Lecture 27 (11/20/20)

This begins the material for the Final Exam

TODAY

•Reading: Ch10; 361-368, 370, 372, 376

•Problems:
Ch10 (text); 1,3,4,8,10,14,16
Ch10 (study-guide: applying); **1,3,4**
Ch10 (study-guide: facts); *1-5,6-8*
Ch11 (study-guide: facts); *8*

NEXT

•Reading:
Ch11; 387-393, 395-401
Ch7; 241-246

•Problems:
Ch10 (text); 12
Ch11 (text); 3,4,5,6,7,9,10,13,14
Ch11 (study-guide: applying); **1,2,3**
Ch11 (study-guide: facts); *1-5,8,9-13,19*
Ch7 (text); 1,2,4,9,10
Ch7 (study-guide: facts); *1,3,7,8,9,11,12*

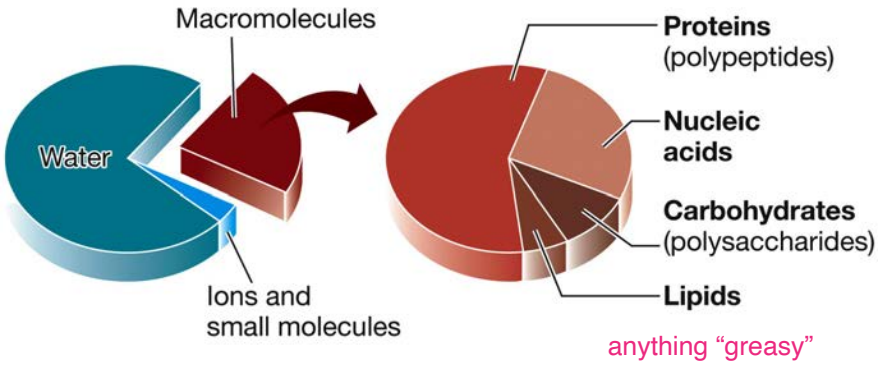
Lipids & Membranes

A. Lipids
1. Roles
2. Classes
   a. Fatty Acids
   b. Fats
   c. Waxes
   d. Membrane lipids
   e. Terpenes

B. Membranes
1. Introduction
2. The 4 S's
   a. Size
   b. Solubility
   c. Shape
   d. Stability
3. Models for Membrane structure
   a. Old Model
   b. Data
   c. Fluid Mosaic Model
   d. Testing the model
4. The Red-Blood Cell Membrane
5. Membrane Asymmetry
   a. transverse
   b. lateral
   c. anchoring
6. Membrane Fluidity

Lipids & Membranes

Lipids



anything "greasy"

Lipids: Roles

- Membrane structure
  - main structure of cell membranes
- Storage of energy
  - reduced compounds: lots of available energy
  - hydrophobic nature: good packing
- Signaling molecules
  - paracrine signals (act locally)
  - steroid hormones (act body-wide)
  - growth factors
  - vitamins A and D (hormone precursors)
- Vitamins, Cofactors, and secondary products
  - Vitamins E & K: antioxidant & blood clot formation, resp.
  - coenzyme Q: ATP synthesis in mitochondria
  - Pigments, e.g., tomatoes, carrots, pumpkins, some birds
  - Water repellant in feathers and hides
  - Insulation & bouyancy control in marine mammals (blubber)

