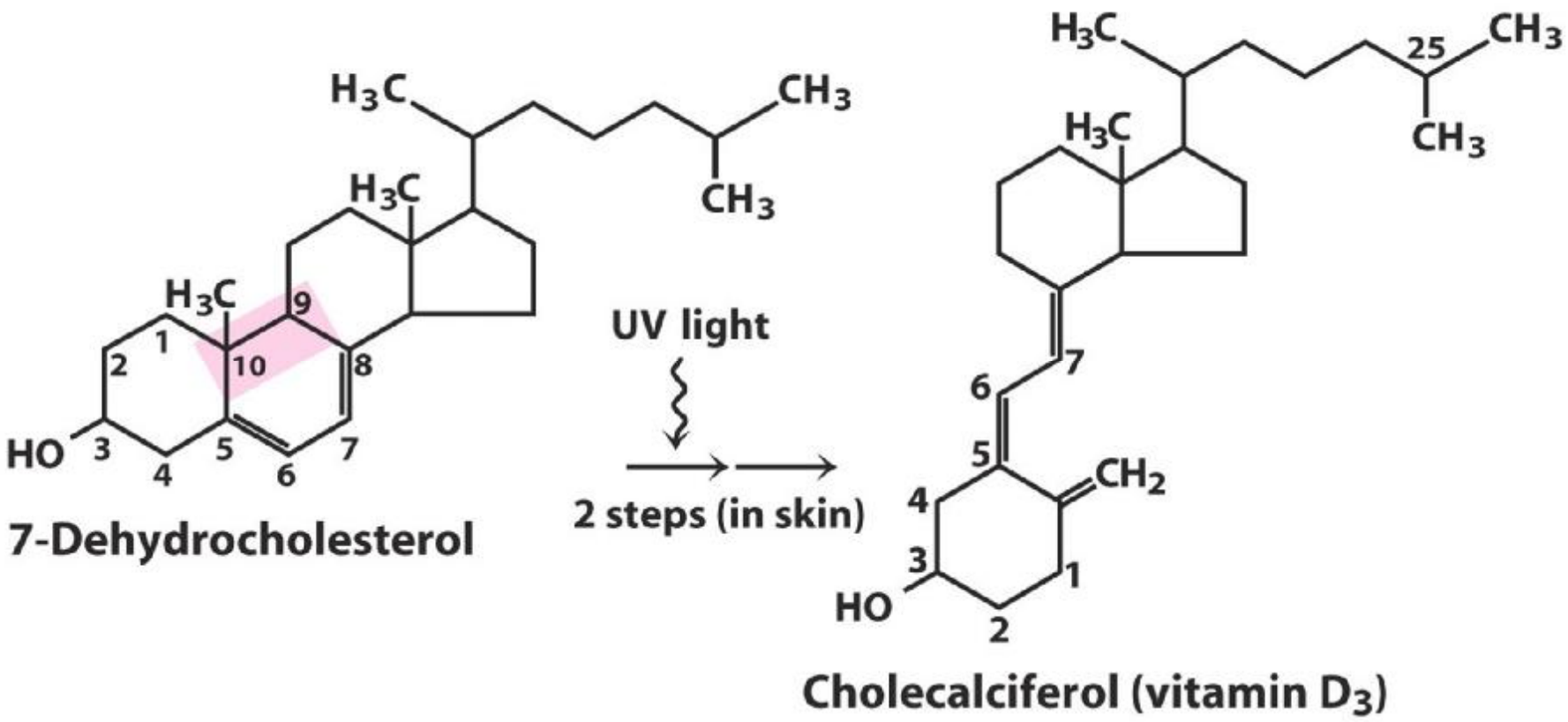
Aldosterone

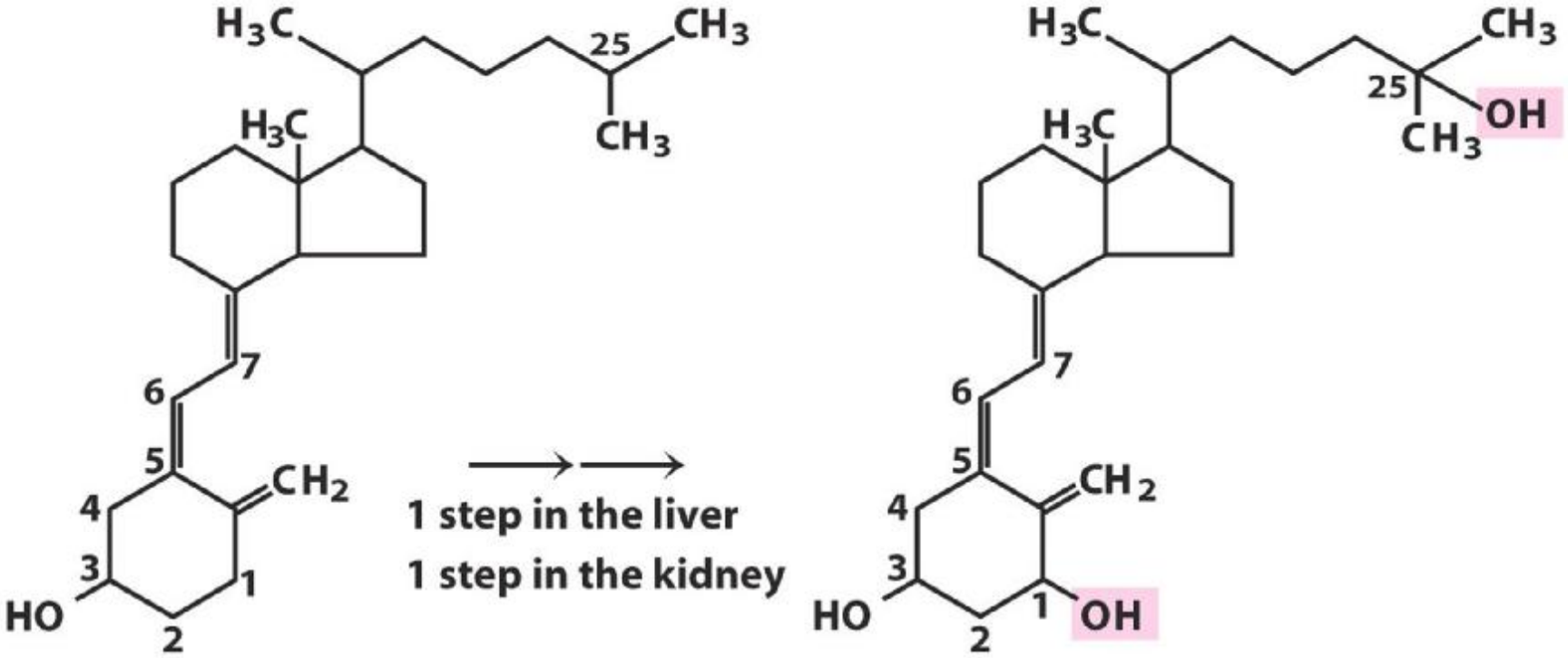


Prednisolone



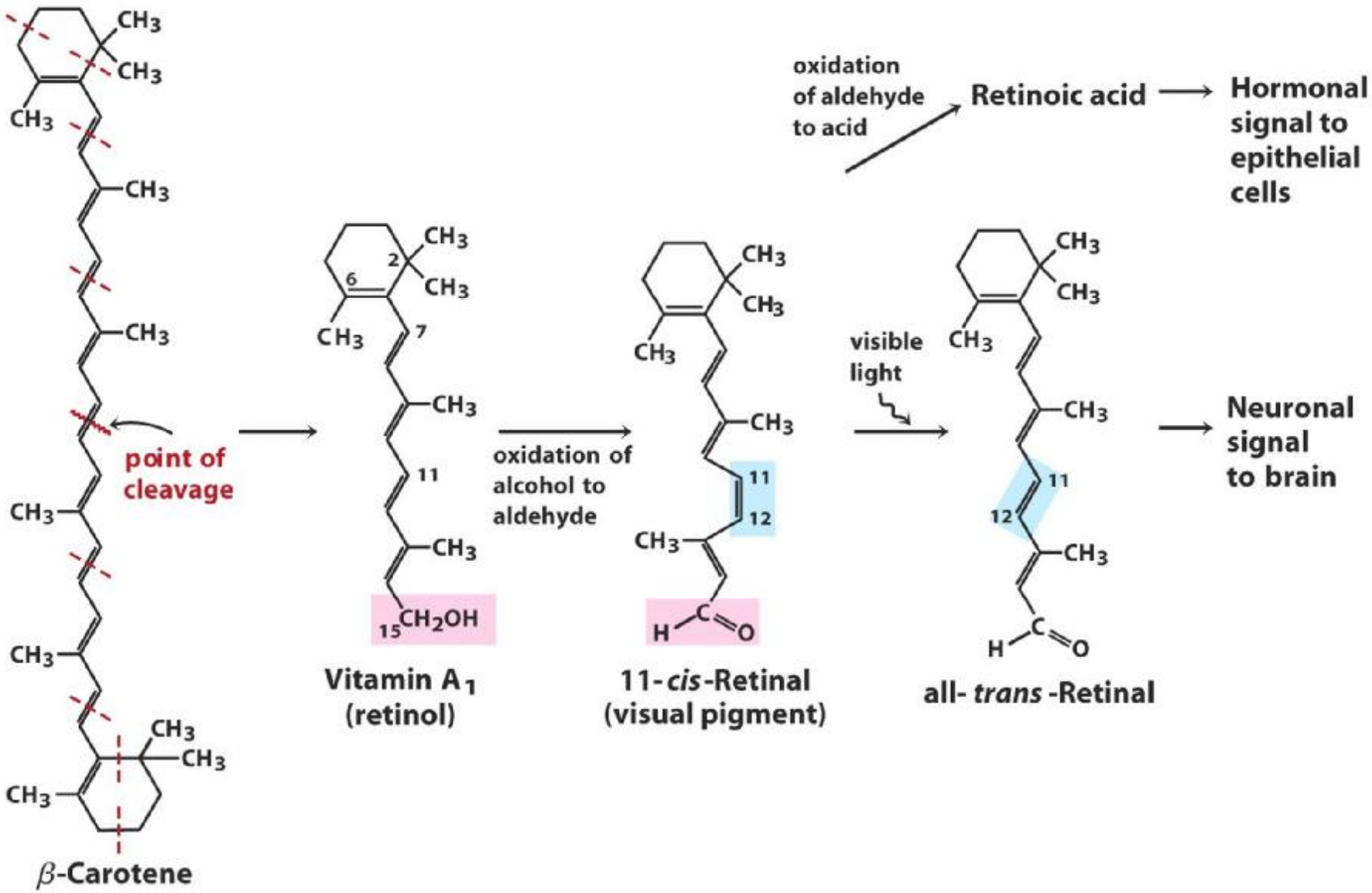
Prednisone

