

Classification of Lipids:-

- Fatty acids
 - Sat.
 - Unsat.
- Glycerides
 - neutral glycerides
 - phosphoglycerides
- Non-glycerides - Sphingo lipids, Steroids, Waxes
- Complex lipids - Lipoproteins, glycolipids

LIPID FUNCTIONS

- Diverse structures
- Cell membrane : e.g. amphipathic lipids
- Energy storage : TG
- Hormones, Vitamins(A, K, D, E), gangliosides & other glycosphingolipids on cell membrane (Recognition), signals(prostaglandin), electron carriers(ubiquinone)
- Thermal insulation and padding
Waxes in cell wall, exoskeleton & skins protect surfaces

Major Classes of Lipids

2

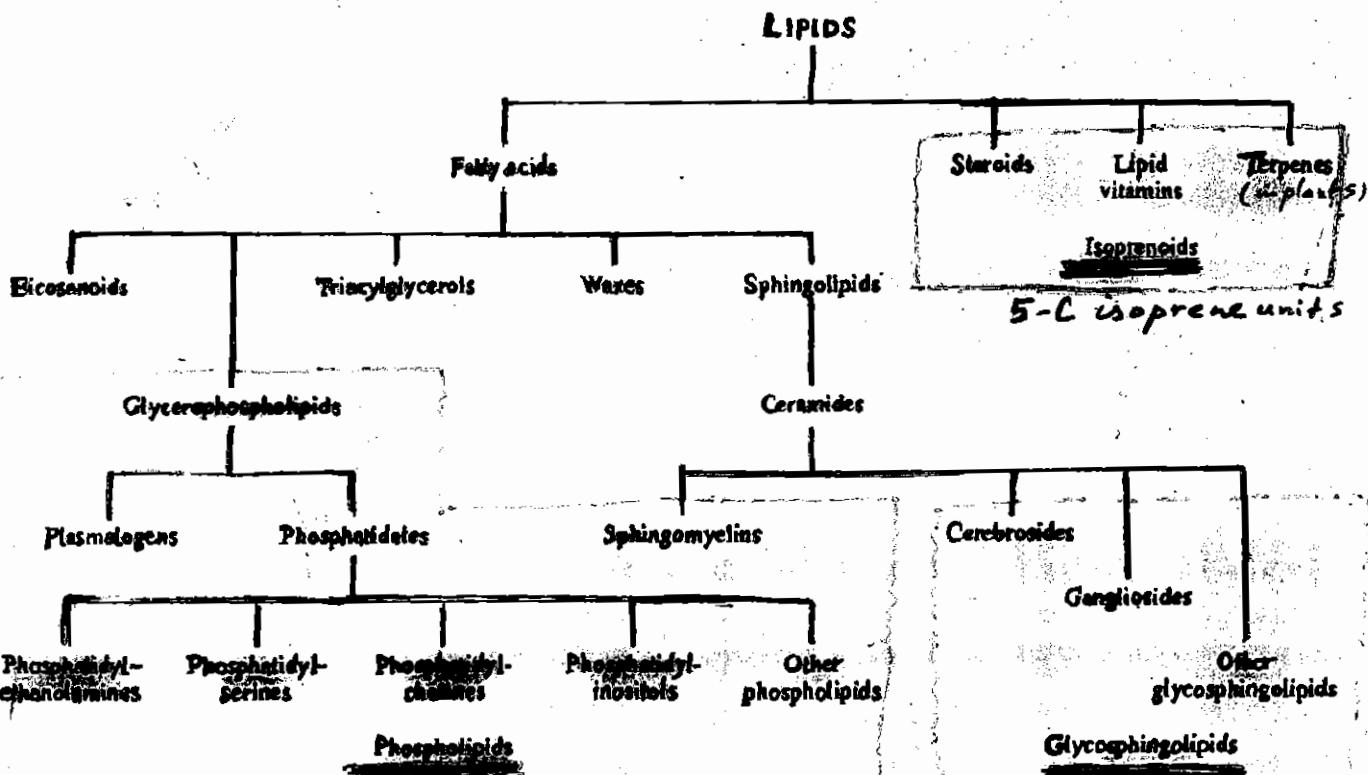
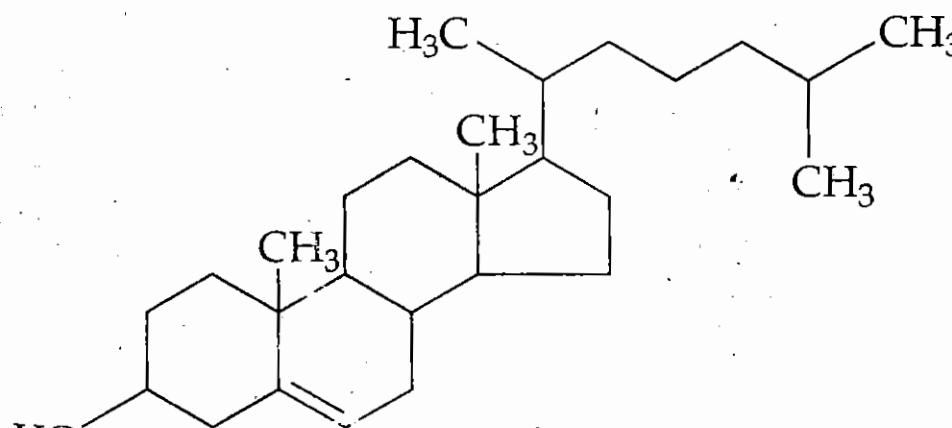
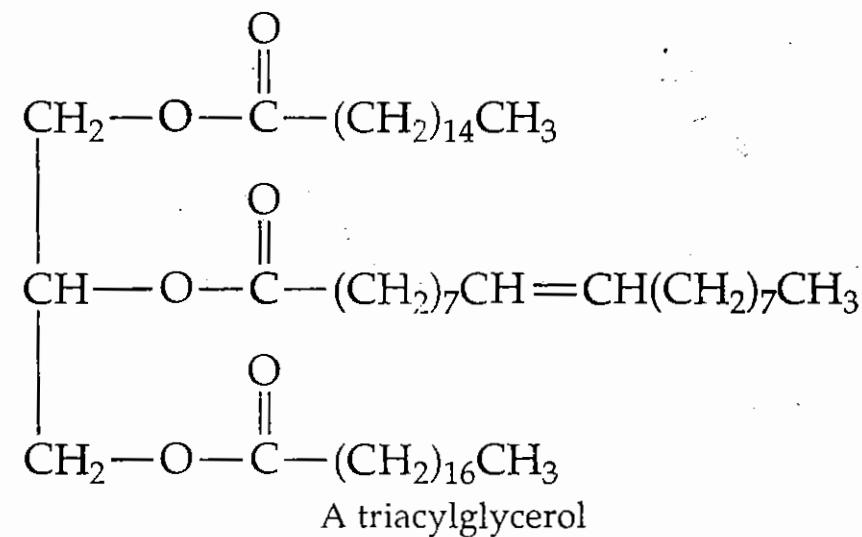
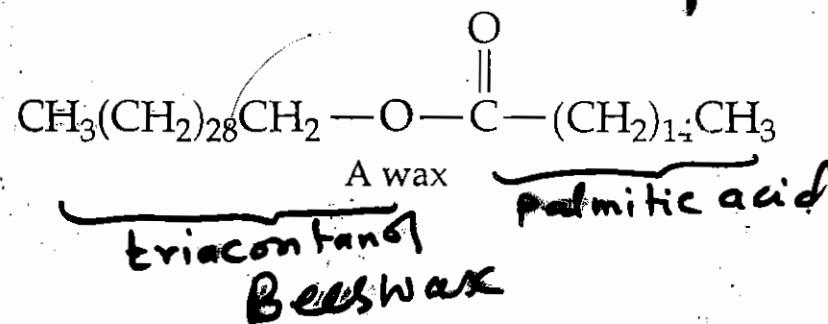


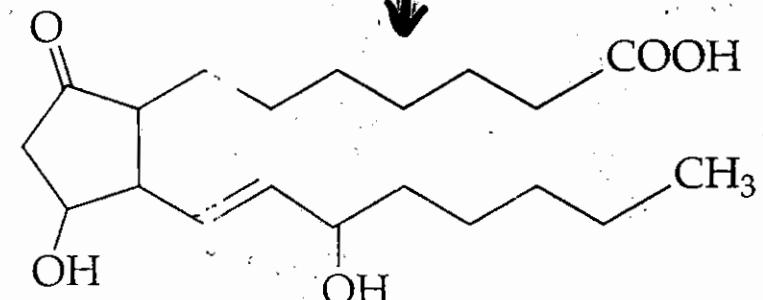
Figure 10·1
 Major classes of lipids. Fatty acids are the simplest lipids. A number of other lipids either contain or are derived from fatty acids. The glycerophospholipids and the sphingomyelins contain phosphate and are classified as phospholipids. Cerebrosides and gangliosides contain sphingosine and carbohydrate and are classified as glycosphingolipids. Steroids, lipid vitamins, and terpenes are called isoprenoids because they are related to the five-carbon molecule isoprene.

Various Lipid Structures



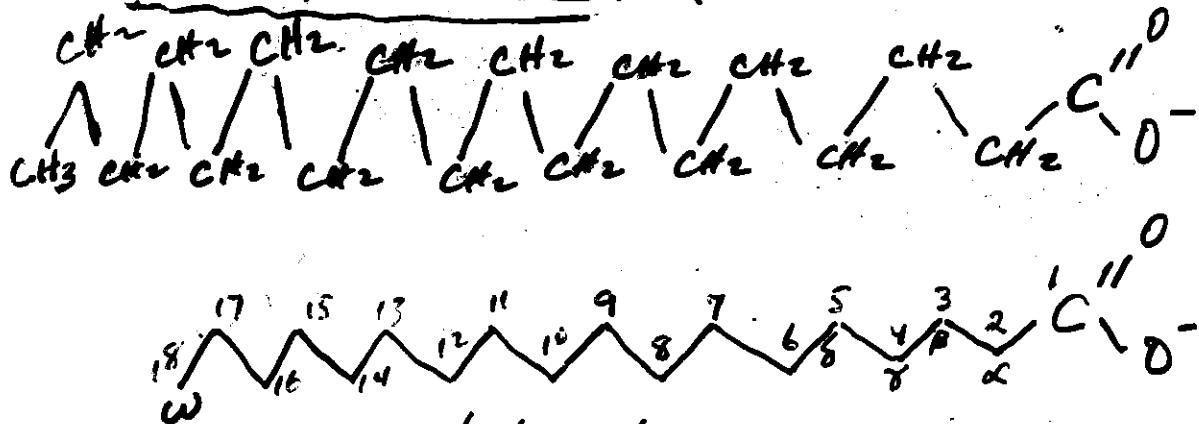
Cholesterol, a steroid

Arachidonic acid
 20:4 Δ_{5, 8, 11, 14}



A prostaglandin

FATTY ACIDS: (> 100 different F.A.)



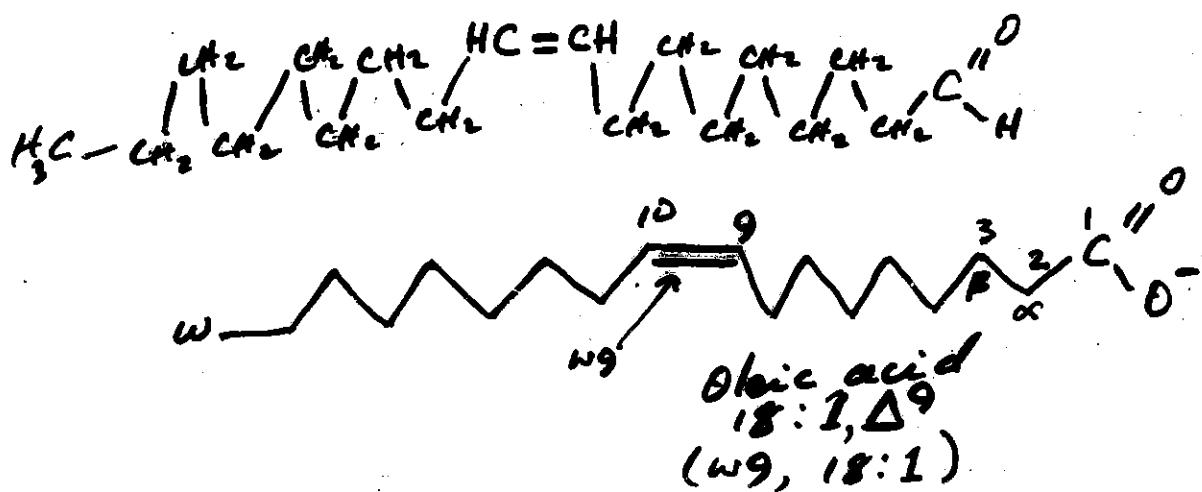
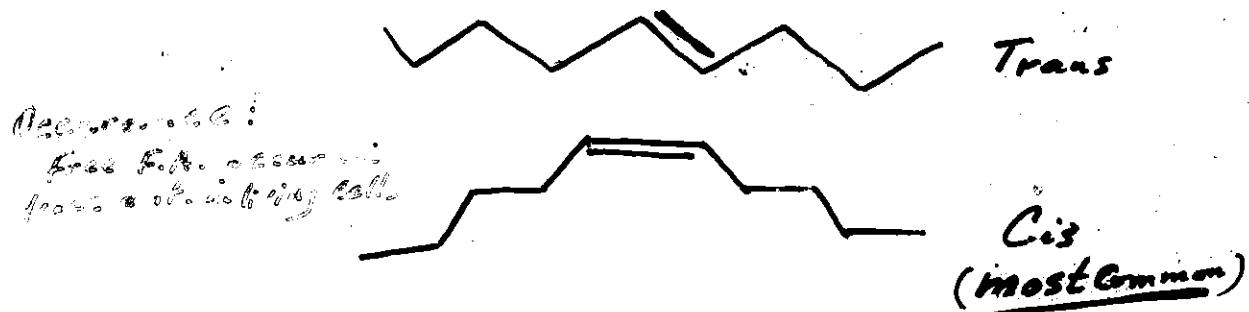
Saturated

Unsaturated :- number & positions of double bonds

Nomenclature

$18:0$; $18:1, \Delta 9$; ~~$18:1(\Delta 12)$~~
 Location of last double bond $w-3 (18:3 \Delta^{9,12,15})$
 Occurrence in human $w-6 (18:2 \Delta^{9,12})$
 $w-9 (18:1 \Delta^9)$

Isomerism:



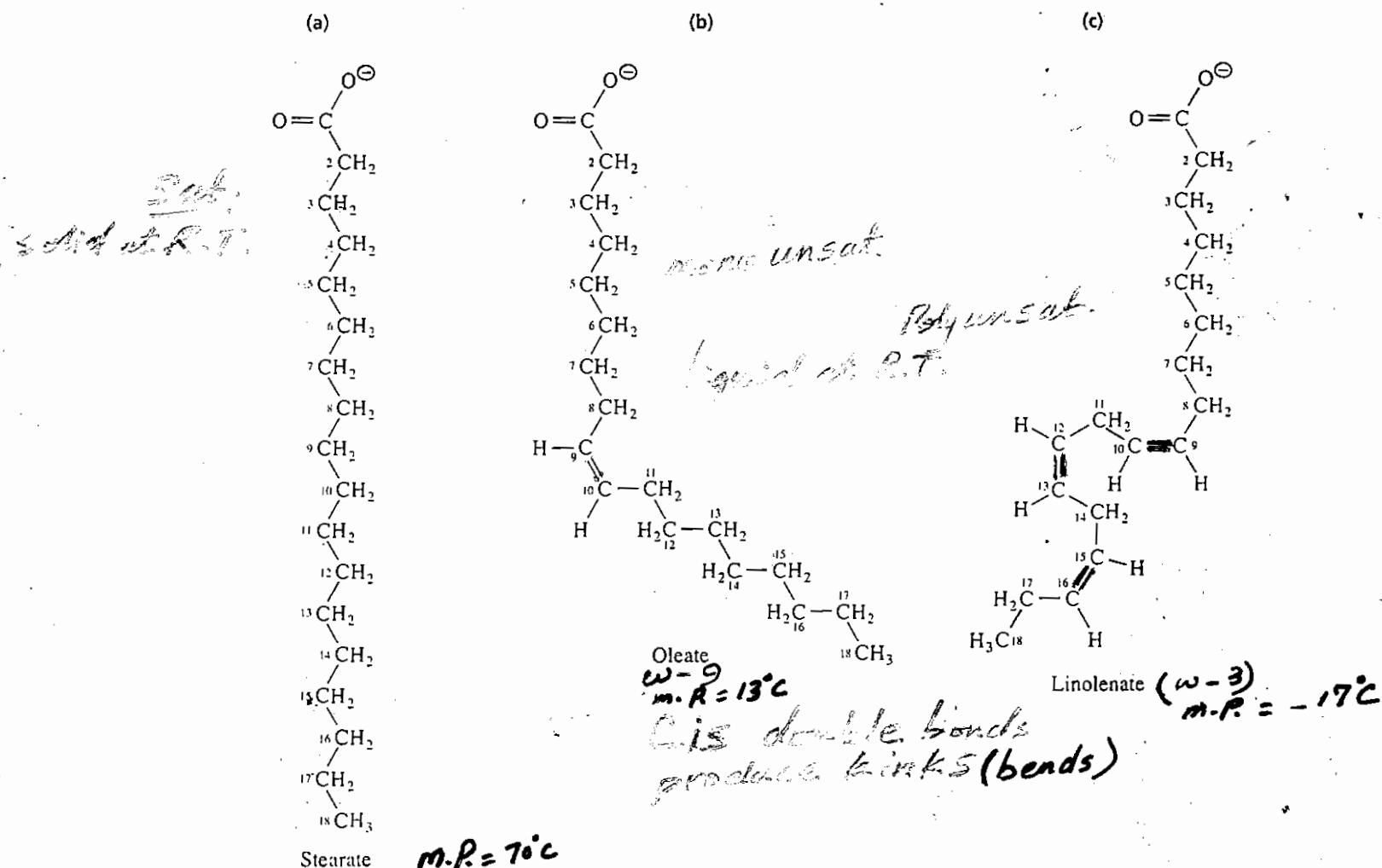


Figure 10-3
 Structures of three C_{18} fatty acids.
 (a) Stearate (octadecanoate), a saturated fatty acid. (b) Oleate (*cis*- Δ^9 -octadecenoate), a monounsaturated fatty acid. (c) Linolenate (all *cis*- $\Delta^{9,12,15}$ -octadecatrienoate), a polyunsaturated fatty acid. The *cis* double bonds produce kinks in the tails of the unsaturated fatty acids.