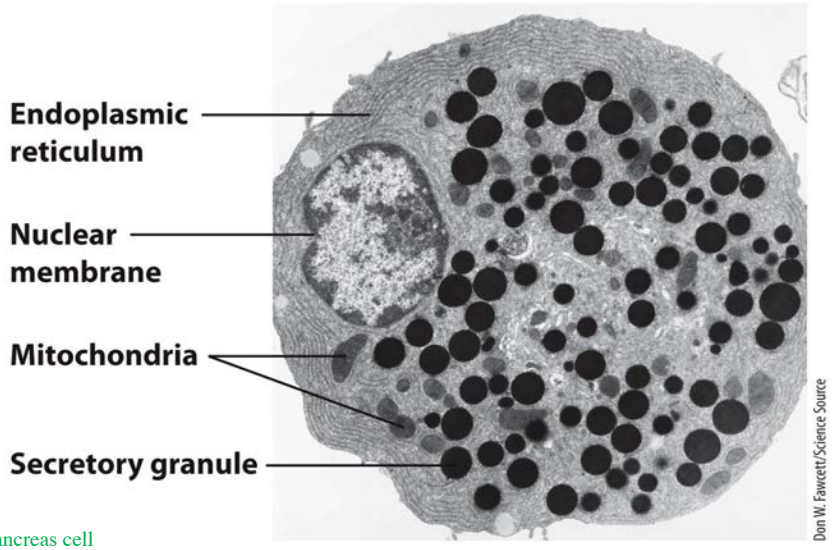
Lipids: Roles

Functions of Membranes

- Define the boundaries of the cell
- Allow import and export
  - Selective import of nutrients (e.g. lactose)
  - Selective export of waste and toxins (e.g. antibiotics)
- Retain metabolites and ions within the cell
- Sense external signals and transmit information into the cell
- Provide compartmentalization within the cell
  - separate energy-producing reactions from energy-consuming ones
  - keep proteolytic enzymes away from important cellular proteins
- Produce and transmit nerve signals
- Store energy as a proton gradient
- Support synthesis of ATP

Lipids: Roles

Electron Micrograph of Biological Membranes



Pancreas cell

Lipids: Classes

Biological molecules that are characterized by low solubility in water, that is, are relatively hydrophobic.

They have a high hydrocarbon content

TABLE 10-2 Eight Major Categories of Biological Lipids

Category		Category code	Examples
Fatty acids	①	FA	Oleate, stearoyl-CoA, palmitoylcarnitine
Glycerolipids	②	GL	Di- and triacylglycerols
Glycerophospholipids	④	GP	Phosphatidylcholine, phosphatidylserine, phosphatidyethanoloamine
Sphingolipids	④	SP	Sphingomyelin, ganglioside GM2
Sterol lipids	⑤	ST	Cholesterol, progesterone, bile acids
Prenol lipids	⑤	PR	Farnesol, geraniol, retinol, ubiquinone
Saccharolipids		SL	Lipopolysaccharide
Polyketides		PK	Tetracycline, erythromycin, aflatoxin B_1
Waxes	③		

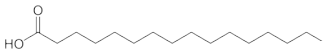
Lipids: Classes

Biological molecules that are characterized by low solubility in water, that is, are relatively hydrophobic.

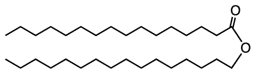
Classes of Lipids

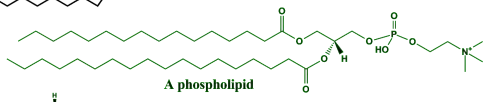
They have a high hydrocarbon content

1. Fatty acids
2. Fats (triglycerides)
3. Waxes
4. Membrane Lipids
5. Isoprenes

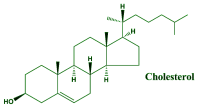


Structure of a fat





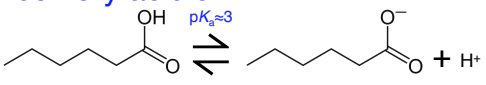
A phospholipid



Cholesterol

Lipids: Fatty Acids

- Carboxylic acids with hydrocarbon chains containing between 4 to 36 carbons
  - Almost all natural fatty acids have an even number of carbons.
  - Most natural fatty acids are unbranched.
- Biologically, most are found in ester linkages as the pK_a is ~3.0, and would otherwise be very acidic.