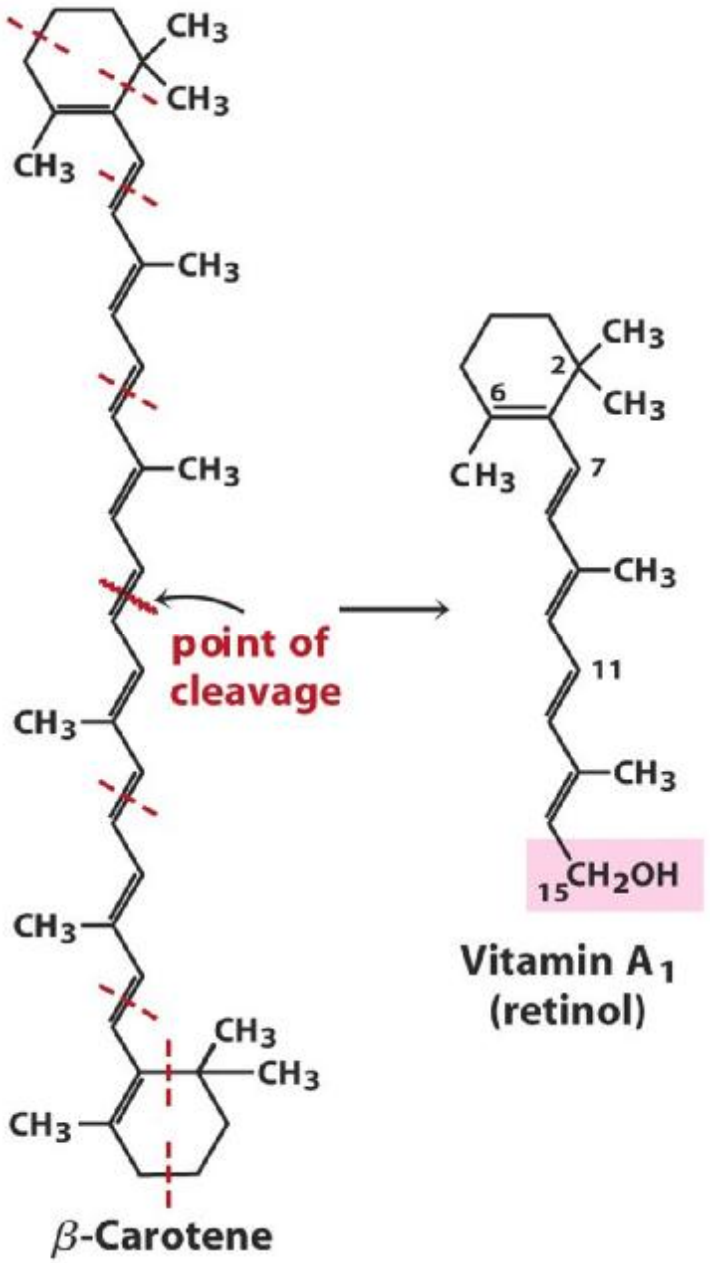

H3C
CH3
H3C
CH3
H3C
9
1
2
10
8
HO
3
5
7
4
6
7-Dehydrocholesterol
UV light
2 steps (in skin)
H3C
25
CH3
H3C
CH3
7
6
5
CH2
4
3
1
