Structure of Lipids

S. M. Shafiee, PhD

Department of Biochemistry, SUMS

An Overview

- **Lipids are non-polar** (hydrophobic) compounds
- Lipids have various structures which are common in:

1- Insolubility in water

2- Solubility in organic solvents such as chloroform

- They are not biopolymers! (Only Terpenes)

Lipid Classification

- It is not easy to classify them according to their various structures

1- Fatty acids

2- Glyceryl esters (including phosphoglycerides)

3- Waxes

4- Sphingolipids

5- Sterol derivatives

6- Terpenes (Isopernoids)

1- Fatty Acids

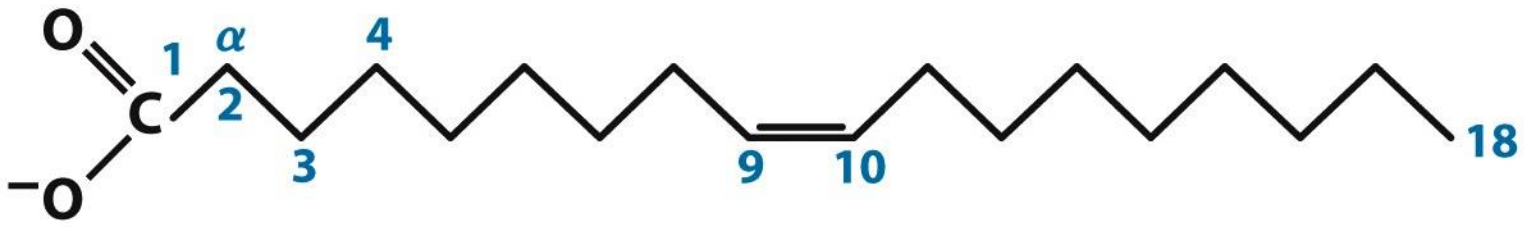
- A 16-C fatty acid: $CH_3(CH_2)_{14}$-COO^-

  Non-polar polar

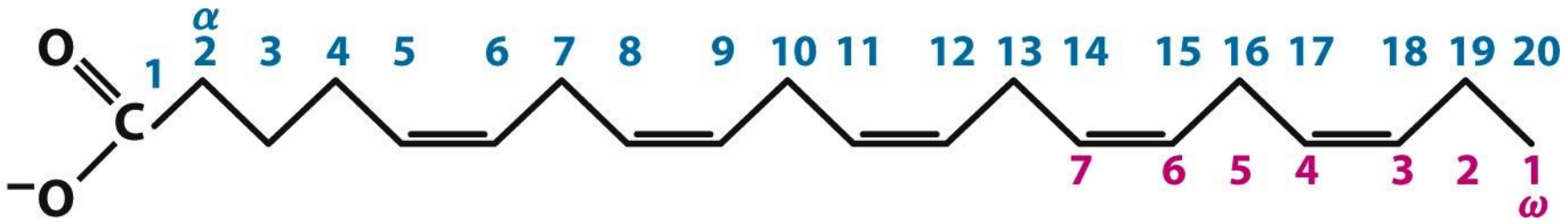
FAs usually have even numbers of carbons without branches

There are exceptions such as phytanic acid (3,7,11,15-tetramethyl hexadecanoic acid) which has methyl groups.

Fatty acids and their nomenclature



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



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

Figure 10-1
Lehninger Principles of Biochemistry, Fifth Edition

Omega (ω) Nomenclature of fatty acids

- Omega (ω) is the last letter in the Greek alphabet, and is therefore used to indicate **the "last" carbon atom** in the fatty acid chain.
- Since the ω-n notation is used almost exclusively to indicate the positions of the double bonds close to the -CH_3 end in essential fatty acids

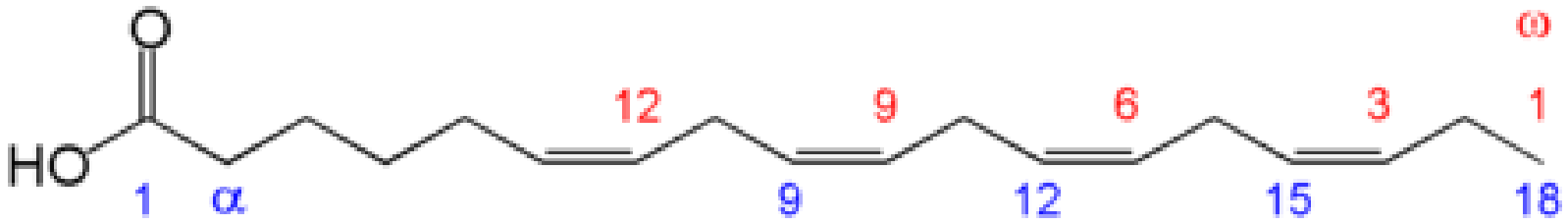


TABLE 10–1 Some Naturally Occurring Fatty Acids: Structure, Properties, and Nomenclature

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 to –0.5		
18:1(Δ^9)	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$	*cis*-9-Octadecenoic acid	Oleic acid (Latin *oleum*, "oil")	13.4		
18:2($\Delta^{9,12}$)	$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$	*cis*-,*cis*-9,12-Octadecadienoic acid	Linoleic acid (Greek *linon*, "flax")	1–5		
18:3($\Delta^{9,12,15}$)	$CH_3CH_2CH{=}CHCH_2CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$	*cis*-,*cis*-,*cis*-9,12,15-Octadecatrienoic acid	α-Linolenic acid	−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.

Table 10-1

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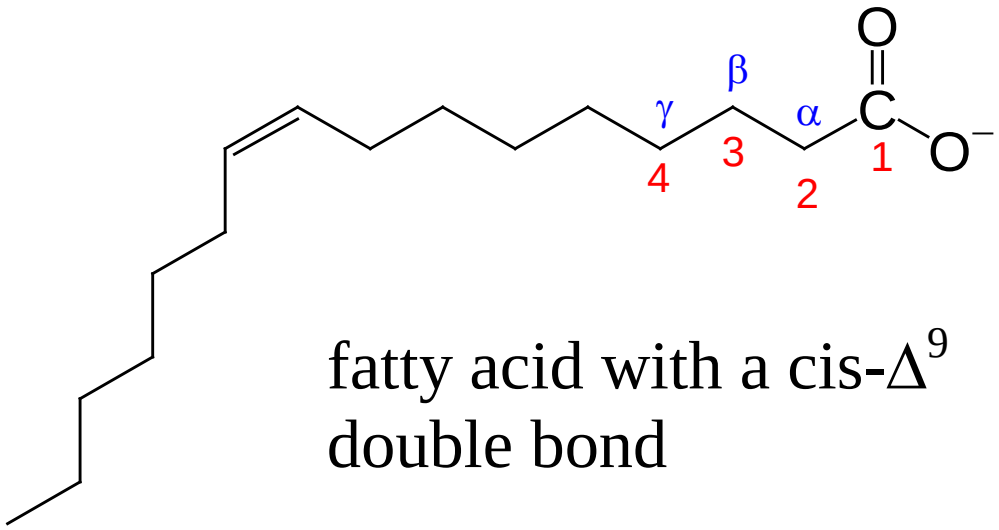
Double bonds in fatty acids usually have the **cis** configuration.

Most naturally occurring fatty acids have an **even number** of carbon atoms.



fatty acid with a cis-Δ^9 double bond

Some fatty acids and their common names:

14:0 myristic acid; 16:0 palmitic acid; 18:0 stearic acid; 18:1 cisΔ^9 oleic acid

18:2 cis$\Delta^{9,12}$ linoleic acid

18:3 cis$\Delta^{9,12,15}$ α-linonenic acid

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

} Essential Fatty Acids

20:5 cis$\Delta^{5,8,11,14,17}$ eicosapentaenoic acid (an omega-3)

Essential Fatty Acids

- **Essential fatty acids**, or **EFAs**, are fatty acids that humans and other animals must ingest (by food that they intake) because the body requires them for good health but **cannot synthesize them**

OMEGA 3

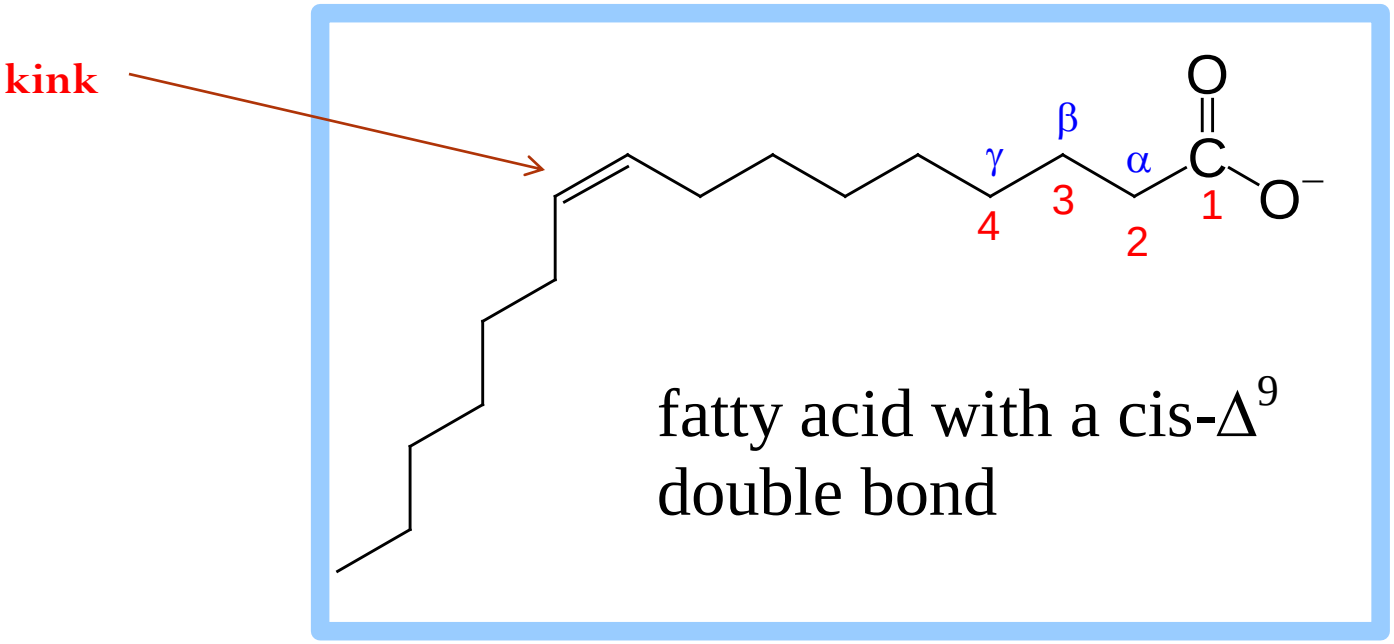
OMEGA 6

Essential Fatty Acids

18:2 cis$\Delta^{9,12}$ linoleic acid (omega 6)

18:3 cis$\Delta^{9,12,15}$ α-linonenic acid (omega 3)

20:4 cis$\Delta^{5,8,11,14}$ arachidonic acid (omega 6)



There is free rotation about **C-C** bonds in the fatty acid hydrocarbon, except where there is a double bond.

Each cis double bond causes a **kink** in the chain.

Rotation about other **C-C** bonds would permit a more linear structure than shown, but there would be a kink.

