MSB 100/BPT 111/NSB 111 & BDS/MPY/MLS: BASICS OF BIOMEDICAL SCIENCES

Topics: Lipids-classification, structure, function & properties

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What are Lipids?

- Lipids are a broad range of organic compounds (C, H and other polar atoms) that dissolve easily in organic solvents, but range in their solubility in water i.e. they are **hydrophobic** – "water-fearing" or can be defined as **lipophilic** – "fat-loving" compounds.

I. Lipids are classified as simple or complex

1. Simple lipids

a. Fatty acids
b. Neutral fats (Monoacylglycerols-MAGs, diacylglycerols-DAGs, triacylglycerols-TAGs)
c. Waxes (esters of fatty acids with higher alcohols)-sterol esters, Vit A

2. Complex lipids

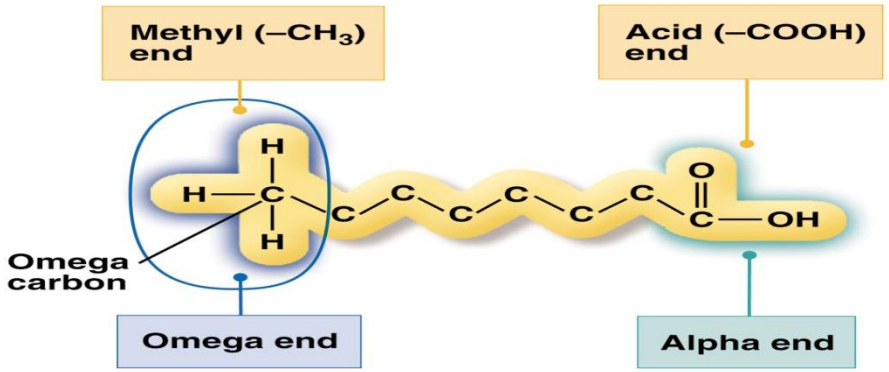
a. Phospholipids (e.g lecithin, sphingomyelins)
b. Glycolipids
c. Lipoproteins

3. Derived lipids (derivatives such as sterols and straight chain alcohols obtained from hydrolysis of those lipids in groups 1 and 2)

II. Cont.-Lipid classification (Other)

A. Storage Lipids: Fatty Acids

- Key building blocks for lipids
- Chains of carbon atoms with a carboxyl group at one end, and a methyl group at the other
- May be "free" or attached to another compound
- Structure determines the characteristics of the fat



NOMENCLATURE

1. Alpha and Omega
2. 18:0, 18:1, etc. (18 refers to carbon chain length, and the number following the colon refers to the total number of double bonds)

Fatty Acids

CHAIN LENGTH

- Short chain = less than 6 carbons
- Medium chain = 6-12 carbons
- Long chain = 14 or more carbons
- The shorter the carbon chain, the more liquid the fatty acid is

SATURATION

SATURATED FATTY ACID =If all the carbon atoms in the chain are joined with single bonds, and the remaining bonds are attached to hydrogen

UNSATURATED FATTY ACID = If adjoining carbons are joined by double bonds

-One double bond = **monounsaturated fatty acid**

-Two or more double bonds = **poly-unsaturated fatty acid**

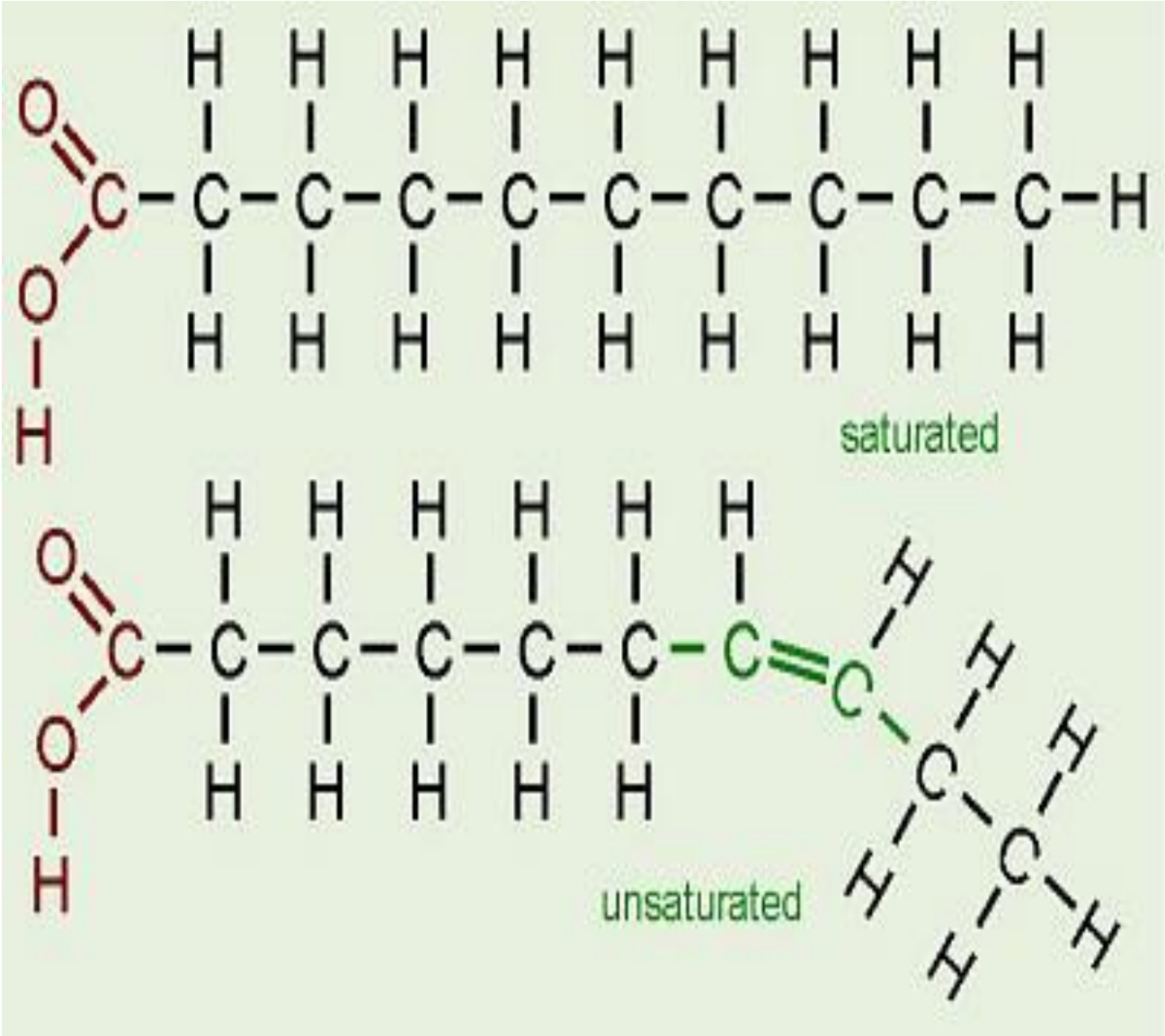
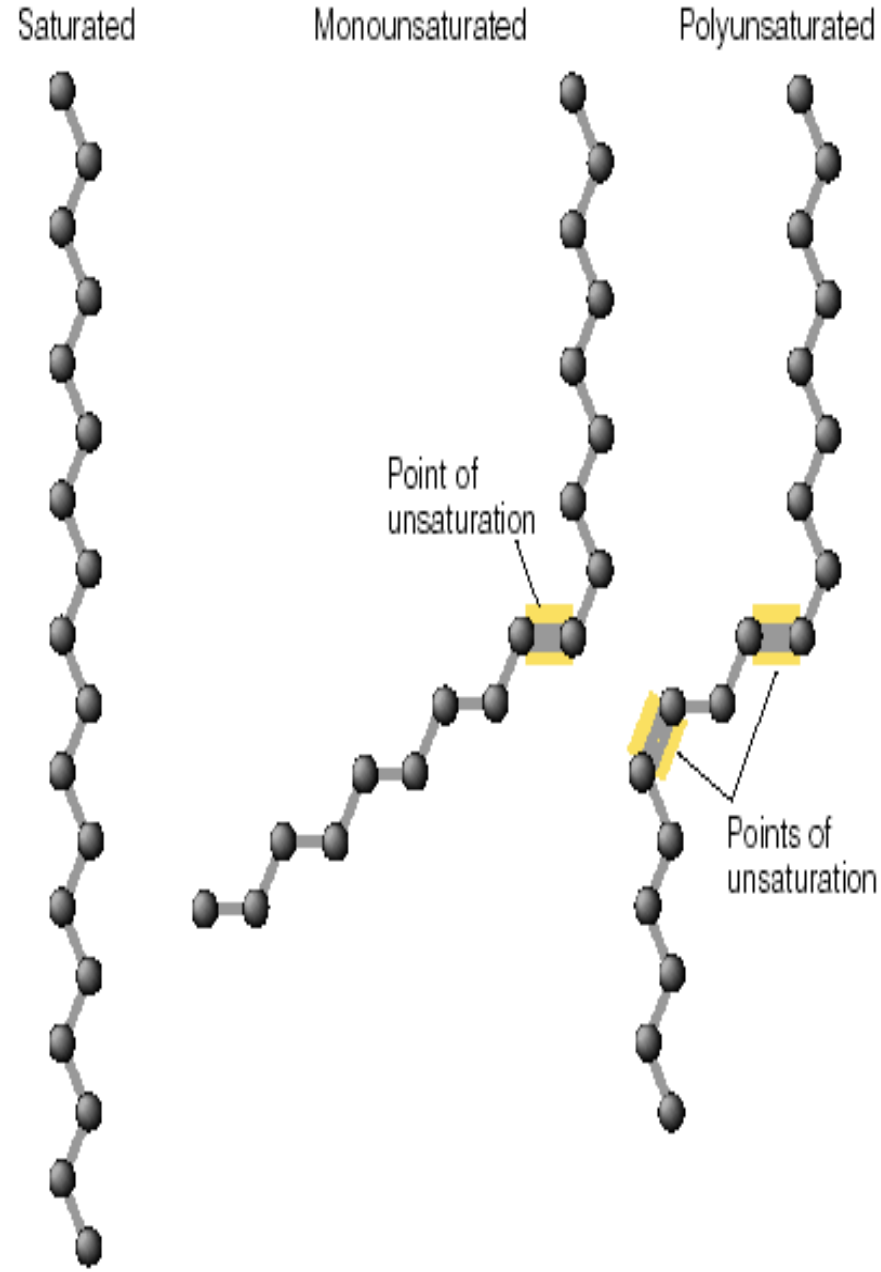

saturated
unsaturated

Figure 3–3

Three Fatty Acids

The more carbon atoms in a fatty acid, the longer its chain. The more hydrogen atoms attached to those carbons, the more saturated the fatty acid.



Fatty Acids

- Long-chain saturated fatty acids stack tightly and form solids at room temperature

- Monounsaturated and polyunsaturated fatty acids do not stack compactly and are liquid at room temperature

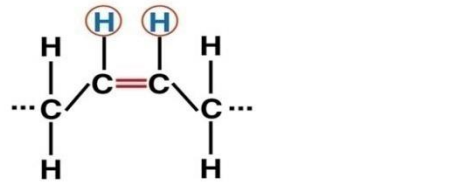
- Short-chain saturated fatty acids are also liquid at room temperature

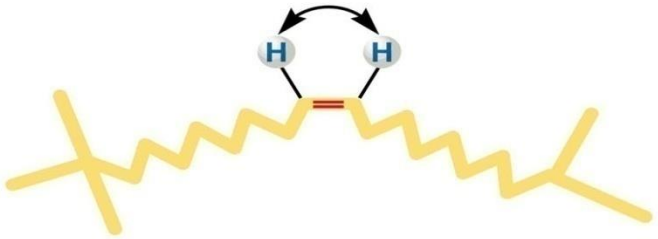
At room temperature, unsaturated fats (such as those found in oil), are usually liquid, whereas saturated fats (such as those found in butter) are solid.