HO
2
Cholecalciferol (vitamin D3)

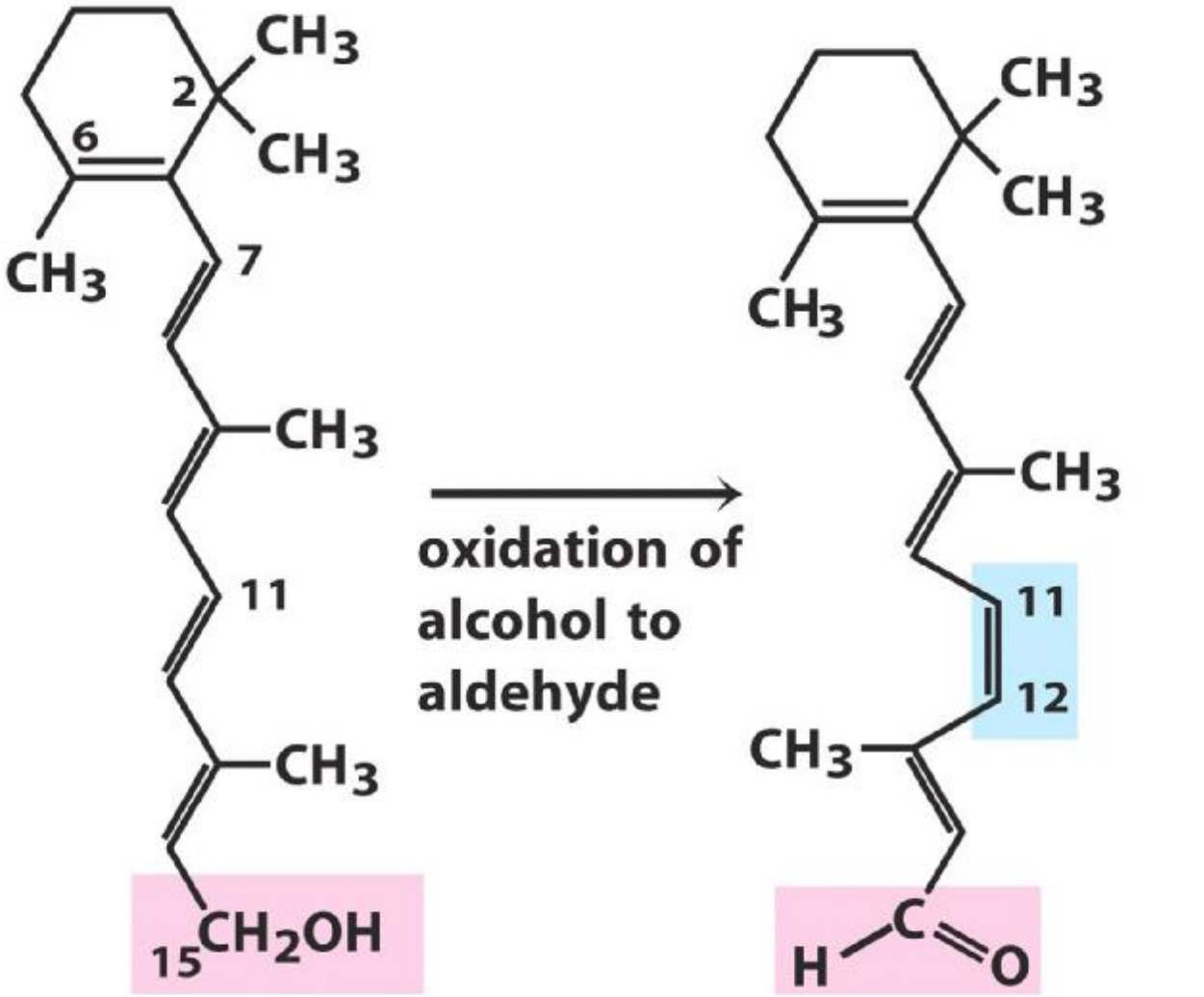


Cholecalciferol (vitamin D_3)

1,25-Dihydroxycholecalciferol
(1,25-dihydroxyvitamin D_3)