The packing of fatty acids into stable aggregates

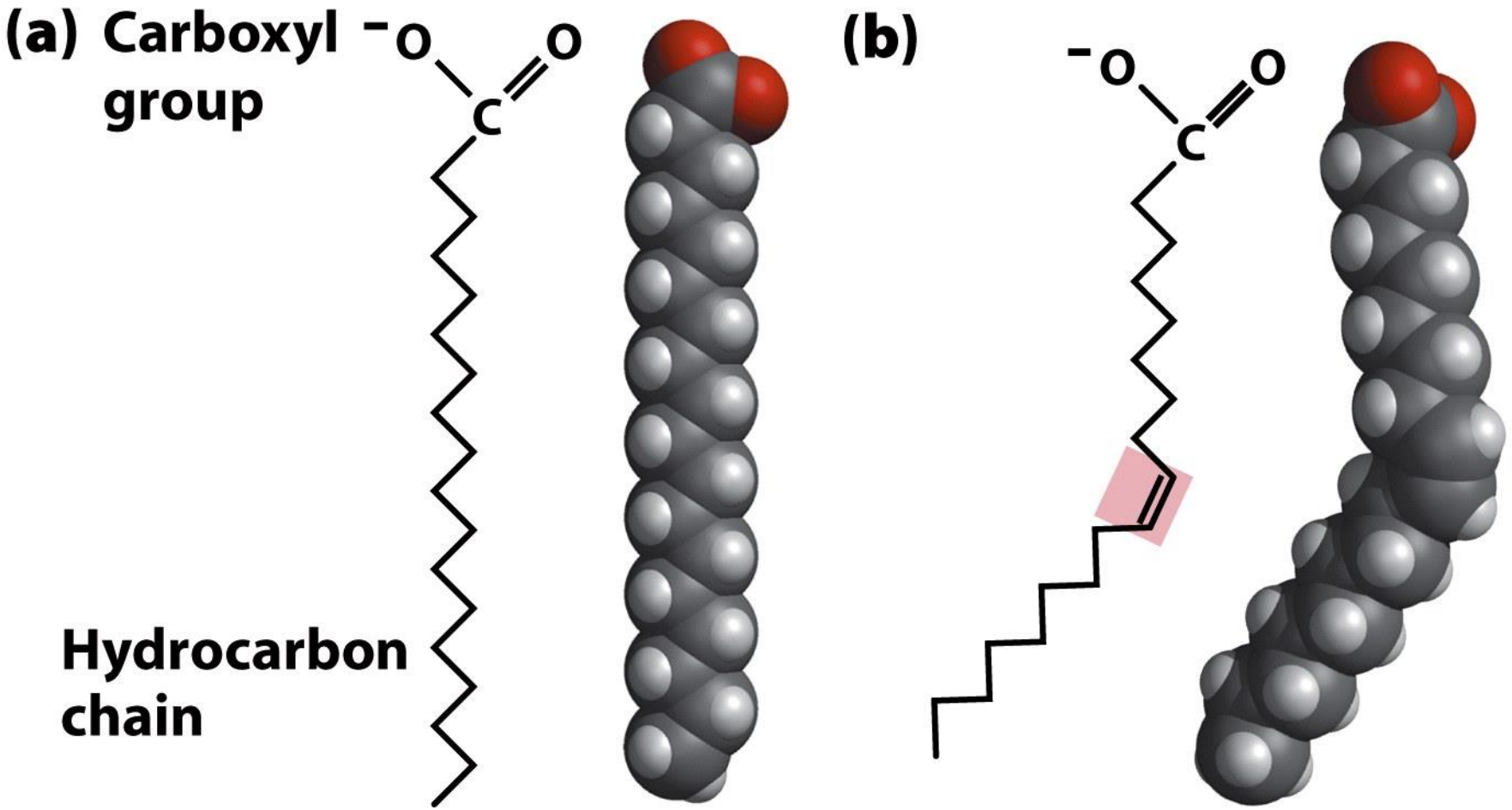


Figure 10-2ab
Lehninger Principles of Biochemistry, Fifth Edition

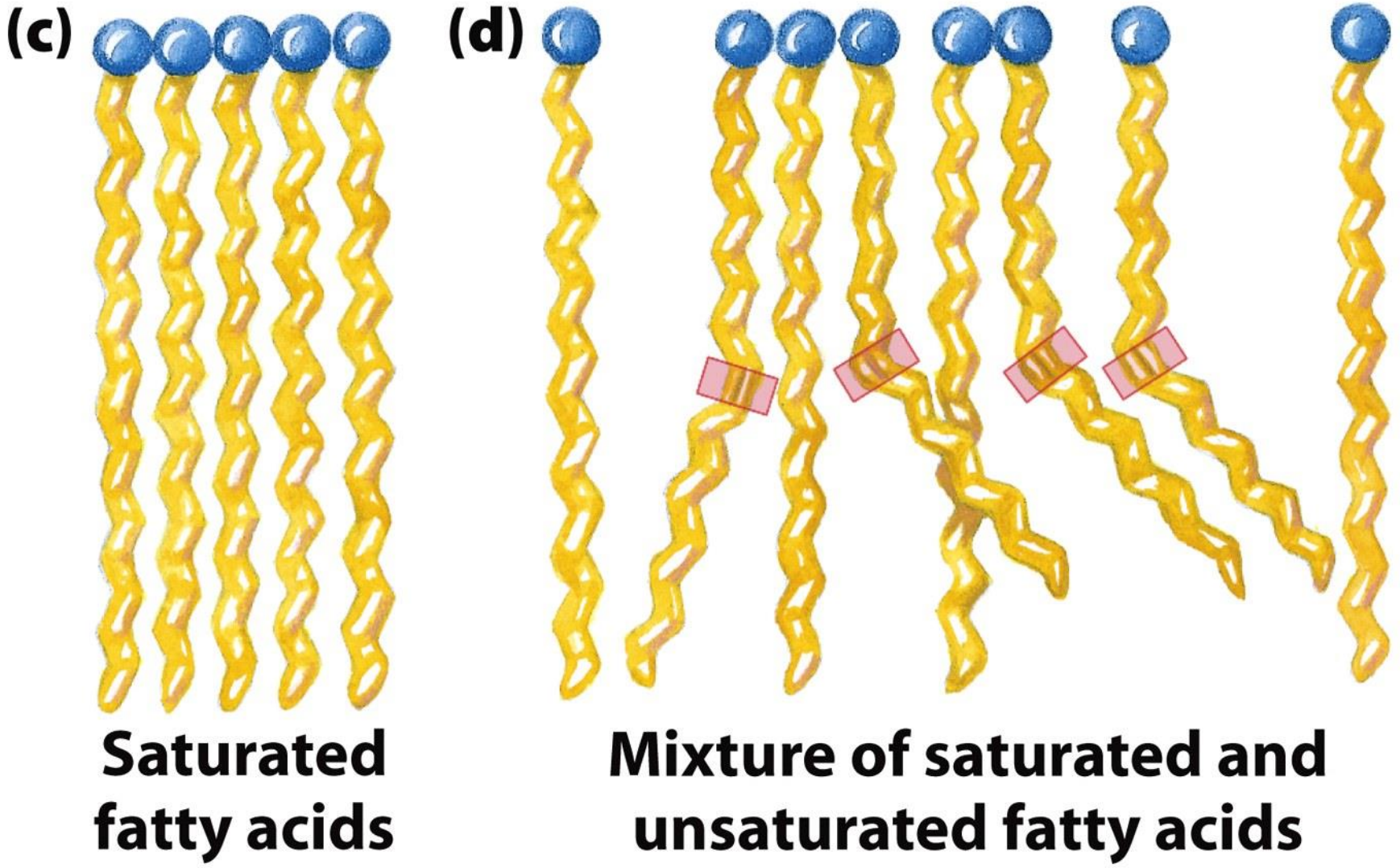


Figure 10-2cd
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Physical properties of FAs

- **Solubility in water**: FAs with more than 6 C are almost insoluble
  They form micelles to thermodynamically stable

- **Boiling point**
  It is due to the number of C atoms and the unsaturated bonds
  FAs with more than 10 C are solid in room temperature
  Unsaturated FAs are liquid in room temperature

Amphipathic compounds in aqueous solution

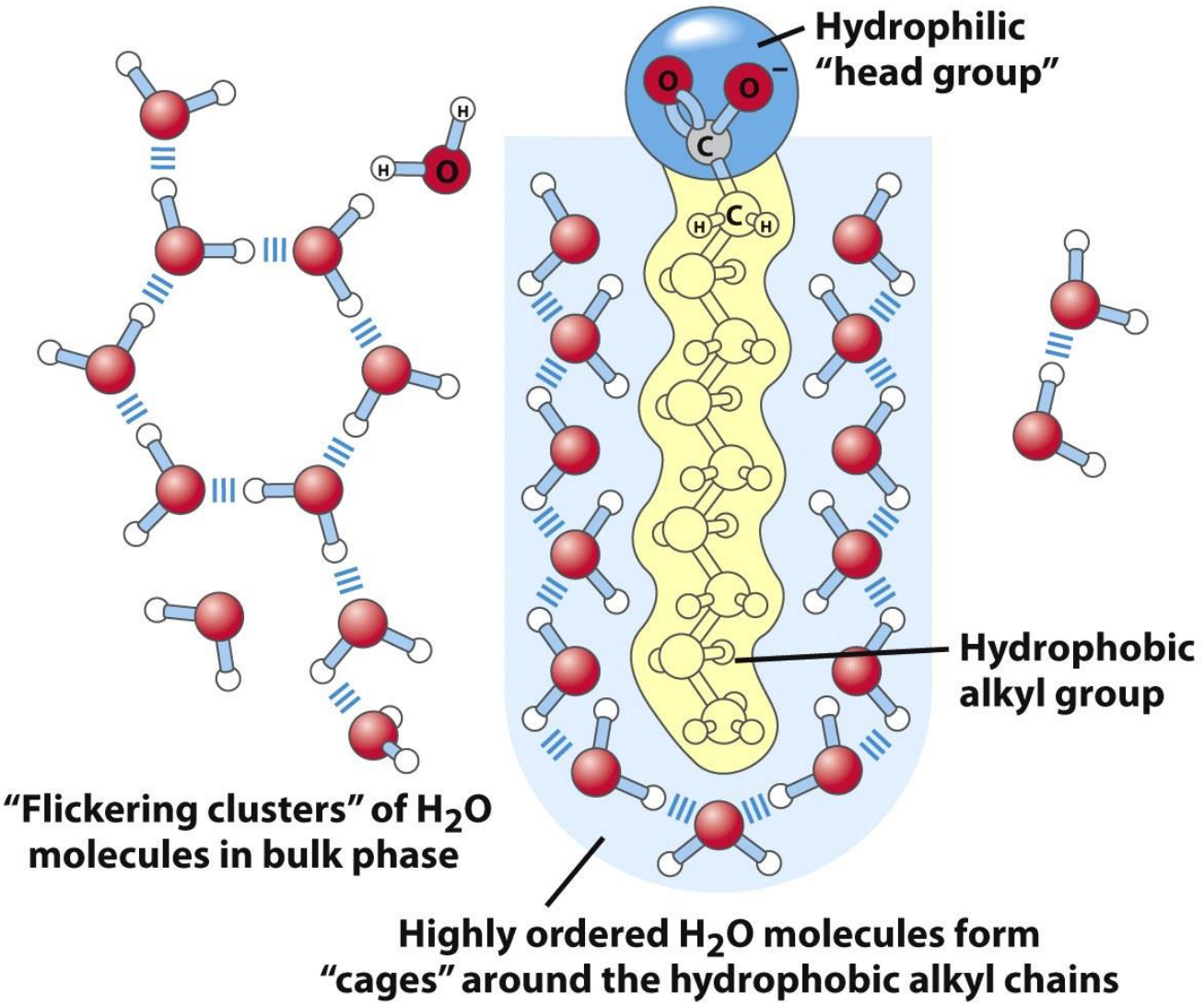

Figure 2-7a
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Clustering of FAs together in micelles

- FAs with more than 6 C are almost insoluble
  They form **micelles** to thermodynamically stable

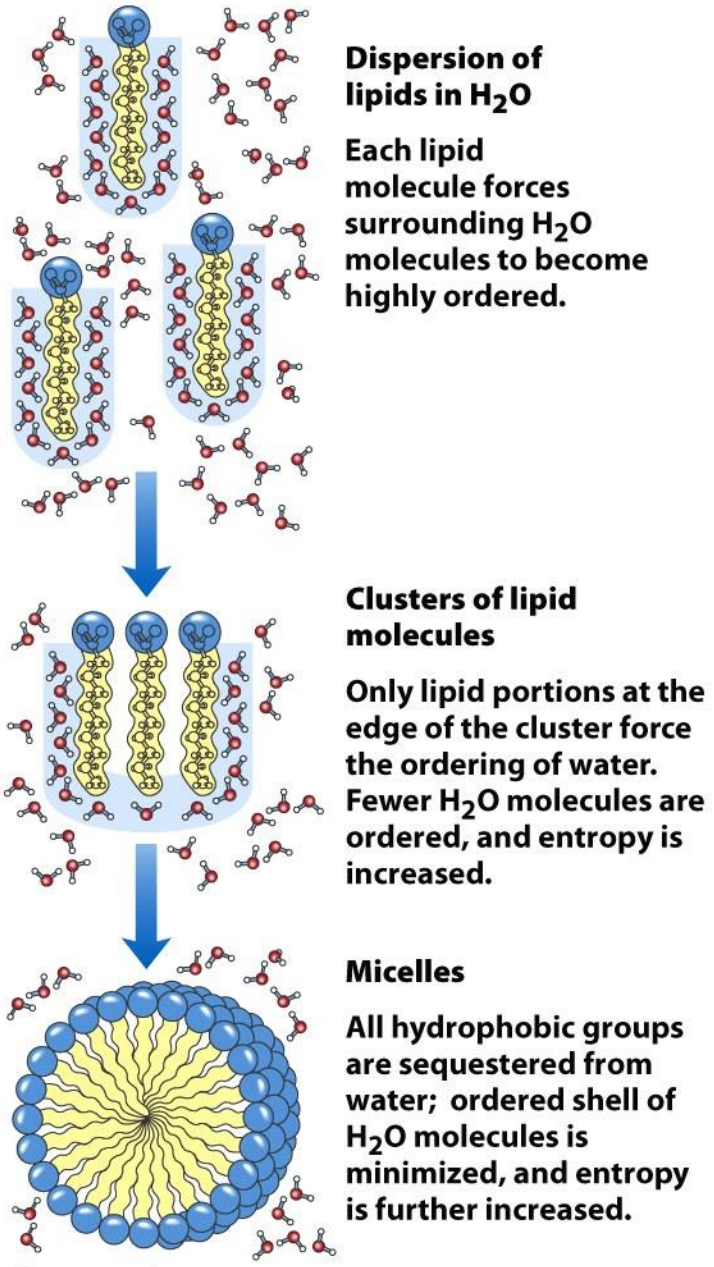

Figure 2-7b
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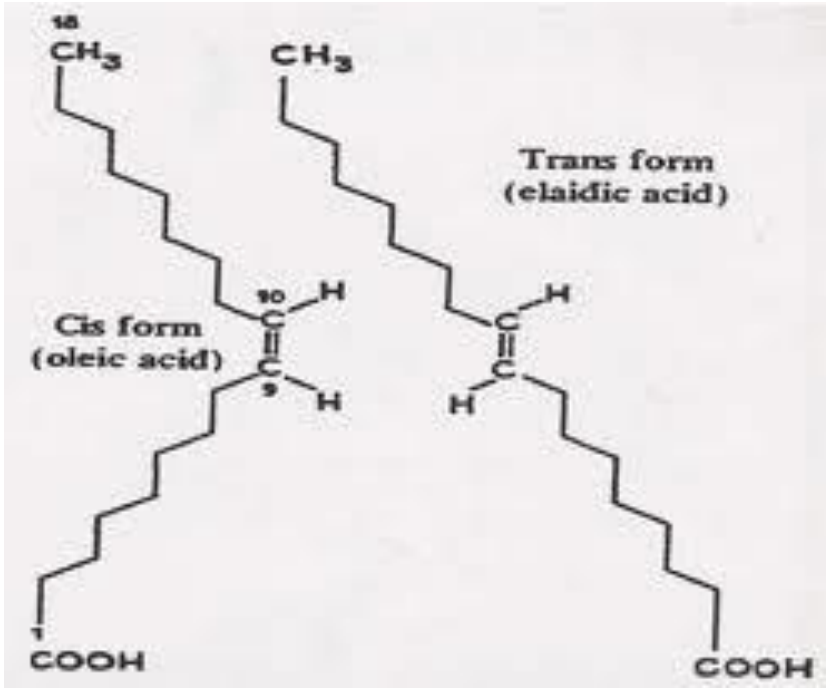
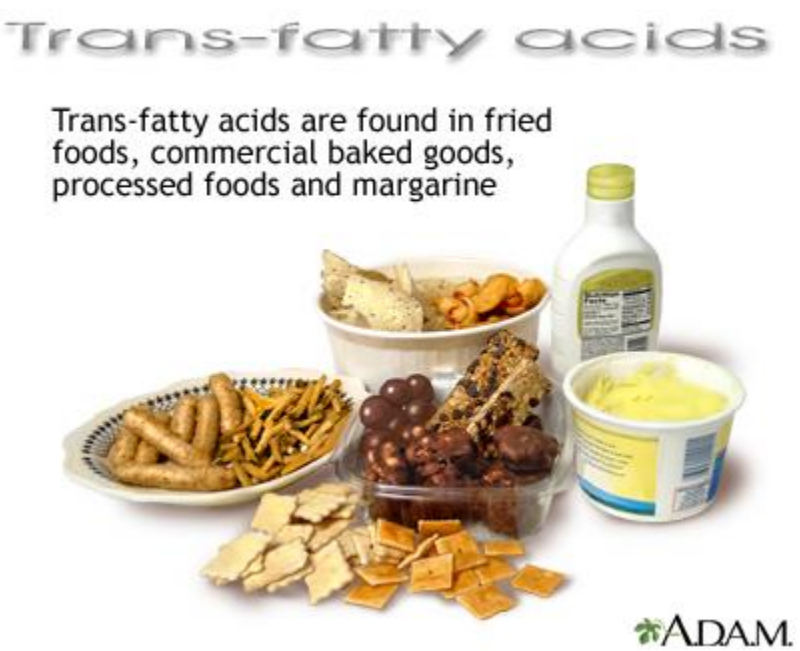
Chemical properties of FAs

- Cis and trans isomerism
- Hydrogenation of UFAs
- Peroxidation of UFAs





***Trans* fats**, or **trans-unsaturated fatty acids**, **trans fatty acids**, are a type of unsaturated fats that are **uncommon in nature** but became commonly **produced industrially** from vegetable fats for use in margarine, snack food, packaged baked goods and frying fast food starting in the 1950s.