Fatty Acids

TWO TYPES OF BOND FORMATION:

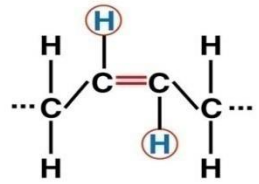
- CIS - hydrogens on the carbons joined by a double bond are on the same side = the carbon chain is bent

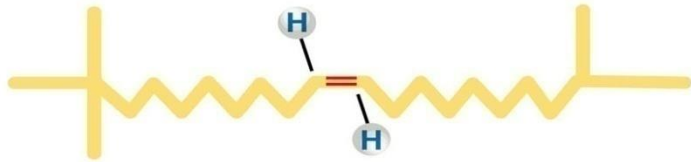




Cis form (bent)

- TRANS – hydrogens on the carbons joined by a double bond are on the opposite side = the carbon chain is straighter



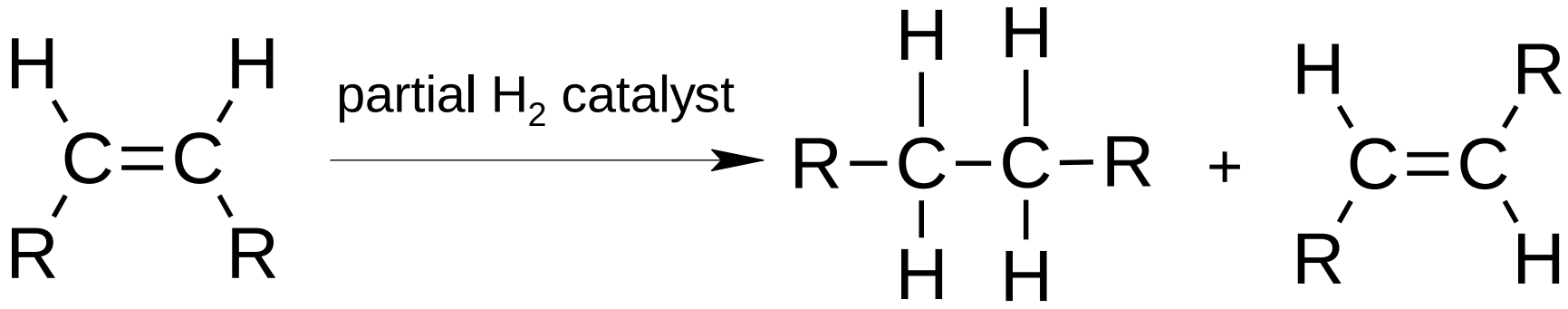


Trans form (straighter)

Cis vs. Trans Fatty acids

- Almost all natural unsaturated fatty acids have cis stereochemistry in C=C's.
- Small amounts of trans are produced in stomachs of ruminating animals by partial enzymatic hydrogenation of polyunsaturated fats, and thus are present in small amounts in milk and butter

Commercial Hydrogenation of Fatty Acids

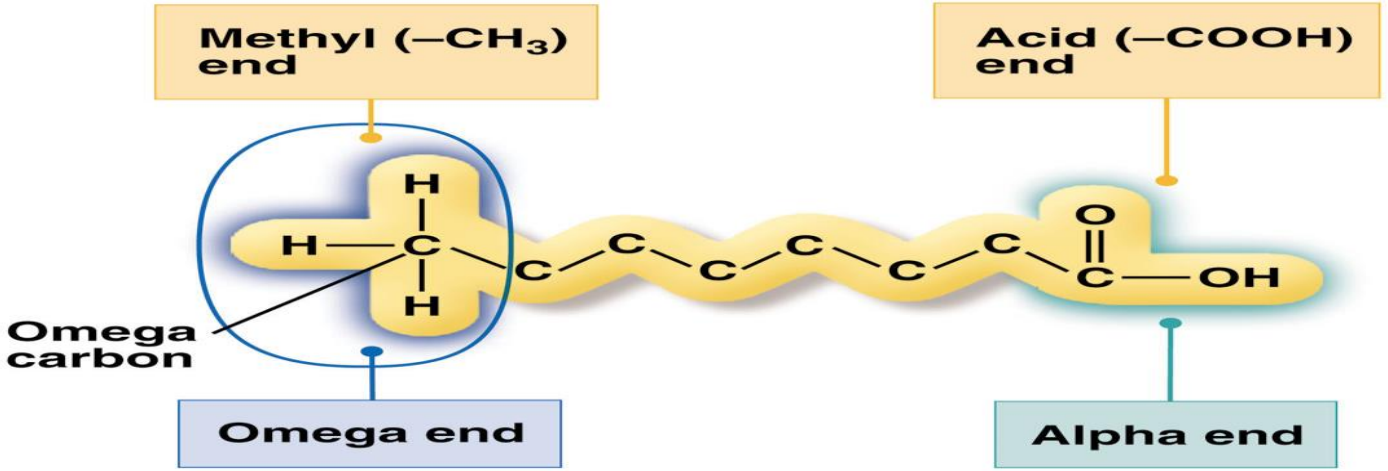


‘cis’		‘trans’
unsaturated	saturated	unsaturated
natural	natural	unnatural
good	bad	bad

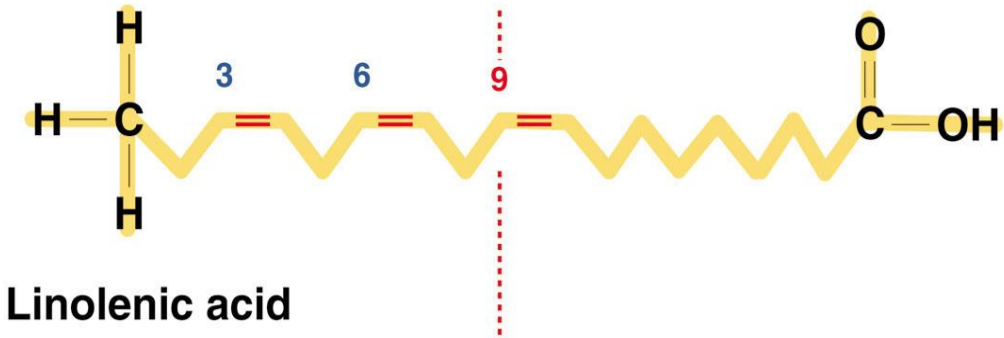
Fatty Acids

- Omega-3 Fatty Acid – double bond at carbon 3
- Omega-6 Fatty Acid – double bond at carbon 6
- Omega-9 Fatty Acid – double bond at carbon 9

- *count carbons from the methyl (omega) end

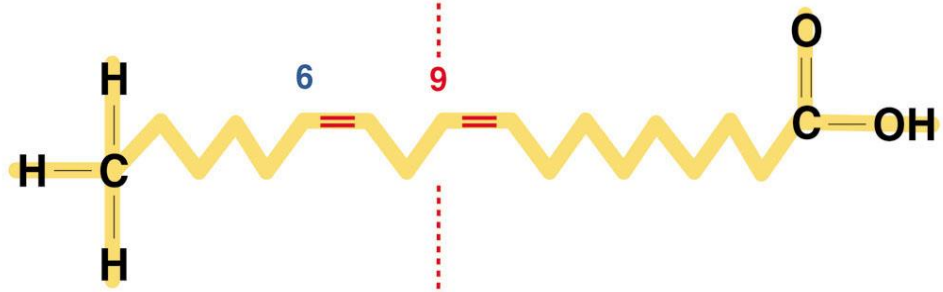


- Omega 3



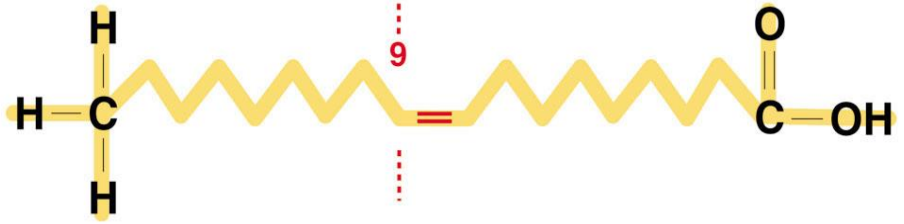
Linolenic acid

- Omega 6



Linoleic acid

- Omega 9



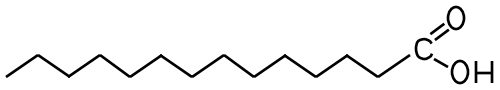
Oleic acid

Essential fatty acids (humans cannot synthesize and have to get from diet-linoleic & linolenic

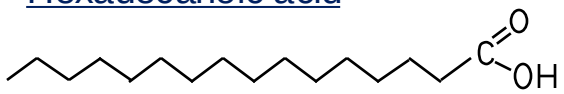
Examples of Fatty Acids

Saturated Fatty Acids

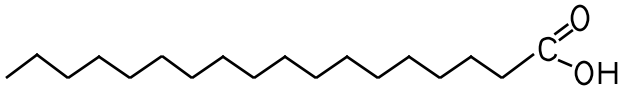
Myristic acid 14:0
Tetradecanoic acid



Palmitic acid 16:0
Hexadecanoic acid

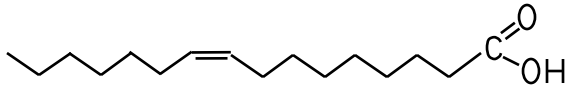


Stearic acid 18:0
Octadecanoic acid

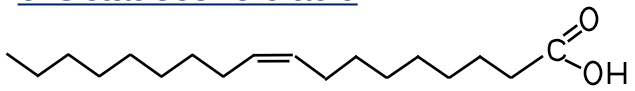


Mono-unsaturated Fatty Acids

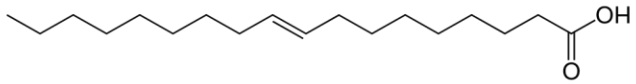
Palmitoleic acid 16:1 Δ9
9-Hexadecenoic acid



Oleic acid 18:1 Δ9
9-Octadecenoic acid

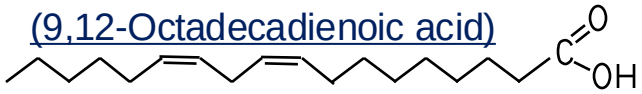


Elaidic acid 18:1 Δ9 trans
9-trans-Octadecenoic acid

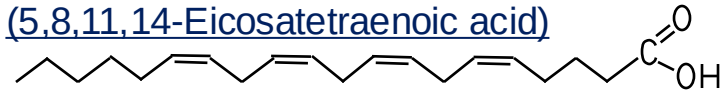


Poly-unsaturated Fatty Acids

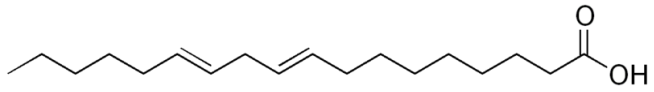
Linoleic acid 18:2 Δ9,12
(9,12-Octadecadienoic acid)



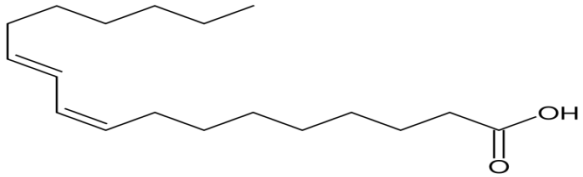
Arachidonic acid 20:4 Δ5,8,11,14
(5,8,11,14-Eicosatetraenoic acid)



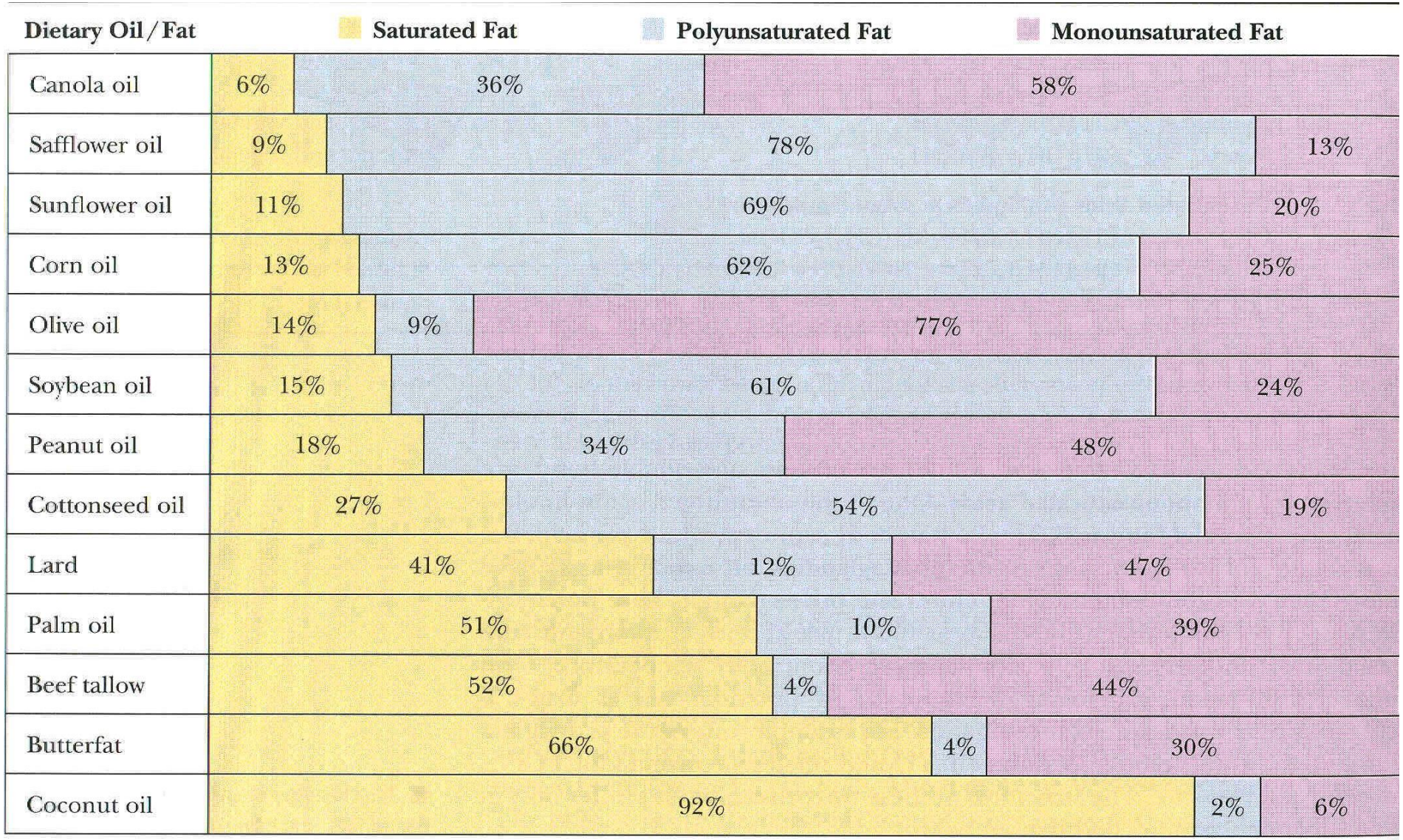
Linoelaidic acid 18:2 Δ9,12 trans
trans, trans-9,12-octadecadienoic acid