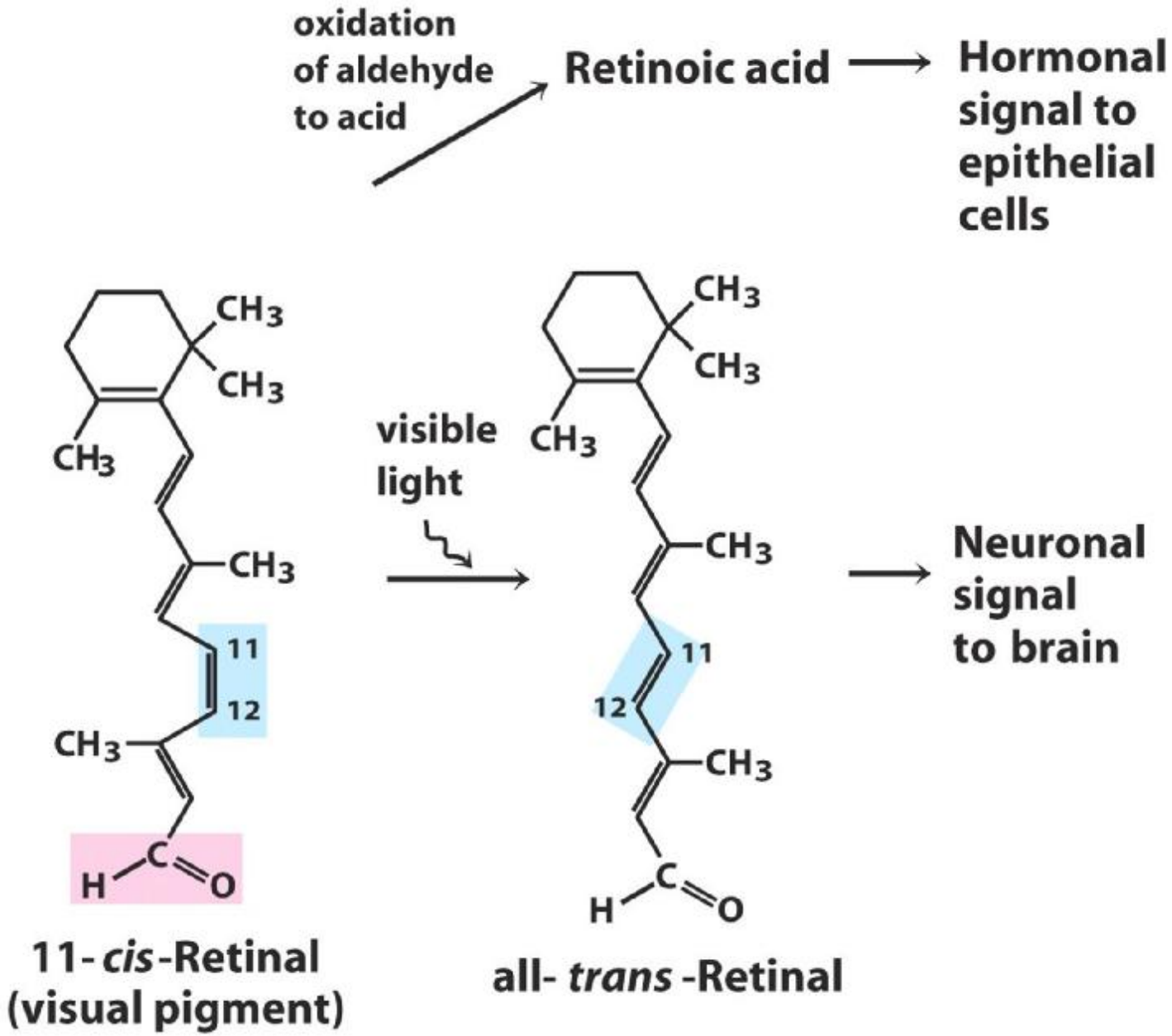

oxidation of aldehyde to acid
Retinoic acid
Hormonal signal to epithelial cells
point of cleavage
oxidation of alcohol to aldehyde
visible light
Neuronal signal to brain
β-Carotene
Vitamin A1 (retinol)
11-cis-Retinal (visual pigment)
all-trans-Retinal

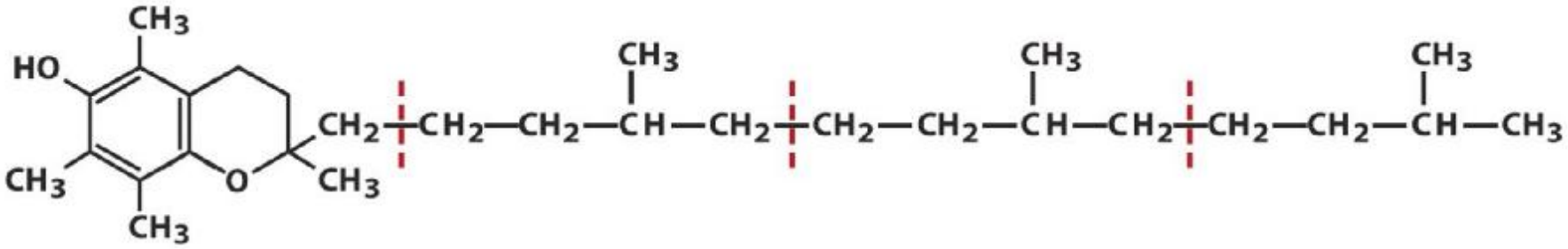

CH3
CH3
CH3
CH3
CH3
CH3
CH3
CH3
CH3
point of
cleavage
2
6
7
11
15
CH2OH
β-Carotene
Vitamin A1
(retinol)



Vitamin A_1 (retinol)

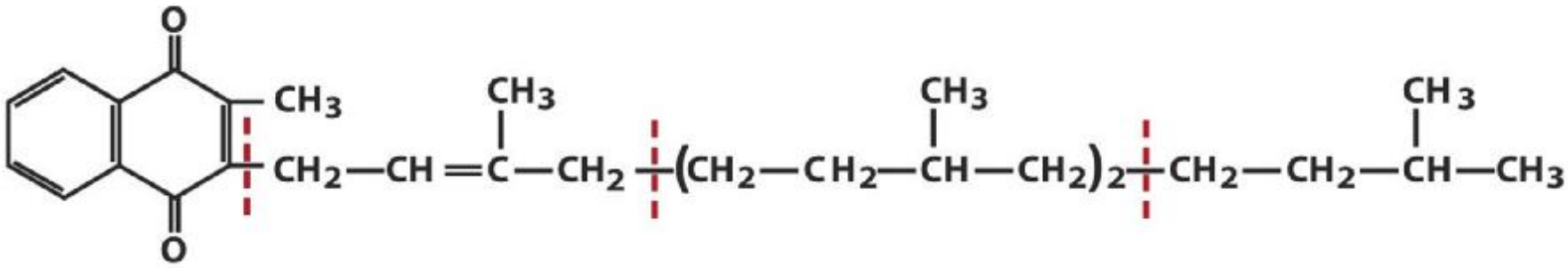
11-*cis*-Retinal (visual pigment)


oxidation
of aldehyde
to acid
Retinoic acid
Hormonal
signal to
epithelial
cells
visible
light
Neuronal
signal
to brain
11- *cis* -Retinal
(visual pigment)
all- *trans* -Retinal



(a)