Some Common unsaturated fatty acids:-

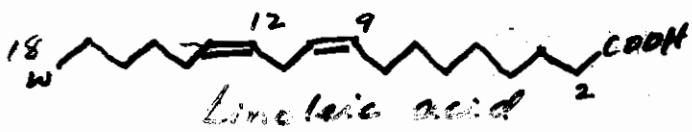
$16:1 \Delta^9$
(w7)



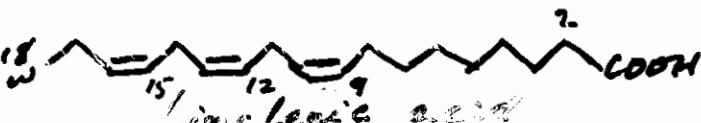
$18:1 \Delta^9$
(w9)



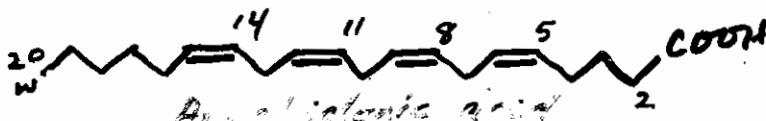
$18:2 \Delta^{9,12}$
(w6)



$18:3 \Delta^{9,12,15}$
(w3)



$20:4 \Delta^{5,8,11,14}$
(w6)



Name & Composition of Common Carboxylic Acids

Classification

Name

1.

Formic

produced in body as acid
or CoA derivative

2.0

Acetic

3.0

Propionic

In food particularly dairy
product e.g. butter

4.0

Butyric

5.0

Valeric

6.0

Capric

F.A.

Caprylic

8.0

Capric

10.0

Capric

↓

12.0

Lauric

14.0

Myristic

16.0

• Palmitic

In food of plant origin
product of fatty acid synthesis

16:1 Δ^9

Palmitoleic

18:0

• Stearic

18:1 Δ^9

• Oleic

Produced from palmitic
acid

18:2 $\Delta^{9,12}$
18:3 $\Delta^{9,12,15}$

Linoleic
Linolenic

Essential fatty acids,
obtained from plant oils

20:4 $\Delta^{5,8,11,14}$

Arachidonic

Produced from linoleic acid;
precursor of eicosanoids

• most abundant F.A. in animals

Naturally occurring fatty acids

No. of C-atoms : 4 (in butter) → 36 (in brain) in nature
 12C to 24C most of them
 16C and 18 are most prevalent

7

Table 8.1
 Structures and names of common, naturally occurring fatty acids

Number of Carbons ^a	Common Name	Systematic Name	Abbreviated Symbol ^b	Structure ^c
12	Lauric acid	n-Dodecanoic acid	12:0	<chem>CH3(CH2)10COOH</chem>
14	Myristic acid	n-Tetradecanoic acid	14:0	<chem>CH3(CH2)12COOH</chem>
16	Palmitic acid	n-Hexadecanoic acid	16:0	<chem>CH3(CH2)14COOH</chem>
16	Palmitoleic acid	n-Hexadecenoic acid	16:1 ^{Δ9}	<chem>CH3(CH2)5CH=CH(CH2)7COOH</chem>
18	Stearic acid	n-Octadecanoic acid	18:0	<chem>CH3(CH2)16COOH</chem>
18	Oleic acid	n-Octadecenoic acid	18:1 ^{Δ9}	<chem>CH3(CH2)7CH=CH(CH2)7COOH</chem>
18	Linoleic acid	—	18:2 ^{Δ9,12}	<chem>CH3(CH2)4CH=CHCH2CH=CH(CH2)7COOH</chem>
18	Linolenic acid	—	18:3 ^{Δ9,12,15}	<chem>CH3CH2CH=CHCH2CH=CHCH2CH=CH(CH2)7COOH</chem>
20	Arachidonic acid	—	20:4 ^{Δ5,8,11,14}	<chem>CH3(CH2)4CH=CHCH2CH=CHCH2CH=CHCH2CH=CH(CH2)3COOH</chem>
20	EPA	Eicosapentaenoic acid	20:5 ^{Δ5,8,11,14,17}	
22	DHA	Docosahexaenoic acid	22:6 ^{Δ4,7,10,13,16,19}	

^aNote that all have an even number of carbons.

^bIndicates the number of carbon atoms and the position of the carbon-carbon double bonds.

^cAll double bonds are cis.

Table 8.1 Concepts in Biochemistry, 3/e

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Most F.A have even number and unbranched

Mono unsat = between 9 & 10 C

diunsat. = = 9+10 and 12+13

double bond is in Cis

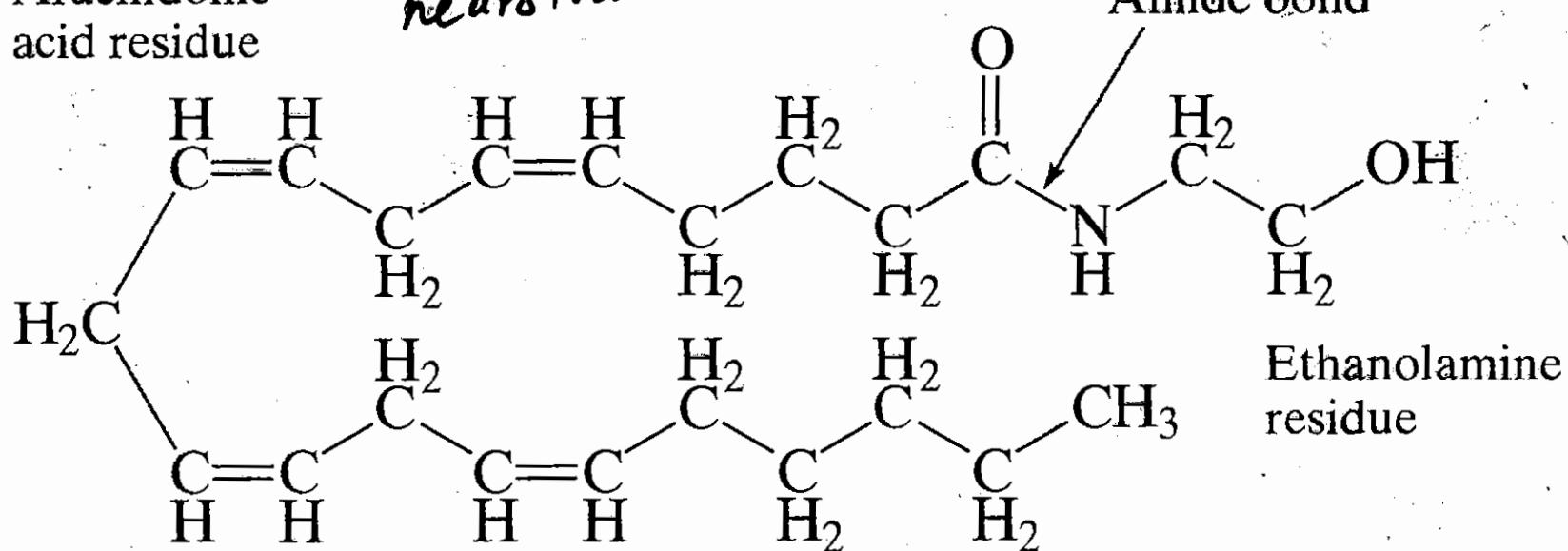
= bonds are not conjugated but separated by a methylene unit

Anandamide

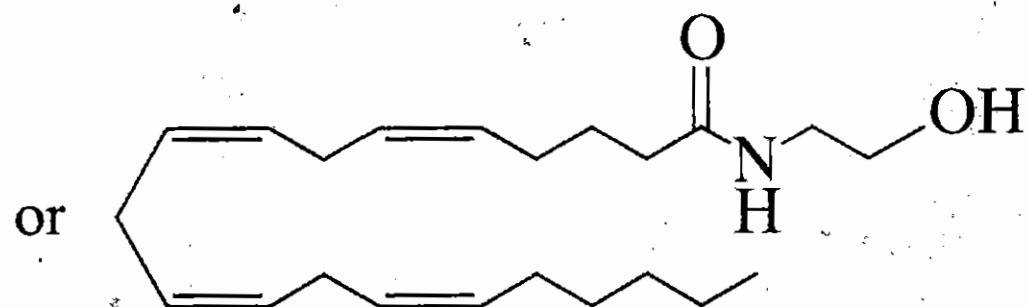
7b

→ brain
→ Cocoa & chocolate
neurotransmitter → Pain reliever

Arachidonic acid residue



Ethanolamine residue



or

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Physical and Chemical Properties of fatty acids

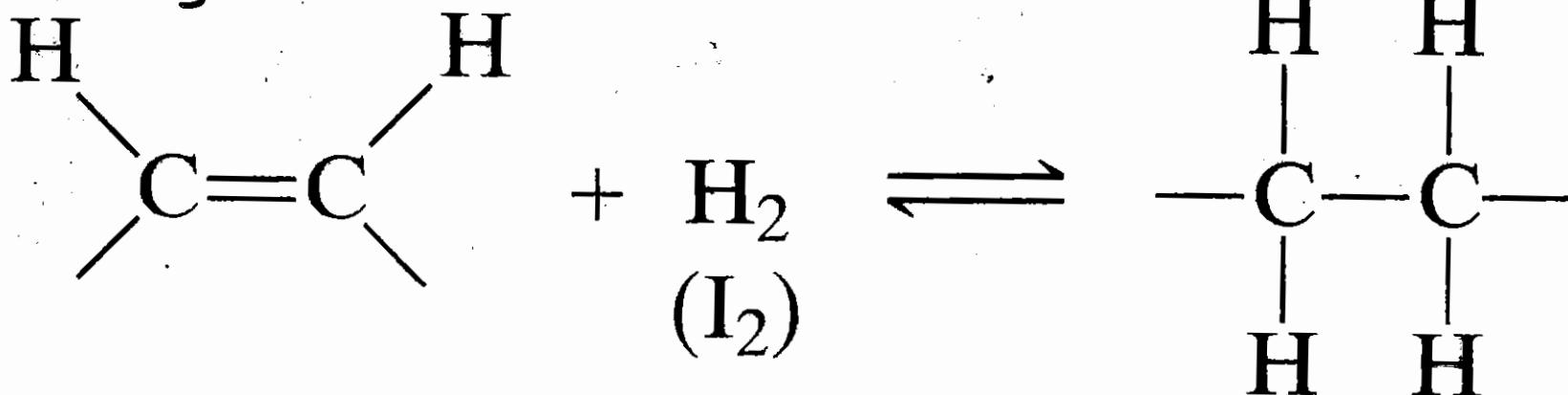
Soluble in organic solvents

Smaller chains (2:0 ; 3:0 ; 4:0) are very soluble, decrease in solubility with chain length

Sat. F.A. > 10 are solid at R.T.

Sat. F.A. < 10 & all unsat F.A. are liquid at R.T.

Larger F.A. soluble in dil NaOH or KOH \rightarrow micelles (Soap)



Sat. F.A. are unreactive

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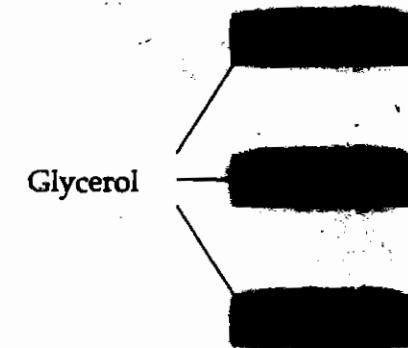
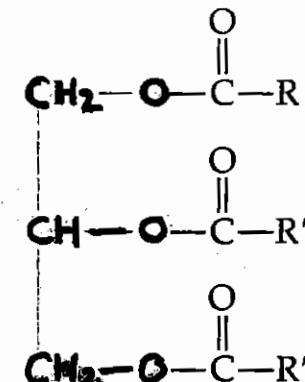
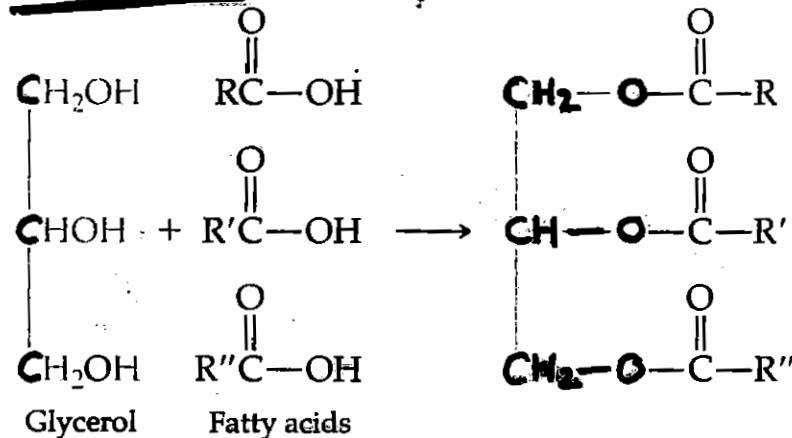
= bonds are attacked by O_2
 \rightarrow aldehydes & acids (yellow with odour)

(I) (I)
to measure no. of C=C bonds

Non-Polar lipids

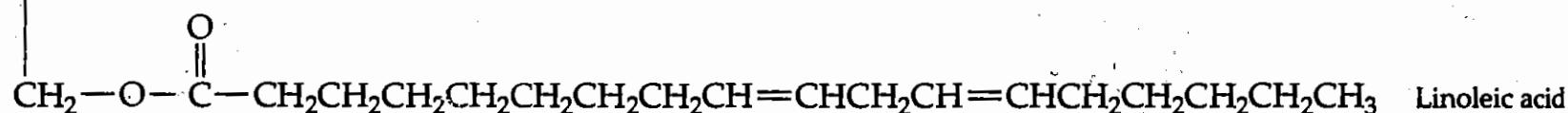
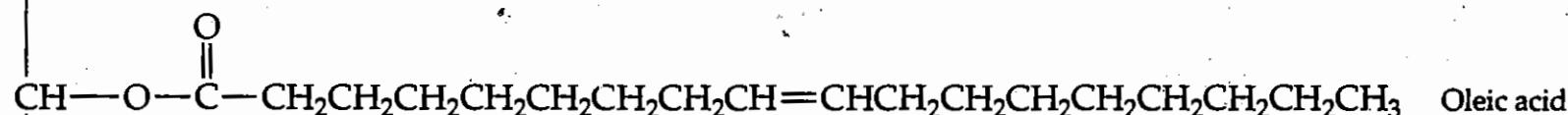
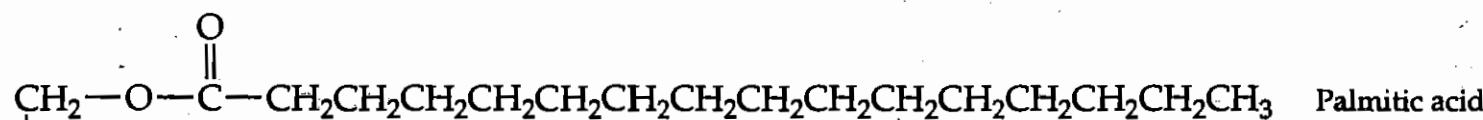
Animal TG → solid at R.T.
Plant TG → liquid + =
2 or 3 different F.A.

Triacylglycerols (TG)



The three fatty acids of any specific triacylglycerol are not necessarily the same, as shown in the following example.