Conjugated linoleic acid (CLA) 18:2 Δ9,12 cis, trans
9-cis-11-trans-octadecadienoic acid



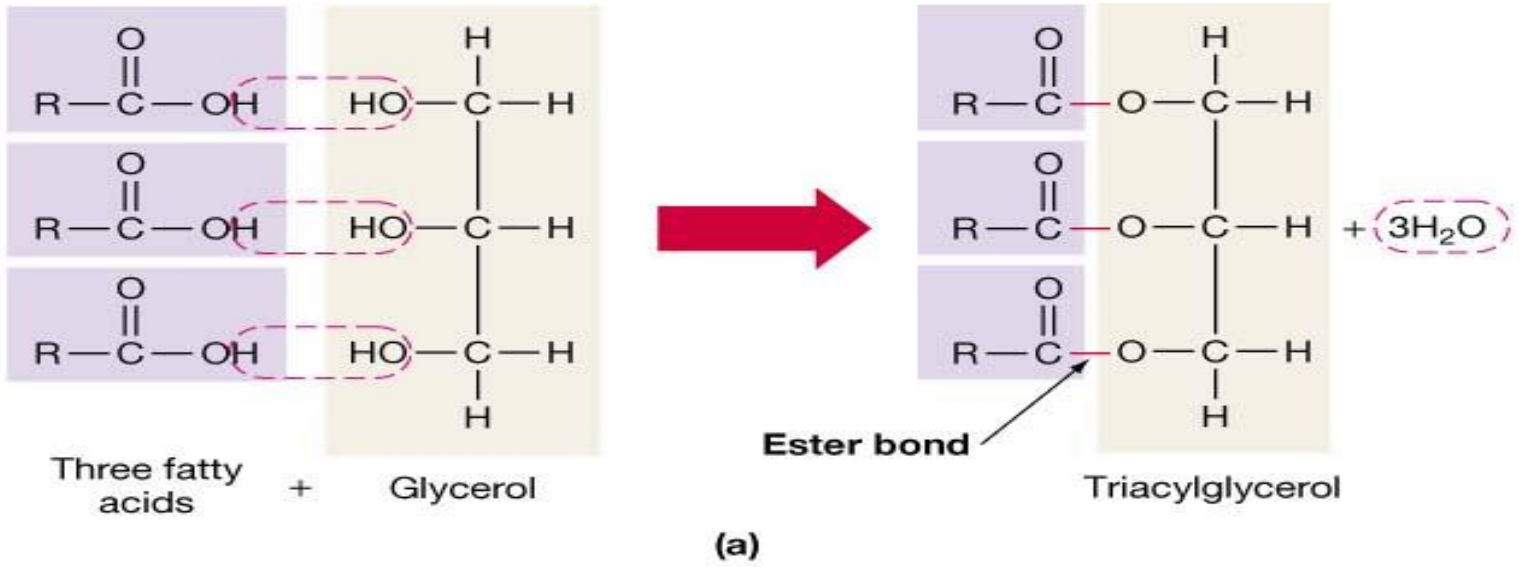
Fatty Acid Content of some Fats/Oils



Dietary Oil / Fat	Saturated Fat	Polyunsaturated Fat	Monounsaturated Fat
Canola oil	6%	36%	58%
Safflower oil	9%	78%	13%
Sunflower oil	11%	69%	20%
Corn oil	13%	62%	25%
Olive oil	14%	9%	77%
Soybean oil	15%	61%	24%
Peanut oil	18%	34%	48%
Cottonseed oil	27%	54%	19%
Lard	41%	12%	47%
Palm oil	51%	10%	39%
Beef tallow	52%	4%	44%
Butterfat	66%	4%	30%
Coconut oil	92%	2%	6%

B. Storage Lipids: Triacylglyecrol

- Triacylglycerols contain **three fatty acid molecules** esterified to the three hydroxyl groups of **glycerol**. They are primarily storage fats and are present in many foods.



Triacylglycerols

STRUCTURE

- Triacylglycerol - three fatty acids attached to a glycerol backbone
- Diacylglycerol– two fatty acids + glycerol
- Monoacylglycerol – one fatty acid + glycerol

FUNCTIONS

-Major lipid in the body and diet
-Stored fat (in adipose tissue) provides about 60% of the body's resting energy needs
-Insulation and protection
-Carrier of fat-soluble compounds
-Sensory qualities – flavor and texture

--TAGs account for nearly 95% of dietary fat

Adipose Tissue / Fat

- Adipose tissue forms cushioning shields around our major organs, protecting them against damage from physical shock and provides insulation to our bodies, guarding against a rapid loss of body heat to the external environment.

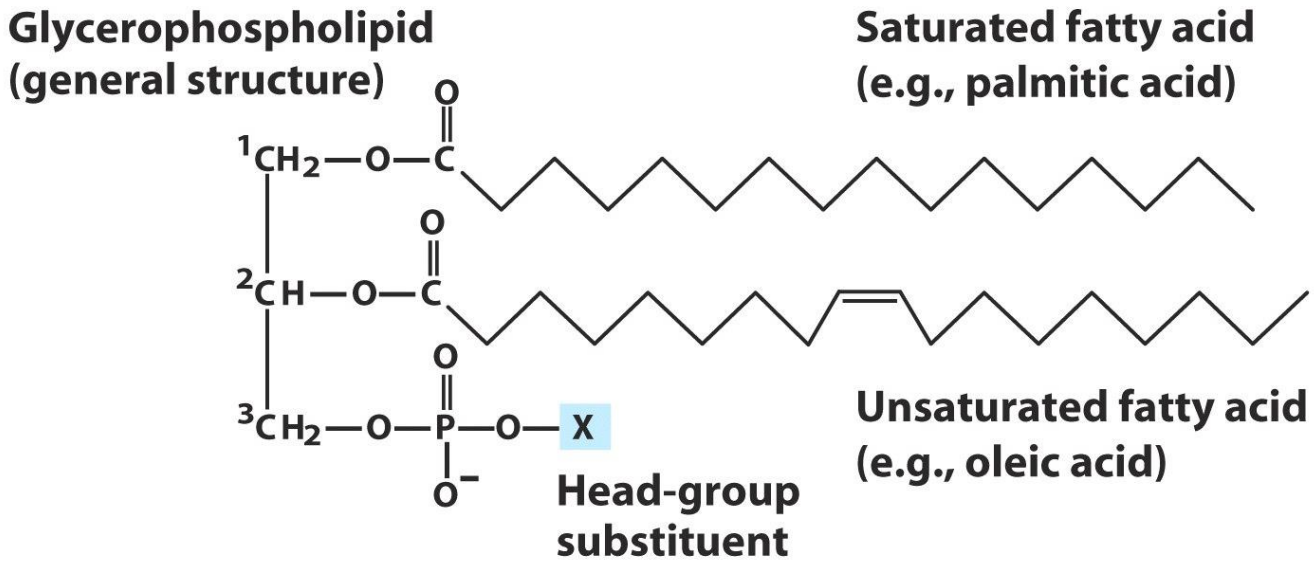
- Fats carry the flavours and vitamins of many of our foods although fats have no flavours of their own, eg. carrying vitamins A, D, E and K from our foods to our tissues.

- Fatty acids form not only the triglycerides but other compounds as well, including such vital classes as prostaglandins and phospholipids.

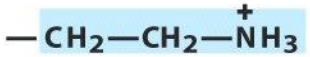
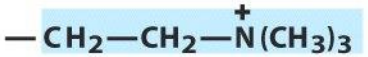
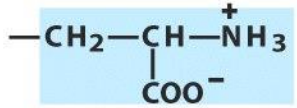
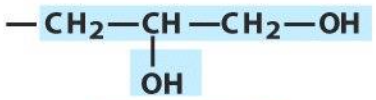
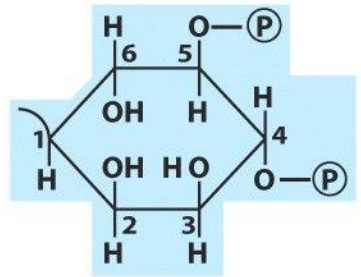
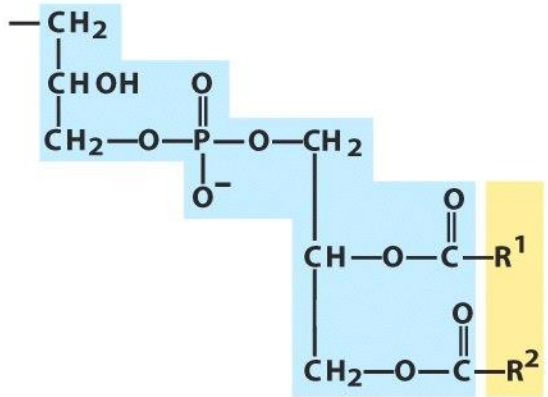
C. Structural Lipids; Phospholipids

(i) Glycerophospholipids

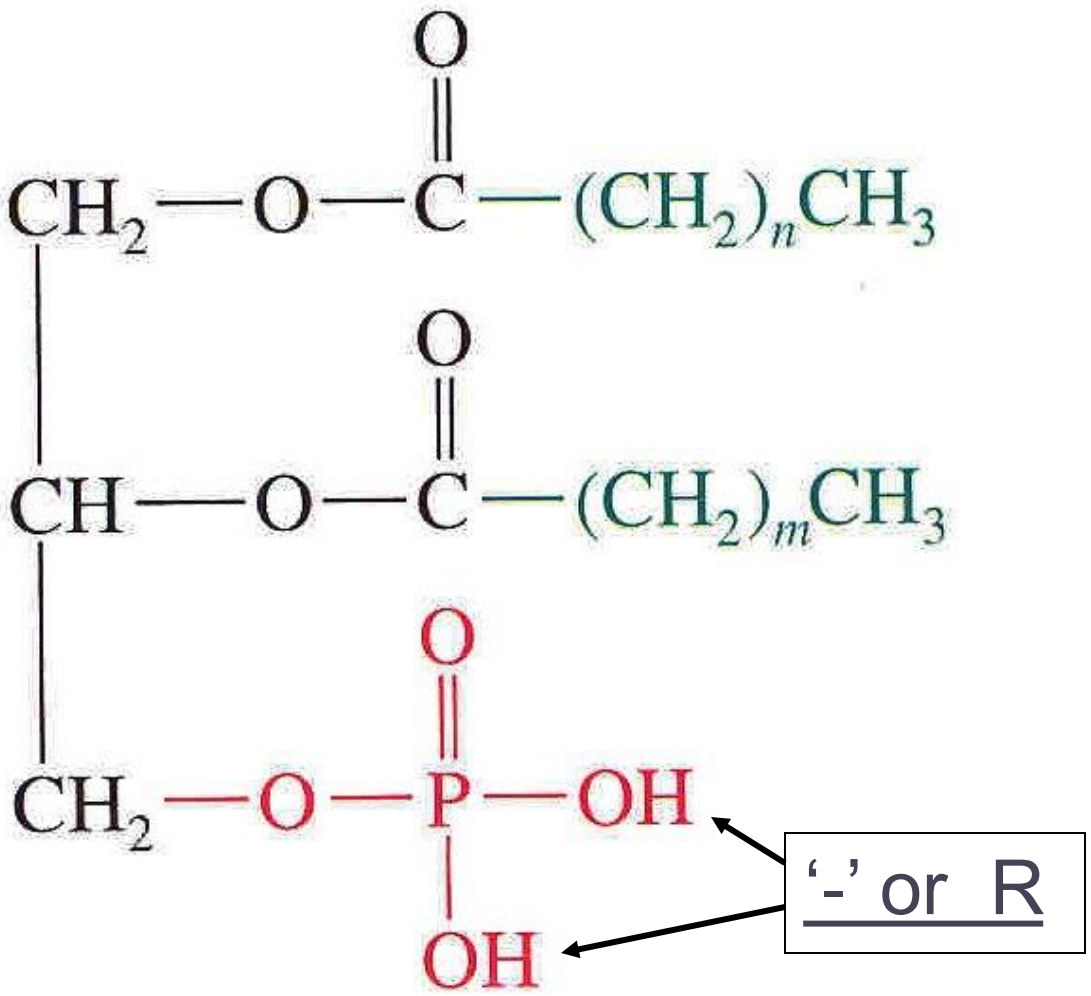
- They are membrane lipids in which two fatty acids are attached in ester linkage to the first and second carbons of glycerol, and a highly polar or charged group is attached through a phosphodiester linkage to the third carbon.