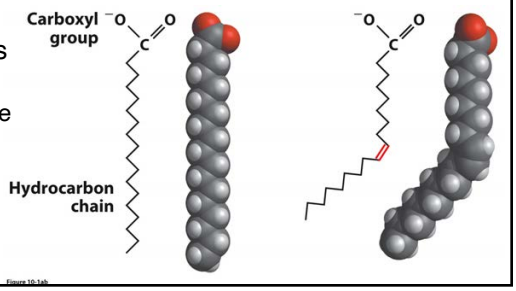
- TWO CLASSES
  - Saturated: no double bonds between carbons in the chain

m.p. > 37 °C

  - Unsaturated: ≥1 double bonds between carbons in the chain

m.p. < 20 °C

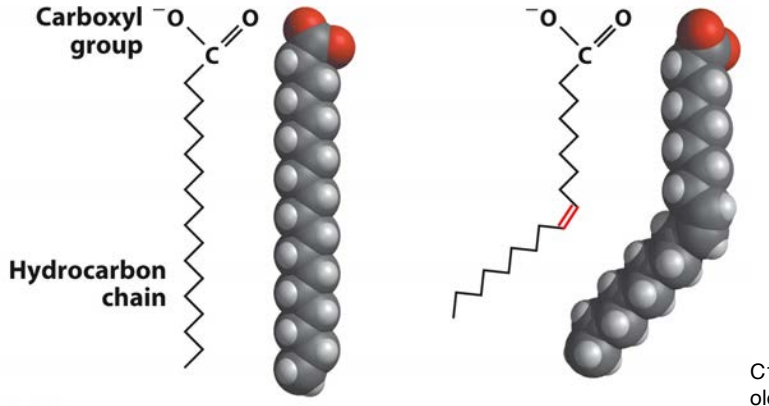
    - Monounsaturated: one double bond between carbons in the alkyl chain
    - Polyunsaturated: more than one double bond in the alkyl chain – never conjugated



Lipids: Fatty Acids

Conformation of Fatty Acids

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



C18:0 = stearate

C18:1 = oleate

Lipids: Fatty Acids

Fatty Acid Compositions of Some Dietary Lipids*

Source	Lauric and Myristic	Palmitic	Stearic	Oleic	Linoleic
Beef	5	24–32	20–25	37–43	2–3
Milk		25	12	33	3
Turkey	1	18-20	12-14	18-20	25-30
Coconut	74	10	2	7	—
Corn		8–12	3–4	19–49	34–62
Olive		9	2	84	4
Palm		39	4	40	8
Safflower		6	3	13	78
Soybean		9	6	20	52
Sunflower		6	1	21	66

Data from *Merck Index*, 10th ed. Rahway, NJ: Merck and Co., and Wilson et al., 1967, *Principles of Nutrition*, 2nd ed. New York: Wiley.

Saturated FA

Unsaturated FA

Lipids: Fatty Acids

Common Biological Fatty Acids

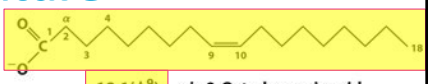
Number of Carbons	Common Name	Systematic Name	Symbol	Structure
Saturated fatty acids				
12	Lauric acid	Dodecanoic acid	12:0	$CH_3(CH_2)_{10}COOH$
14	Myristic acid	Tetradecanoic acid	14:0	$CH_3(CH_2)_{12}COOH$
16	Palmitic acid	Hexadecanoic acid	16:0	$CH_3(CH_2)_{14}COOH$
18	Stearic acid	Octadecanoic acid	18:0	$CH_3(CH_2)_{16}COOH$
20	Arachidic acid	Eicosanoic acid	20:0	$CH_3(CH_2)_{18}COOH$
22	Behenic acid	Docosanoic acid	22:0	$CH_3(CH_2)_{20}COOH$
24	Lignoceric acid	Tetracosanoic acid	24:0	$CH_3(CH_2)_{22}COOH$
Unsaturated fatty acids (all double bonds are cis)				
16	Palmitoleic acid	9-Hexadecenoic acid	16:1	$CH_3(CH_2)_5CH{=}CH(CH_2)_7COOH$
18	Oleic acid	9-Octadecenoic acid	18:1	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$
18	Linoleic acid	9,12-Octadecadienoic acid	18:2	$CH_3(CH_2)_4(CH{=}CHCH_2)_2(CH_2)_6COOH$
18	α-Linolenic acid	9,12,15-Octadecatrienoic acid	18:3	$CH_3CH_2(CH{=}CHCH_2)_3(CH_2)_6COOH$
18	γ-Linolenic acid	6,9,12-Octadecatrienoic acid	18:3	$CH_3(CH_2)_4(CH{=}CHCH_2)_3(CH_2)_3COOH$
20	Arachidonic acid	5,8,11,14-Eicosatetraenoic acid	20:4	$CH_3(CH_2)_4(CH{=}CHCH_2)_4(CH_2)_2COOH$
24	Nervonic acid	15-Tetracosenoic acid	24:1	$CH_3(CH_2)_7CH{=}CH(CH_2)_{13}COOH$