Example of a triacylglycerol



F.A. Composition (in %) of common oils & fats

	<u>Poly F.A.</u>	<u>Mono F.A.</u>	<u>Total Unsat. F.A.</u>	<u>Sat. F.A.</u>
Sunflower oil	<u>75</u>	<u>12</u>	<u>87</u>	<u>9</u>
Corn oil	<u>59</u>	<u>24</u>	<u>83</u>	<u>13</u>
Soybean oil	<u>58</u>	<u>23</u>	<u>81</u>	<u>14</u>
Canola oil	<u>33</u>	<u>55</u>	<u>88</u>	<u>7</u>
OLIVE OIL	<u>8</u>	<u>74*</u>	<u>82</u>	<u>13</u>
Banat oil	<u>32</u>	<u>41</u>	<u>73</u>	<u>18</u>
Palm oil	<u>9</u>	<u>37</u>	<u>46</u>	<u>49**</u>
Coconut oil	<u>2</u>	<u>6</u>	<u>8</u>	<u>86**</u>
Tuna fat	<u>37</u>	<u>26</u>	<u>63</u>	<u>27</u>
Chicken fat	<u>21</u>	<u>45</u>	<u>66</u>	<u>30</u>
Beef fat	<u>4</u>	<u>42</u>	<u>46</u>	<u>50**</u>
BUTTER FAT	<u>4</u>	<u>29</u>	<u>→ 33</u>	<u>62**</u>

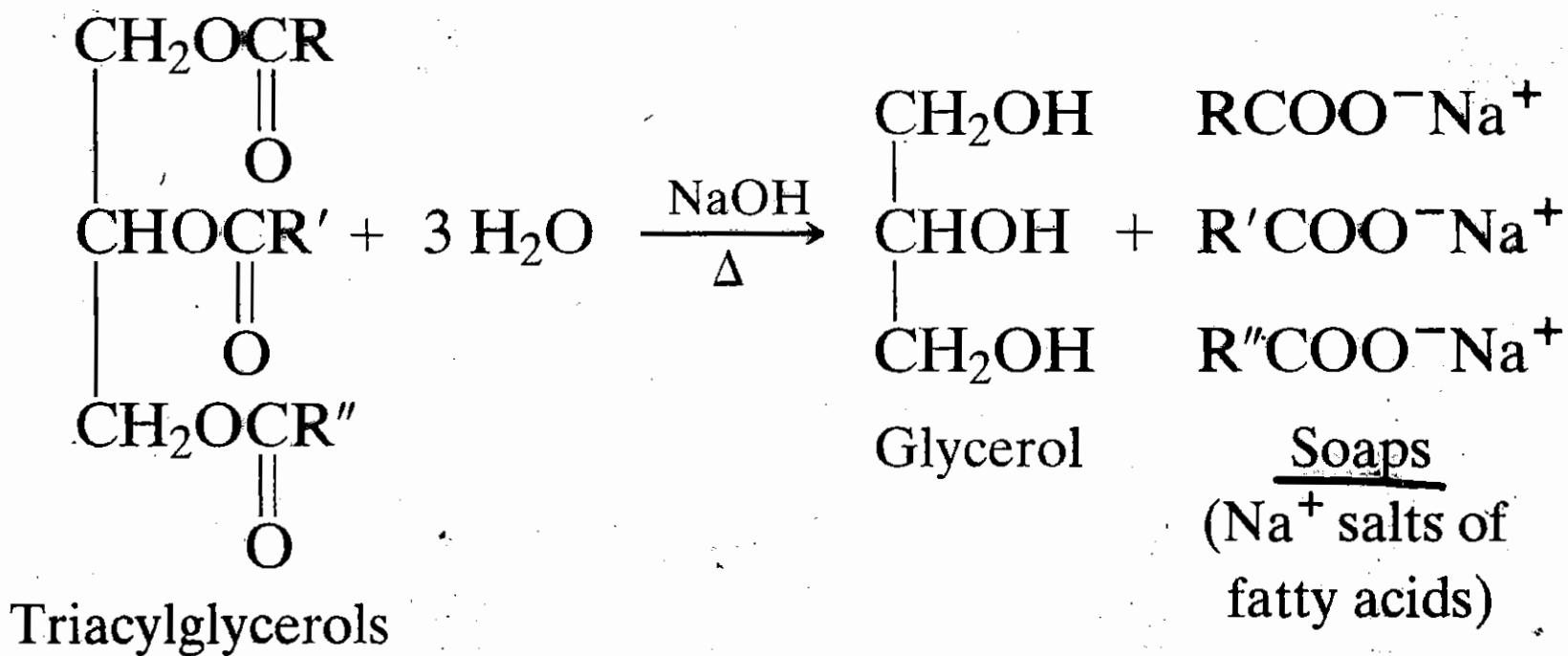
Table 8.3
Fatty acid content of common oils and fats. The fatty acids are present in triacylglycerol form.
The numbers represent percentage of each fatty acid in an oil.

Source	<i>Fatty Acids</i>				
	<i>Saturated</i>	<i>C₁₄</i>	<i>C₁₆</i>	<i>C₁₈</i>	<i>Unsaturated</i>
	<i>C₄-C₁₂</i>				<i>C₁₆ + C₁₈</i>
Canola oil	—	—	5	1	94
Olive oil	2	2	13	3	80
Butter	10	11	29	10	40
Beef fat	2	2	29	21	46
Coconut oil	60	18	11	2	8
Corn oil	—	2	10	3	85
Palm oil	—	2	40	6	52
Nutmeg oil	7	90	3	—	—
Peanut oil	—	5	8	3	84
Soybean oil	—	2	10	3	85
Sunflower oil	—	—	6	3	91

Ester Hydrolysis

Saponification

12.

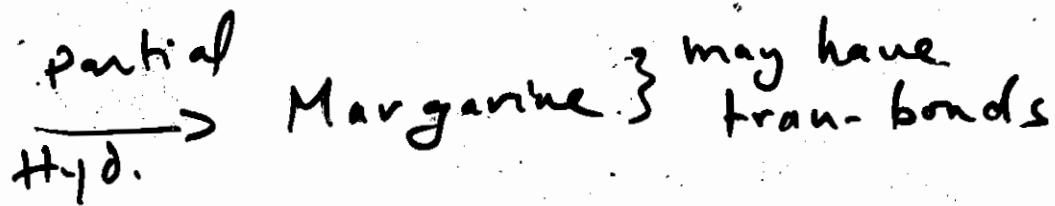


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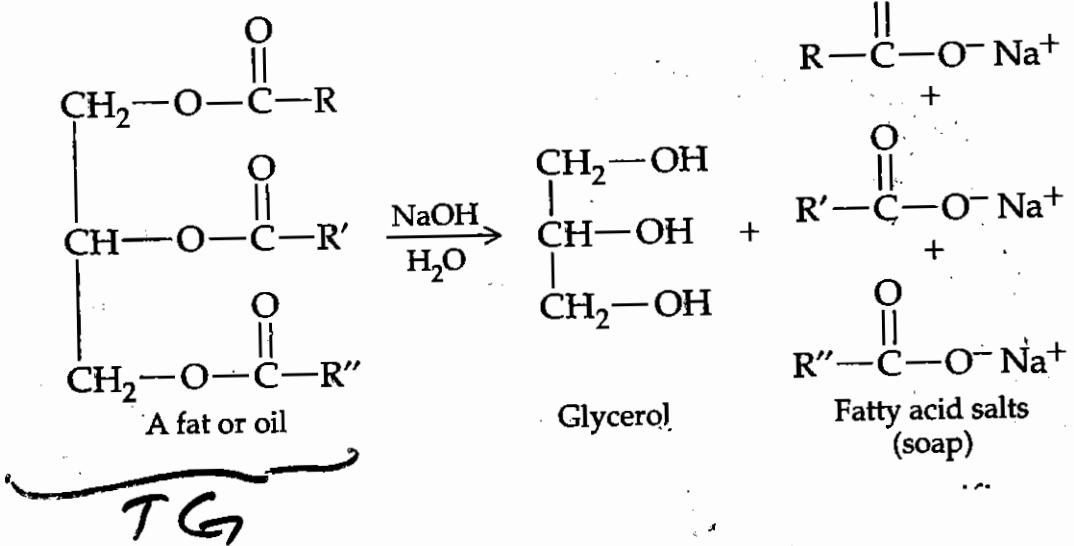
Synthetic soap :- SDS
 Sodium dodecyl sulfate

Hydrogenation of fats

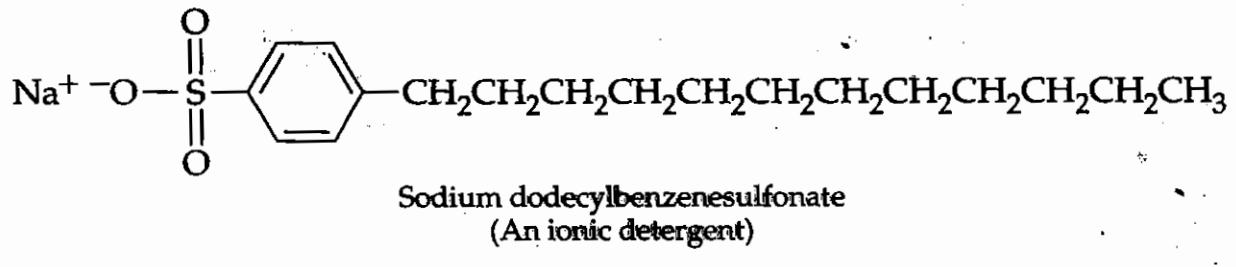
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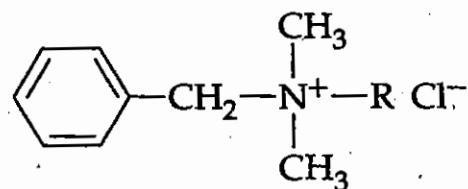
Saponification



Synthetic Detergents

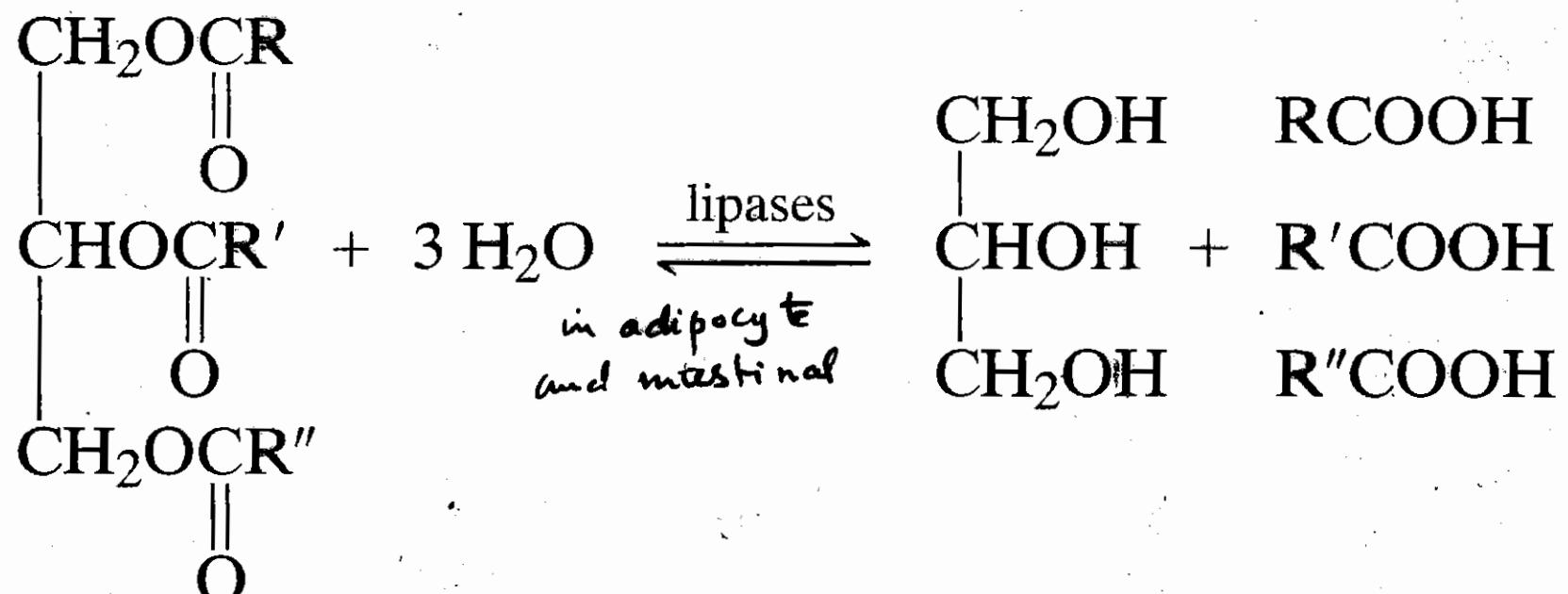


A polyether
 (A nonionic detergent)



A benzalkonium chloride; R=C₈H₁₇ to C₁₈H₃₇
 (A cationic detergent)

Hydrolysis of TG



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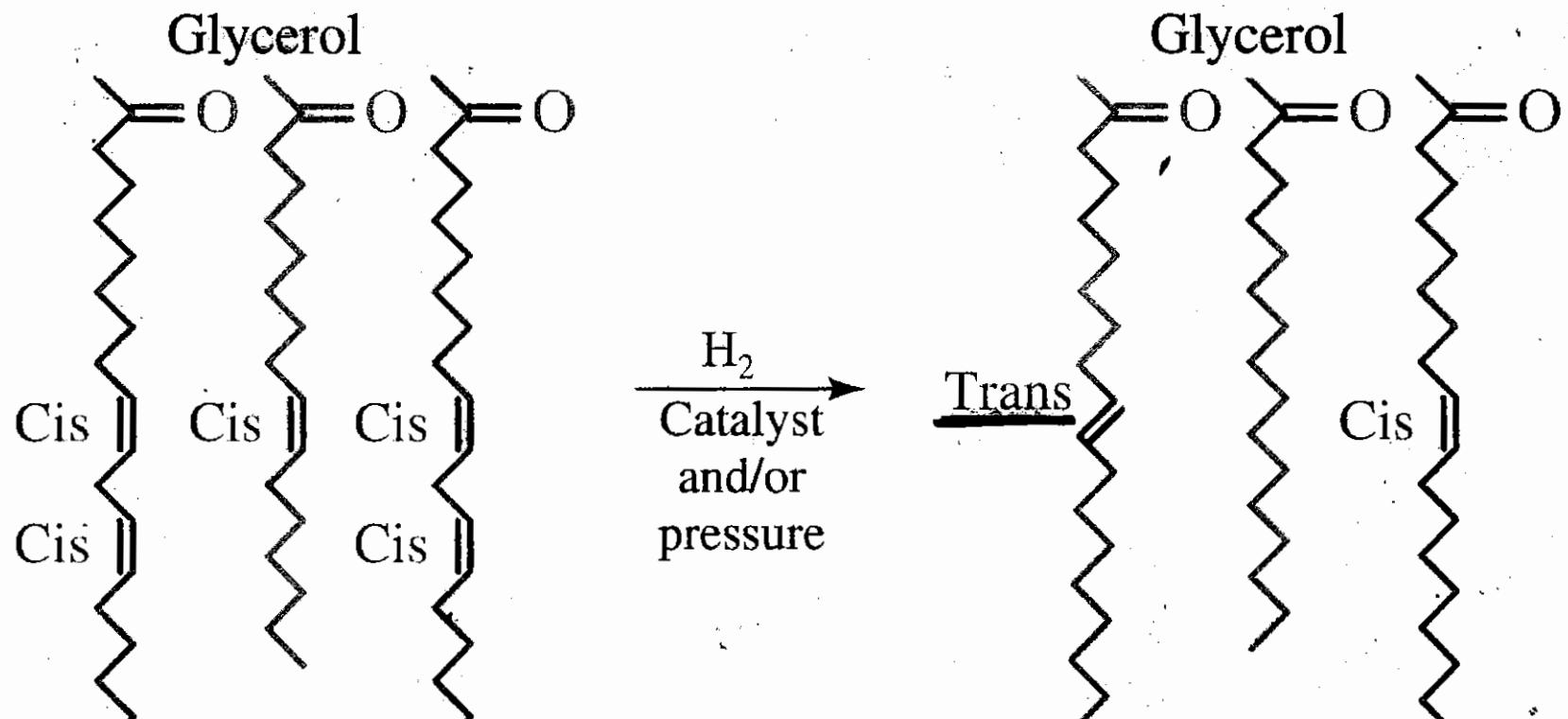
Autoxidation

Partial Hydrogenation

Partial Hydrogenation of Vegetable oils

→ margarine

14



Liquid cis-fat

Solid trans-fat

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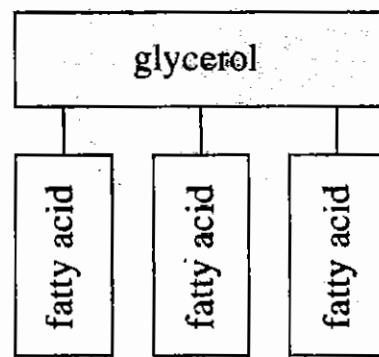
increased cholesterol level
→ increase coronary heart disease

POLAR LIPIDS

15

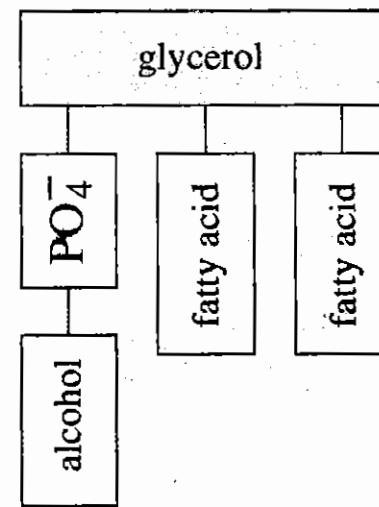
(Non polar)