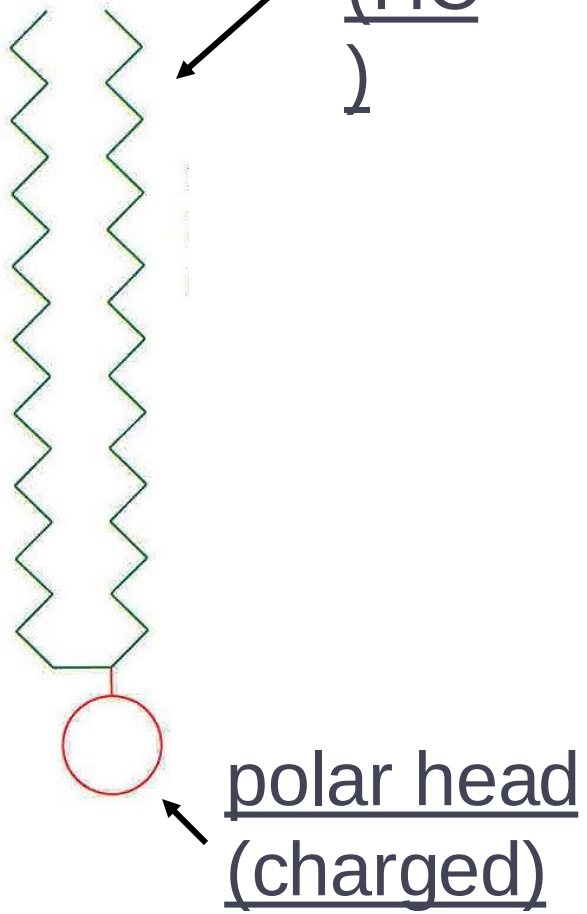
NB: They differ in the structure of their head group; refer to next slide for the different names.

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

Phospholipids



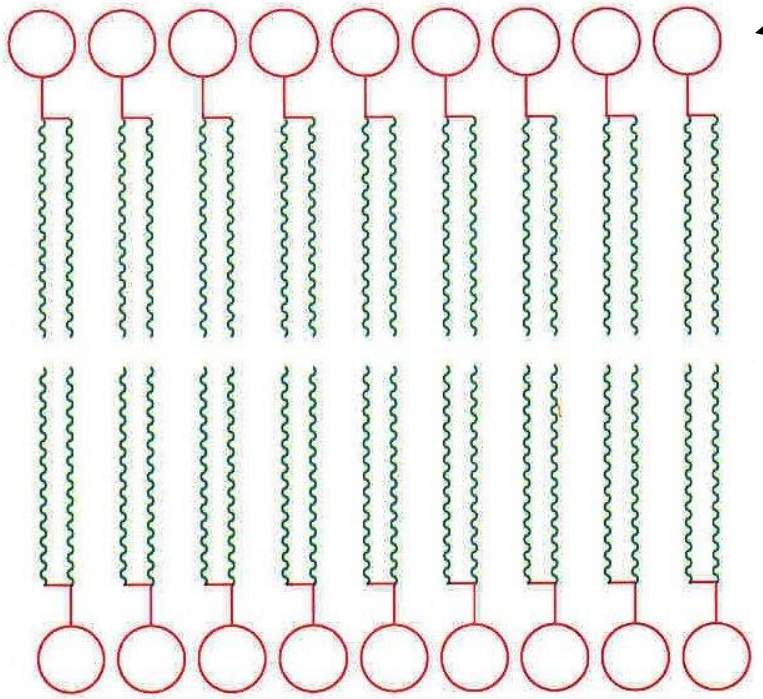
a phosphatidic acid



Phospholipid Bilayer = Cell Membrane/Wall

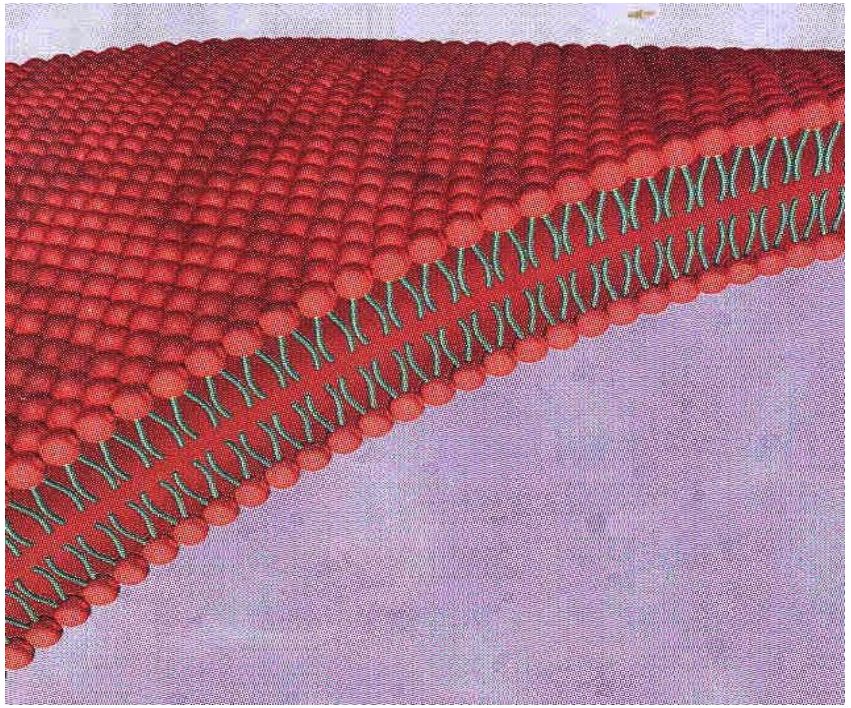
-water outside cell-

hydrophilic surface



hydrophobic interior of cell wall

-water inside cell-



Glycerophospholipids

- Contain a glycerol bonded to two fatty acids, with phosphate group(s)
- The phosphate group is hydrophilic while the fatty acids groups are lipophilic
- Because of this structure, phospholipids are ideal emulsifiers, and the perfect structure for cell membranes

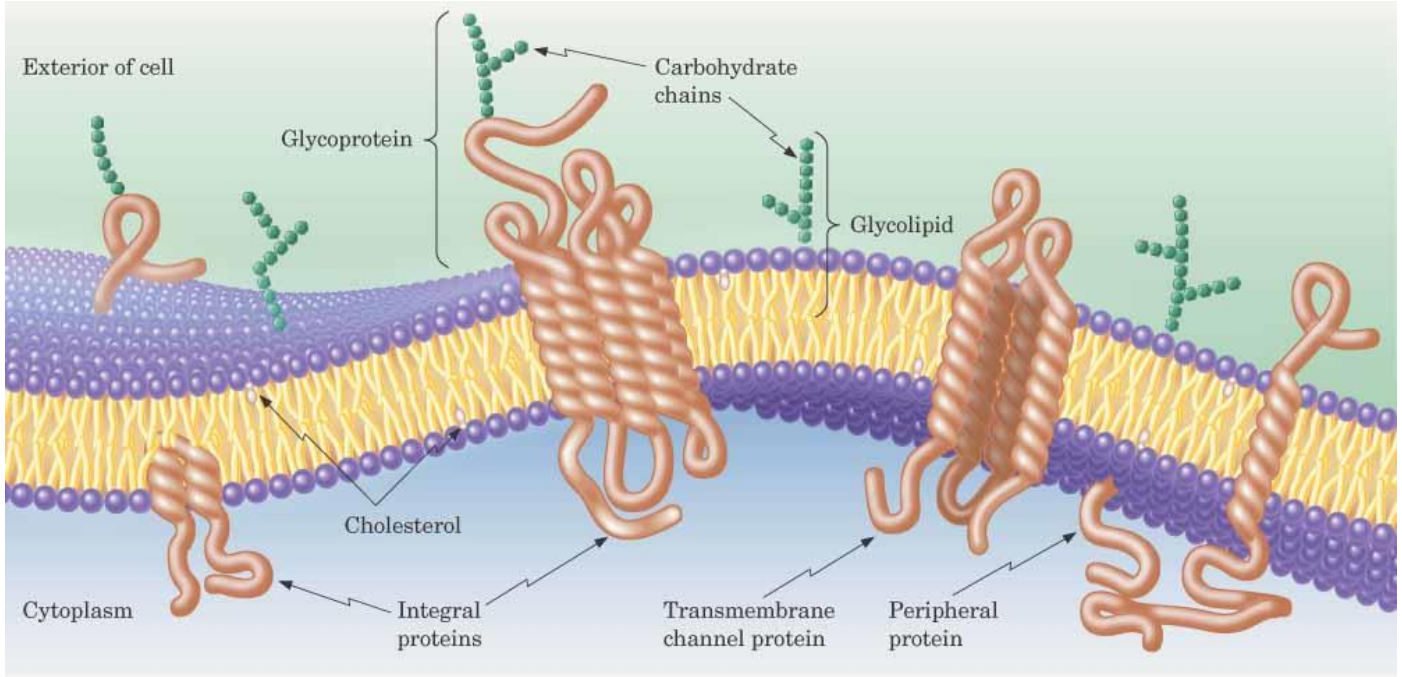
FUNCTIONS

1. Structural components of cell membranes
   - Phosholipids are the major component of cell membranes
   - Fatty acids, choline, as well as other substances are bound in the phospholipid layer
2. Lipid Transport
   - In the stomach
   - In the intestine
3. Emulsifiers

Biological Membranes

- Fluid mosaic model: a biological membrane consists of **a phospholipid bilayer** with proteins, carbohydrates, and **other lipids embedded** on the surface and in the bilayer
  - fluid signifies that the protein components of membranes "float"in the bilayer and can move freely along the plane of the membrane
  - mosaic signifies that the various components of the membrane exist side-by-side, as discrete units rather than combining to form new molecules and ions

The yellow part is the **phospholipid bilayer**



C. Structural Lipids; Phospholipids
(ii) Sphingolipids

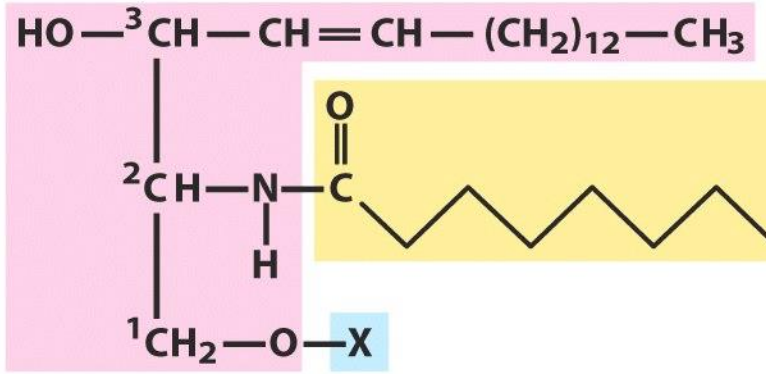
• Sphingolipids have a polar head group and two nonpolar tails, but unlike glycerophospholipids and galactolipids they contain no glycerol.