Need to Know: Common names, structure, symbol

Lipids: Fatty Acids

Nomenclature

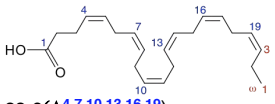
- Fatty acids can be described by:
  - systematic name: *cis*-9-octadecanoic acid
  - common name: oleic acid
  - delta numbering of carbon skeleton: $18:1^{\Delta 9}$
    - describes location of the first carbon of the alkene in relationship to the carbonyl carbon
  - omega numbering of carbon skeleton: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



18:1(Δ^9) *cis*-9-Octadecenoic acid

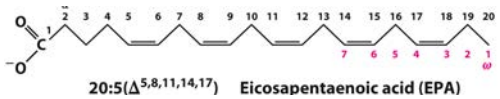
$18:1^{\omega 9}$

- Omega-3 fatty acids are essential nutrients.
  - Humans need them but cannot synthesize them.
  - They include α-linolenic acid (ALA) ($18:3^{\Delta 9,12,15}$)($18:3^{\omega 3,6,9}$), Eicosapentaenoic acid (EPA), and Docosahexaenoic Acid (DHA).
    - although DHA (22:6) and EPA (20:5) can be synthesized from ALA



22:6($\Delta^{4,7,10,13,16,19}$) Docosahexaenoic Acid (DHA)

$22:6^{\omega 3,6,9,12,15,18}$



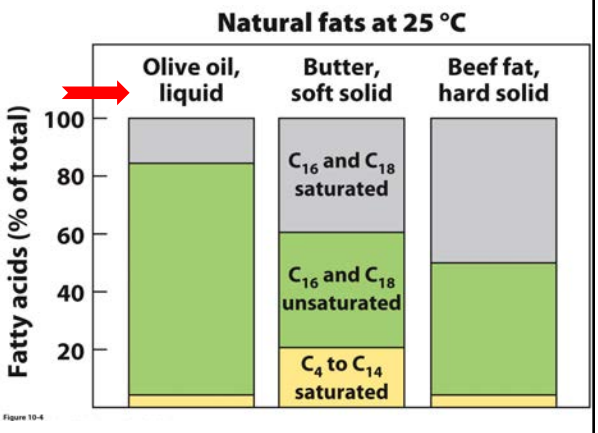
20:5($\Delta^{5,8,11,14,17}$) Eicosapentaenoic acid (EPA)

$20:5^{\omega 3,6,9,12,15}$

Lipids: Fatty Acids

Solubility and Melting Point of Fatty Acids

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



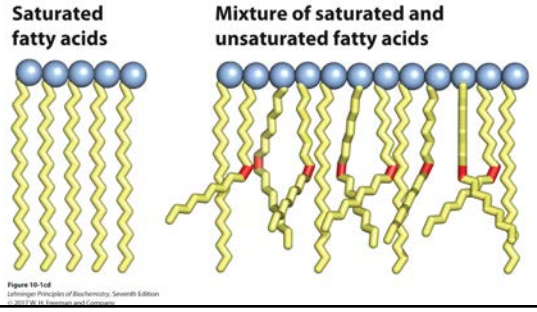
Lipids: Fatty Acids

Melting Point and Double Bonds

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

What kind of interaction?

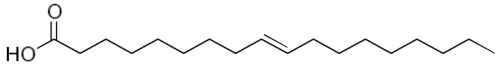
…. van der Waals



Lipids: Fatty Acids

Trans Fatty Acids

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



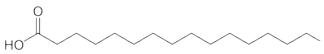
trans-Oleic acid (Eliadic acid)

Lipids: Classes

Biological molecules that are characterized by low solubility in water, that is, are relatively hydrophobic.