Vitamin E: an antioxidant

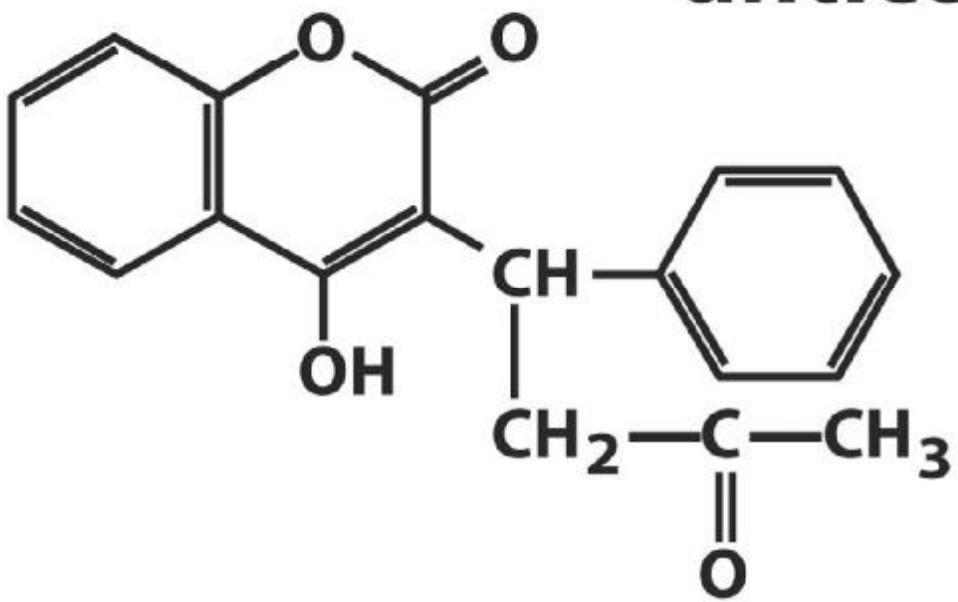


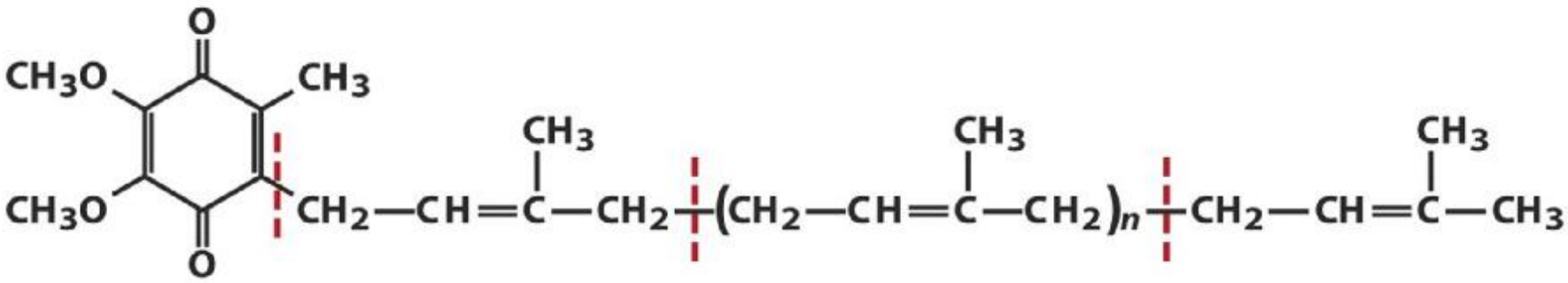
(b)

Vitamin K_1: a blood-clotting cofactor (phylloquinone)

(c)

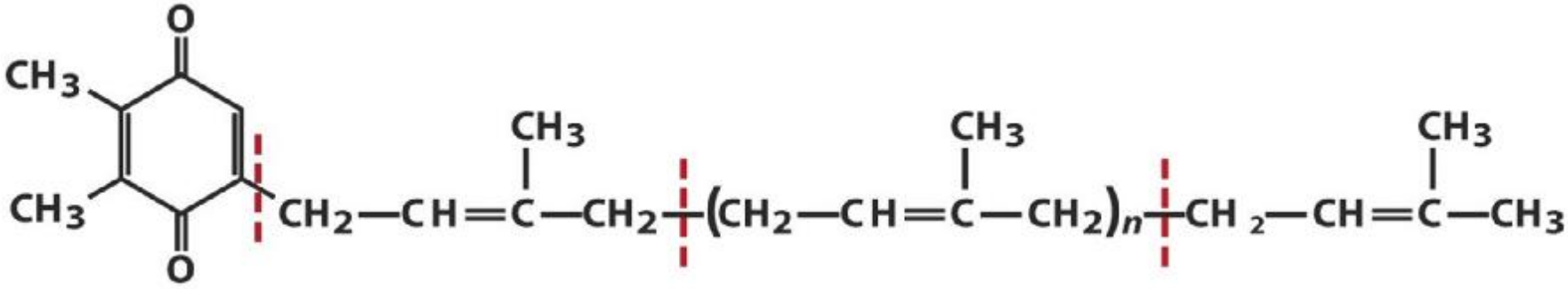
Warfarin: a blood anticoagulant





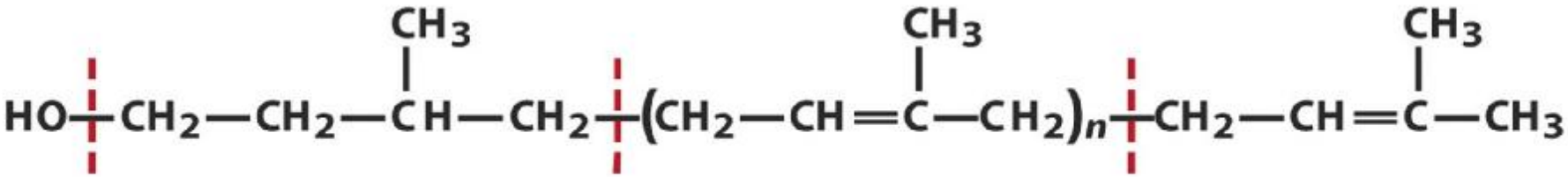
(d)

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



(e)