• Sphingolipids are composed of one molecule of the long-chain amino alcohol **sphingosine** (also called 4-sphingenine) or one of its derivatives, one molecule of a **long-chain fatty acid**, and **a polar head group** that is joined by a glycosidic linkage in some cases and by a phosphodiester in others.

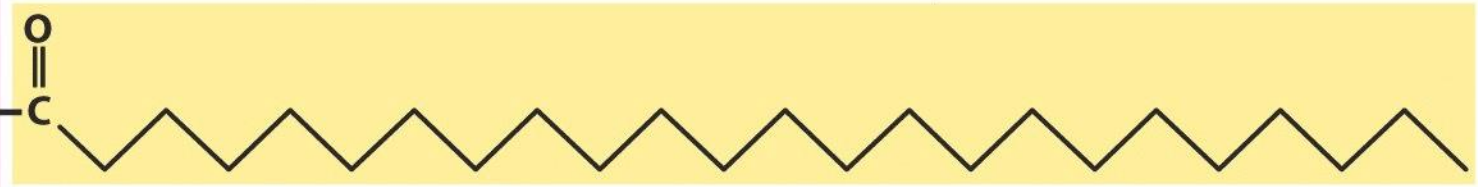
• Examples of sphingolipids: **ceramide, sphingomyelin, neutral glycolipids, gangliosides**

• Sphingomyelins are present in the plasma membranes of animal cells and are especially prominent in myelin, a membranous sheath that surrounds and insulates the axons of some neurons—thus the name "sphingomyelins."

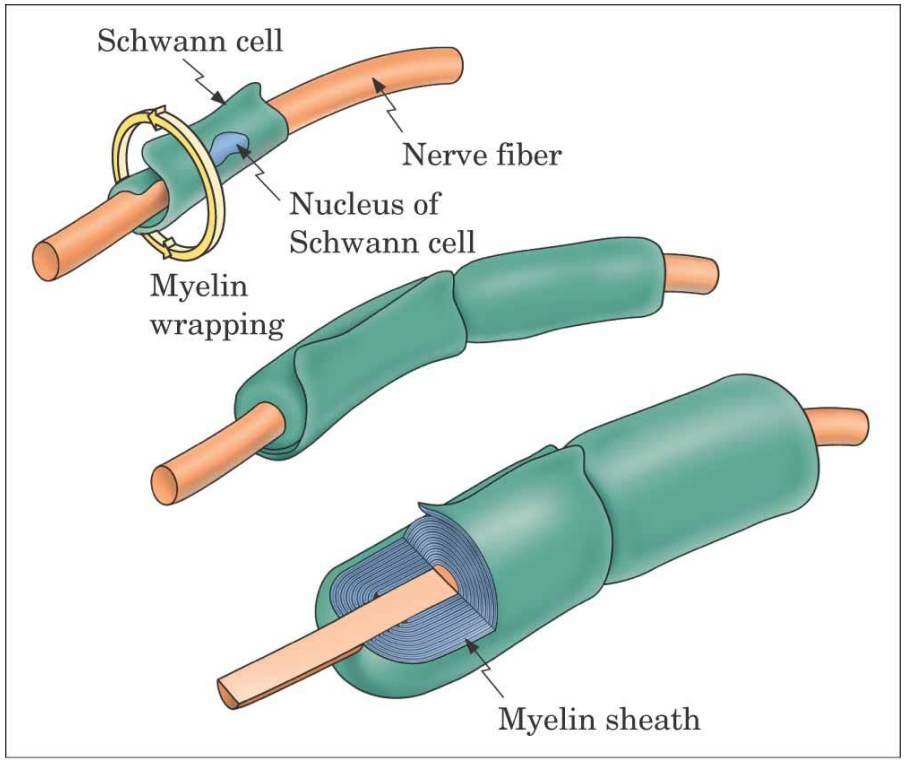
Sphingosine

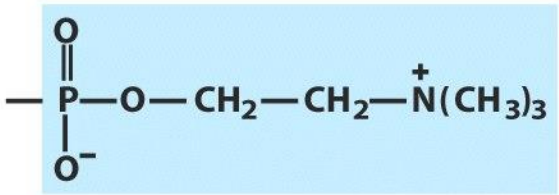
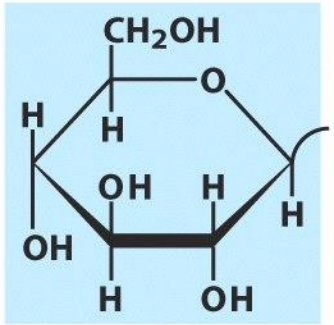
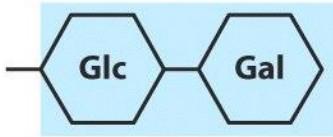
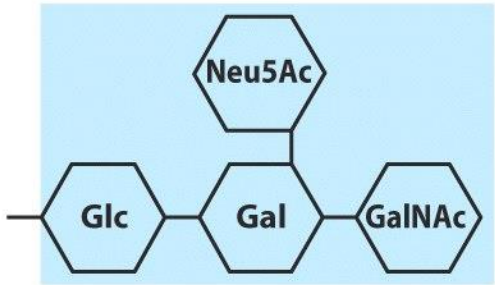


Fatty acid



Sphingolipid (general structure)



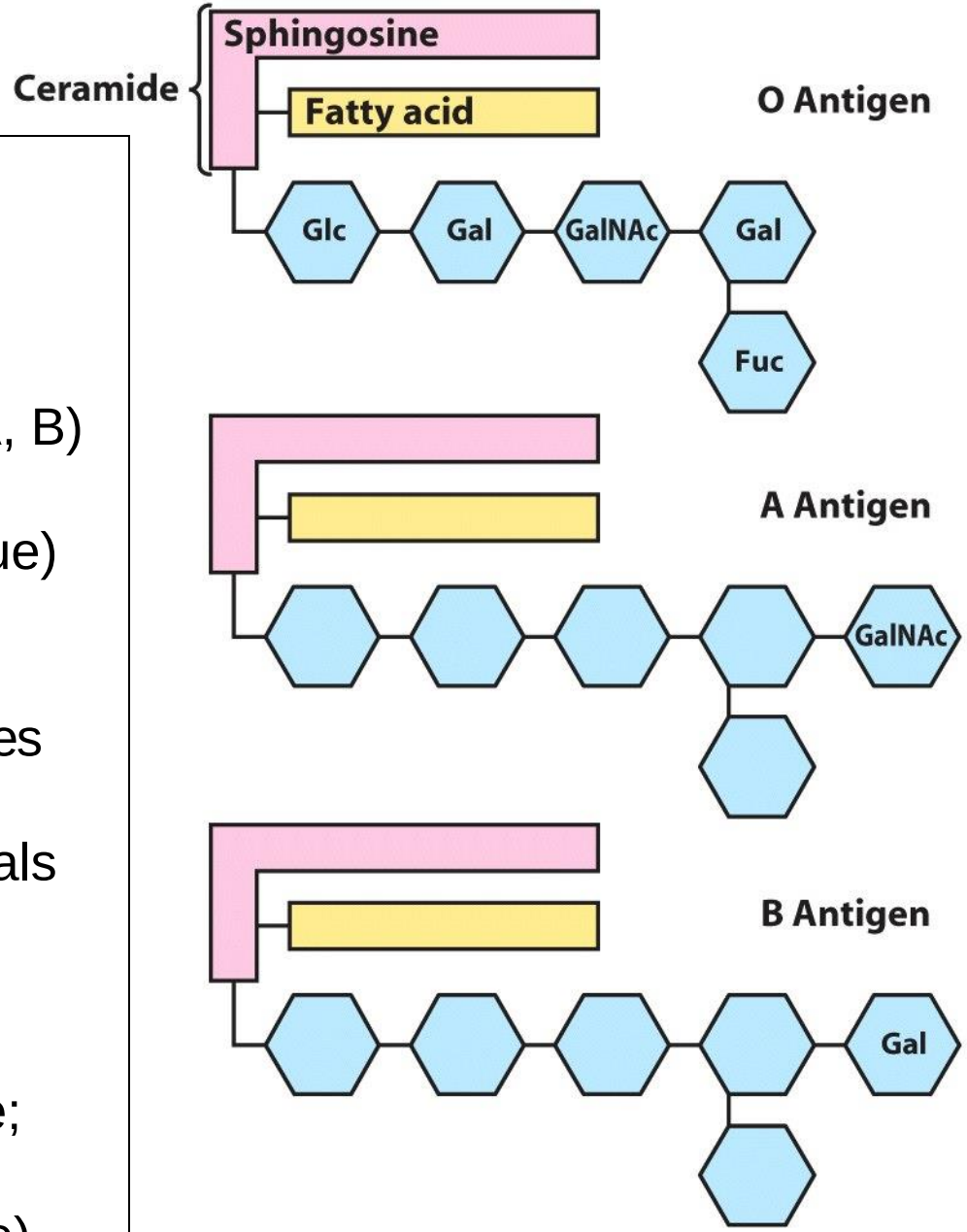
Name of sphingolipid	Name of X	Formula of X
Ceramide	—	— H
Sphingomyelin	Phosphocholine	
Neutral glycolipids Glucosylcerebroside	Glucose	
Lactosylceramide (a globoside)	Di-, tri-, or tetrasaccharide	
Ganglioside GM2	Complex oligosaccharide	

Glycosphingolipids as determinants of blood groups.

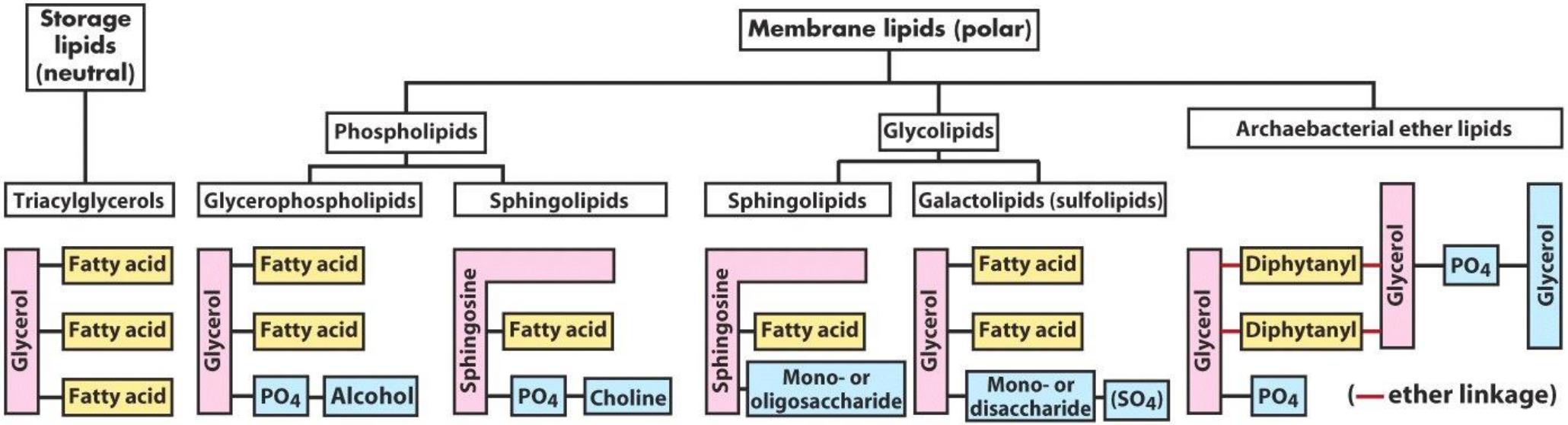
--The human blood groups (O, A, B) are determined in part by the oligosaccharide head groups (blue) of these glycosphingolipids.

--The same three oligosaccharides are also found attached to certain blood proteins of individuals of blood types O, A, and B, respectively.