Triacylglycerols



Storage lipids (nonpolar)
(a)

Glycerophospholipids



Membrane lipids (polar)
(b)

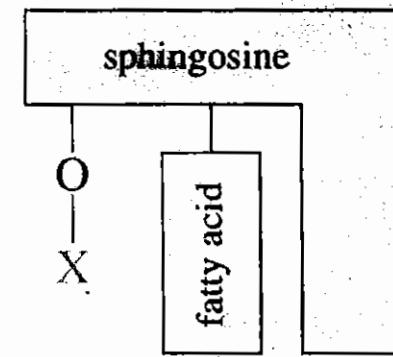
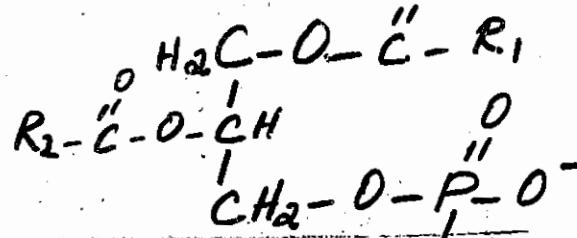
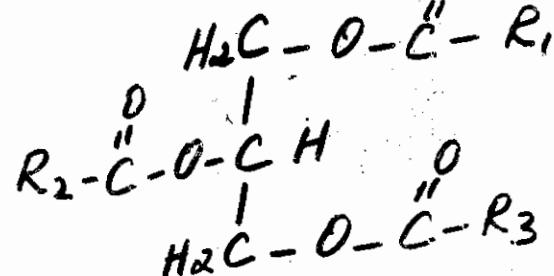


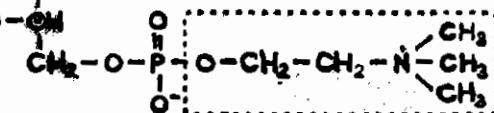
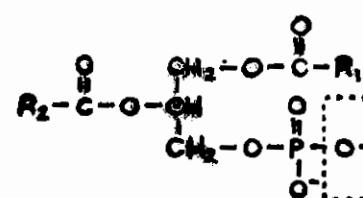
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GLYCERIDES + Glycerophospholipids

15

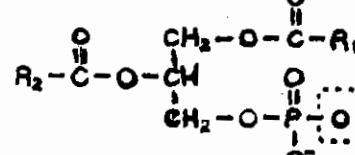


TG
(Triacylglycerol)



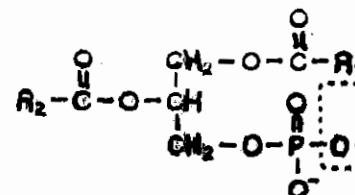
choline

Phosphatidylcholine (lecithine)

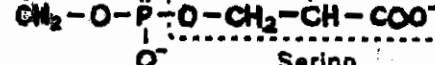


Ethanolamine

Phosphatidylethanolamine



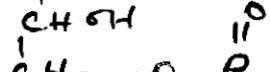
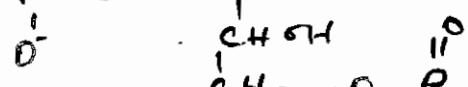
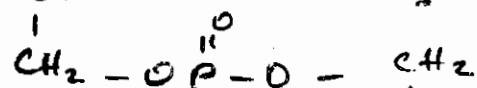
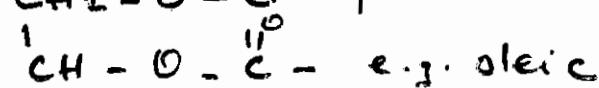
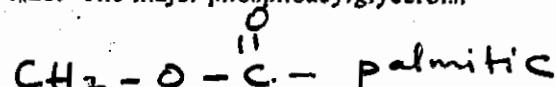
NH₃⁺



Serino

Phosphatidylserine

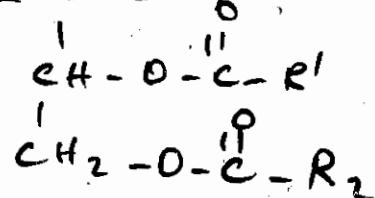
Fig. 6.28. The major phosphoacylglycerols.



Cardiolipin

is a double headed

phosphoacylglycerol



19

phosphatidic acid

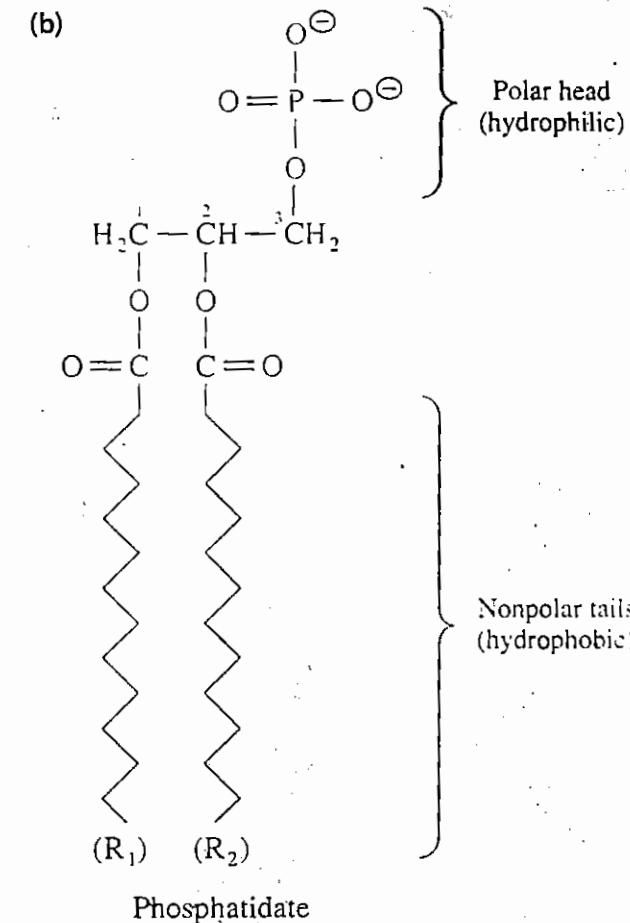
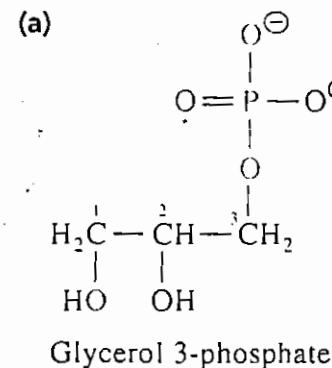


Figure 10·7

(a) Glycerol 3-phosphate and (b) phosphatidate. A phosphatidate consists of glycerol 3-phosphate with two fatty acyl groups (R_1 and R_2) esterified to its C-1 and C-2 hydroxyl groups. The structures of glycerophospholipids can be drawn as derivatives of L-glycerol 3-phosphate, with the C-2 substituent on the left in a Fischer projection; to save space, we will usually show these compounds as stereochemically uncommitted structures.

Glycerophospholipids

18

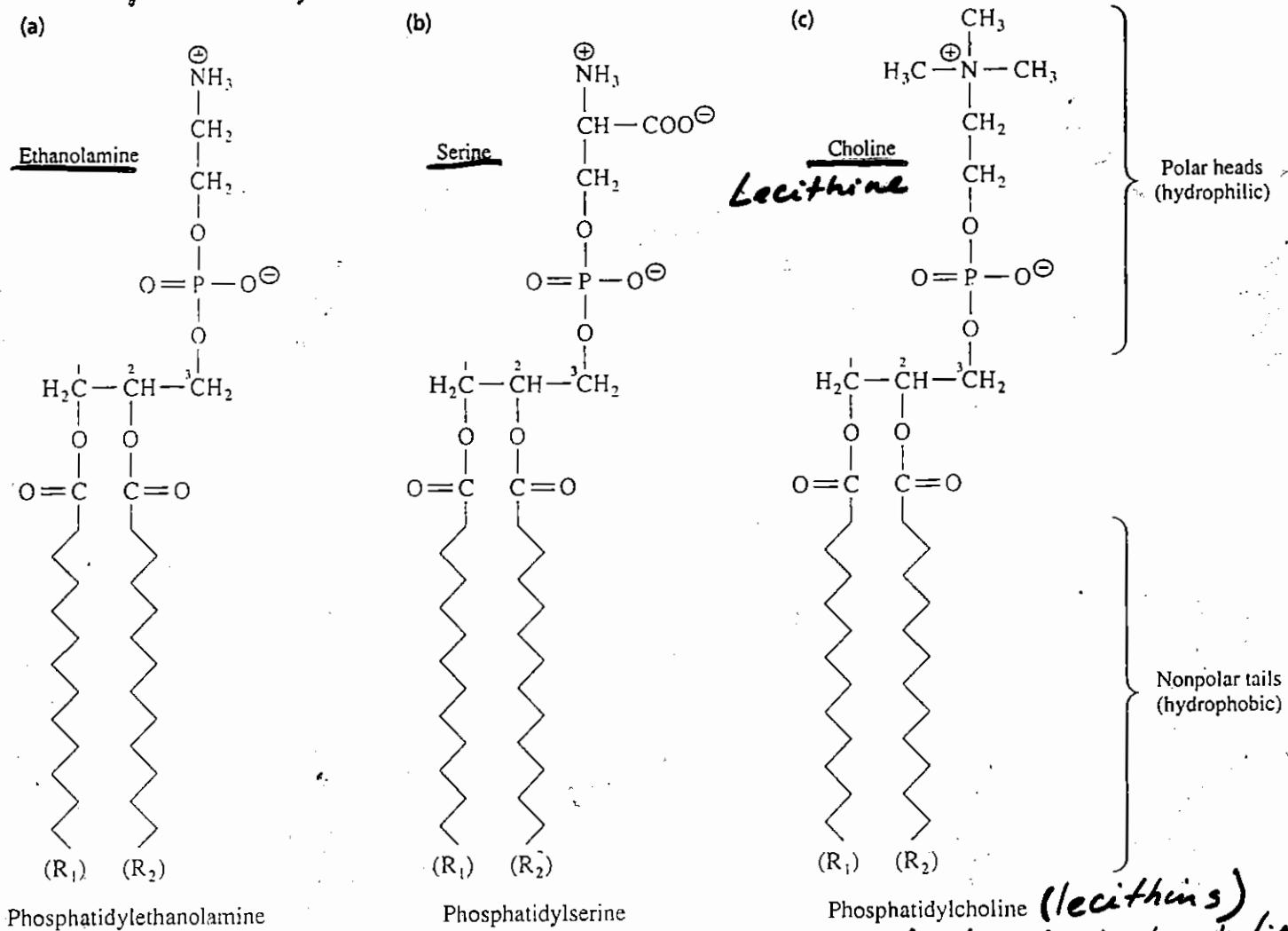
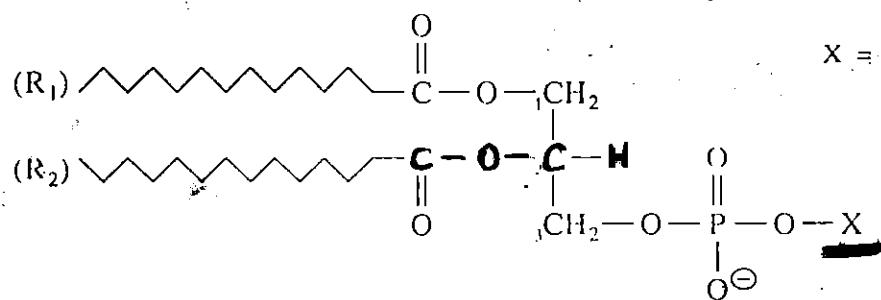


Figure 10-8

Structures of (a) phosphatidylethanolamine, (b) phosphatidylserine, and (c) phosphatidylcholine. Functional groups derived from the esterified alcohols are shown in blue. Since each of these lipids can contain many combinations of fatty acyl groups, the general name refers to a family of compounds, not to a single molecule.

Table 10·2 Some common types of glycerophospholipids



Precursor of X $(\text{HO} - \text{X})$	Formula of $-\text{O} - \text{X}$	Name of resulting glycerophospholipid
Water	$-\text{O} - \text{H}$	Phosphatidate
Choline	$-\text{O} - \text{CH}_2\text{CH}_2\text{N}^+(\text{CH}_3)_3$	Phosphatidylcholine (lecithin)
Ethanolamine	$-\text{O} - \text{CH}_2\text{CH}_2\text{NH}_3^+$	Phosphatidylethanolamine
Serine	$-\text{O} - \text{CH}_2 - \text{CH}(\text{NH}_3^+) - \text{COO}^-$	Phosphatidylserine
Glycerol	$-\text{O} - \text{CH}_2\text{CH}(\text{OH}) - \text{CH}_2\text{OH}$	Phosphatidylglycerol
Phosphatidyl-glycerol	$-\text{O} - \text{CH}_2\text{CH}(\text{OH}) - \text{CH}_2 - \text{O} - \text{P}(\text{O}^-) - \text{O} - \text{CH}_2 - \text{CO}(\text{R}_4) - \text{CH}_2 - \text{O} - \text{CR}_3$	Diphosphatidylglycerol (Cardiolipin)
myo-Inositol		Phosphatidylinositol

CHAPTERS OF THE MAJOR COMPOUNDS OF THE BODY 61

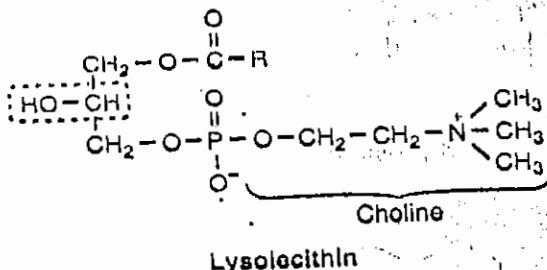


Fig. 6.29. Lyssolecithin. This compound is produced by removal of a fatty acid from position 2 of the glycerol moiety of phosphatidylcholine (lecithin).

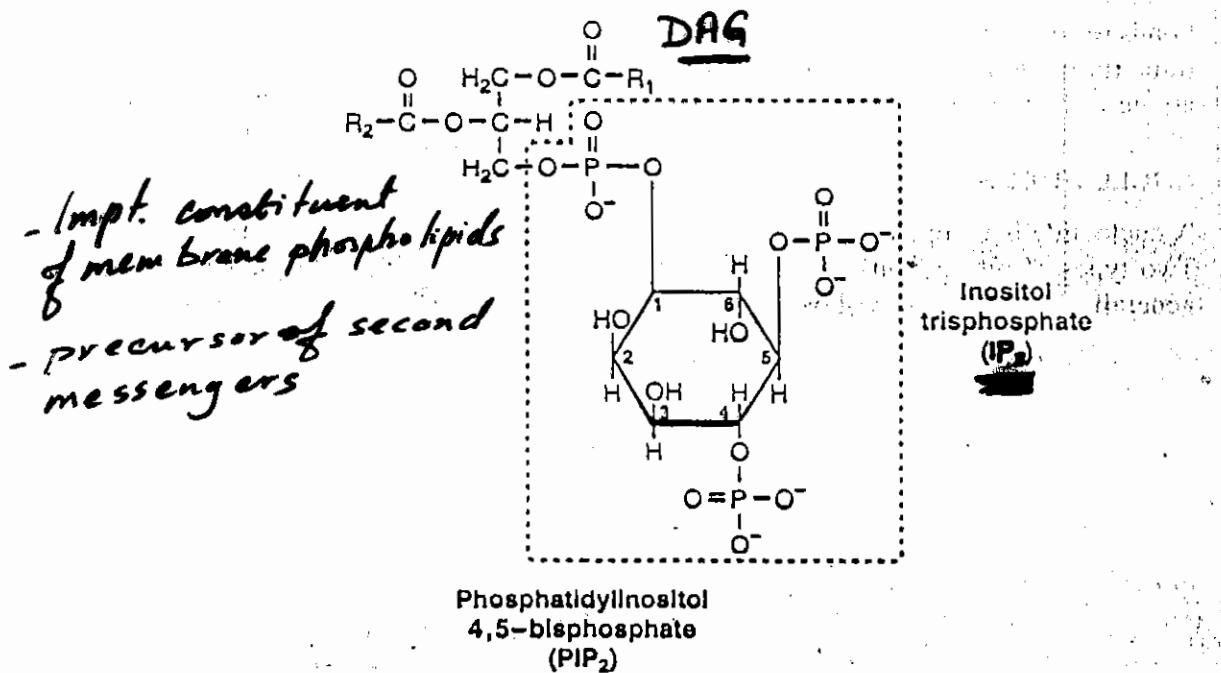
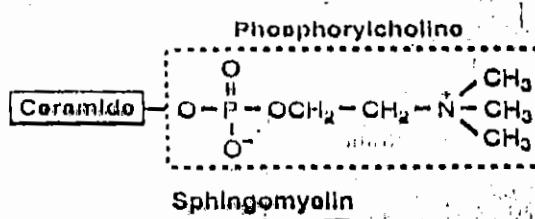


Fig. 6.30. Phosphatidylinositol bisphosphate (PIP₂). PIP₂, a membrane phospholipid, is cleaved to form inositol triphosphate (in blue) and diacylglycerol, which serve as second messengers.