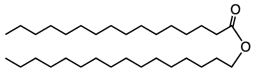
Classes of Lipids They have a high hydrocarbon content

1. Fatty acids

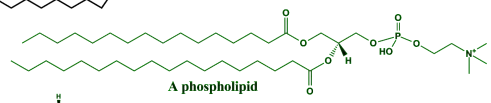


2. Fats (triglycerides)

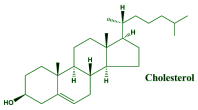
3. Waxes



4. Membrane Lipids



5. Isoprenes



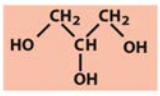
Lipids: Fat

Triacylglycerols (Nonpolar)

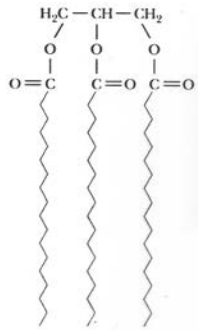
- The majority of fatty acids in biological systems are found in the form of triacylglycerols.
  - Solid ones are called fats.
  - Liquid ones are called oils.
- The primary storage form of lipids (body fat)
- Less soluble in water than fatty acids due to the esterification of the carboxylate group
-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

Lipids: Fat

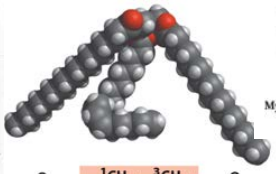
Triacylglycerols

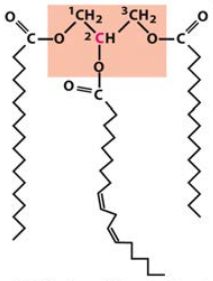


Glycerol

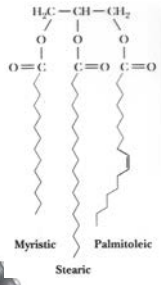


Tristear**oyl** glycerol





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



Name?

1-Myrist**oyl**-2-stear**oyl**-3-palmitole**oyl** glycerol

Lipids: Fat

Fats Provide Efficient Fuel Storage

- The advantage of fats over polysaccharides:
  - Fats and oils carry more energy per carbon because they are more reduced.
  - Fats and oils carry less water per gram because they are nonpolar.
- Glucose and glycogen are for short-term energy needs and quick delivery.
- Fats are for long-term (months) energy needs, good storage, and slow delivery.
- Fats can be treated with alkaline (NaOH), which will hydrolyze the ester bonds leading to glycerol and salts of the fatty acids…...soap! Process is called saponification.

Lipids: Fat

Fats Provide Efficient Fuel Storage

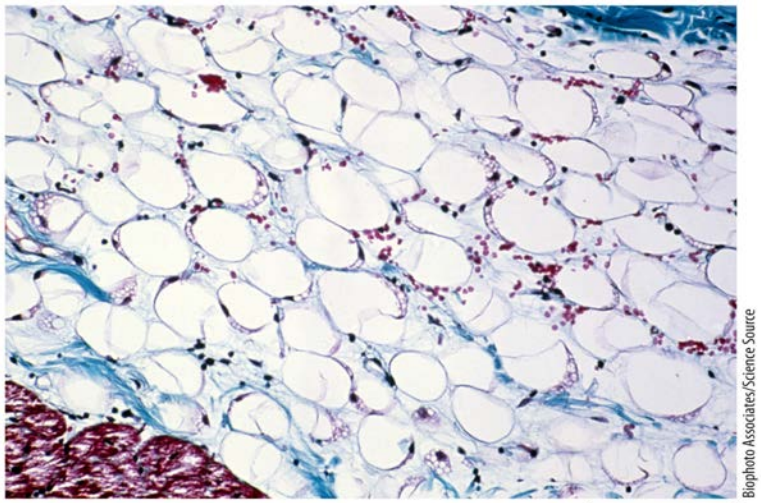


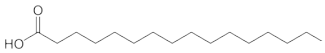
Figure 10-3a

Lipids: Classes

Biological molecules that are characterized by low solubility in water, that is, are relatively hydrophobic.