(Fuc represents the sugar fucose; Glc=glucose; Gal=galactose; GalNAc= N-Acetyl galactosamine)

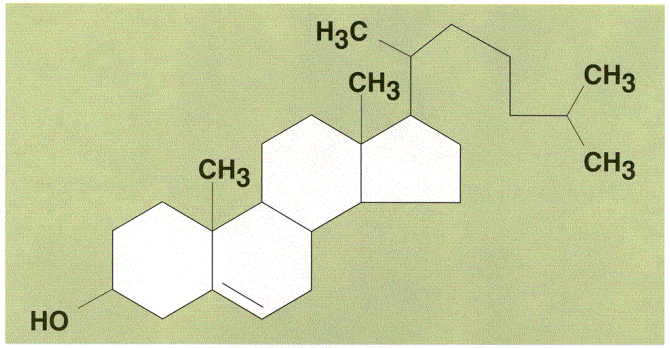


Summary

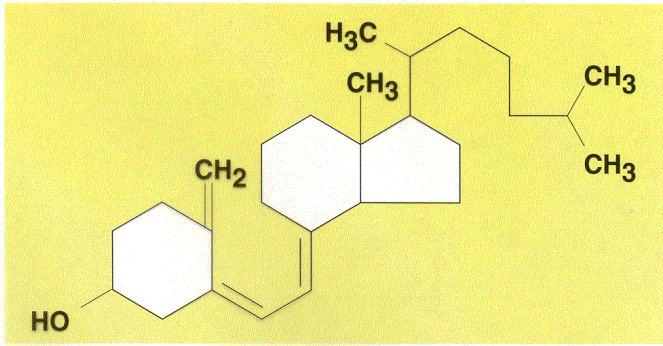

Storage lipids (neutral)
Membrane lipids (polar)
Phospholipids
Glycolipids
Archaebacterial ether lipids
Triacylglycerols
Glycerophospholipids
Sphingolipids
Sphingolipids
Galactolipids (sulfolipids)
Glycerol
Fatty acid
Fatty acid
Fatty acid
Glycerol
Fatty acid
Fatty acid
PO4
Alcohol
Sphingosine
Fatty 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)

D. Structural Derived Lipids: Sterols

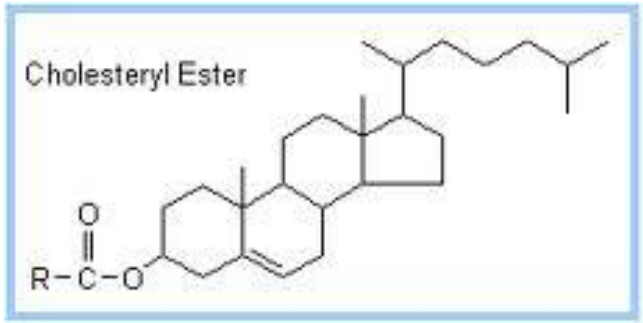
- Sterols are hydrocarbons with a multiple ring structure
- They are hydrophobic and lipophilic
- **Cholesterol** contain no fatty acids, but when it has fatty acids then they are referred to as **cholesterol esters,** which are neutral fats
- Cholesterol is the best-known sterol, found only in animal products
- Major component of cell membranes (especially abundant in nerve and brain tissue)
- Precursor molecule: Example - Vitamin D and steroid hormones e.g., estrogen are synthesized from cholesterol
- Important in the synthesis of bile acids that aid in lipid digestion by acting as emulsifying agents
- Unlike the TAGs and fatty acids, cholesterol is not an energy-producing nutrient



Cholesterol



Vitamin D_3

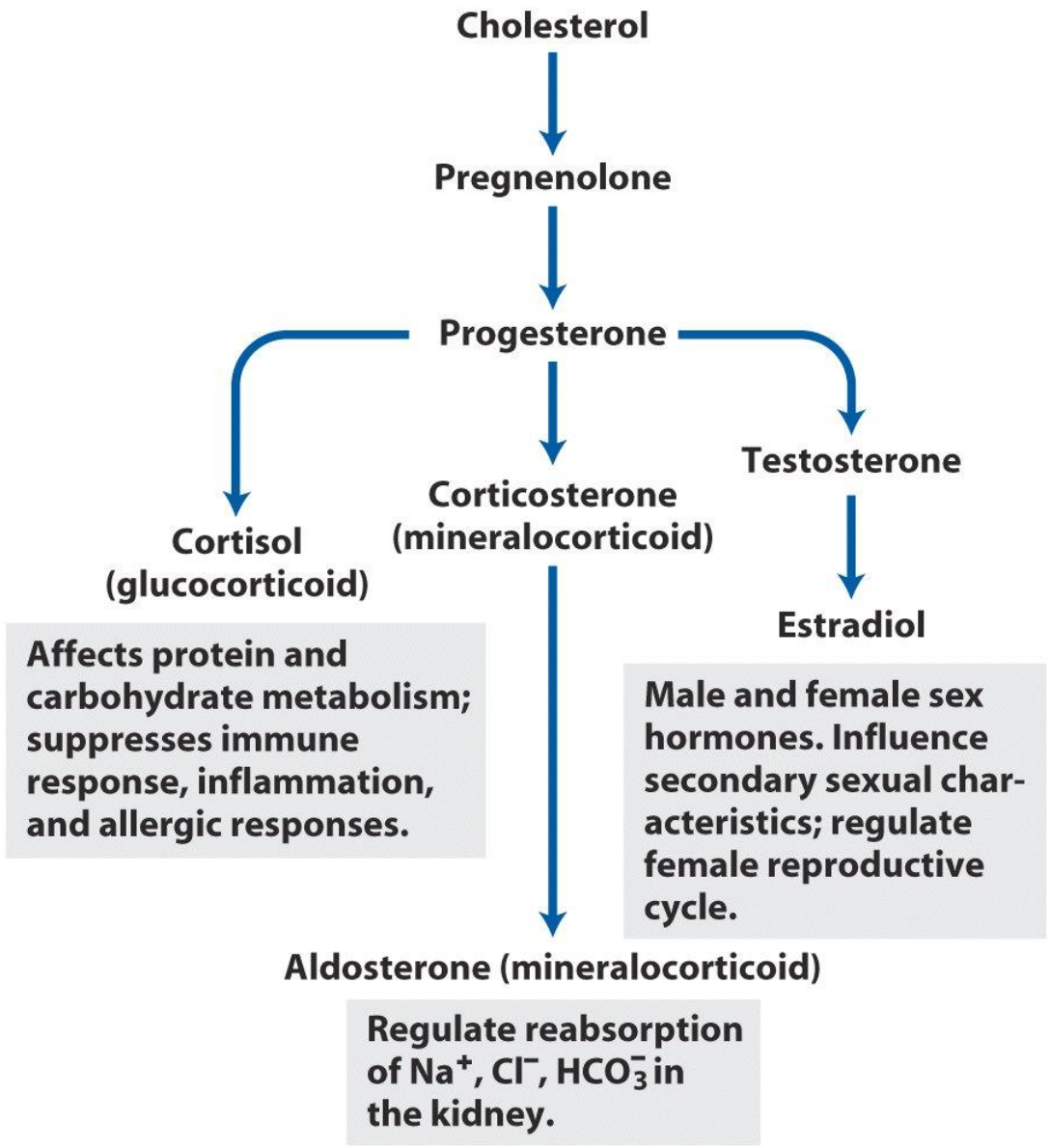


Before vitamin D treatment

After 14 months of vitamin D treatment

- **Vitamin D** (synthesized in the skin from cholesterol) is precursor to a hormone-**calcitriol** (active form of Vit D is called calcitriol) that regulates calcium metabolism

Some Steroid Hormones Derived from Cholesterol

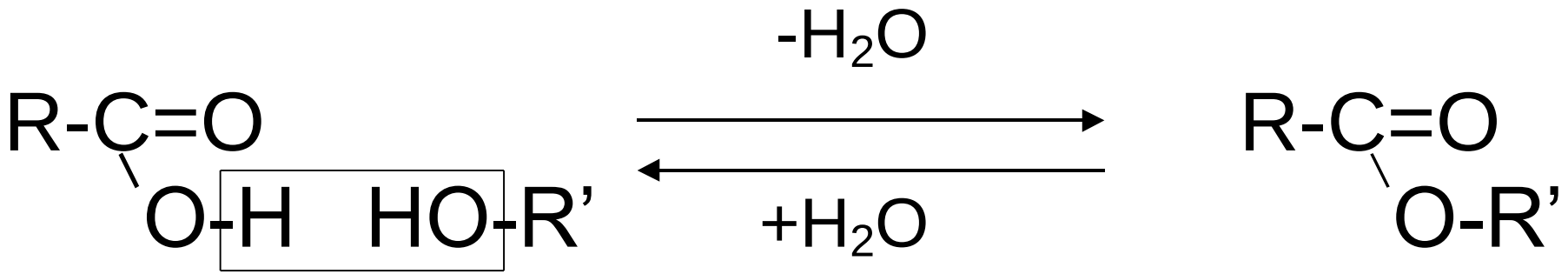


Key chemical properties of lipids

- Lipids may be either liquids or non-crystalline solids at room temperature.
- Pure fats and oils are colorless, odorless, and tasteless.
- They are energy-rich organic molecules
- Insoluble in water (hydrophobic)
- Soluble in organic solvents (lipophilic) like alcohol, chloroform, acetone, benzene, etc.
- No ionic charges
- Solid triacylglycerols (Fats) have high proportions of saturated fatty acids.
- Liquid triacylglycerols (Oils) have high proportions of unsaturated fatty acids

- Next slides; **other properties**-hydrolysis of TAGs, saponification, hydrogenation, halogenation & rancidity

Hydrolyse: to convert (*lyse* = to cleave) a compound into other substances through the action of water.

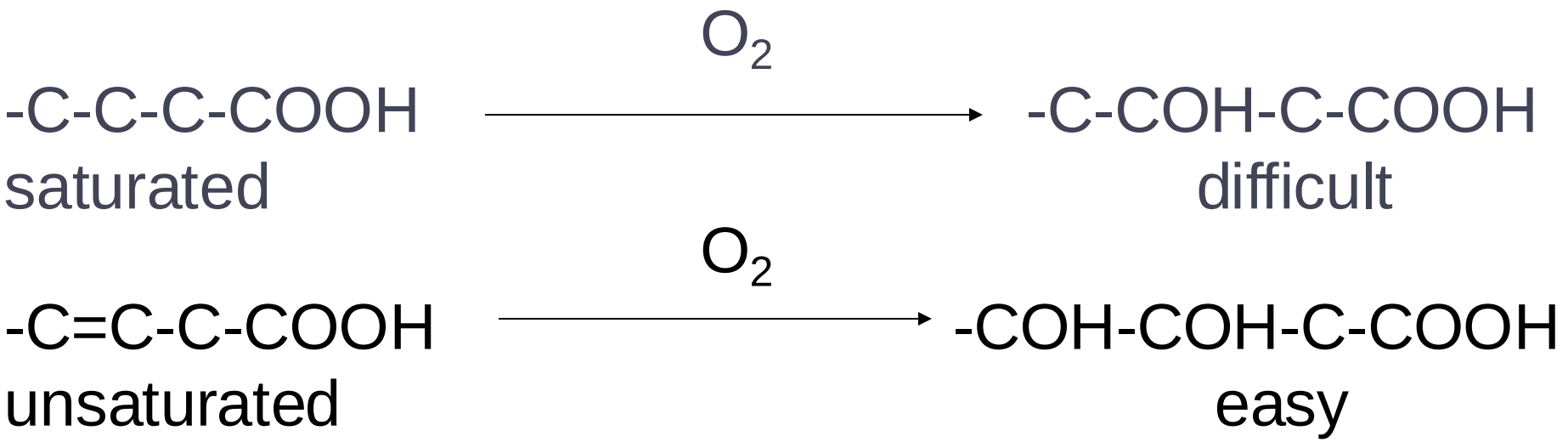


acid + alcohol ⟷ ester

(fatty acid + glycerol ⟷ triglyceride)

- **<u>Hydrolysis of triglycerols</u>**; triglycerols like any other esters react with water to form their carboxylic acid and alcohol– a process known as hydrolysis.

Oxidation of Organic Compounds,
eg. fatty acids



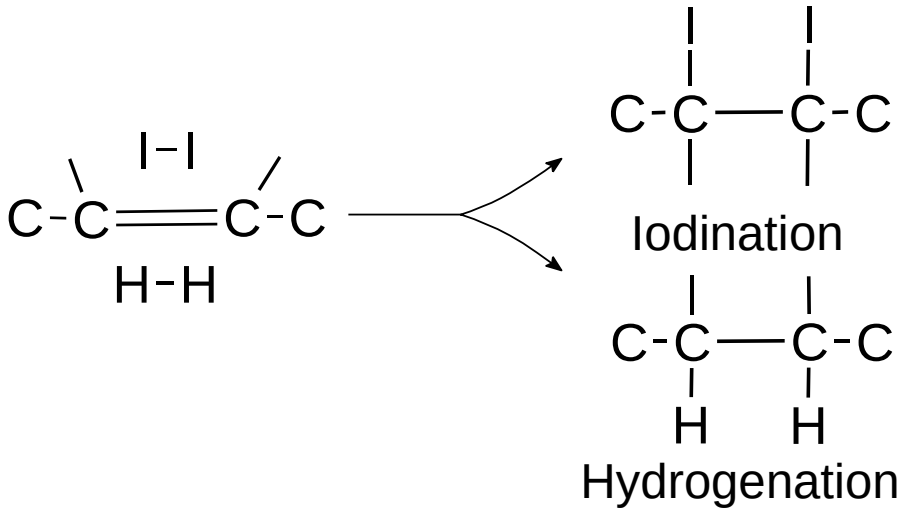
Oxidation = decomposition = rancidity

- More saturated = more stable, i.e.. longer 'shelf life', e.g. commercial baked goods
- More unsaturated = faster deterioration, i.e.. need antioxidants to protect compounds (in the body?)