Trans fat has been shown to consistently be associated, in an intake-dependent way, with **increased risk of coronary heart disease**, a leading cause of death in Western nations

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

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

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

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

Table 10-2

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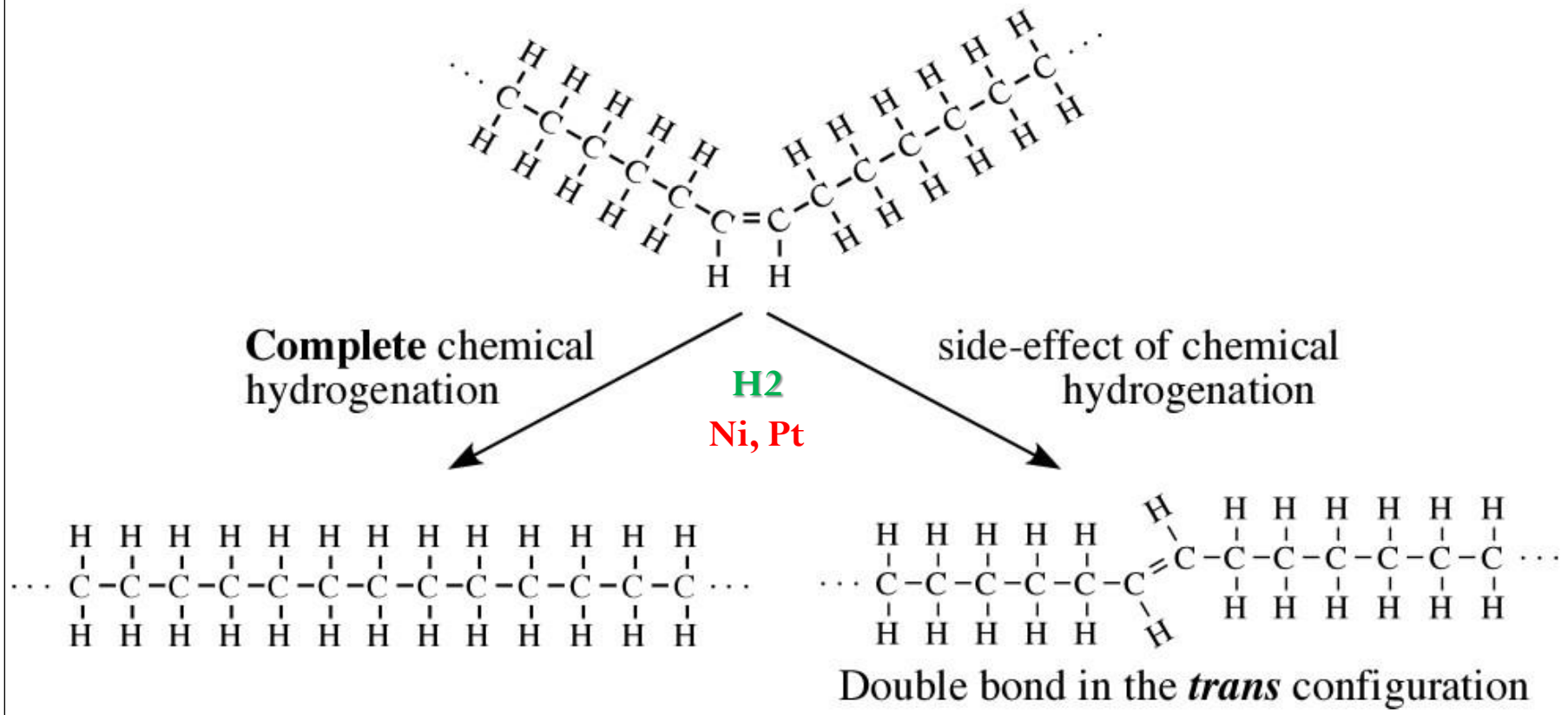
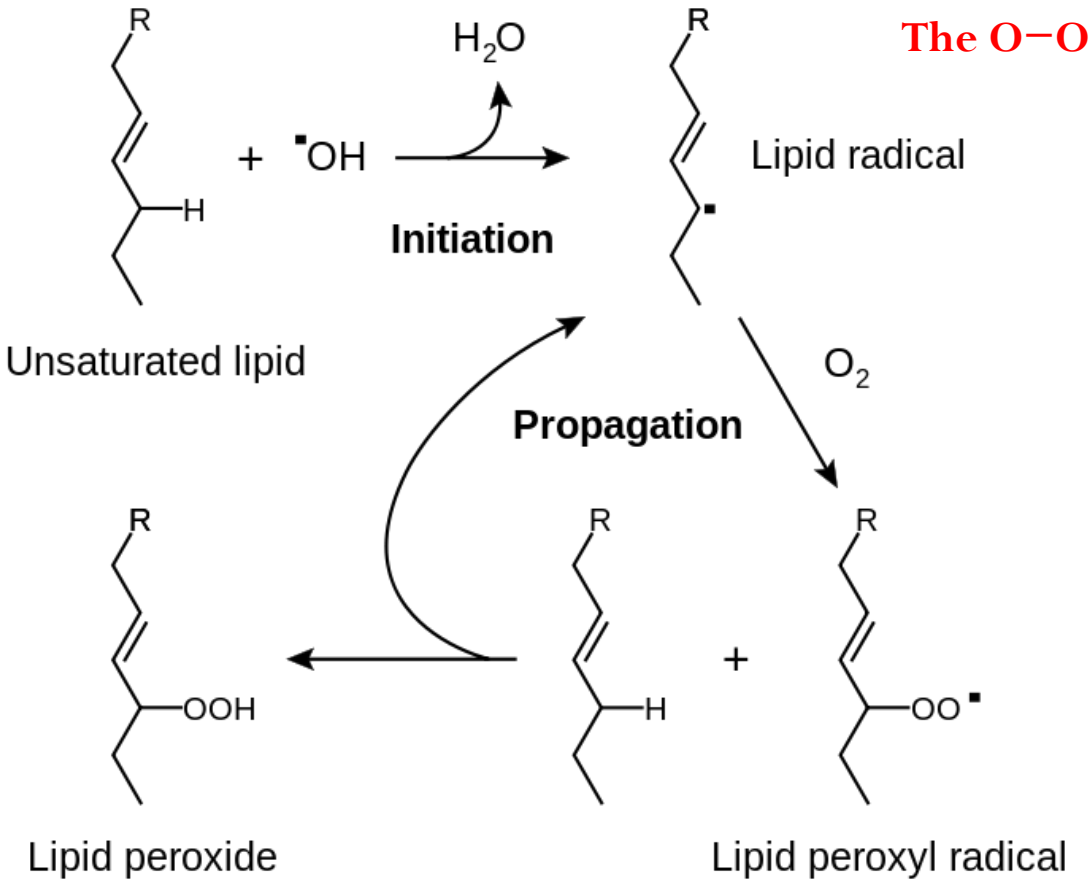
UFA Hydrogenation

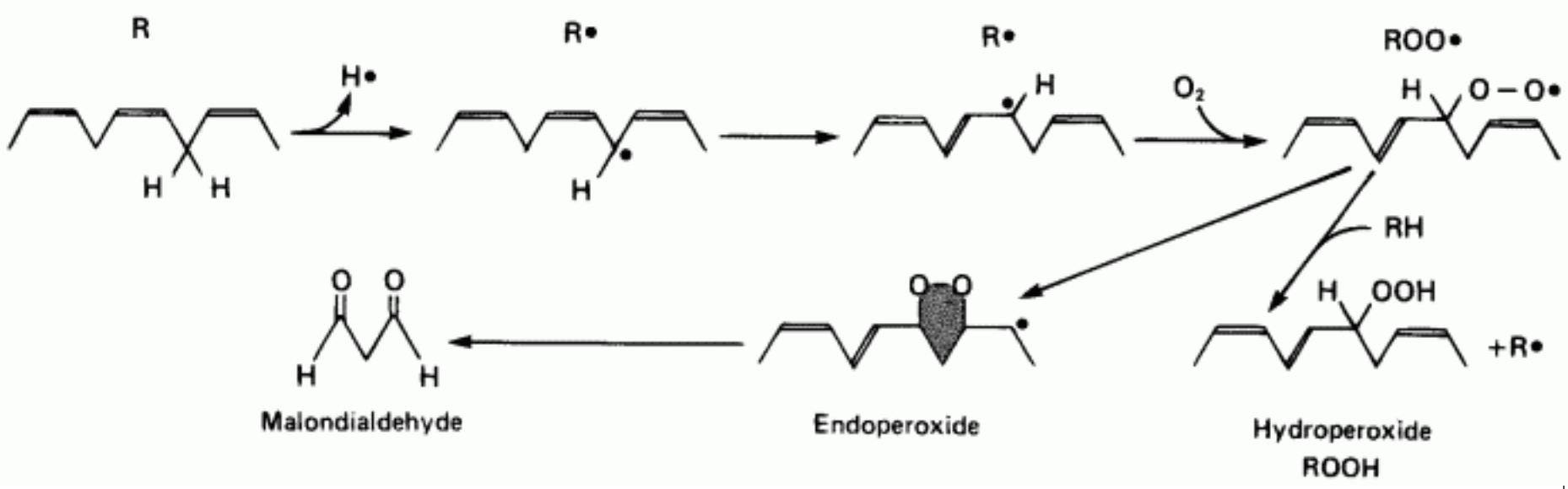


Lipid Peroxidation is the oxidative degeneration of FAs



The O–O group is called the peroxide group

The end products of lipid peroxidation are reactive aldehydes, such as malondialdehyde (MDA)



The end products of lipid peroxidation are reactive aldehydes, such as malondialdehyde (**MDA**)