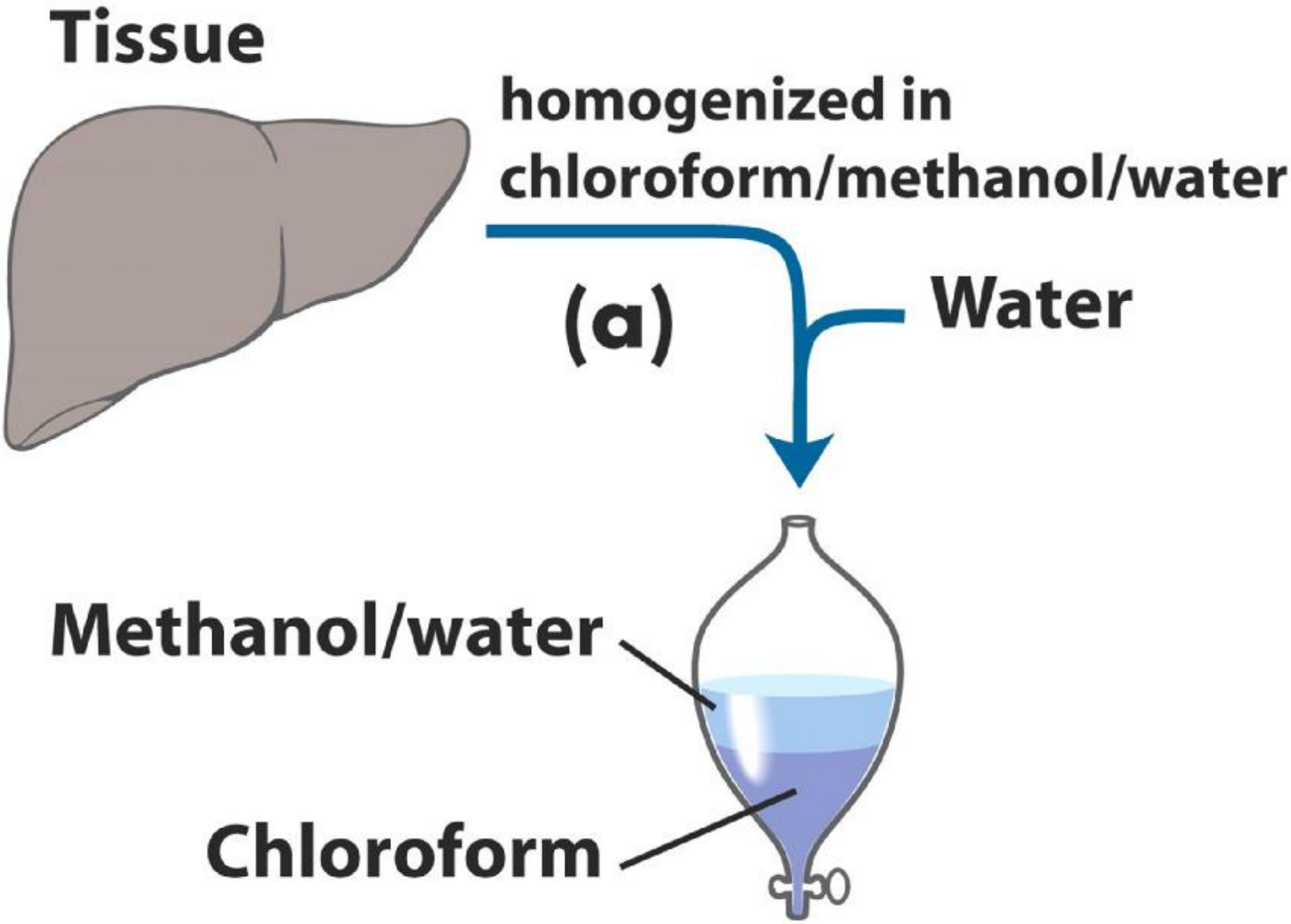
Plastoquinone: a chloroplast electron carrier (n = 4 to 8)