Classes of Lipids They have a high hydrocarbon content

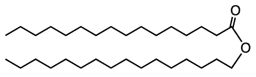
1. Fatty acids



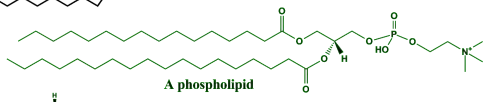
2. Fats (triglycerides)

Structure of a fat

3. Waxes

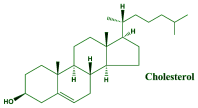


4. Membrane Lipids



A phospholipid

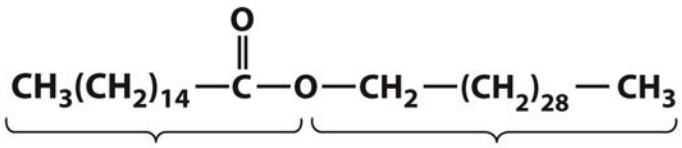
5. Isoprenes



Cholesterol

Lipids: Waxes

- Waxes are esters of long-chain saturated fatty acids with and saturated or unsaturated long-chain alcohols.
- Insoluble and have high melting points
- Variety of functions:
  - waterproofing of feathers in birds
  - protection from evaporation in tropical plants and ivy
  - protection and pliability for hair and skin in vertebrates
  - storage of metabolic fuel in plankton
  - used by people in lotions, ointments, and polishes



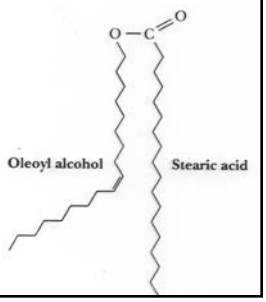


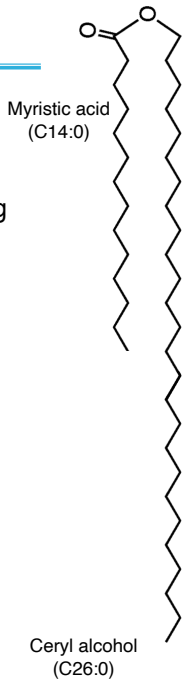
Figure 10-5a

Lipids: Waxes

Wax: The Material of the Honeycomb

Beeswax is a mixture of a large number of lipids, including esters of triacontanol (C30:0) and cerylanol (C26:0).

Figure 10-5b



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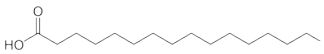
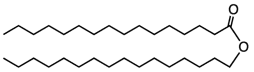


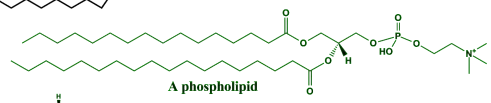
2. Fats (triglycerides)

Structure of a fat

3. Waxes

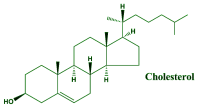


4. Membrane Lipids



A phospholipid

5. Isoprenes



Cholesterol

Lipids: Membrane Lipids

Classification of Membrane Lipids

Two major categories based on the structure and function:

1. Lipids that contain phosphate
2. Lipids that do not contain phosphate
   - each can be further separated into:
     - Glycerol-based and sphingosine-based