در روغن های مایع مخصوص سرخ کردن چه نوع اسید چربی غالب است؟

- الف) PUFA
- ب) MUFA
- ج) Short Chain SFA
- د) Long Chain SFA

Eicosanoid

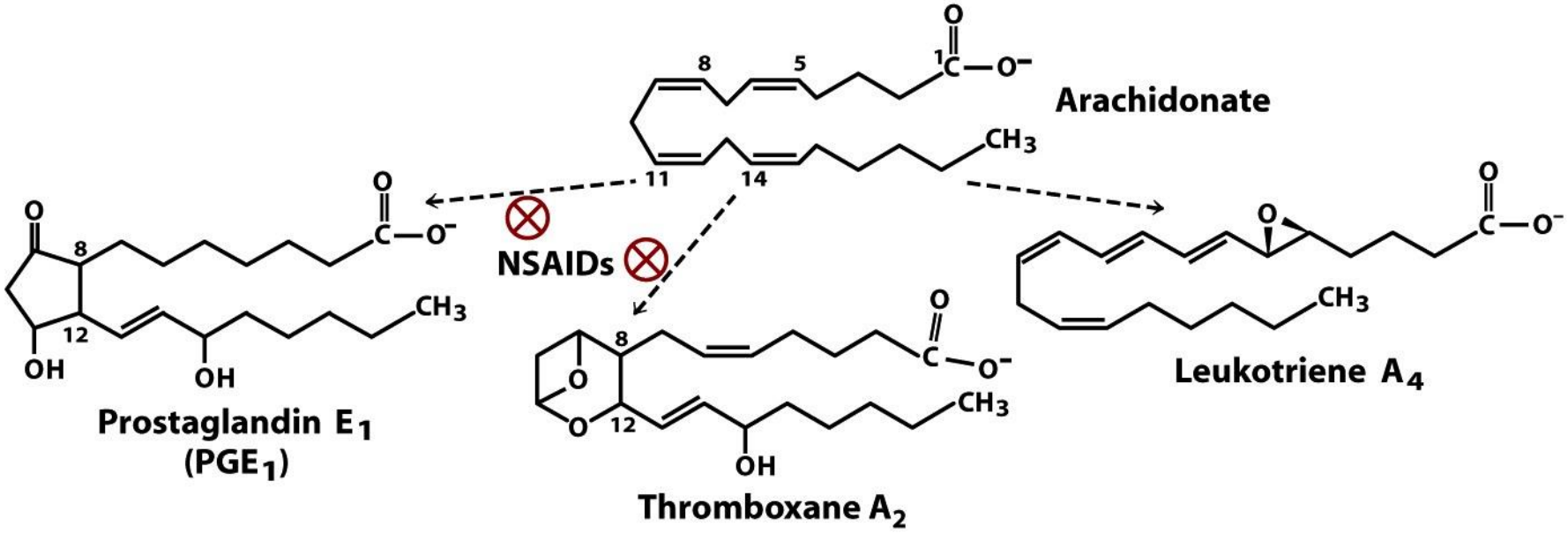


Figure 10-18
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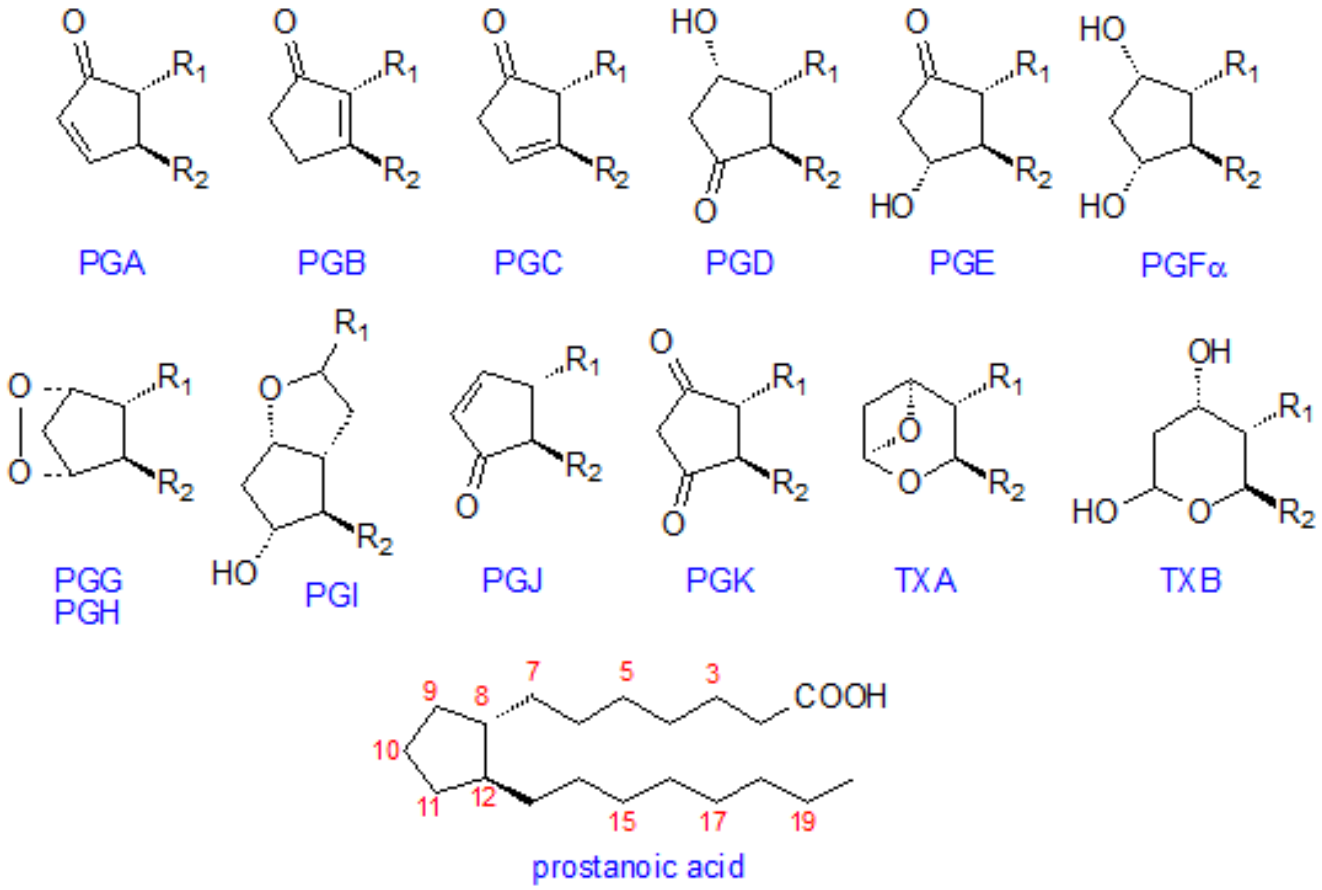
NSAIDs: Nonsteroidal antiinflammatory drugs such as aspirin and ibuprofen



PGs are important in biological processes such as pain, platelet aggregation and smooth muscle contraction. LTs are also important in allergic responses and chemotaxis.

Lipid Classification

- It is not easy to classify them according to their various structures

1- Fatty acids

2- Glyceryl esters (including phosphoglycerides)

3- Waxes

4- Sphingolipids

5- Sterol derivatives

6- Terpenes (Isopernoids)

2- Esters of FAs and alcohols

- Glyceryl esters

  1- Acyl glycerols (Glycerides)

  2- Phosphoglycerides

- Waxes

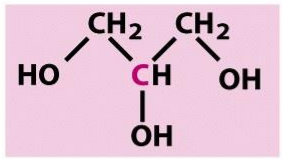
Acyl glycerols

Monoglycerides

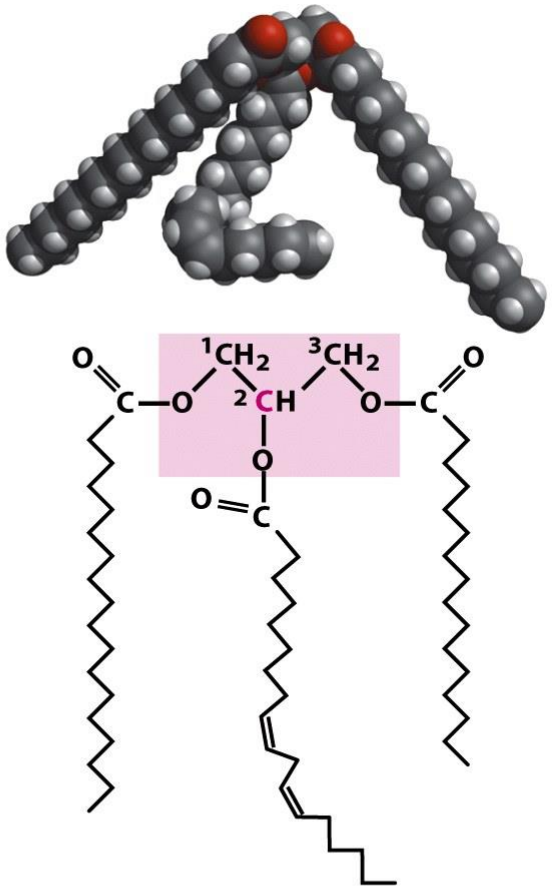
Diglycerides

Triglycerides (TG)

- The characteristics of glycerides are due to the FAs participated in their structure



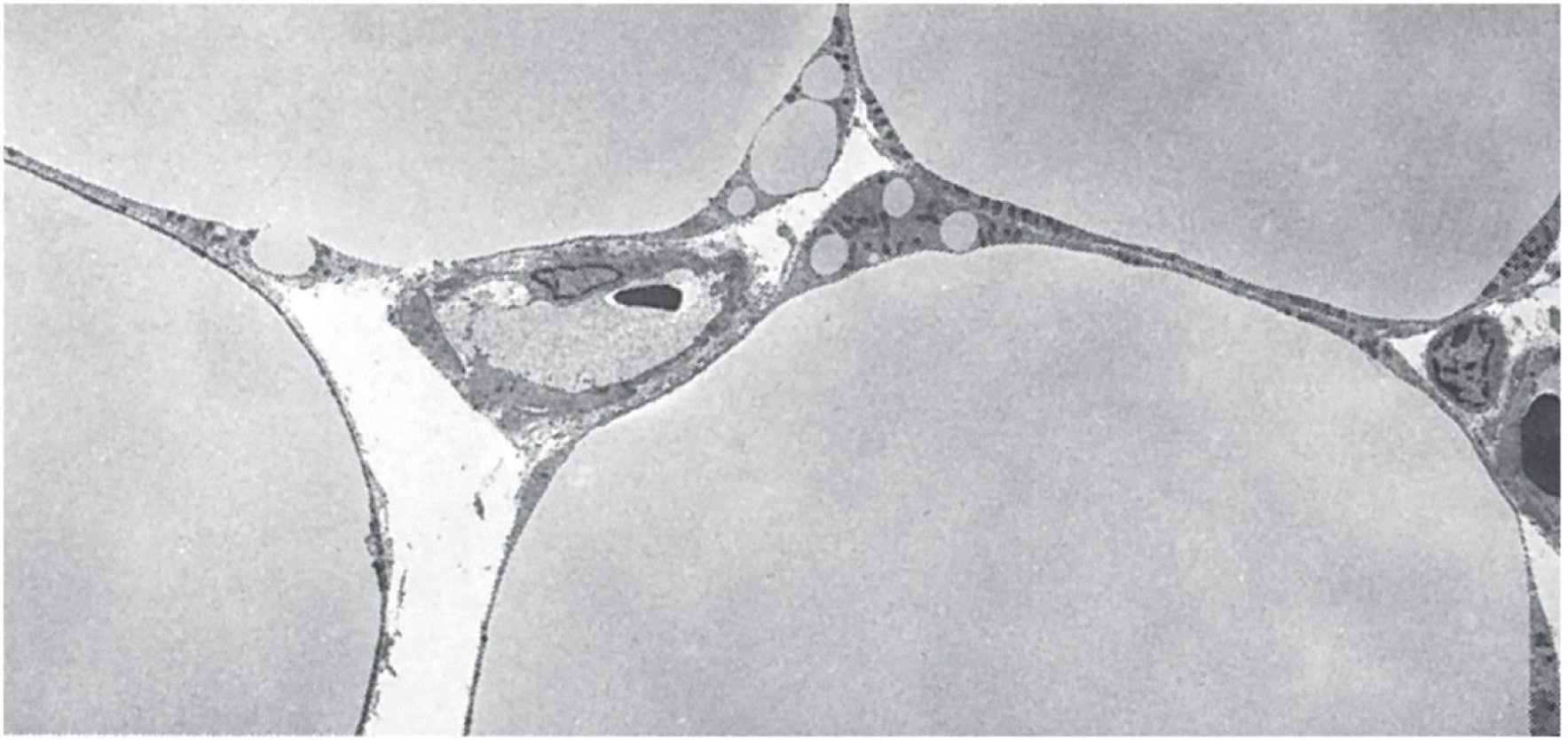
Glycerol



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

The mixed triacylglycerol shown here has three different fatty acids attached to the glycerol

Fat stores in cells



Cross section of four guinea pig adipocytes

Figure 10-4a
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Esters of FAs and alcohols

- Glyceryl esters

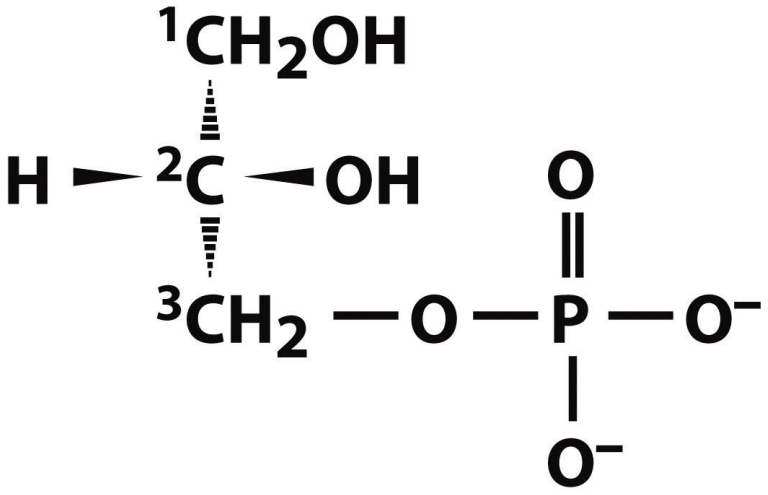
  1- Acyl glycerols (Glycerides)

  2- Phosphoglycerides

- Waxes

Phosphoglycerides

- There are abundant in biological membranes



L-Glycerol 3-phosphate

(The backbone of phospholipids)

Figure 10-8
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❖ The common glycerophospholipids are diacylglycerols linked to head-group alcohols through a phosphodiester bond.

❖ Phosphatidic acid, a phosphomonoester, is the parent compound

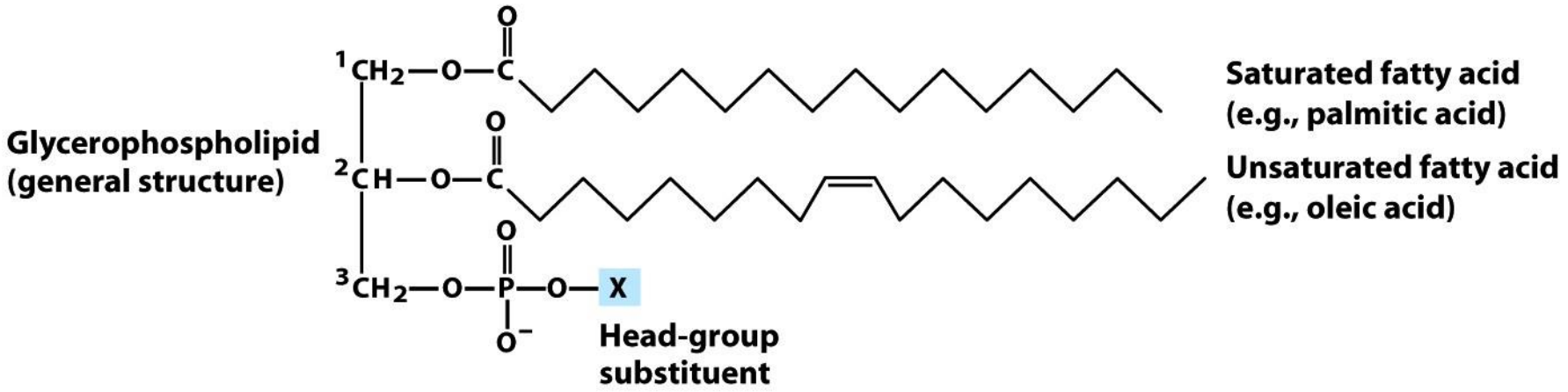

Figure 10-9 part 1
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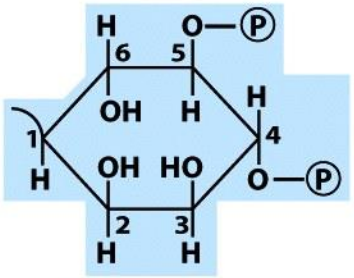
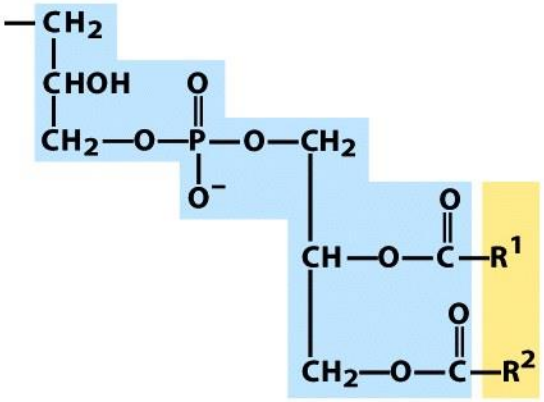
Name of glycerophospholipid	Name of X	Formula of X		Net charge (at pH 7)
Phosphatidic acid	—	—H		−1
Phosphatidylethanolamine	Ethanolamine	—CH_2—CH_2—$\overset{+}{N}H_3$	Cephalin	0
Phosphatidylcholine	Choline	—CH_2—CH_2—$\overset{+}{N}(CH_3)_3$	Lecithin	0
Phosphatidylserine	Serine	—CH_2—$CH(\overset{+}{N}H_3)$—COO^-		−1
Phosphatidylglycerol	Glycerol	—CH_2—$CH(OH)$—CH_2—OH		−1
Phosphatidylinositol 4,5-bisphosphate	*myo*-Inositol 4,5-bisphosphate			−4
Cardiolipin	Phosphatidyl-glycerol			−2