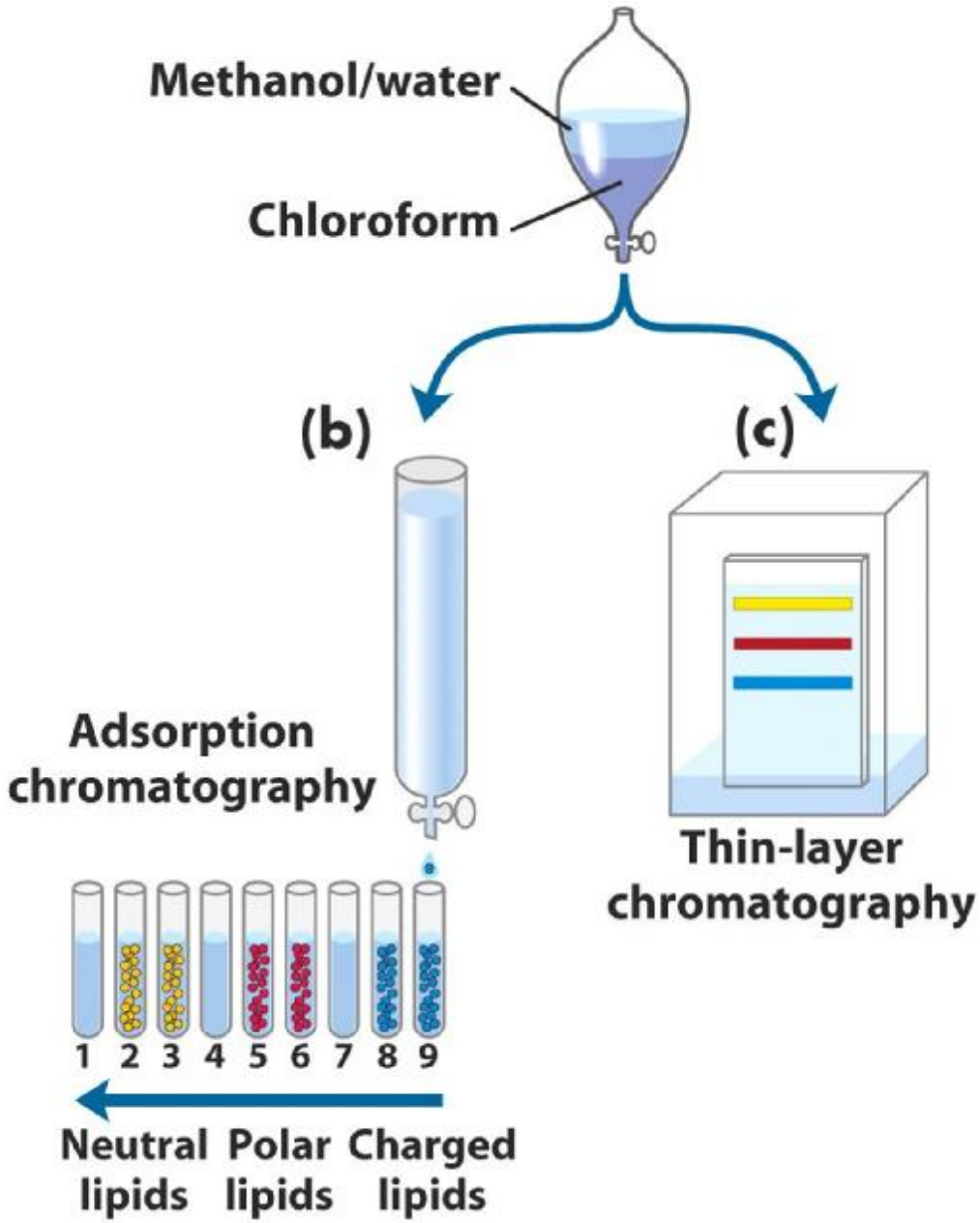


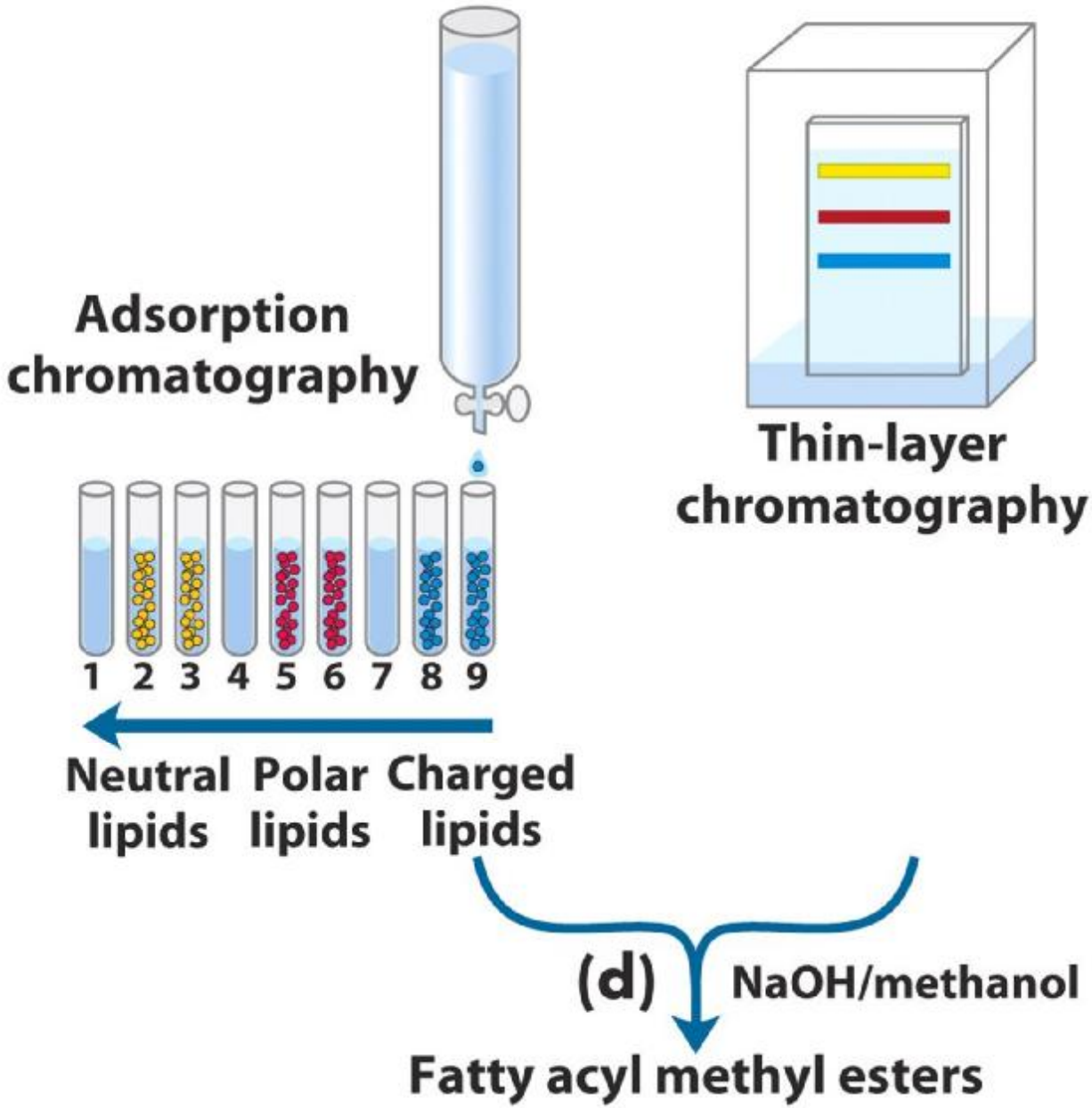
(f)