- **Rancidity;** the term rancid is applied to any fat or oil that develops a disagreeable odor. Hydrolysis and oxidation reactions are responsible for causing rancidity. Oxidative rancidity occurs in triacylglycerols containing unsaturated fatty acids.

Reactions ("Synthetic")

Iodine # (↓sat.↑ unsat.)

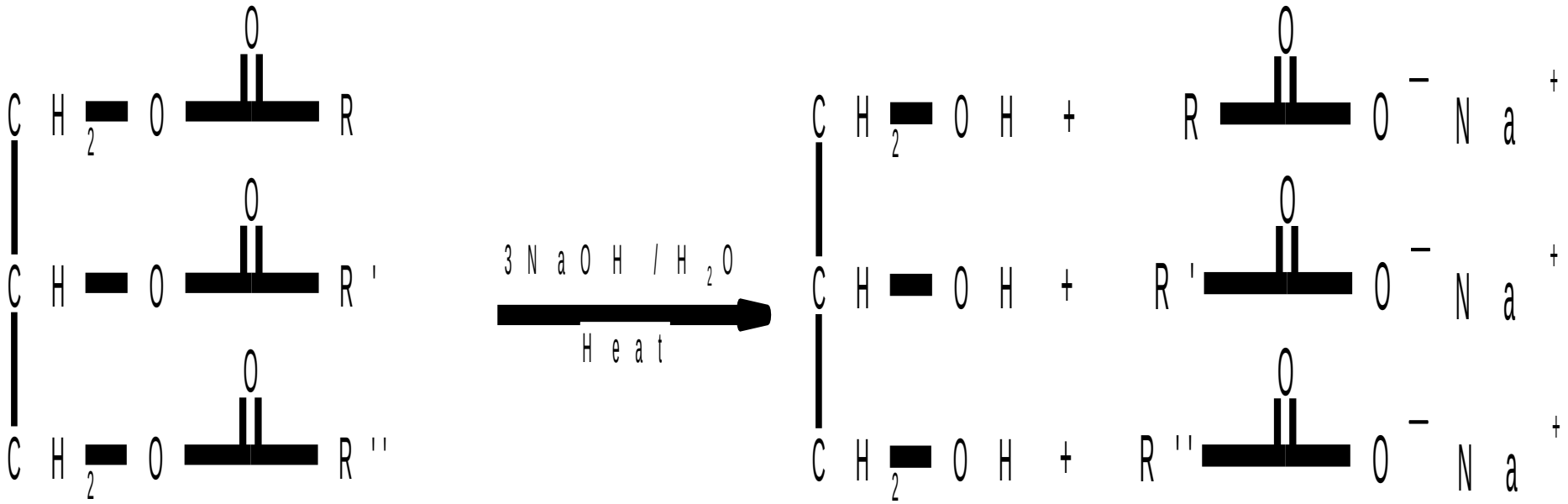


unsaturated saturated

- **Hydrogenation**; The carbon-carbon double bonds in unsaturated fatty acids can be hydrogenated by reacting with hydrogen to produce saturated fatty acids.

- **Halogenation**; Unsaturated fatty acids, whether they are free or combined as esters in fats and oils, react with halogens by addition at the double bond(s). The reaction results in the decolorization of the halogen solution.

Saponification/Hydrolysis of a Triglyceride

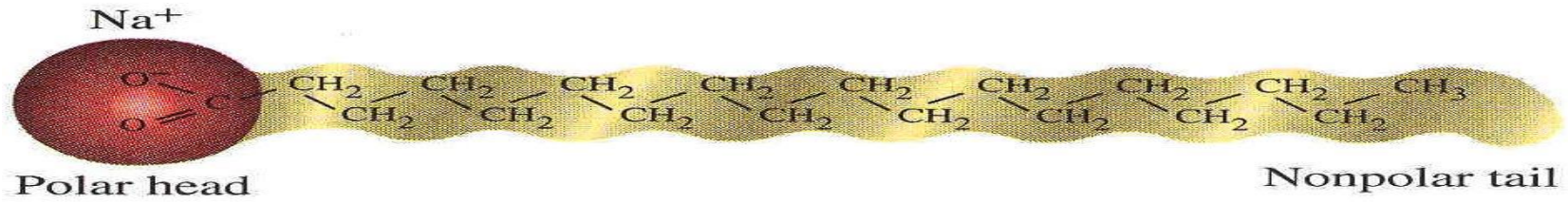


triglyceride glycerol soaps

- **Saponification:** Triacylglycerols may be hydrolyzed by several procedures, the most common of which utilizes alkali or enzymes called lipases. Alkaline hydrolysis is termed saponification because one of the products of the hydrolysis is a soap, generally sodium or potassium salts of fatty acids.

Soaps and Detergents

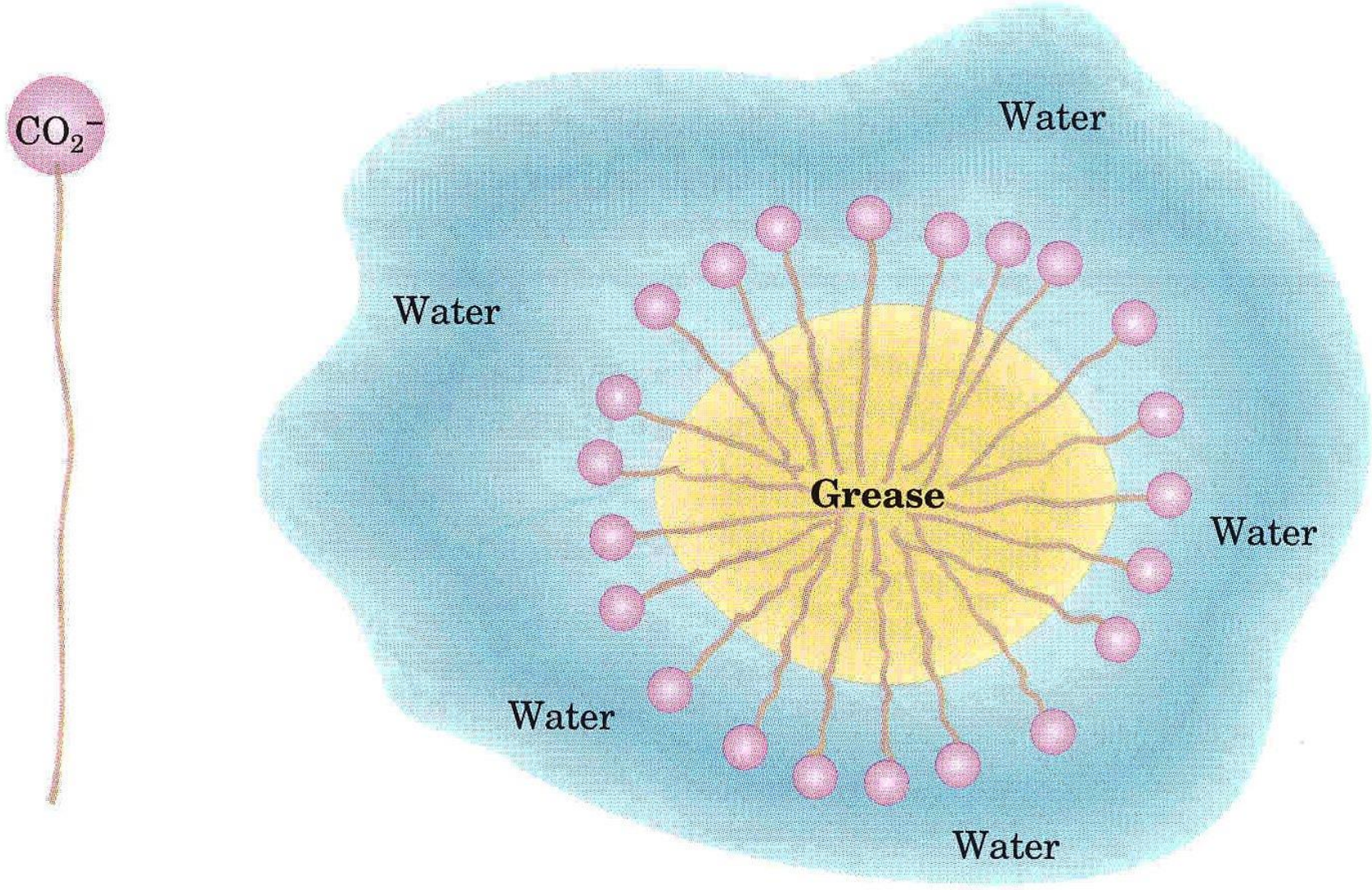
- Soaps clean by acting as emulsifying agents
  - the long hydrophobic hydrocarbon chains of soaps are insoluble in water and tend to cluster in such a way as to minimize their contact with water
  - the polar hydrophilic carboxylate groups, on the other hand, tend to remain in contact with the surrounding water molecules
  - driven by these two forces, soap molecules spontaneously cluster into micelles



hydrophilic
'loves' H_2O

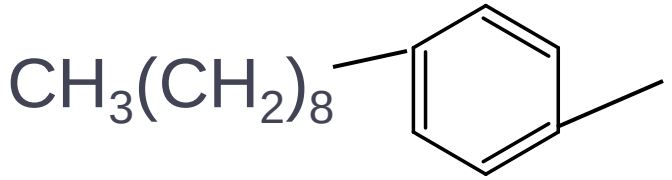
hydrophobic
'hates' H_2O

Soap makes Grease/dirt ‘water-soluble’



Detergents = Synthetic Soaps

i.e. hydrocarbon tail + polar/charged head



$CH_3(CH_2)_8$ SO_3^- Na^+

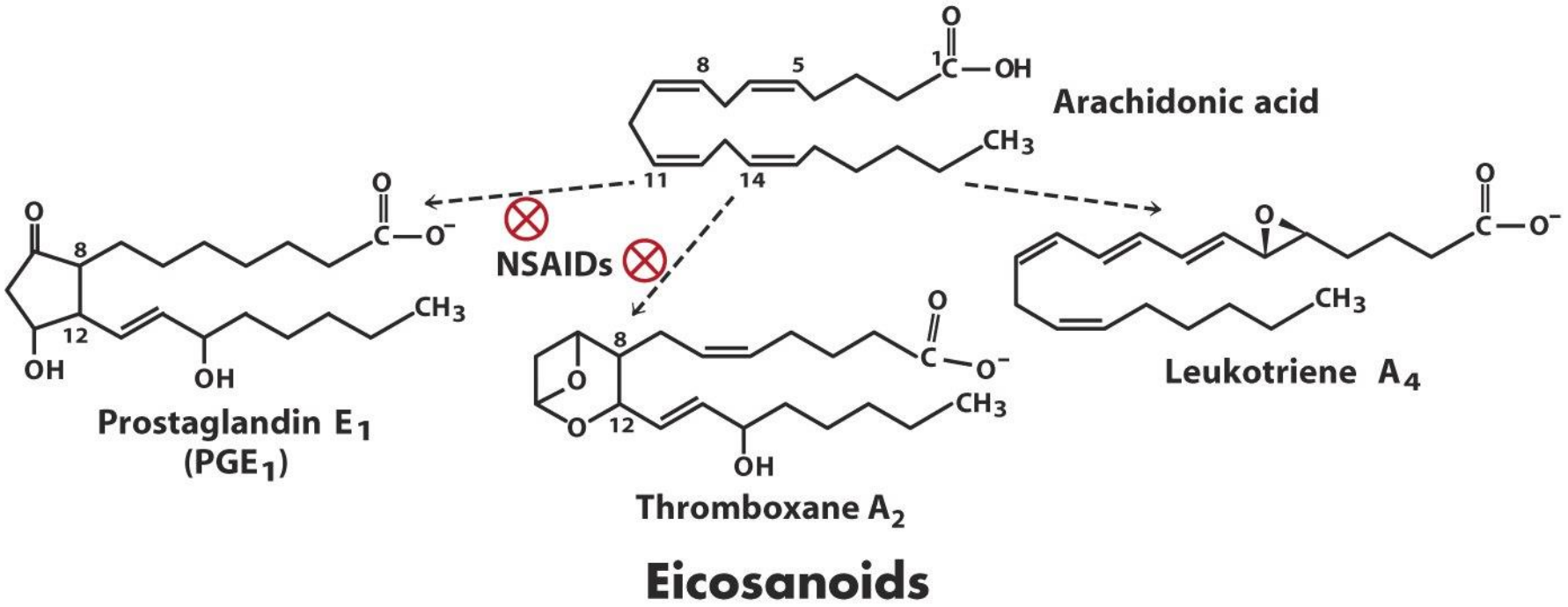
alkylbenzene sufonate(anionic)