SPHINGOLIPIDS

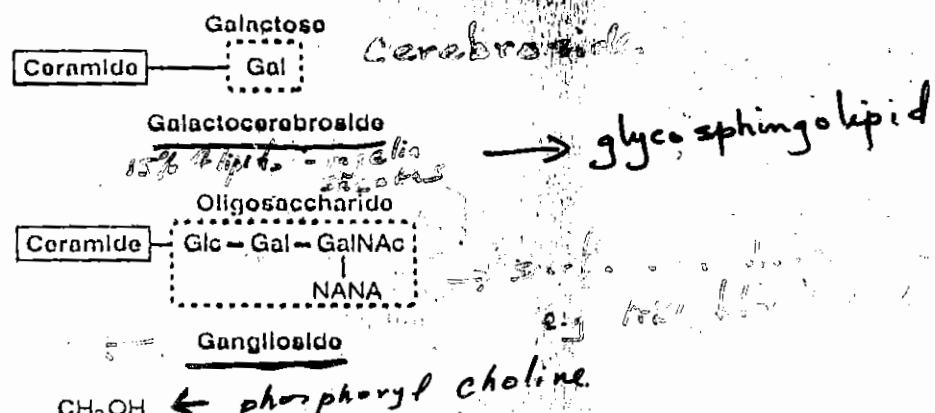
- Major components of myelin and membranes of brain and other nervous tissue
- most abundant after glycerophospholipid in plant and animal membranes.

Sphingomyelin



→ phospholipid

2) glycolipid
(Cerebroside and ganglioside)



Sphingosine →
serine + PalmitoylCoA

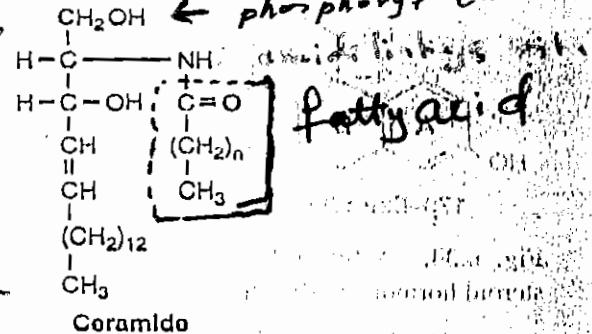
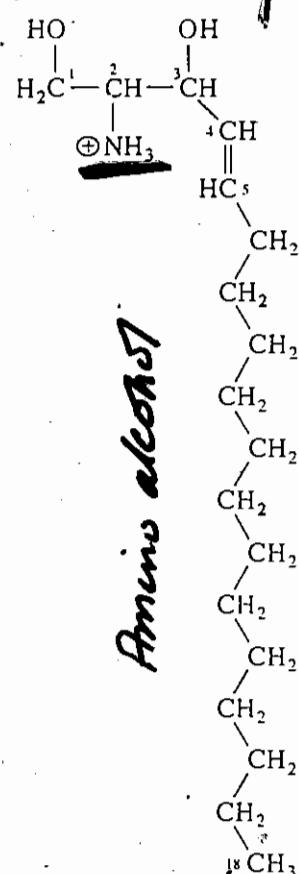


Fig. 6.31. Sphingolipids, derivatives of ceramide. The structure of ceramide is shown above. The highlighted groups are added to ceramide to form sphingomyelins, galactocerebrosides, and gangliosides. NANA = *N*-acetylneuraminic acid; Glc = glucose; Gal = galactose; GalNAc = *N*-acetylgalactosamine.

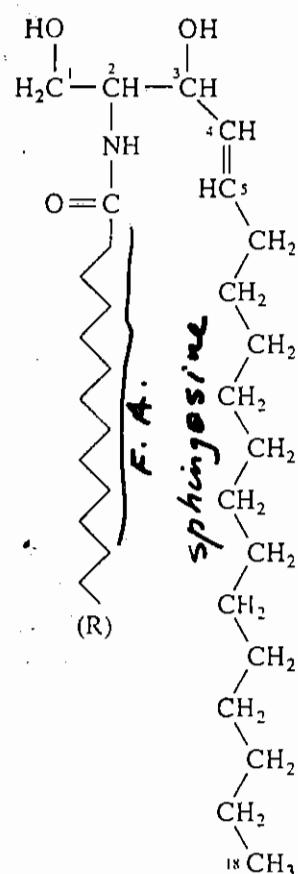
match the
glycerol

(a)

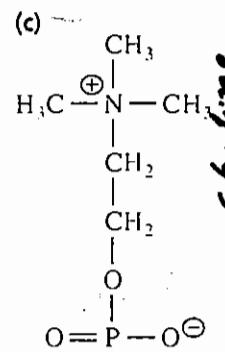


Sphingosine
(*trans*-4-Sphingenine)

(b)



Ceramide



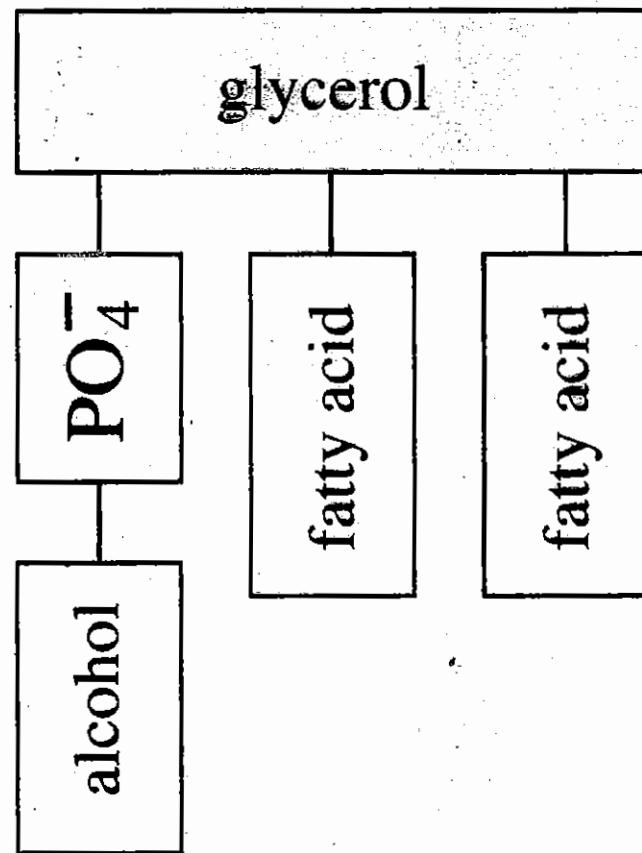
Sphingomyelin

choline

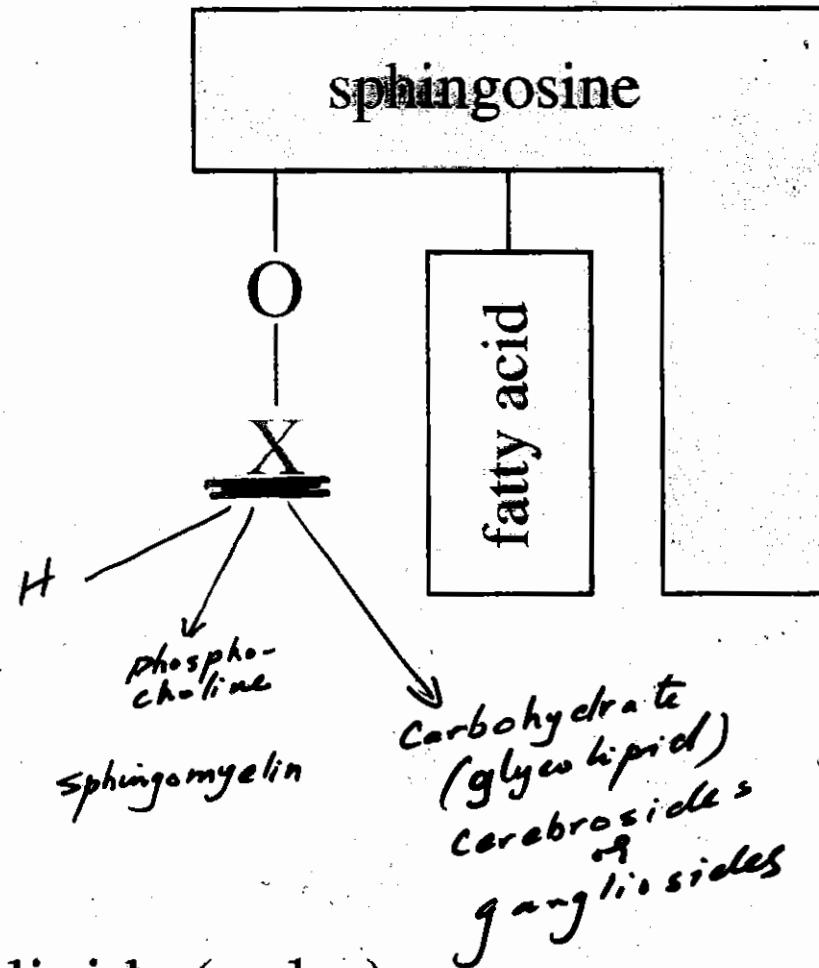
Figure 10-11

Structures of sphingosine, ceramide, and sphingomyelin. (a) Sphingosine is a long-chain alcohol with an amino group at C-2. (b) Ceramides have a long-chain fatty acyl group attached to the amino group of sphingosine. (c) Sphingomyelins have a phosphate group (red) attached to the C-1 hydroxyl group of a ceramide and a choline group (blue) attached to the phosphate.

Glycerophospholipids



Sphingolipids



Membrane lipids (polar)

Figure 8-6b Concepts in Biochemistry, 3/e
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Name of X	Structure of X	Name of Sphingolipid
(b) Hydrogen	—H	Ceramide
(c) Phosphocholine	$ \begin{array}{c} \text{O} \\ \parallel \\ \text{—P—O—CH}_2\text{CH}_2\text{N}^+(\text{CH}_3)_3 \\ \\ \text{O}^- \end{array} $	Sphingomyelin
(d) Glucose <i>galactose</i>		Glucosylcerbroside
(e) Complex oligosaccharide		Ganglioside

Figure 8-8 part 2 Concepts in Biochemistry, 3/e
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Gangliosides (GM)

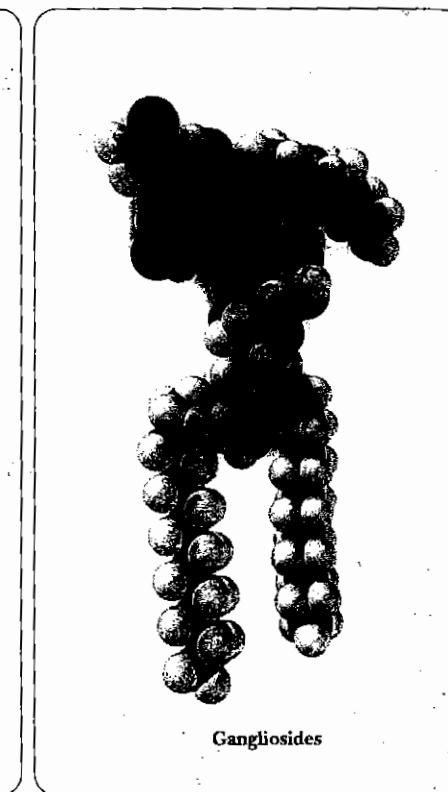
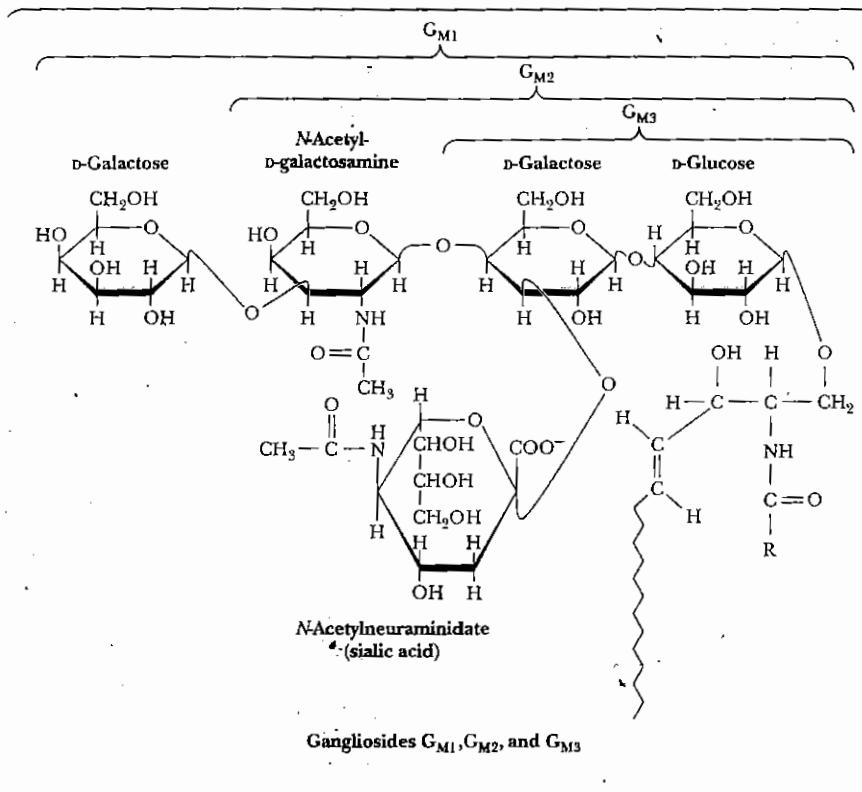


FIGURE 8.8 The structures of several important gangliosides. Also shown is a space-filling model of ganglioside G_{M1}.

16.6 The Structure of Biological Membranes

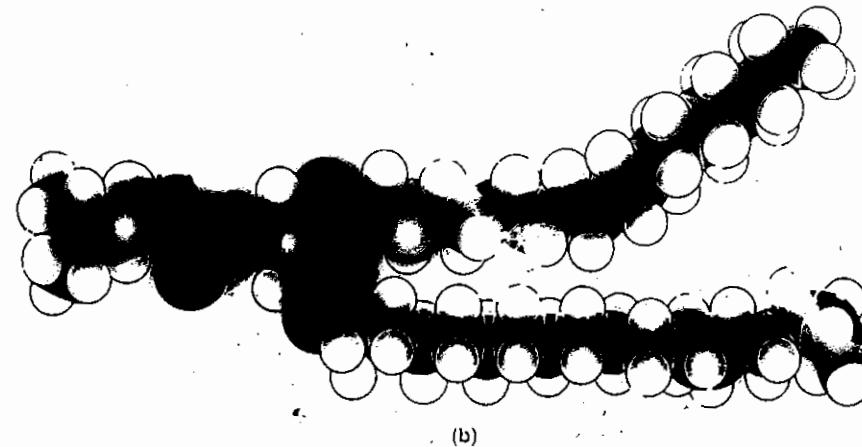
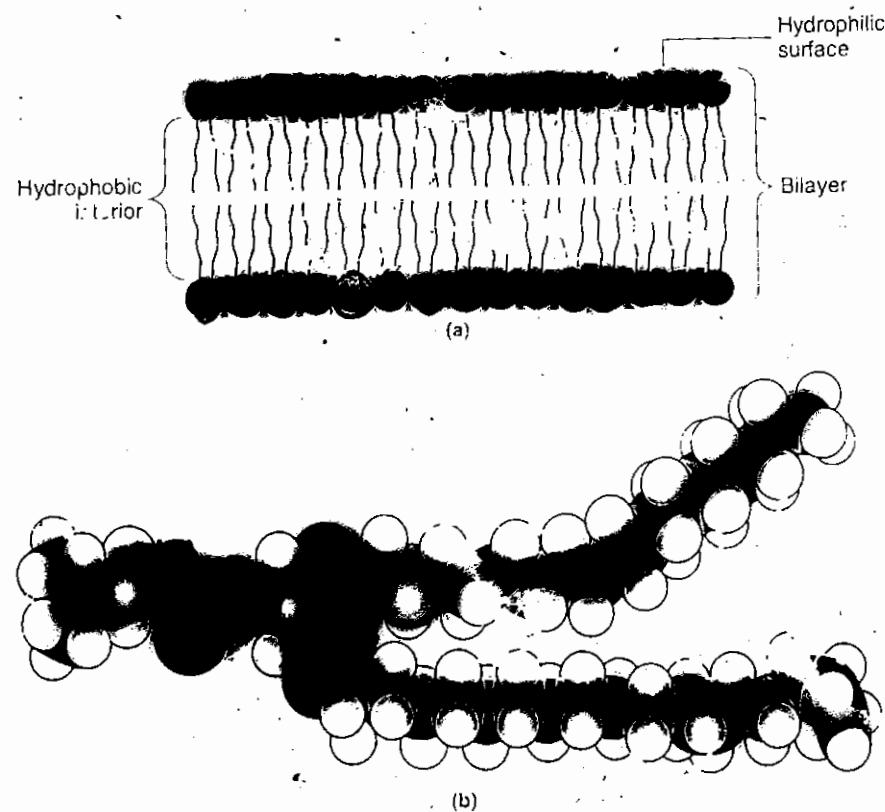
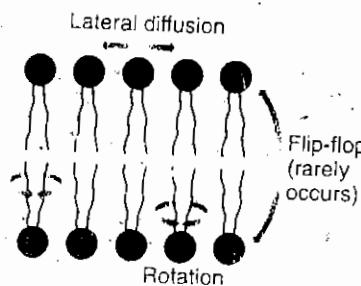


FIGURE 16.13
Schematic diagram of a lipid bilayer. (a) Schematic drawing; (b) view using drawings of "space-filling" models.