Membrane lipids

Lipids: Membrane Lipids

Classification of Membrane Lipids

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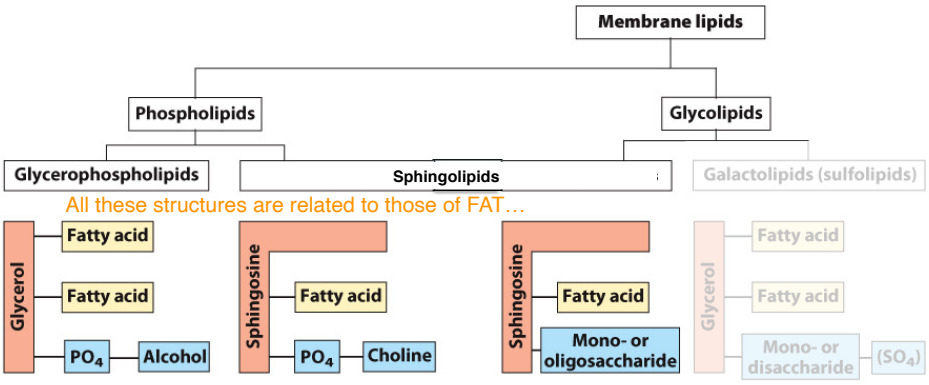
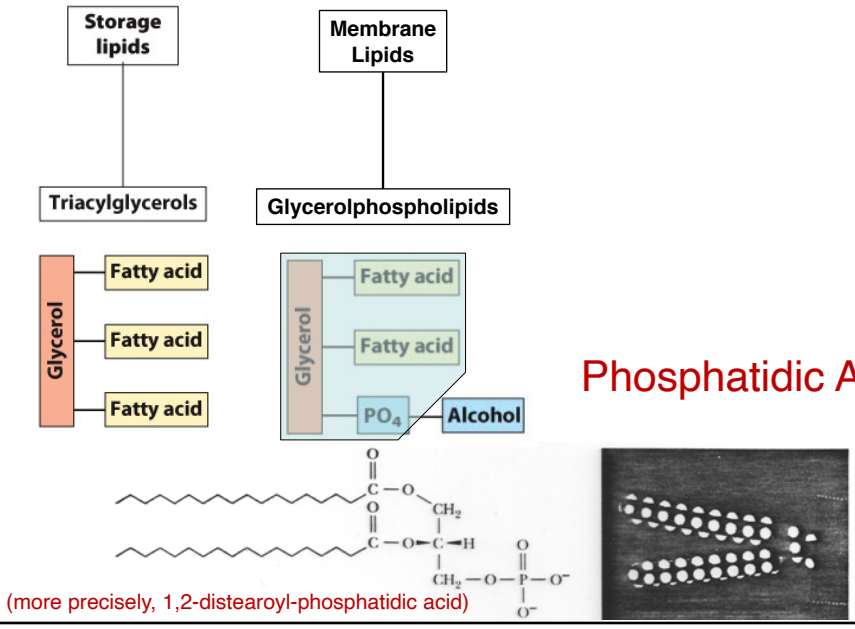
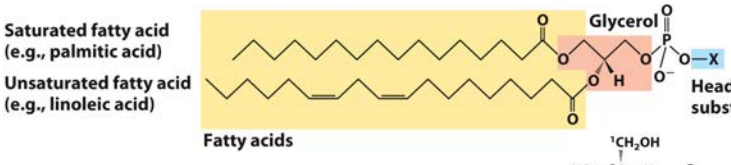


Lipids: Membrane Lipids

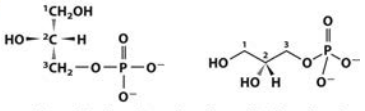


Lipids: Membrane Lipids

General Structure of Glycerophospholipids



1-Palmitoyl-2-linoleoyl-
phosphatidyl-X(name of alcohol)



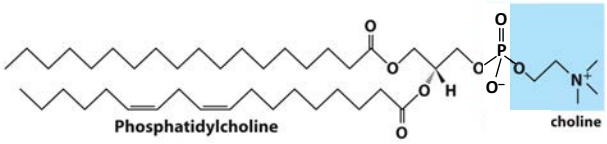
L-Glycerol 3-phosphate (*sn*-glycerol 3-phosphate)

- Primary constituents of cell membranes
- The phosphate group is negatively charged at physiological pH.
- Two fatty acids form ester linkages with the first and second hydroxyl groups of L-glycerol-3-phosphate.
- Unsaturated fatty acids are commonly found connected to C2 of glycerol-3-phosphate.
- The highly polar phosphate group may be further esterified by an alcohol; such substituent groups are called the head groups.