Figure 10-9 part 2

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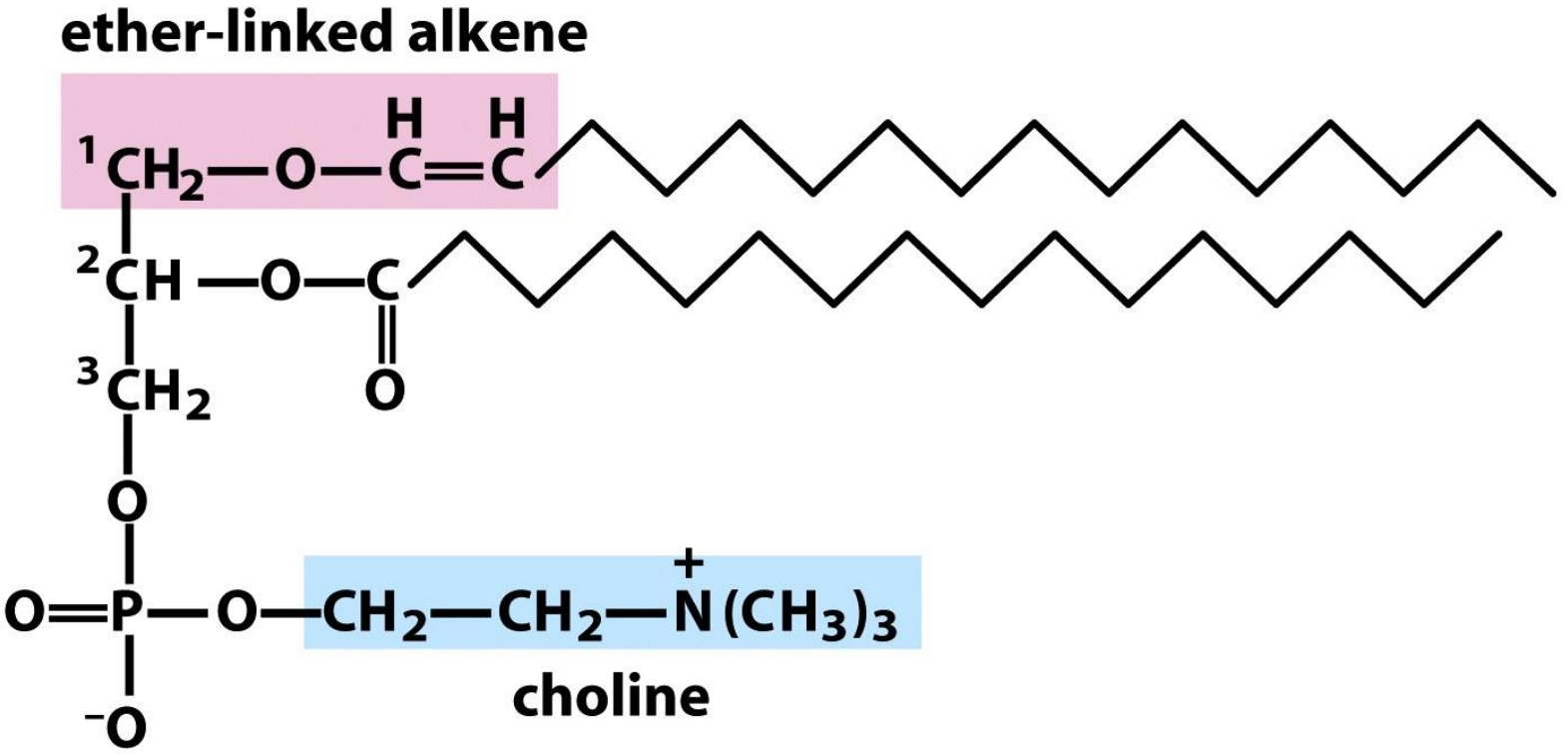
Ether lipids

Plasmalogens have an ether-linked alkenyl chain where most glycerophospholipids have an ester-linked fatty acid.

Platelet-activating factor has a long ether-linked alkyl chain at C-1 of glycerol, but C-2 is ester-linked to acetic acid, which makes the compound much more water-soluble than most glycerophospholipids and plasmalogens.

The head-group alcohol is ethanolamine in plasmalogens and choline in platelet-activating factor.



Plasmalogen (an ether lipid)

- Plasmalogens have an ether-linked alkenyl chain.
- They are about 10% of brain and muscle phospholipids

در یک ملکول کاردیولیپین چند گلیسرول وجود دارد؟

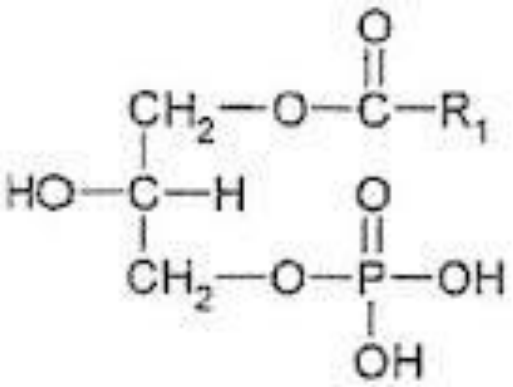
- الف) 1
- ب) 2
- ج) 3
- د) 4

Lysophospholipids

- The term *lysophospholipid* (LPL) refers to any phospholipid that is missing one of its two acyl chain.

- They are more balanced in hydrophobic and hydrophilic parts of the molecule and are more amphipatic.

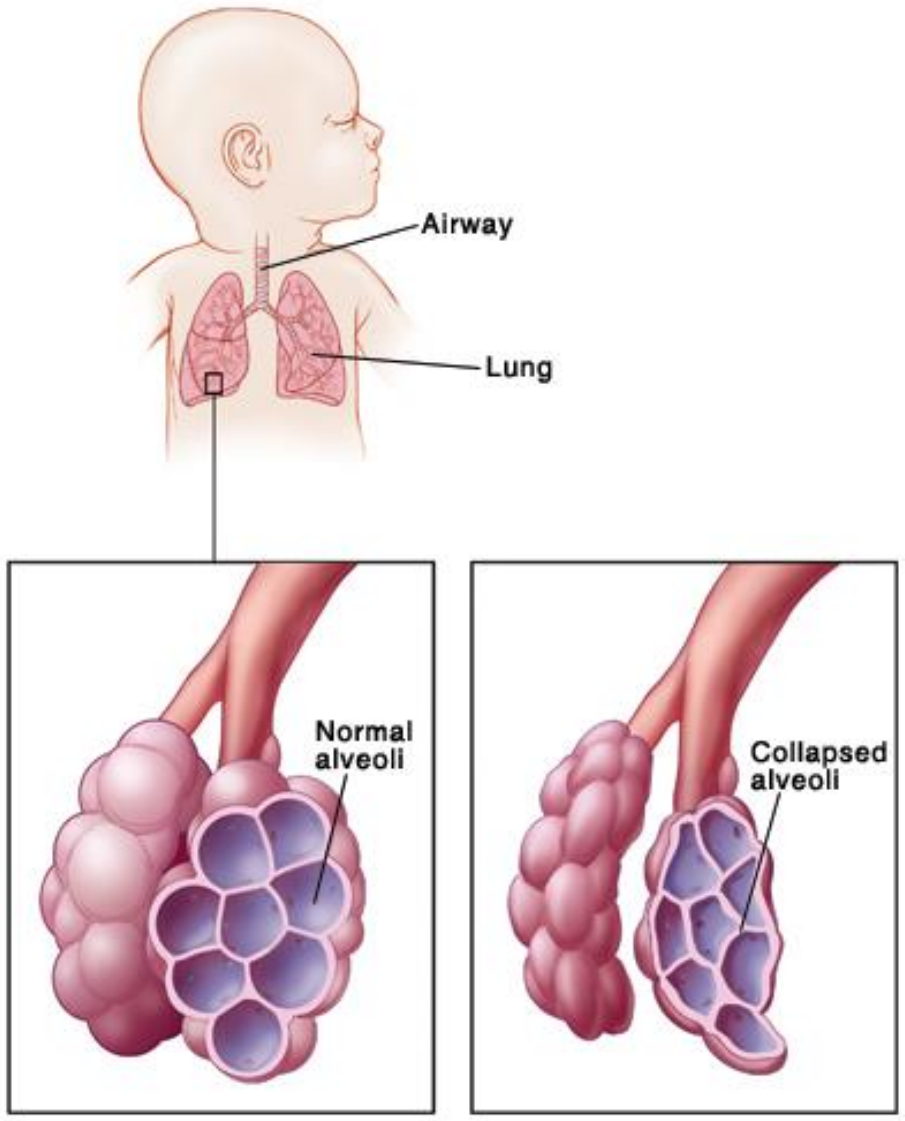
- They are able to lyse membranes.



Pulmonary surfactants

- Respiratory Distress Syndrome (RDS)

- The most important surfactant is dipalmitoyl lecithin which secreted by pnomocytes type II.
- Anti-cancer drugs kill pnomocytes type II



2- Esters of FAs and alcohols

- Glyceryl esters

  1- Acyl glycerols (Glycerides)

  2- Phosphoglycerides

- **Waxes**

3- Biological wax

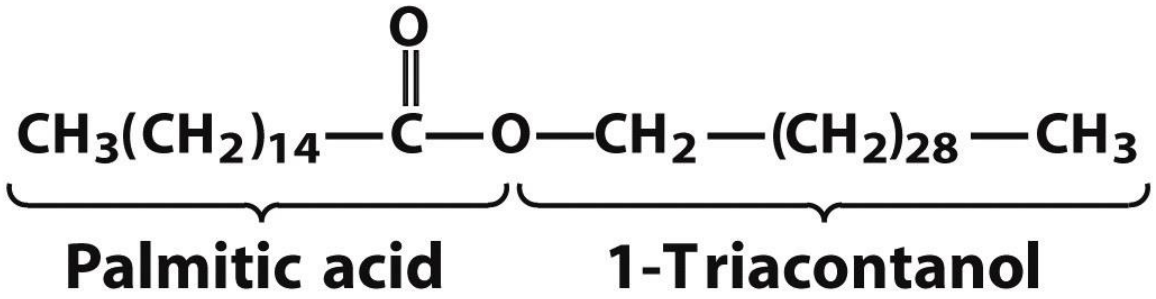


Figure 10-6
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Lipid Classification

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3- Waxes

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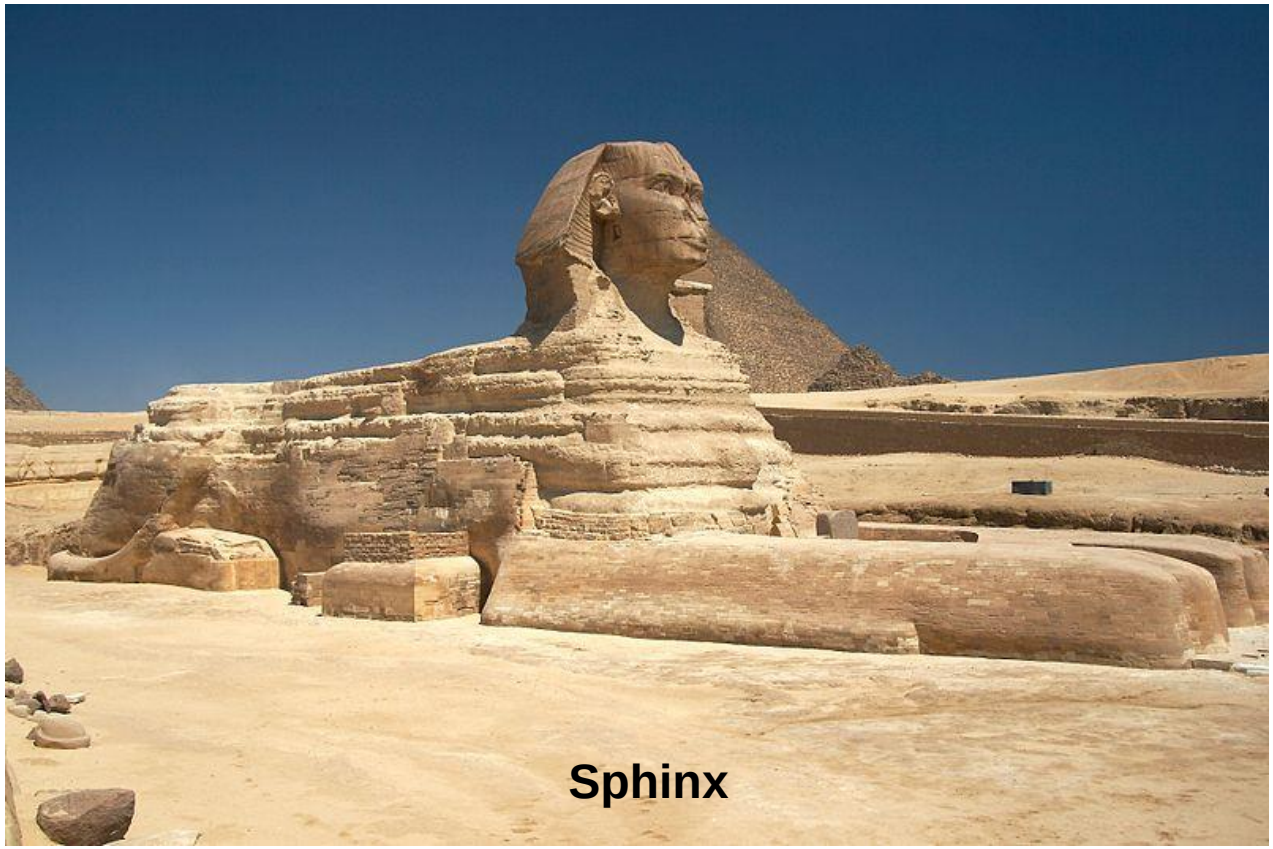
5- Sterol derivatives

6- Terpenes (Isopernoids)