FIGURE 16.14
Lateral diffusion in a biological membrane is rapid, but "lip-flop" across the membrane is very slow and almost never occurs.



26a

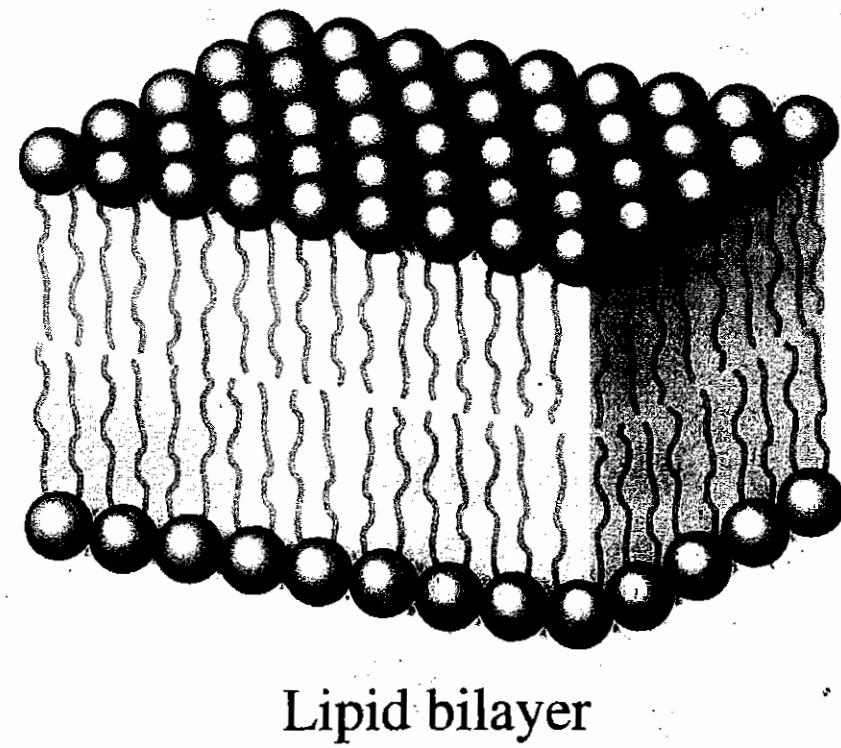
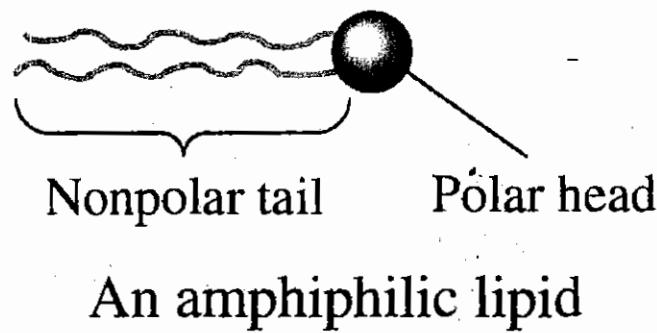


Figure 8-9 Concepts in Biochemistry, 3/e
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Biological Membranes (Lipid bilayers & Proteins)

266

Amphiphilic lipid

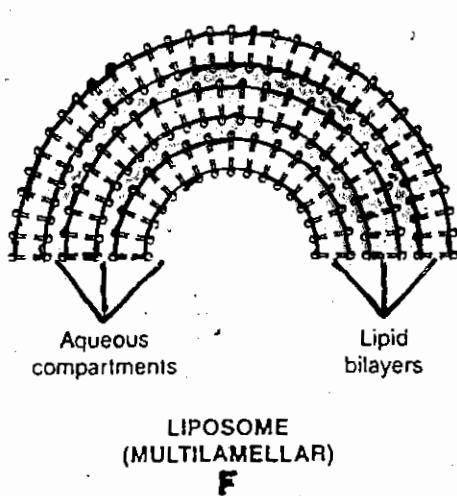
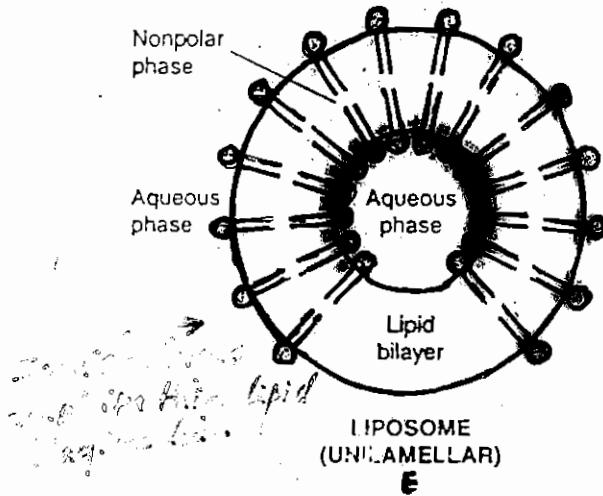
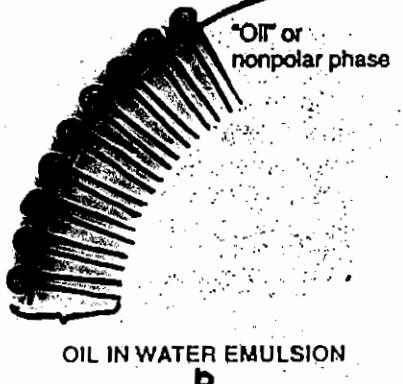
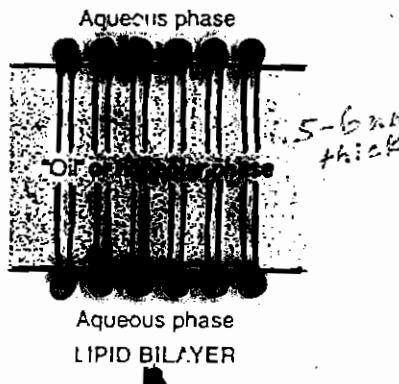
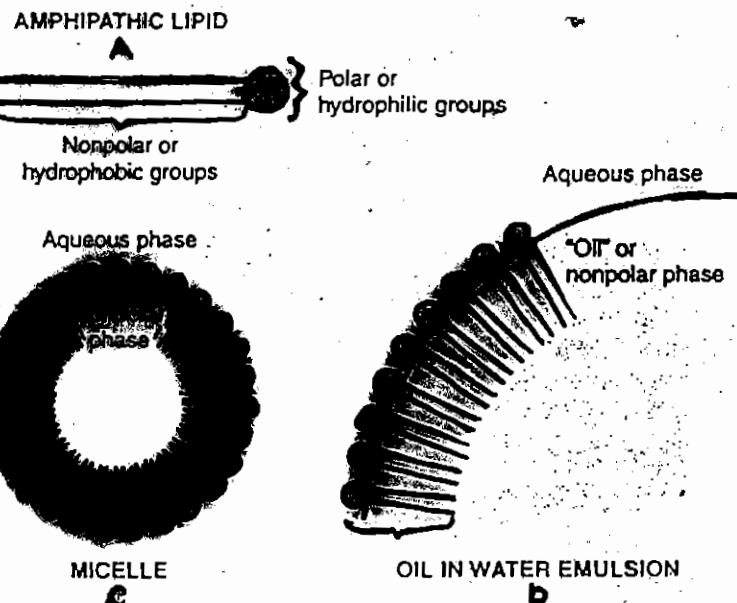
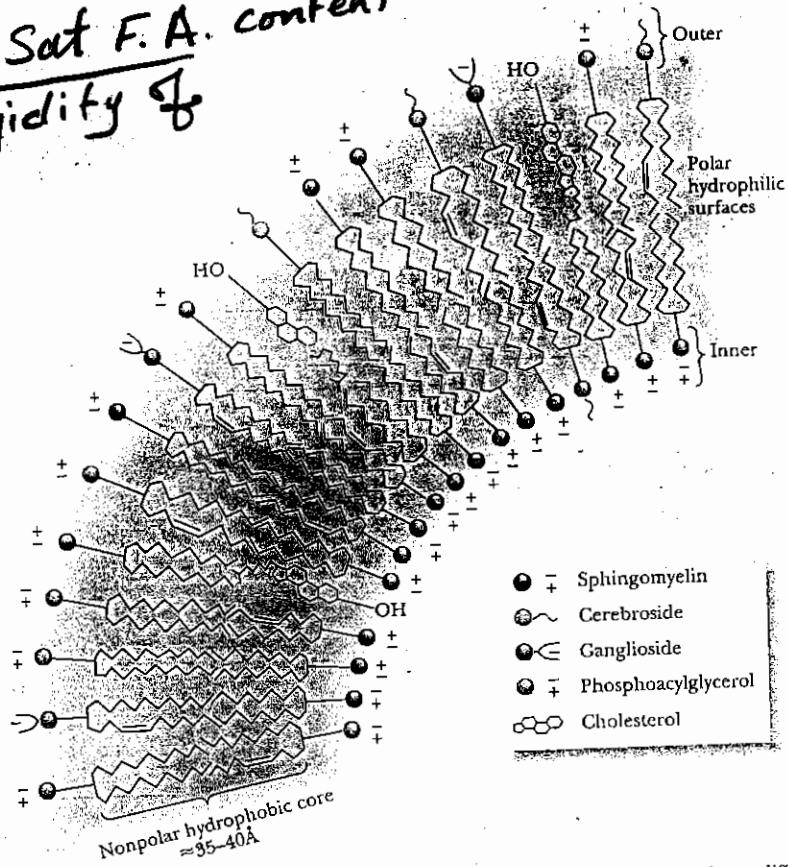


Figure 14-22. Formation of lipid membranes, micelles, emulsions, and liposomes from amphiphilic lipids, e.g., phospholipids.

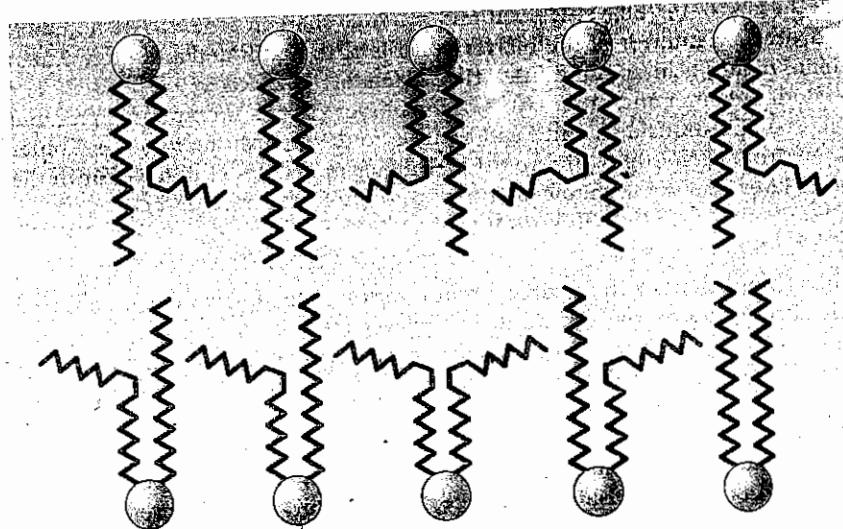
- Liposomes may be used in a mimetic drug delivery system
- Cholesterol cannot form bilayers

Biological Membrane

↑ Cholesterol + Sat F.A. content increases rigidity of membrane



■ FIGURE 8.11 Lipid bilayer asymmetry. The compositions of the outer and inner layers differ; the concentration of bulky molecules is higher in the outer layer, which has more room.



■ FIGURE 8.13 Schematic drawing of a portion of a highly fluid phospholipid bilayer. The kinks in the unsaturated side chains prevent close packing of the hydrocarbon portions of the phospholipids.

TERPENES . 27.

- Molecules derived from the ISOPRENE units $\text{CH}_2=\overset{\text{CH}_3}{\underset{\text{D}}{\text{C}}}=\text{CH}_2$
- e.g. Important terpenes in plants and animals:
- β -Carotene : orange color, precursor of Vit A
- Limonene.
→ distinct odor in Citrus fruits
- Gibberellic acid
plant growth hormone
- Squalene.
Intermediate in cholesterol biosynthesis → other steroids (in animals) and plant steroids.
- Lycopene.
red pigment of tomatoes (and antioxidants)
- Fat-soluble Vitamins
A, D, E & K

STEROIDS

Isoprenoids

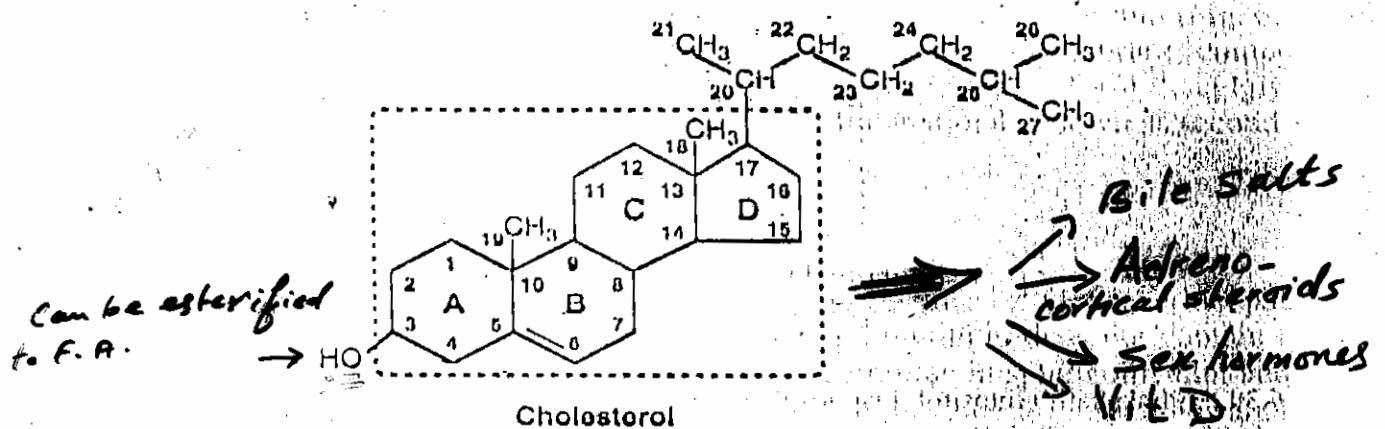
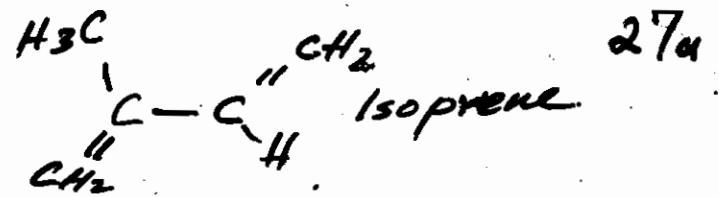


Fig. 6.33. Cholesterol. The steroid nucleus is shown in blue.

Different classes of Steroids

1. Bile acids
2. Adrenocortical hormones
3. Sex hormones
4. Steroid alkaloids

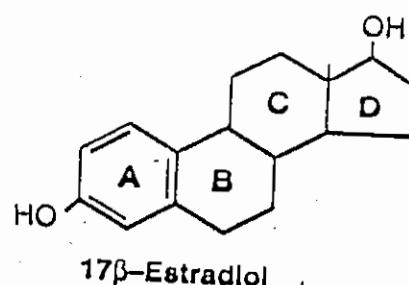
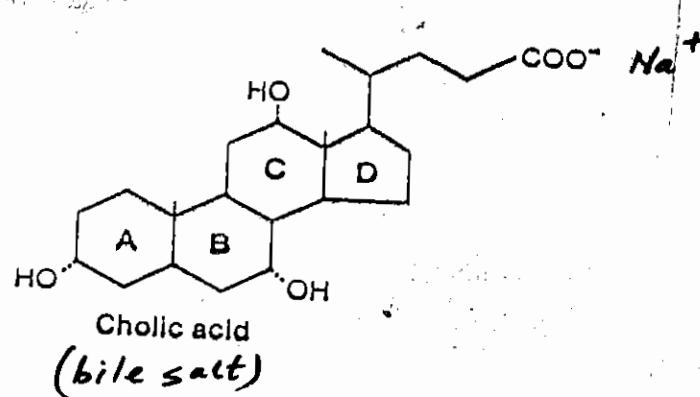


Fig. 6.34. A bile salt (cholic acid) and a steroid hormone (17 β -estradiol).

Testosterone - steroid hormone

Stigmasterol - plant sterol.