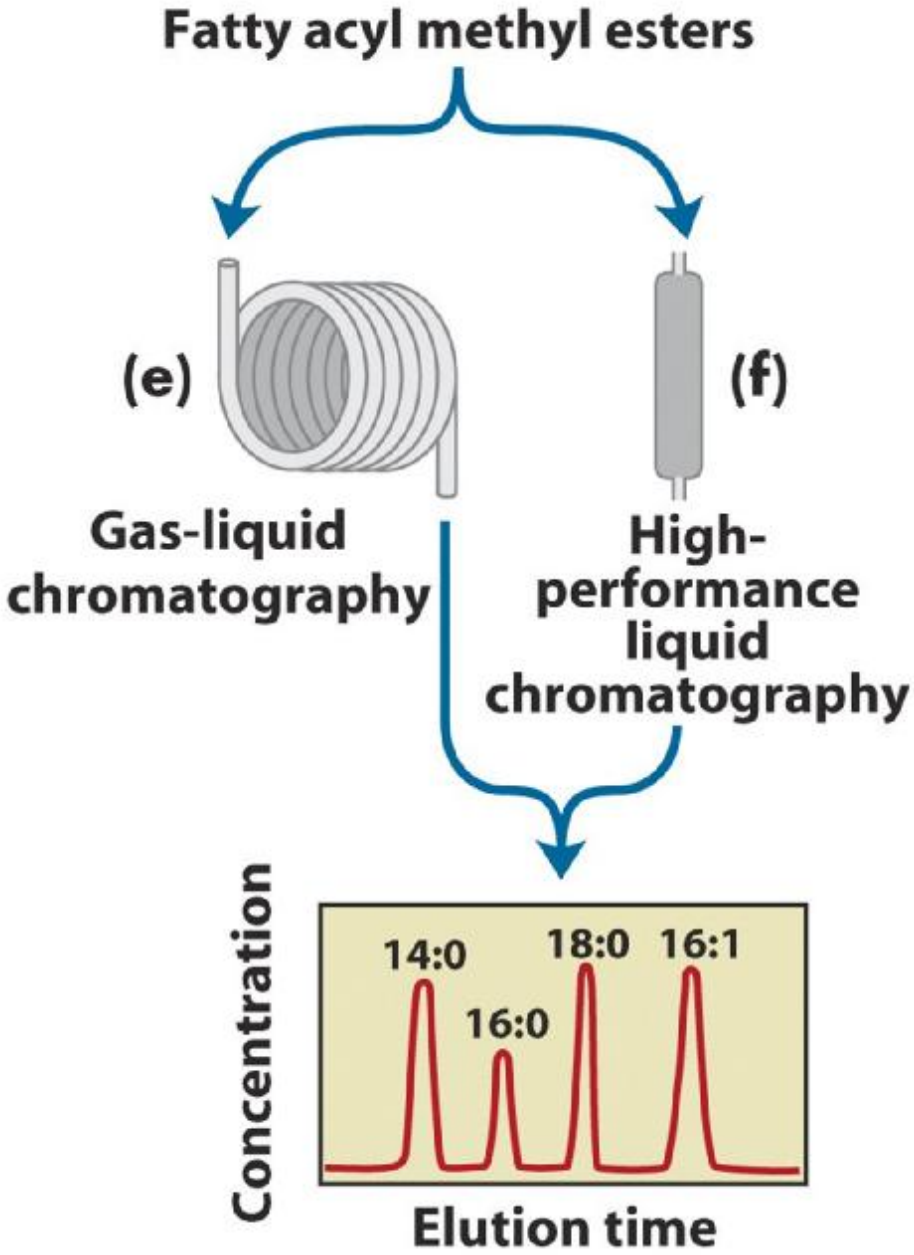
Dolichol: a sugar carrier

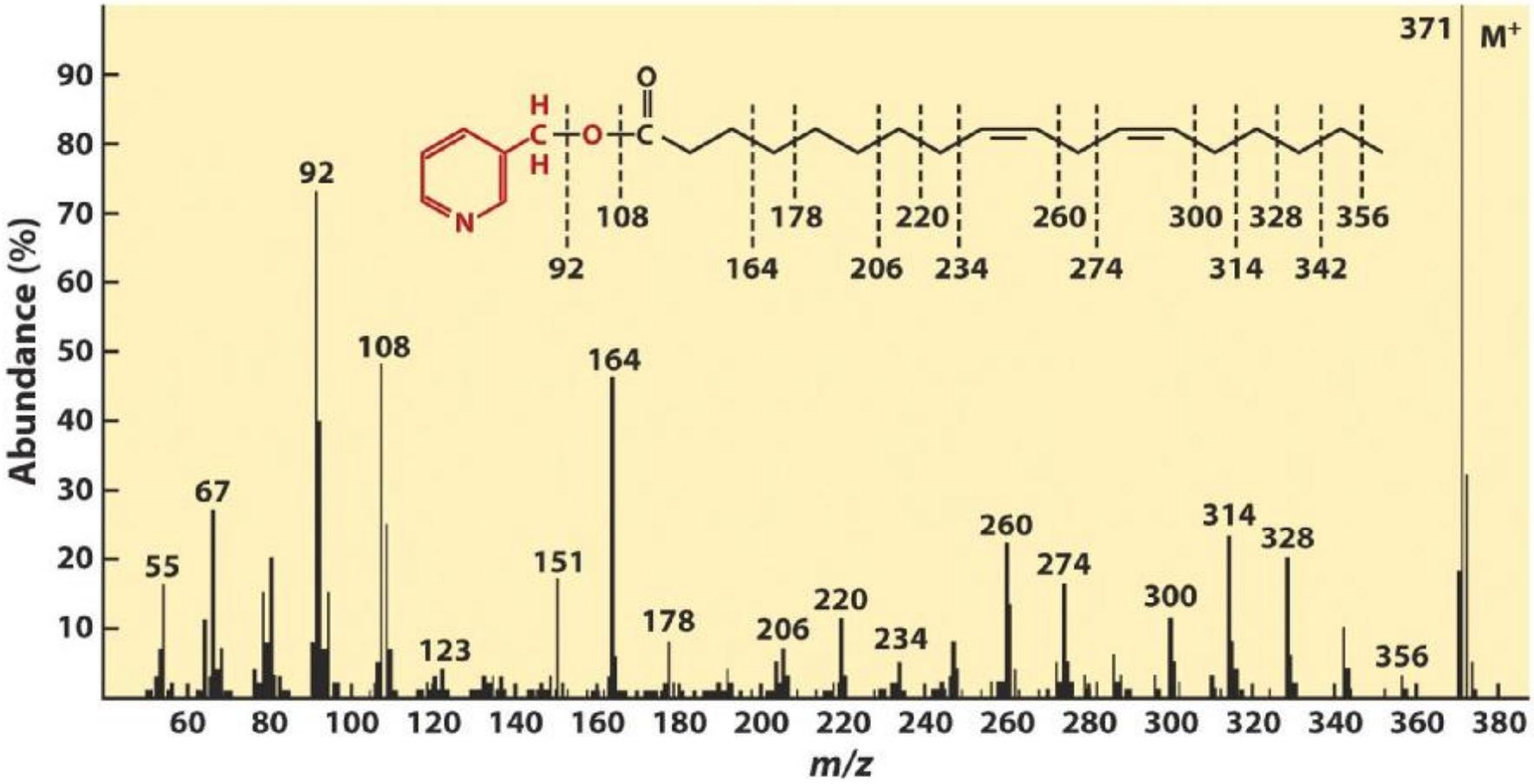
(*n* = 9 to 22)


Tissue
homogenized in
chloroform/methanol/water
(a)
Water
Methanol/water
Chloroform


Methanol/water
Chloroform
(b)
(c)
Adsorption chromatography
Thin-layer chromatography
1 2 3 4 5 6 7 8 9
Neutral lipids
Polar lipids
Charged lipids


Adsorption chromatography
Thin-layer chromatography
1 2 3 4 5 6 7 8 9
Neutral lipids
Polar lipids
Charged lipids
(d)
NaOH/methanol
Fatty acyl methyl esters


Fatty acyl methyl esters
(e)
(f)
Gas-liquid chromatography
High-performance liquid chromatography
Concentration
14:0
16:0
18:0
16:1
Elution time


Abundance (%)
m/z
371
M+
92
108
164
67
55
151
123
178
206
220
234
260
274
300
314
328
356
H
C
H
O
O
C
N
92
108
164
178
206
220
234
260
274
300
314
328
342
356