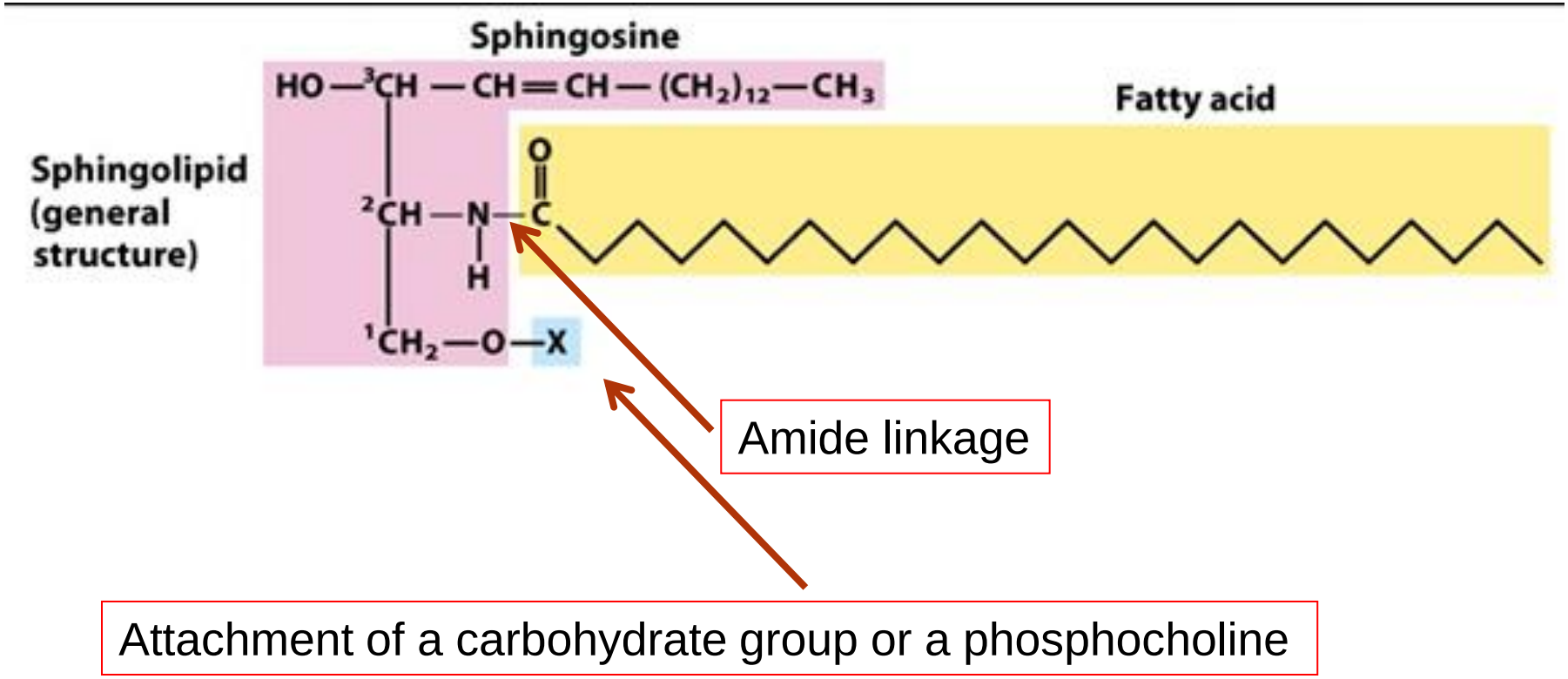
4- Sphingolipids



Sphinx

Sphingolipids general structure

Sphingosine + Fatty acid = Ceramide



Sphingolipids

Sphingomyelin
Glycosphingolipids

1- Cerebrosides
2- Globosides
3- Gangliosides

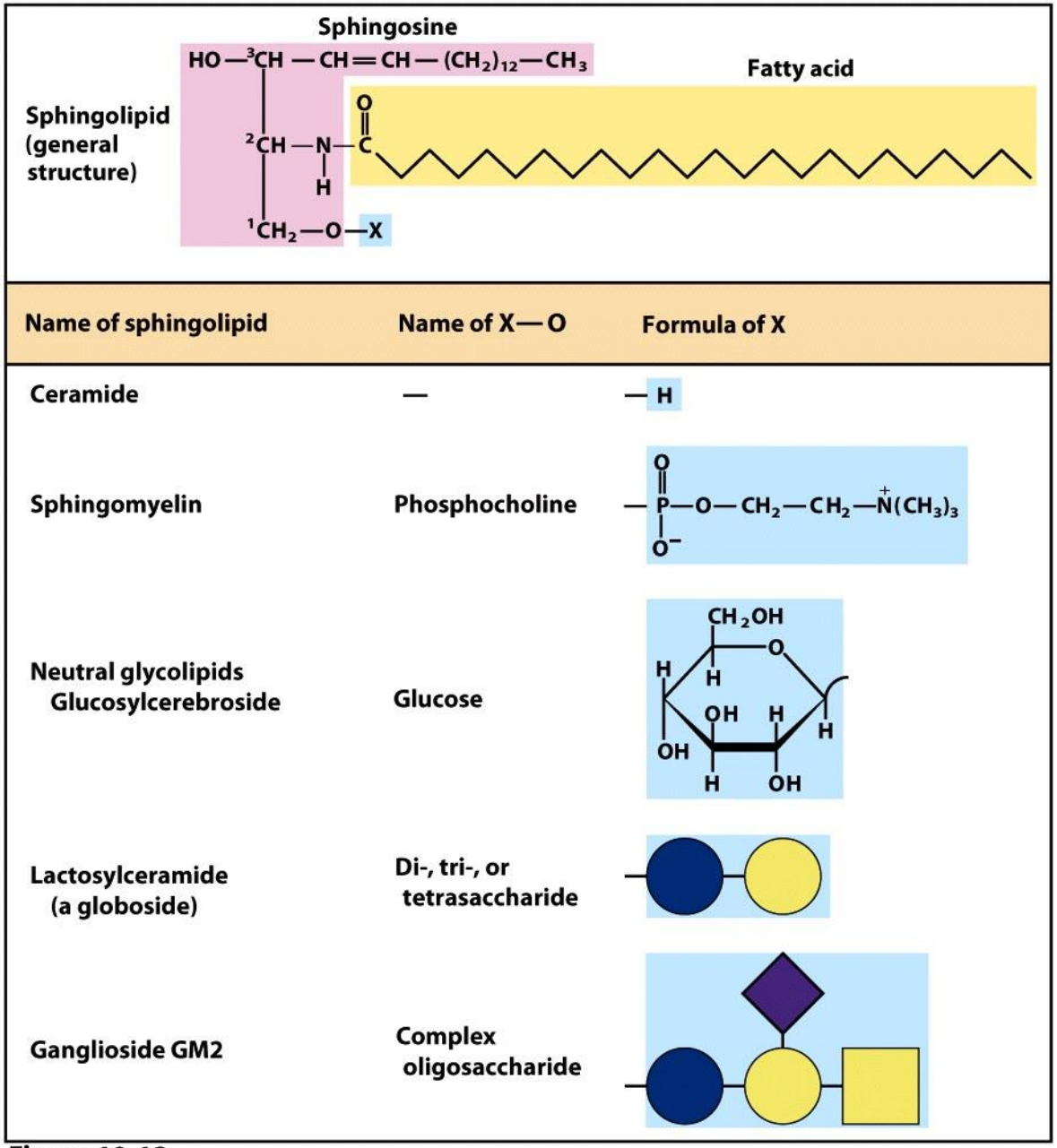


Figure 10-13
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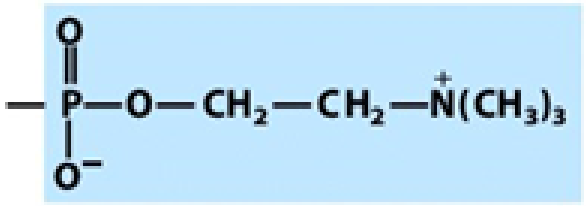
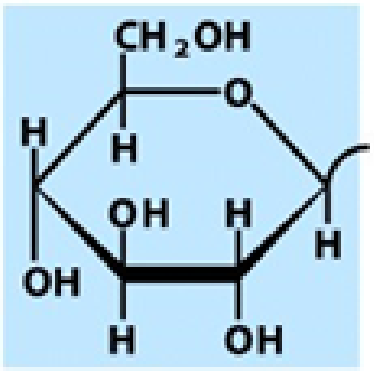
Sphingolipids classification

A. **Ceramide + Phosphocholine = Sphingomyelin**

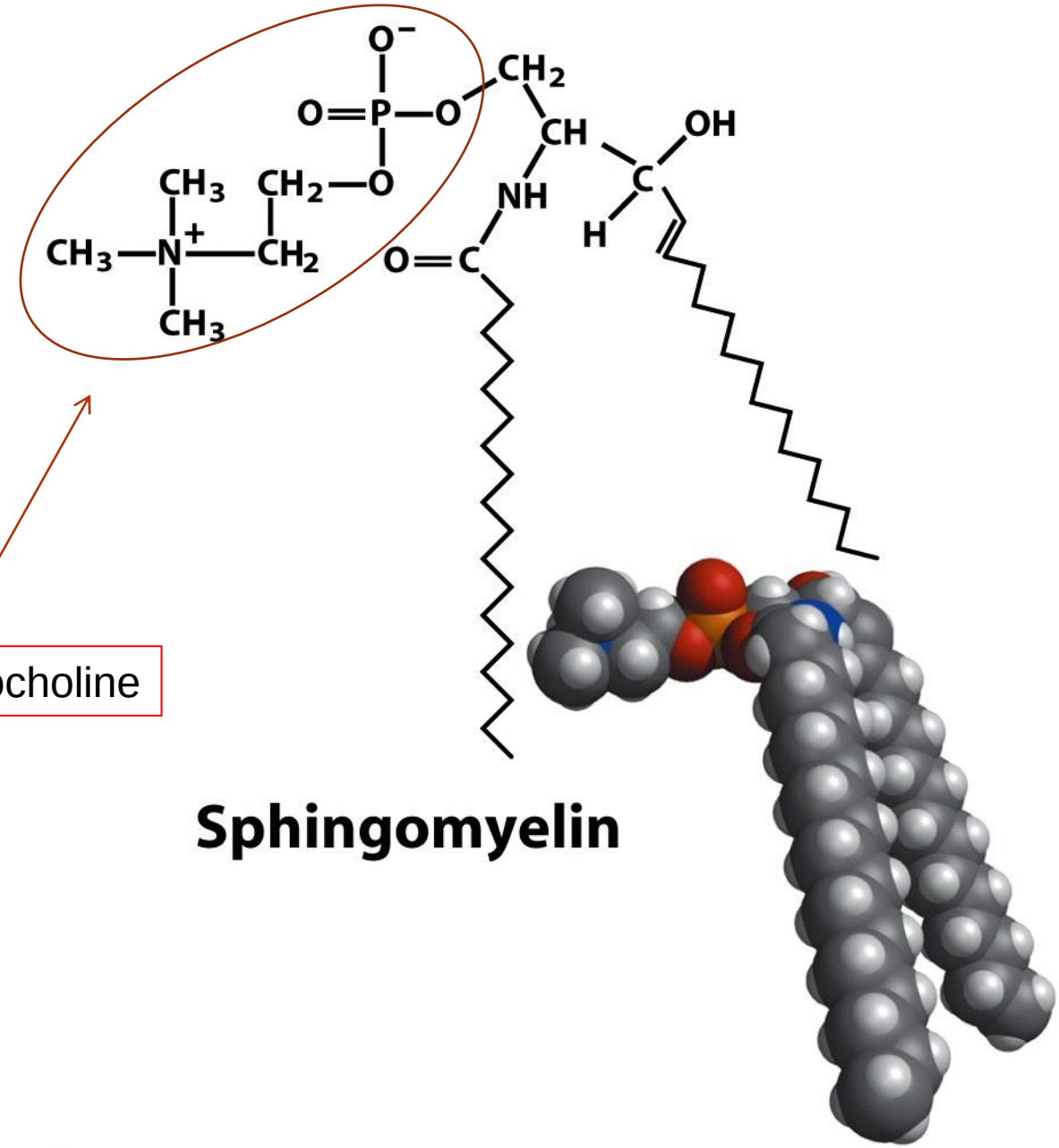


a polar head group is joined by a phosphodiester

A. **Ceramide + Carbohydrate = Glycosphingolipids**



a polar head group is joined by a glycosidic linkage

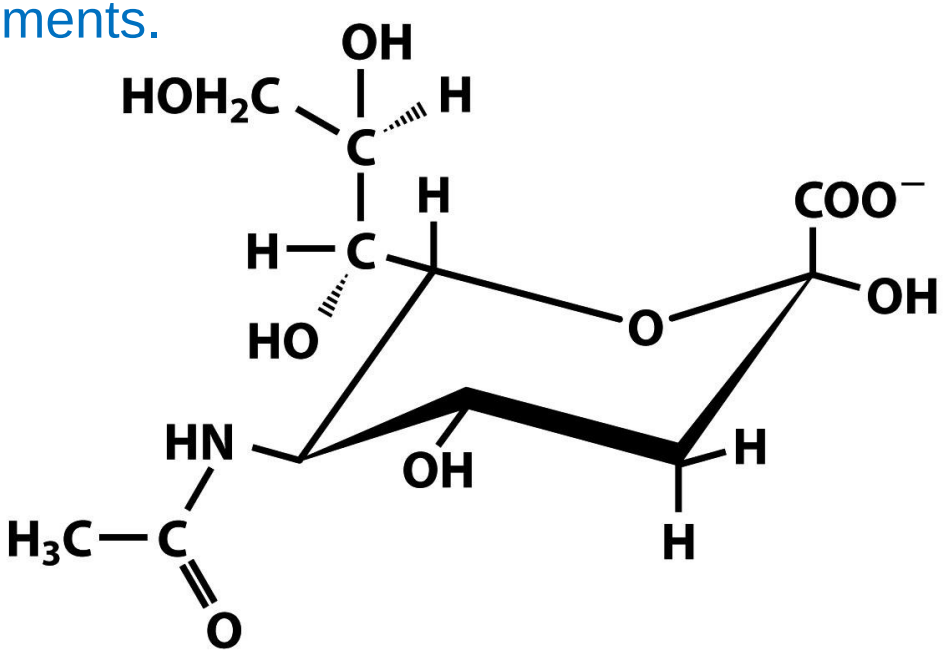


Is present in cell membrane specially on neurons

Gangliosides include an oligosaccharide chan attached to ceramide with at least one sialic acid (NANA) molecule.

GM, GD, GT and GQ has one to four sialic acid molecules.

The under script numbers shows the chromatographic movements.