STEROIDS:

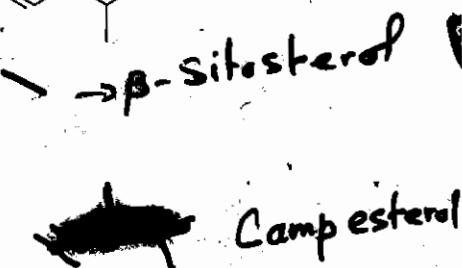
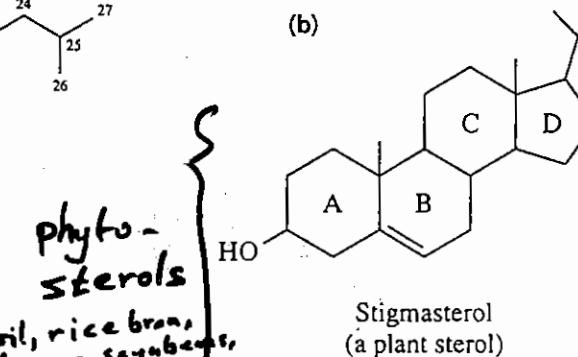
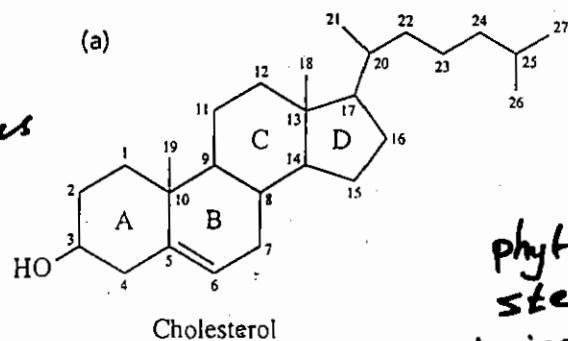
27b

- 3rd class of lipids
- found in membranes of eukaryotes

- Isoprene - basic structural unit
 $\text{CH}_3\text{---C---CH}_2$



estrogens
 androgens
 progestins
 adrenal corticosteroids



phyto-sterols
 Corn oil, rice bran,
 wheat germ, soybeans,
 others.

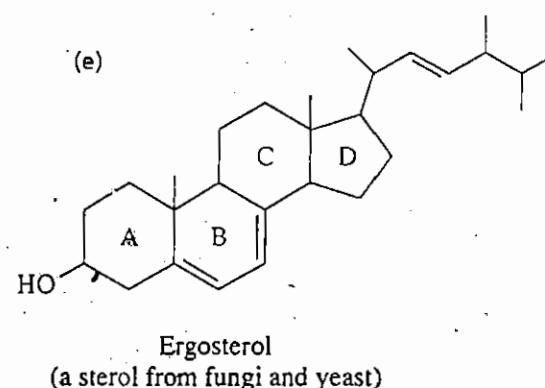
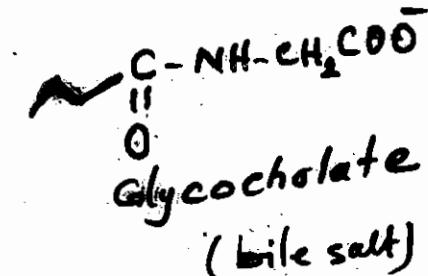
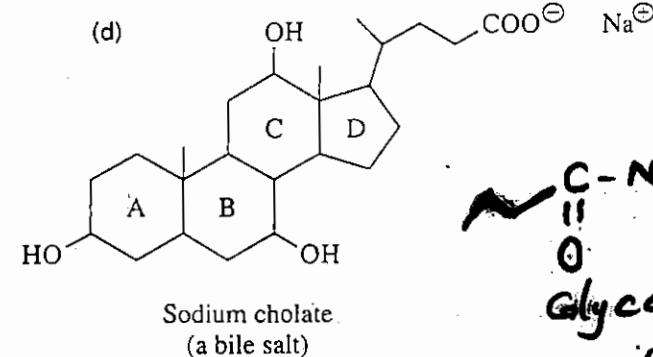
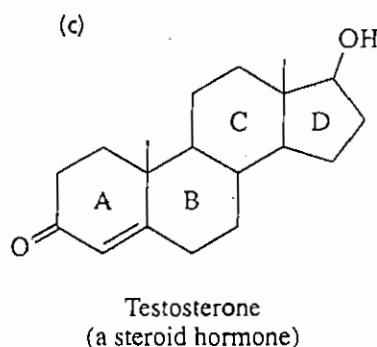


Figure 10-15

Structures of several steroids. Steroids contain four fused rings (lettered A, B, C, and D). (a) Cholesterol. (b) Stigmasterol, a common component of plant membranes. (c) Testosterone, a steroid hormone involved in male development in animals. (d) Sodium cholate, a bile salt, which aids in the digestion of lipids. (e) Ergosterol, a compound from fungi and yeast.

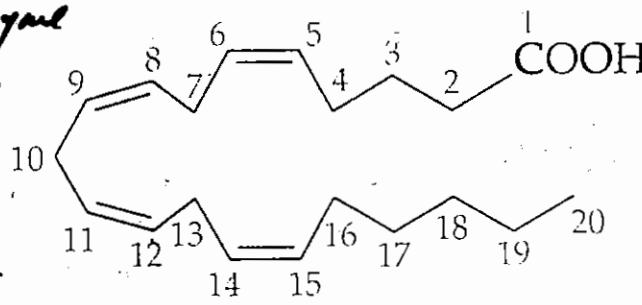
COX-1 constitutive enzyme

COX-2 inducible enzyme

injury
disease $\rightarrow \text{COX-2}^+$

$\text{NSAID} \rightarrow \downarrow \text{COX-1} \quad \downarrow \text{COX-2}$

Aspirin \downarrow
 $\text{NSAIDs} \downarrow$

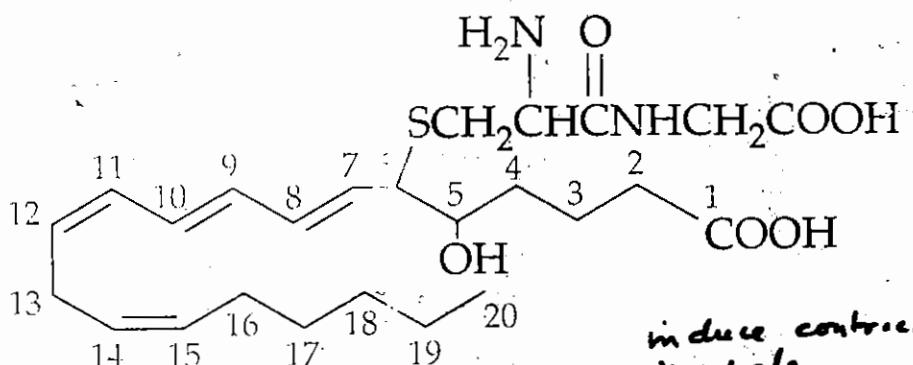
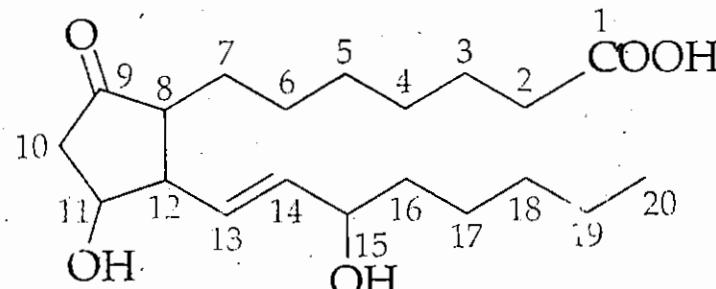


Cortisone (anti-inflammatory steroid)
inhibit phospholipase A₂ which
releases arachidonic acid

Multistep
enzyme-catalyzed
synthesis
*Cyclooxygenase (Prostaglandin
synthase)*

Multistep
enzyme-catalyzed
synthesis
Lipoxygenase

not inhibited by aspirin



induce contraction of
muscle

\downarrow
Thromboxanes (\uparrow blood clotting)

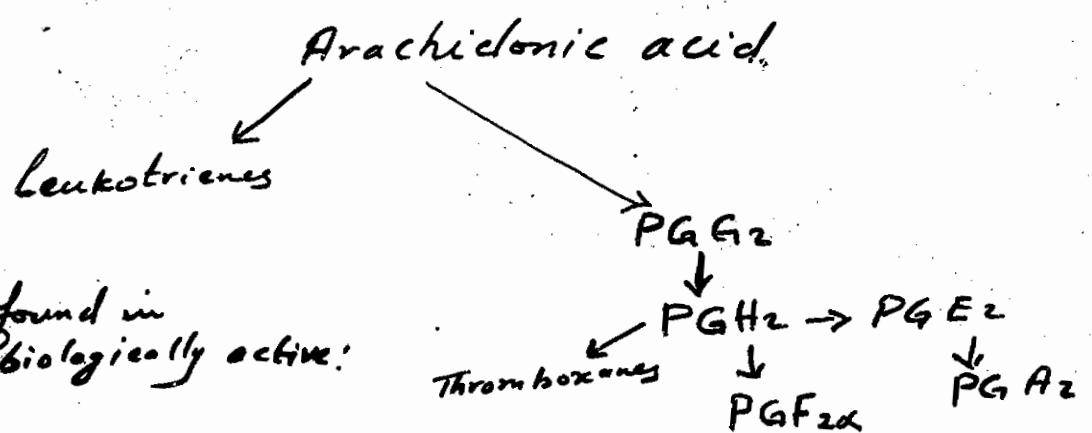
Eicosanoids:-

Lipids, not found in membrane - biologically active.

• Waxes

• Eicosanoids

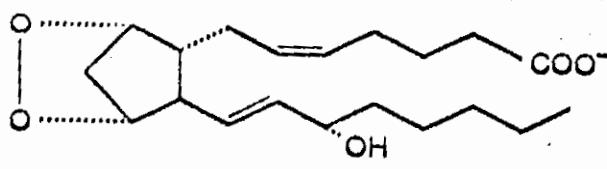
• other isoprenoids



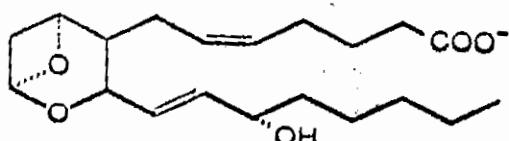
Wax:-

non-polar esters of long chain F.A. and long chain mono-hydroxylic alcohols.

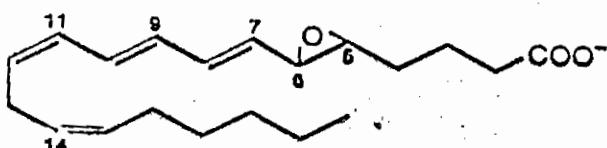
e.g. Mericetyl palmitate
in beeswax



A prostaglandin (PGH₂)



A thromboxane (TXA₂)



A leukotriene (LTA₄)

Fig. 6.32. Some eicosanoids.

- Activation of inflammatory response
- production of fever
- " = pain
- induction of blood clotting
- induction of labor
- regulation of sleeping
- etc. -

The COX Enzymes

COX-1 : [Constitutive enzyme]
in most tissues, house-keep enzyme especially in GI & stomach

COX-2: Inducible enzyme

- Inflammatory stimuli → injury → disease
- ↑ COX-2 → ↑ PG
- pain and swelling

NSAIDs (e.g aspirin, ibuprofen, naproxen)

- Analgesic + antipyretic
- ↓ COX-1 and COX-2
- Have side-effects GI ulceration

Selective COX-2 Inhibitors:

e.g Vioxx, Celebrex

- increase risk of heart attacks and stroke.

COX Inhibitors

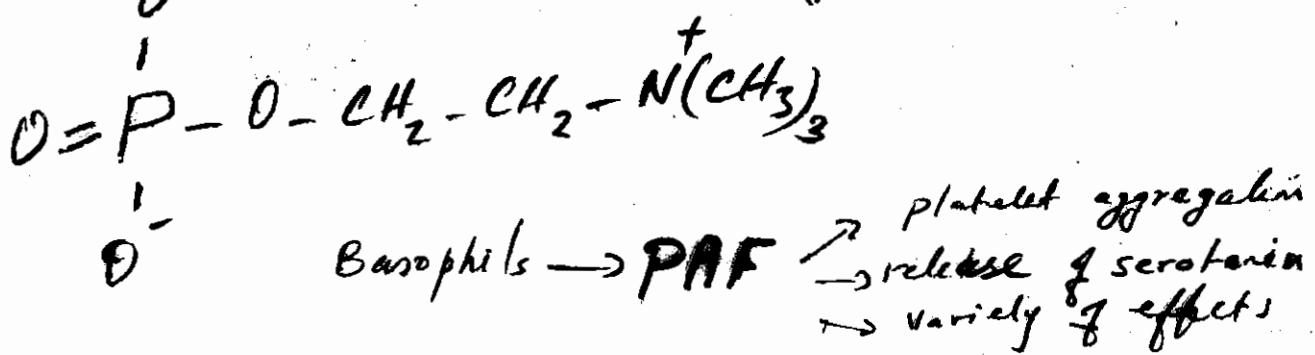
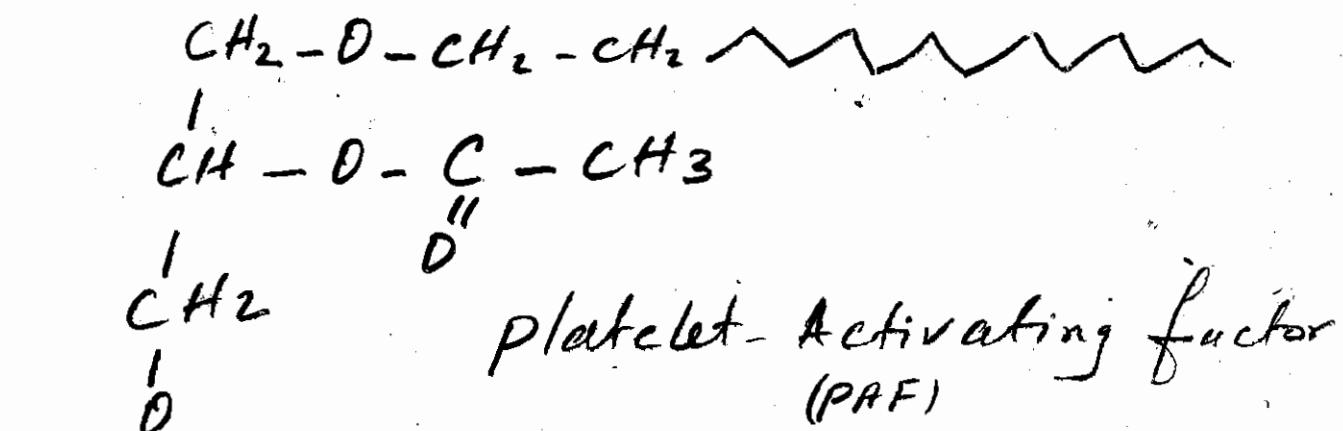
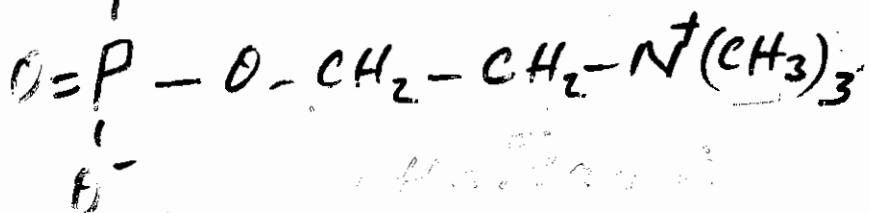
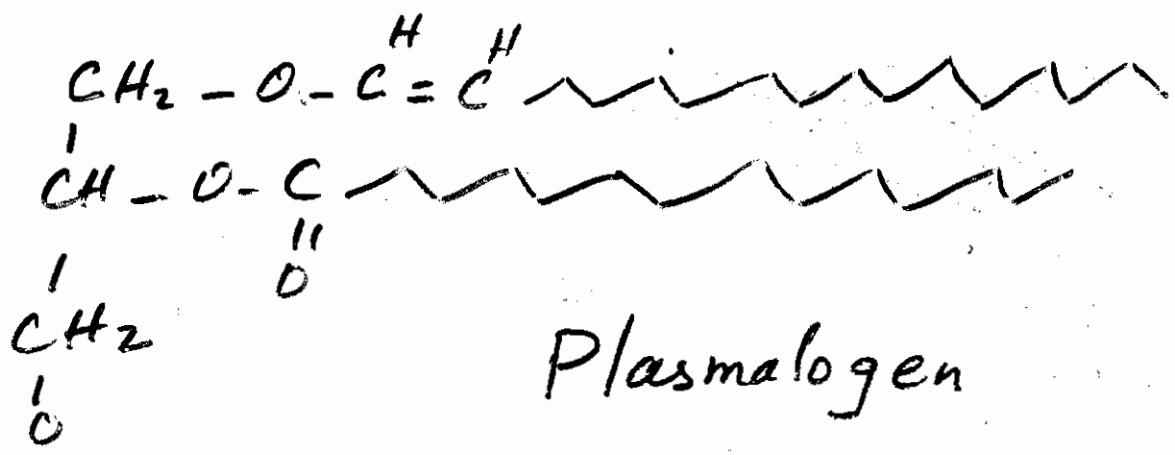
- ↓ Alzheimer's disease
and colorectal cancers

Isoenzyme COX-3 only inhibited by acetaminophen (analgesic + antipyretic)

Plasmalogens:

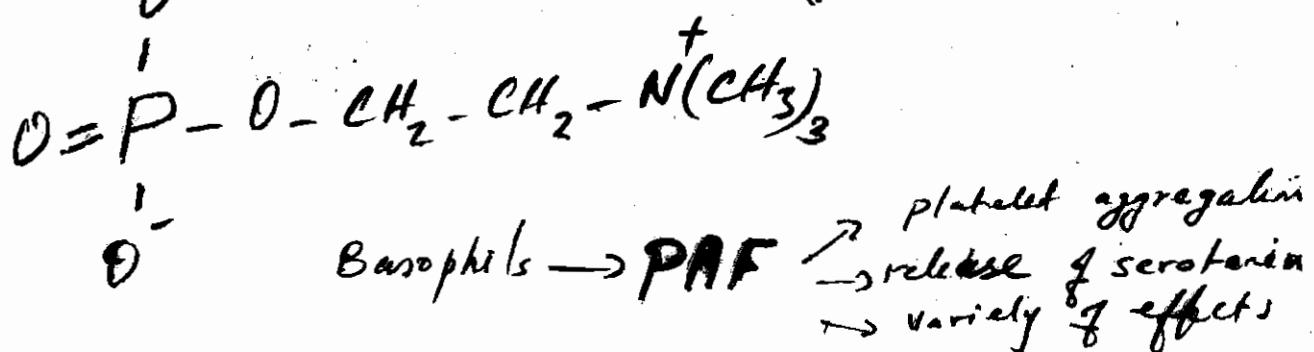
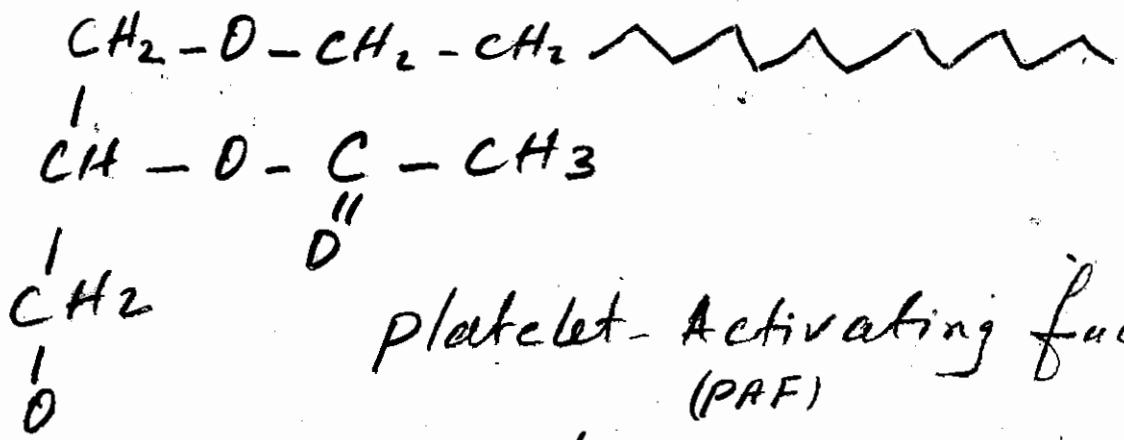
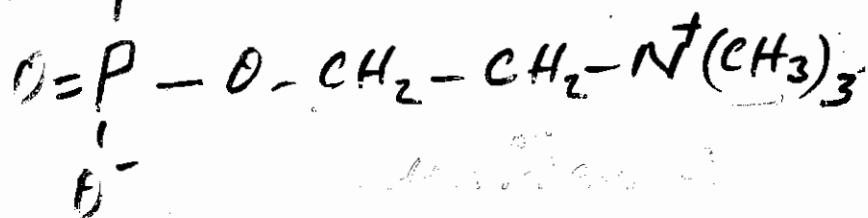
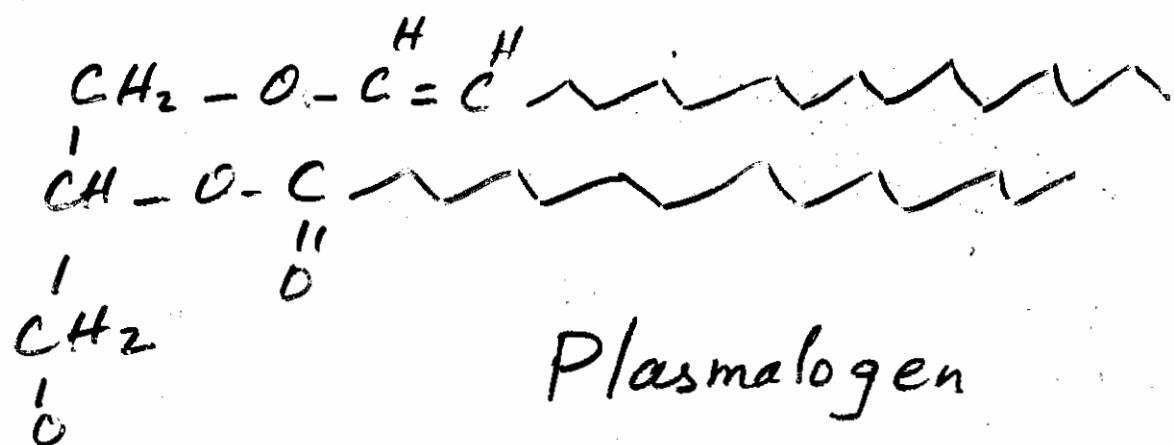
(constitute 10% of muscle phospholipids)

Ether-linked alkyl chain attached to glycerol - present in heart + muscle phospholipids



Plasmalogens: (constitute 15% of muscle phospholipids)
phospholipids)

Ether-linked alkyl chain attached to glycerol - present in heart & muscle phospholipids



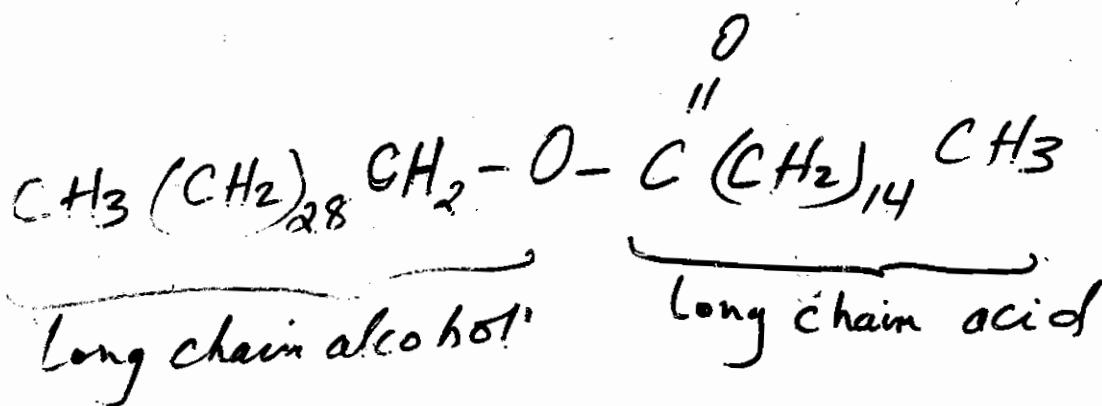
Waxes

Simplest fatty acid ester in nature

Fatty acid - Long-chain alcohol esters

Fatty acid → 16-C to 36-C even no.

Alcohol → 24-C to 36-C



beeswax

Lipid-Soluble Vitamins

Vitamin A -

photochemical reaction
in vision

Vitamin D -

Regulate Ca & P
metabolism

Vitamin E -

Antioxidant

Vitamin K -

regulatory function -
blood clotting

Fish oils - Omega - 3 fatty acids

→ healthy heart & much more

Eicosapentaenoic acid

EPA, 20:5 Δ 5,8,11,14,17

Docosahexaenoic acid Δ 4,7,10,13,16,19

DHA, 22:6

→ 30% of total fat in the oil of
cold-water fish

- Prevention of cardiovascular diseases
TG, LDL cholesterol, BP, heart rate ↓
PGF → blood clotting ↓

- prevention of some cancers, joint stiffness, depression
preservation of cognitive function

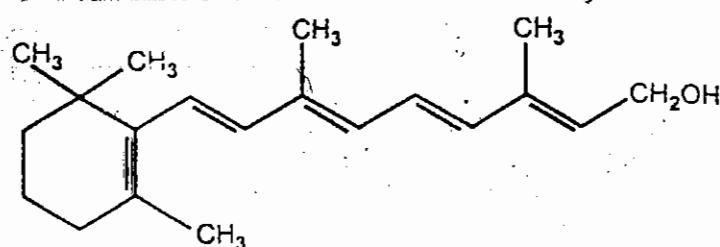


Figure 7.18: Structure of vitamin A, retinol

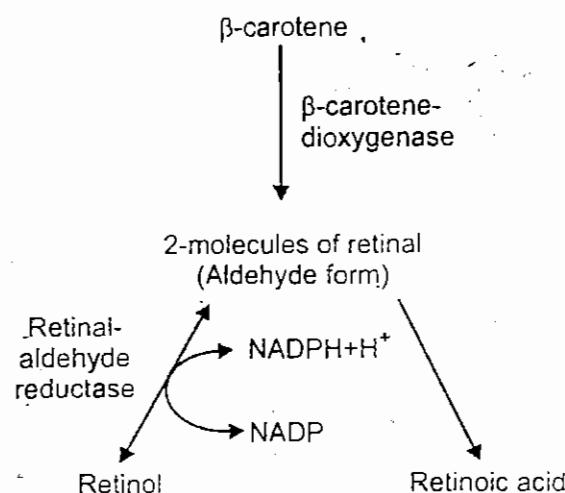


Figure 7.19: Conversion of β -carotene (provitamin) to biologically active forms of vitamin A

CHEMISTRY

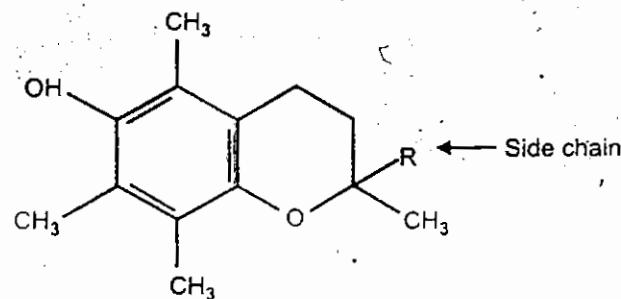


Figure 7.26: Structure of α -tocopherol

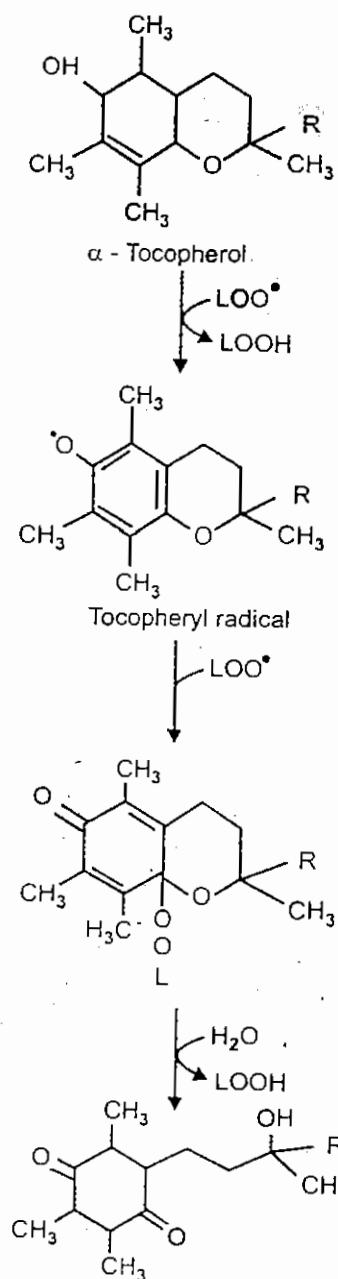


Figure 7.27: The mode of action of vitamin E as antioxidant.
Where $\text{L}\cdot\text{OOH}$ = Lipid peroxide

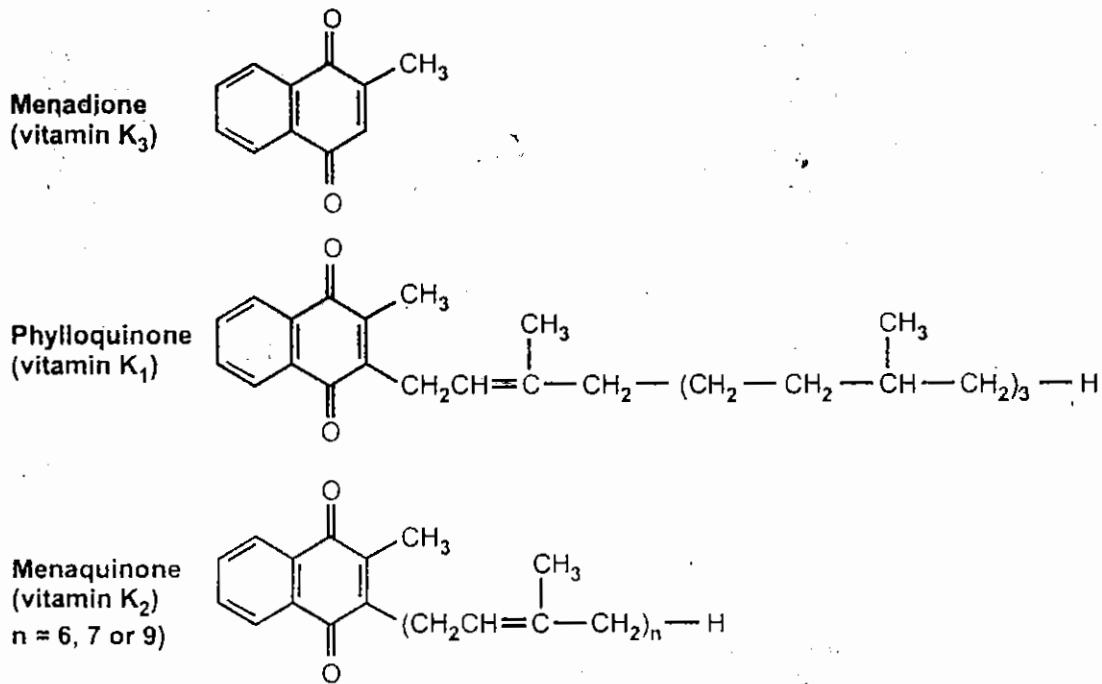


Figure 7.28: Structure of vitamin K

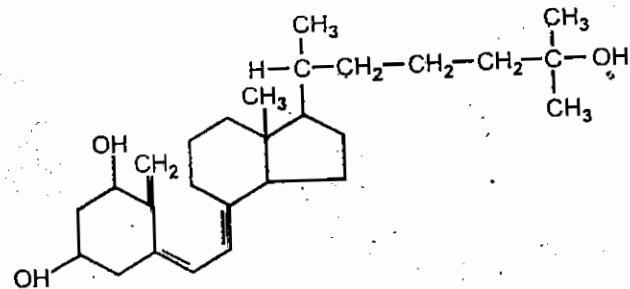


Figure 7.21: Structure of 1,25 dihydroxycholecalciferol an active form of vitamin D₃

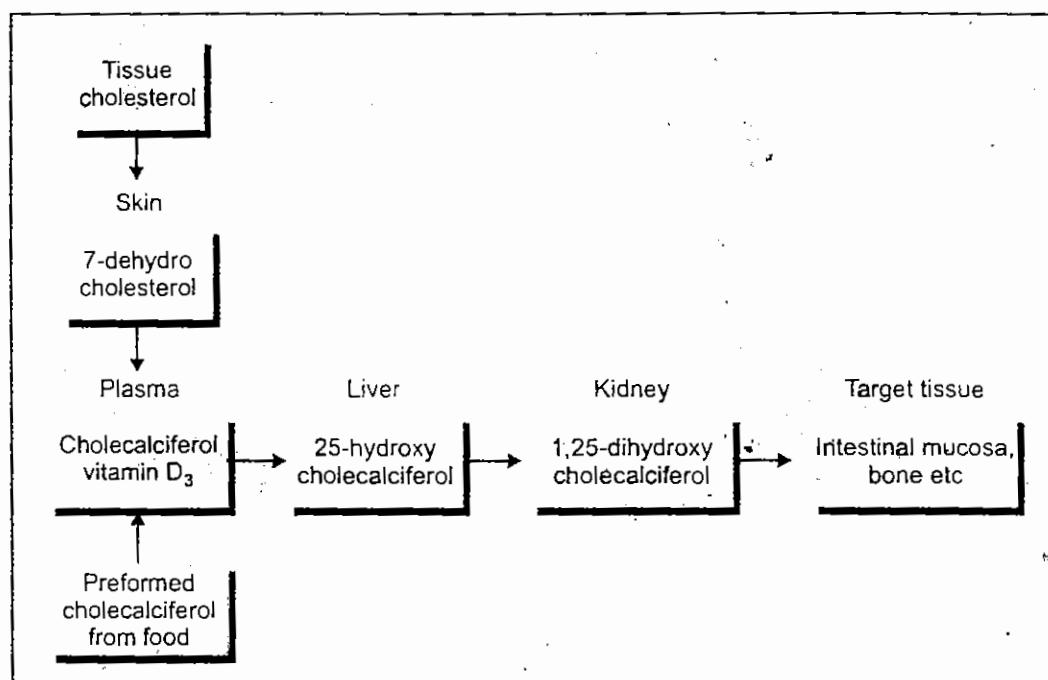


Figure 7.24: Sites of formation of vitamin D₃ to its metabolically active form 1,25-dihydroxy cholecalciferol