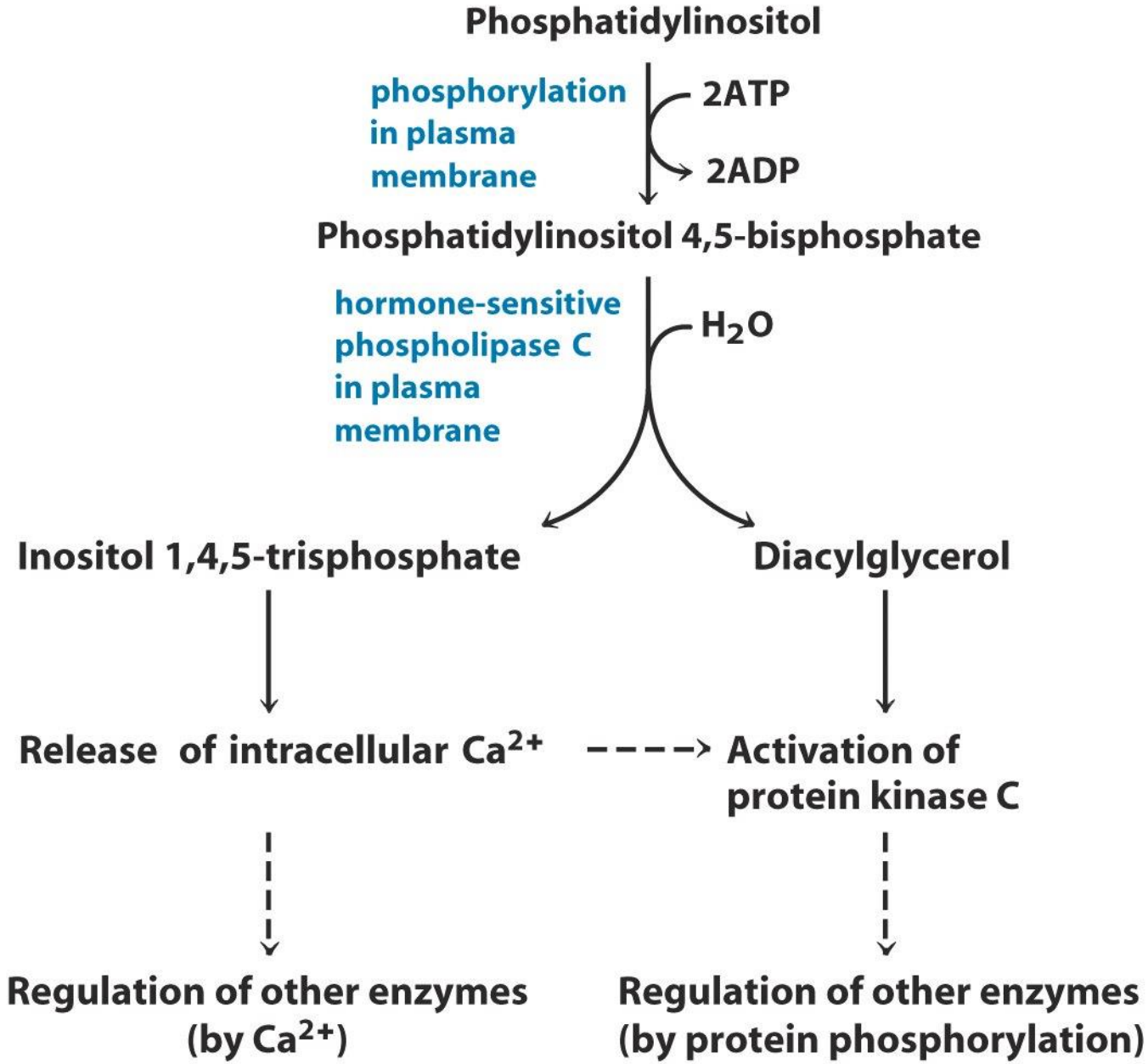
$CH_3(CH_2)_{13}OSO_3^-$ Na^+
alkyl sulfate(anionic)

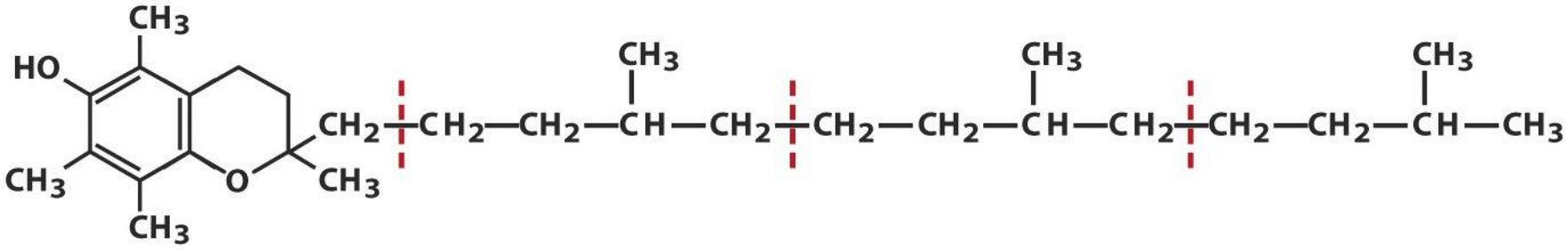
$CH_3(CH_2)_8O(CH_2CH_2O)_nH$
(nonionic)

$CH_3(CH_2)_{11}N^+(CH_3)Cl^-$
trimethylalkylammonium(cationic)

Other Lipid Derivatives and their Functions



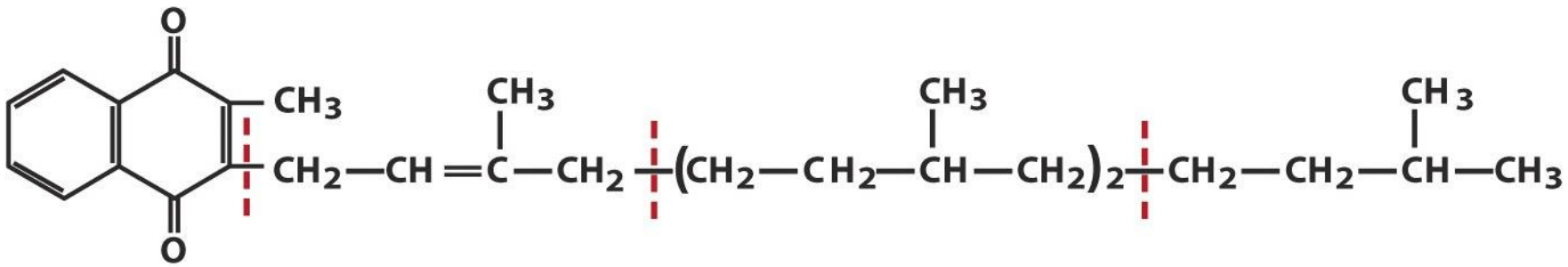

Phosphatidylinositol
phosphorylation in plasma membrane
2ATP
2ADP
Phosphatidylinositol 4,5-bisphosphate
hormone-sensitive phospholipase C in plasma membrane
H_2O
Inositol 1,4,5-trisphosphate
Diacylglycerol
Release of intracellular Ca^{2+}
Activation of protein kinase C
Regulation of other enzymes (by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



(a)

Vitamin E: an antioxidant

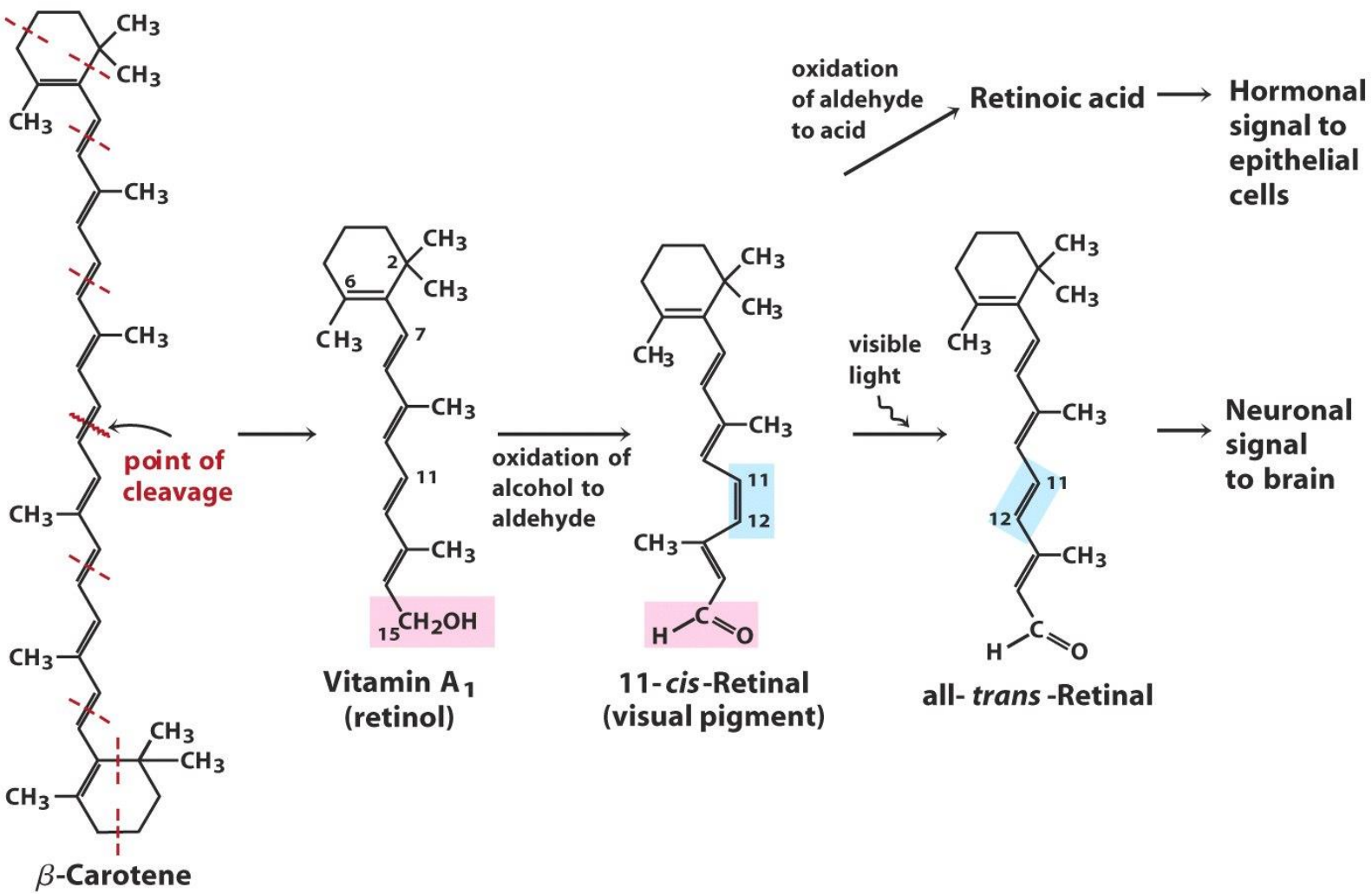
Vitamin E functions in the protection of membrane lipids from oxidative damage,



(b)

Vitamin K_1: a blood-clotting cofactor (phylloquinone)

Vitamin K is essential in the blood-clotting process.



Vitamin A furnishes the visual pigment of the vertebrate eye and is a regulator of gene expression during epithelial cell growth.

Key Functions of Lipids

-Apart from the **storage** and **structural** roles of lipids in animals, they also have other functions;

- **Steroid hormones**, derived from sterols, serve as powerful biological signals, such as the sex hormones, glucocorticoids and aldosterone.
- Phosphatidylinositol bisphosphate is hydrolyzed to yield two **intracellular messengers**, diacylglycerol and inositol 1,4,5-trisphosphate (IP3).
- Derivatives of arachidonic acid are potent **hormones** e.g., prostanglandins, leukotrienes, and thromboxanes
- **Vitamins** D, A, E, and K are fat-soluble compounds derived from intermediates (isoprene units) in the synthesis of sterols.

End of Slides!