***N*-Acetylneuraminic acid (a sialic acid) (Neu5Ac)**

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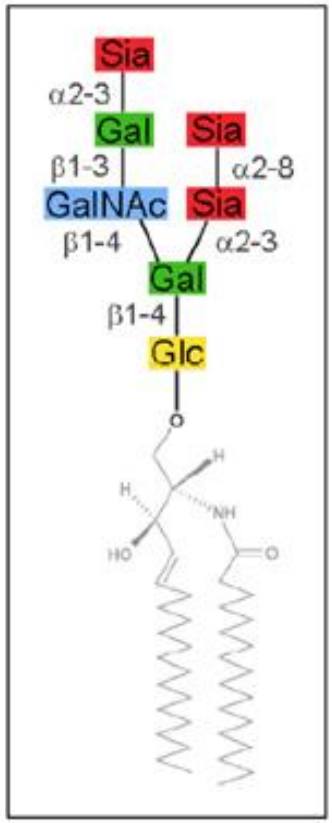
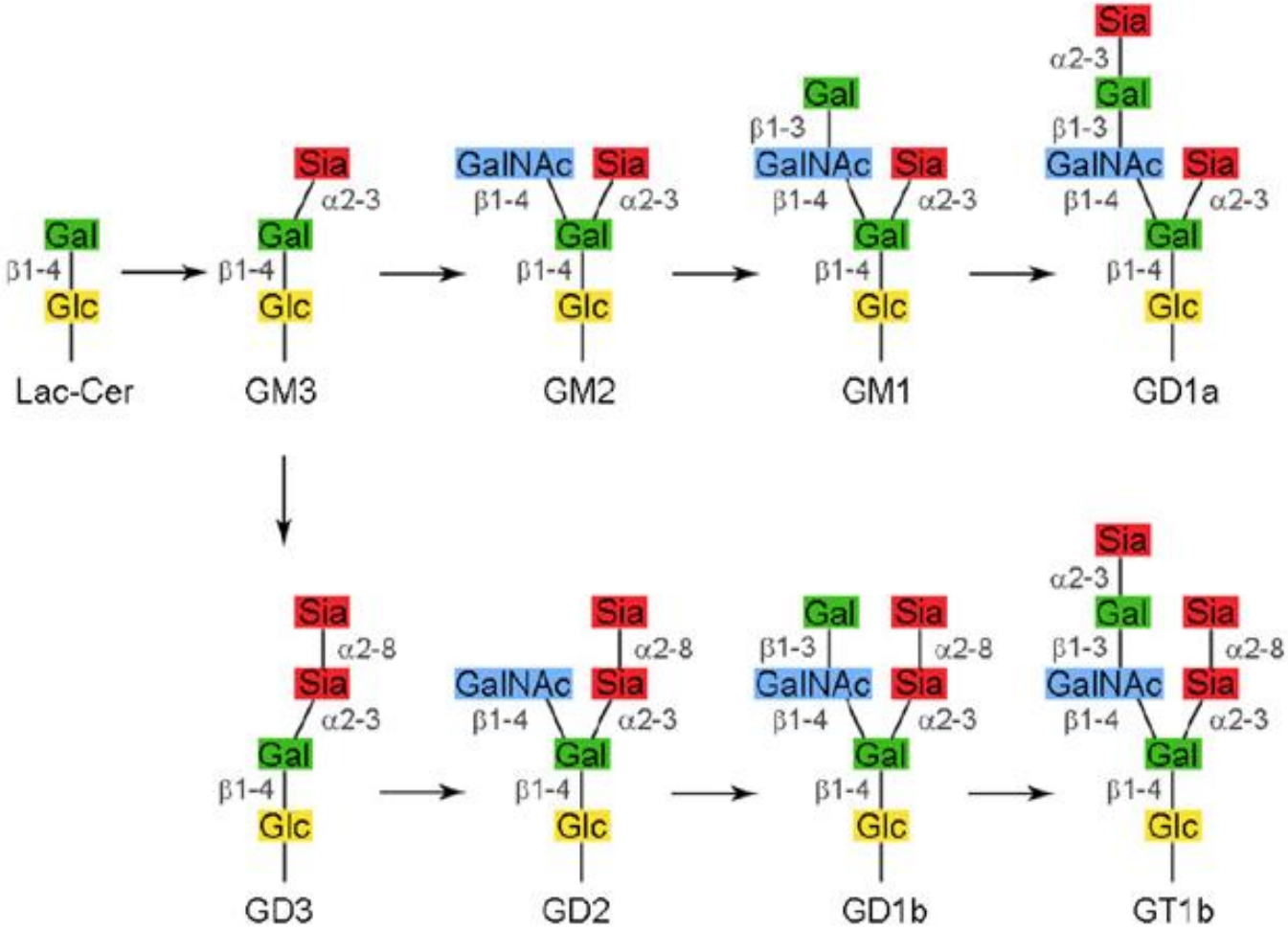
Gangliosides





Glycosphingolipids as determinants of blood groups

They act as cell surface antigens and are important in cell-cell interactions

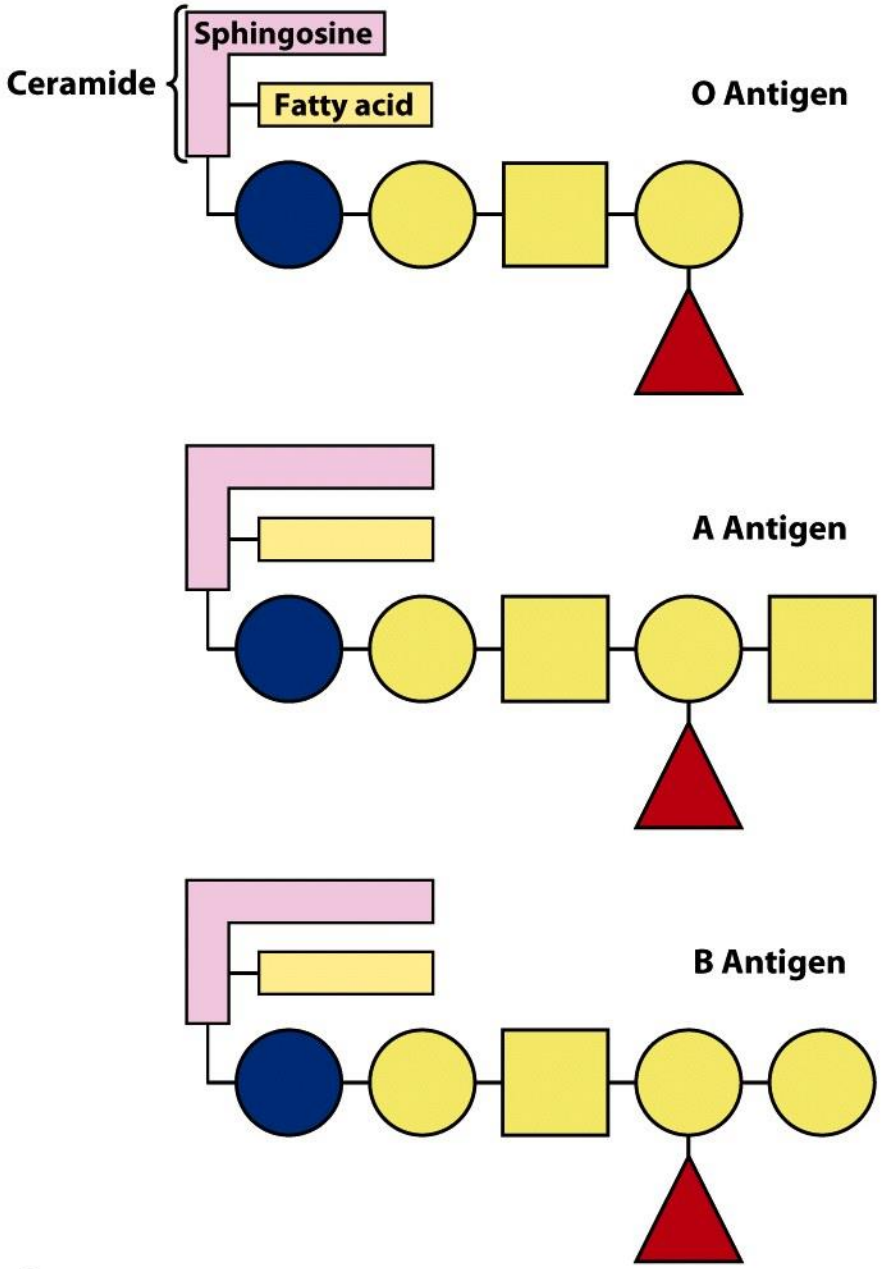


Figure 10-15
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محل قرار گیری گانگلیوزیدها کجاست؟

- الف) سطح داخلی غشاء سلولی
- ب) در آدیپوسیت ها بصورت ذخیره ای
- ج) در سطح خارجی غشاء سلولی
- د) گزینه های الف و ج

Lipid Classification

- It is not easy to classify them according to their various structures

1- Fatty acids

2- Glyceryl esters (including phosphoglycerides)

3- Waxes

4- Sphingolipids

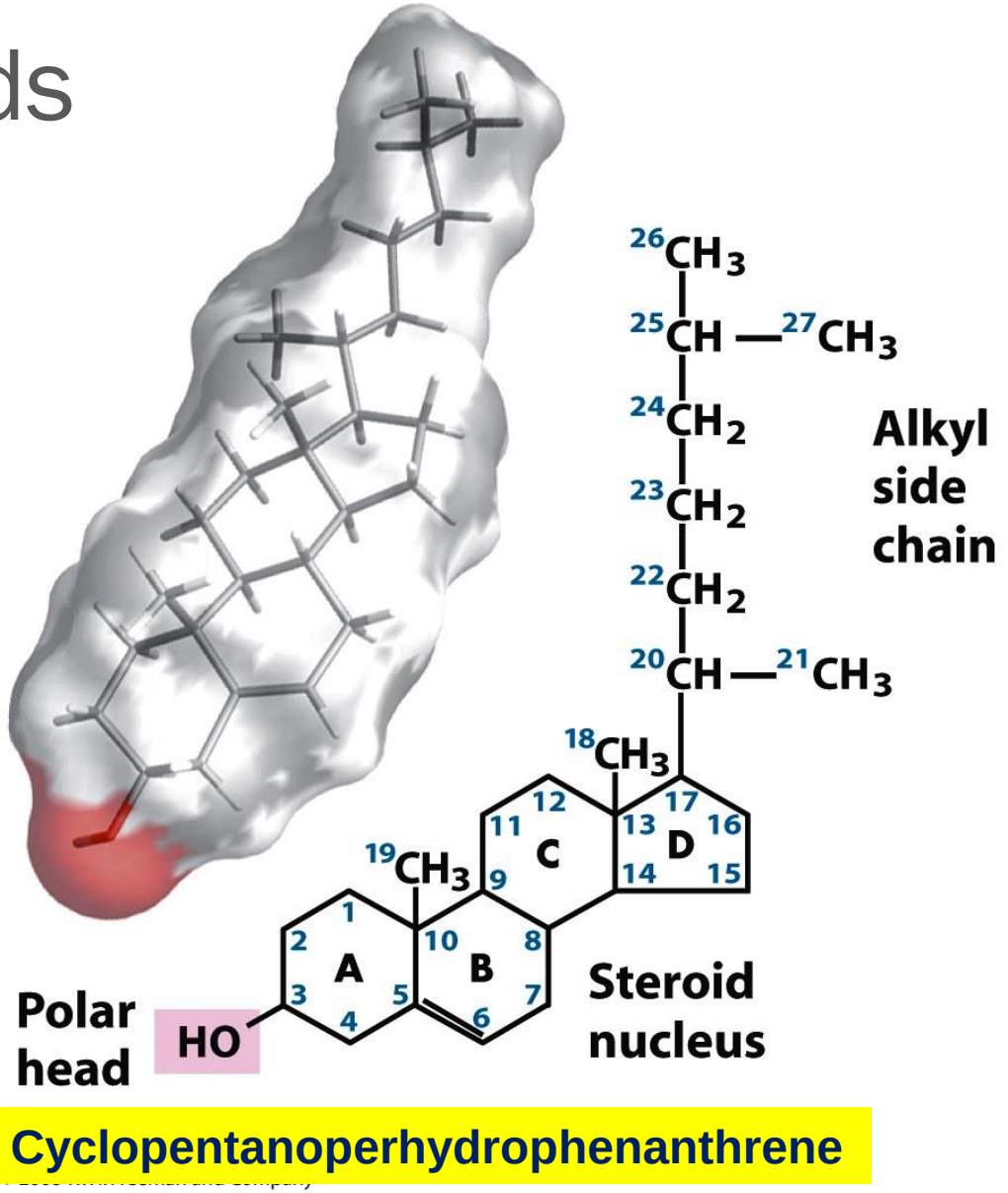
5- Sterol derivatives

6- Terpenes (Isopernoids)

5- Steroids

Cholesterol

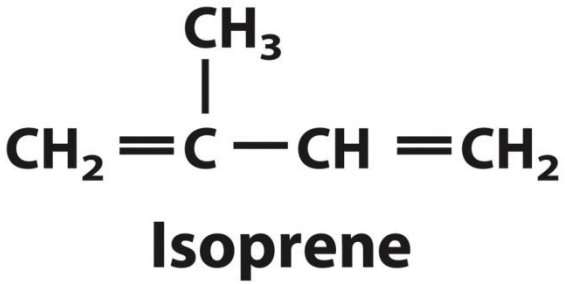
In Membranes?



For storage and transport of the sterol, the hydroxyl group condenses with a fatty acid to form a sterol ester.

Cholesterol

- The sterols of all eukaryotes are synthesized from simple five-carbon isoprene subunits



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- Sterols serve as precursors for a variety of products with specific biological activities:

I. **Steroid hormones**, for example, are potent biological signals that regulate gene expression.

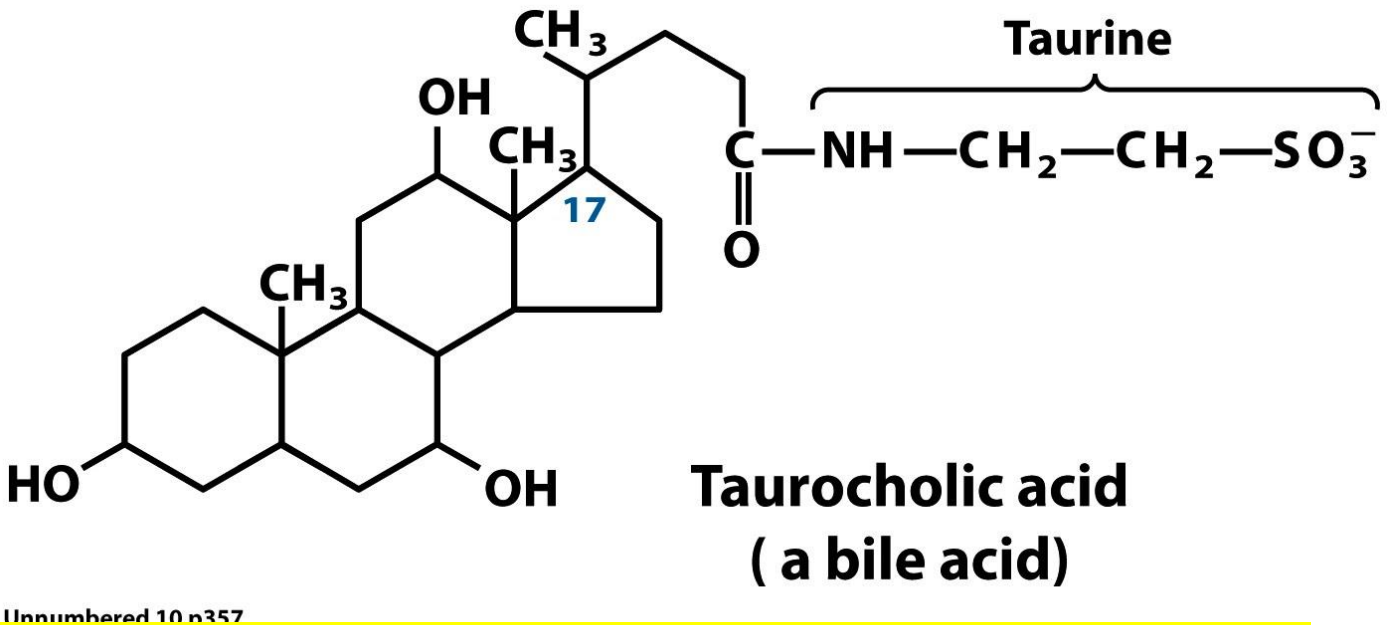
II. **Bile acids (bile salts)** are polar derivatives of cholesterol that act as detergents in the intestine, emulsifying dietary fats to make them more readily accessible to digestive lipases.

III. **Vitamin D**

Bile salts include more OH groups in compare with cholesterol.

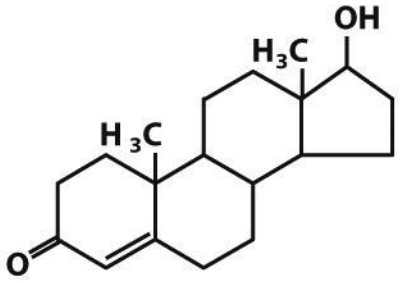
Bile salts such as Cholic acid and Chenodeoxy Cholic acid conjugate by Glycin or Taurine to be more amphipatic.

They participate in lipid **emulsification** during digestion in GI.

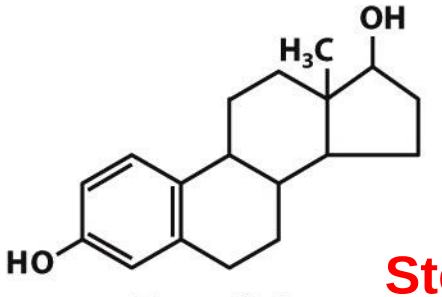


The only way of cholesterol excretion is via bile acids

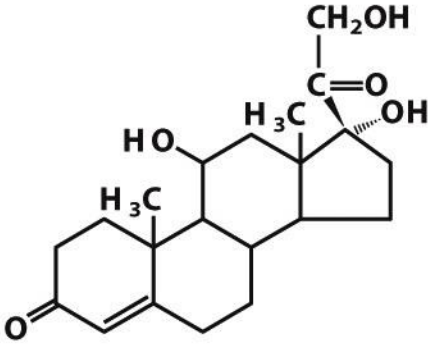
Steroids derived from cholesterol



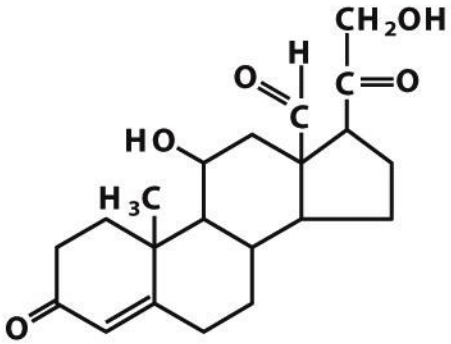
Testosterone



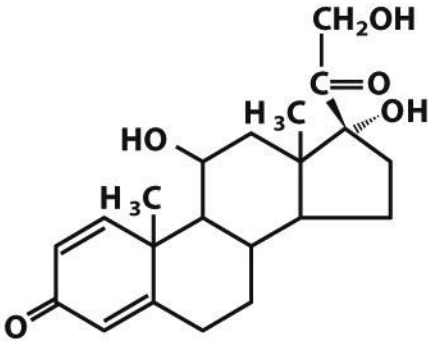
Estradiol



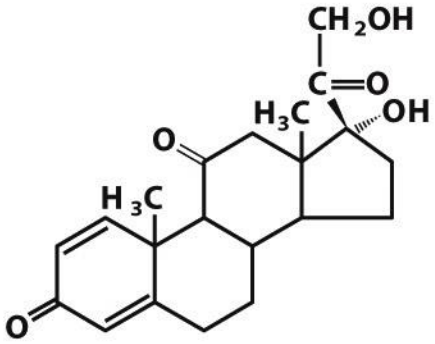
Cortisol



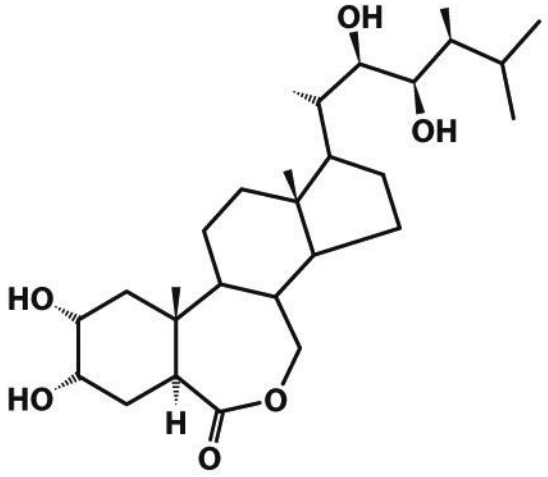
Aldosterone



Prednisolone



Prednisone



Brassinolide
(a brassinosteroid)

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Vitamin D_3 production and metabolism

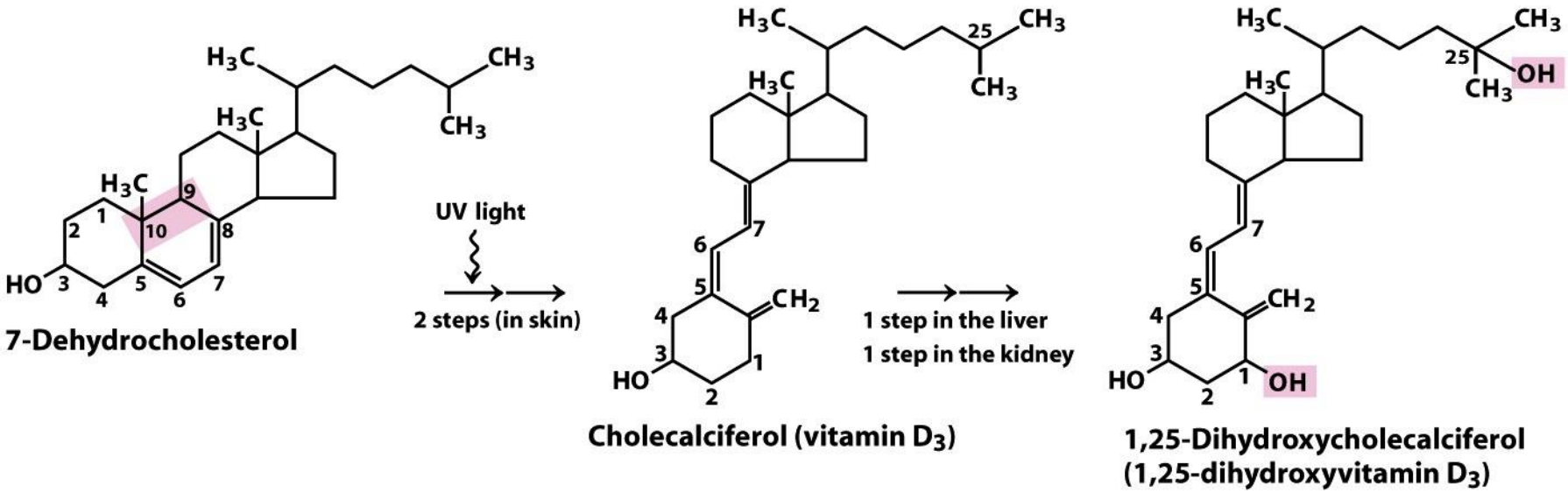

Figure 10-20a
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Lipid Classification

- It is not easy to classify them according to their various structures

1- Fatty acids

2- Glyceryl esters (including phosphoglycerides)

3- Waxes

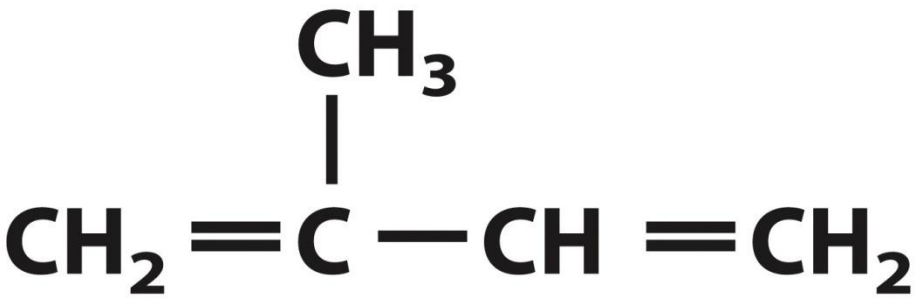
4- Sphingolipids

5- Sterol derivatives

6- Terpenes (Isopernoids)

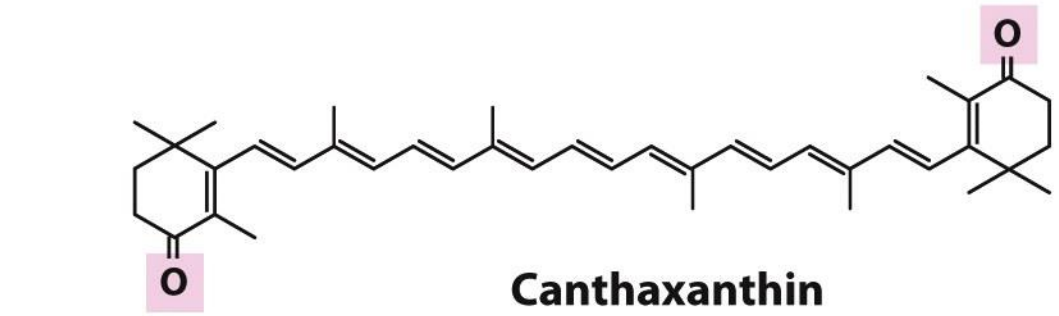
6- Terpenes (Isopernoids)

- **Polymers** containing two or more 5C isoprene units.
- They may be circular or linear.
- Fat soluble vitamins such as vit. A, E and K, camphor, menthol and some natural pigments are terpenes.

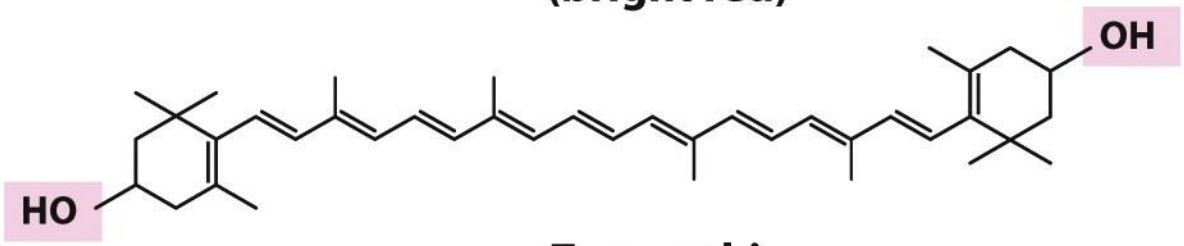


Isoprene

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



Canthaxanthin
(bright red)



Zeaxanthin
(bright yellow)

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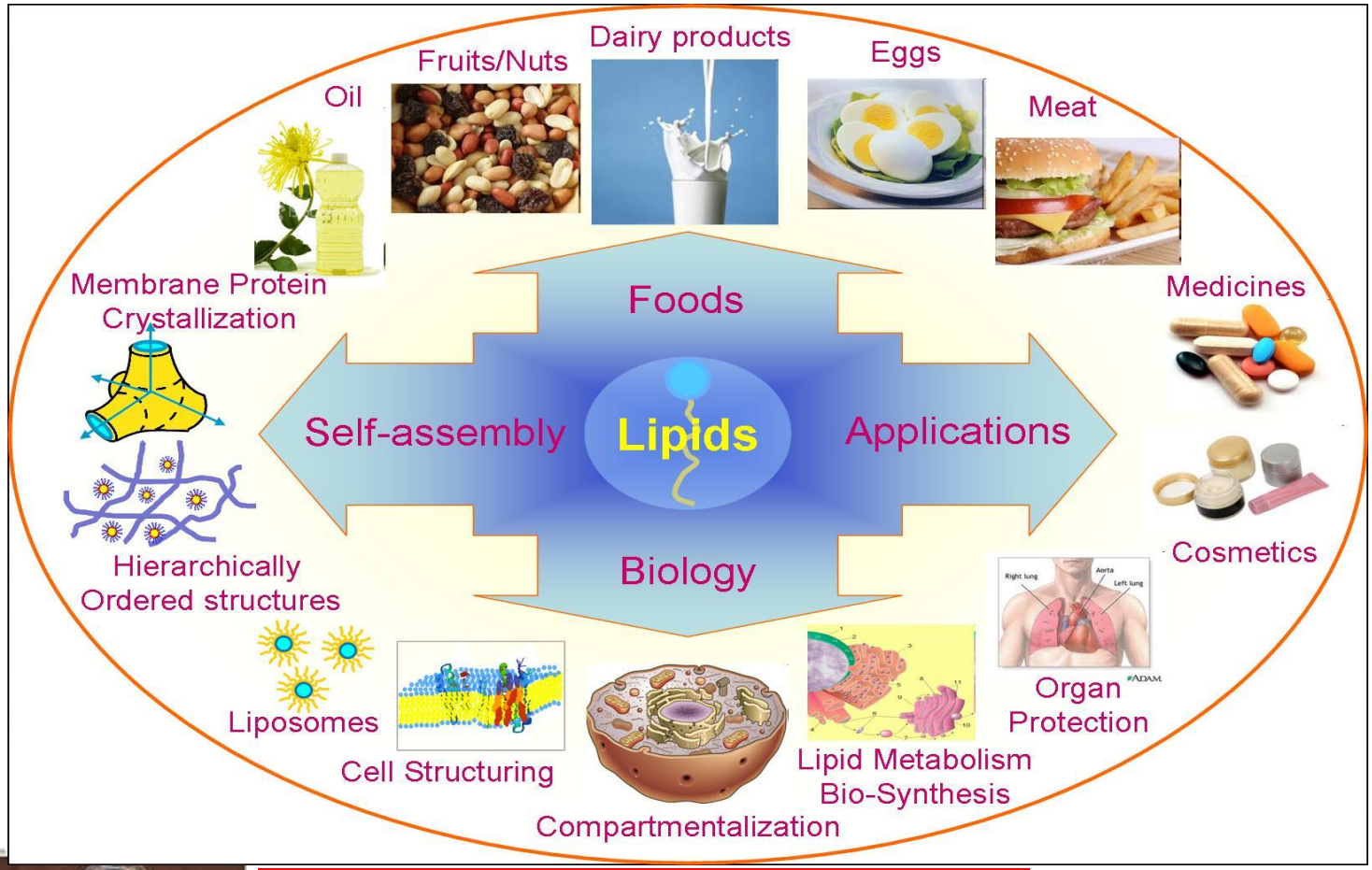

Use healthy lipids
to be always healthy