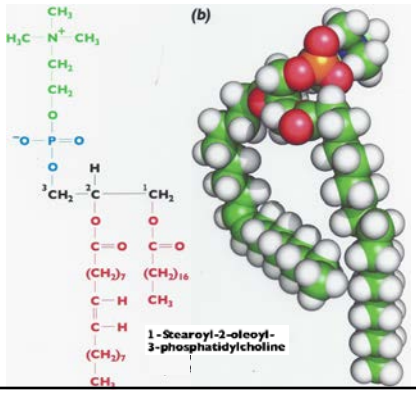
What are these "head groups?"

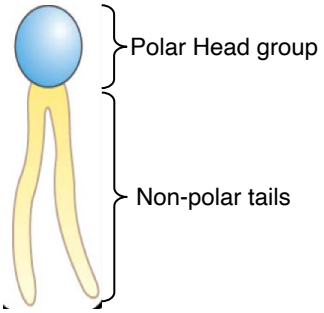
Lipids: Membrane Lipids

Examples of Glycerophospholipids



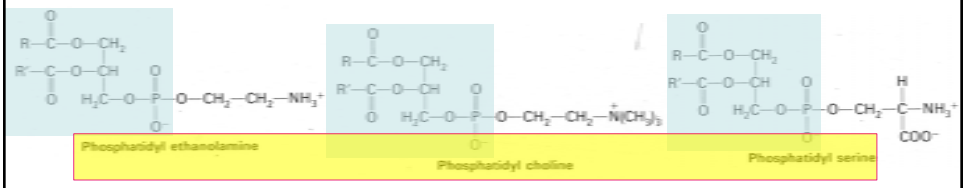
1-Stearoyl-2-linoleoyl-3-phosphatidyl-choline

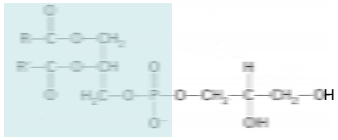




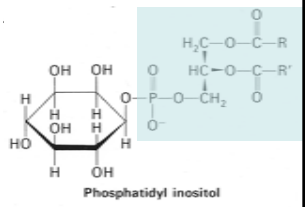
Lipids: Membrane Lipids

Examples of Glycerophospholipids

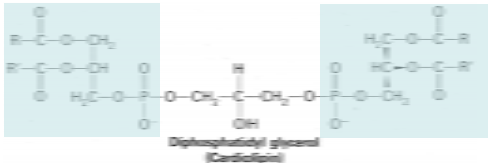




Phosphatidyl glycerol



Phosphatidyl inositol



Phosphatidic Acid =

Lipids: Membrane Lipids

Examples of Glycerophospholipids

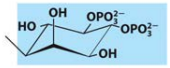
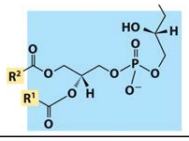
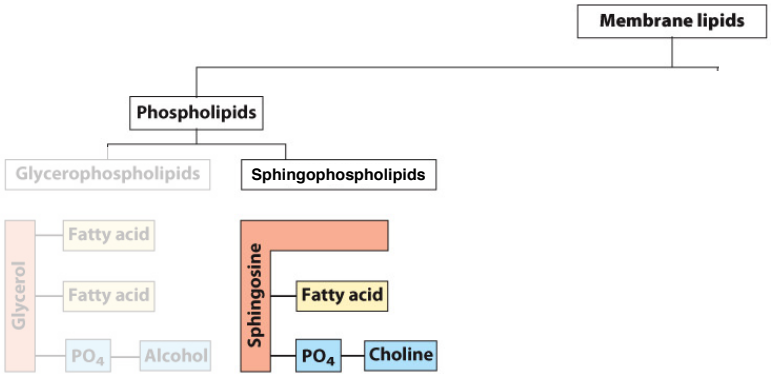
Name of glycerophospholipid	Name of X—O	Formula of X	Net charge (at pH 7)
Phosphatidic acid	—	—H	−2
Phosphatidylethanolamine	Ethanolamine		0
Phosphatidylcholine	Choline		0
Phosphatidylserine	Serine		−1
Phosphatidylglycerol	Glycerol		−1
Phosphatidylinositol 4,5-bisphosphate	*myo*-Inositol 4,5-bisphosphate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

Figure 10-8

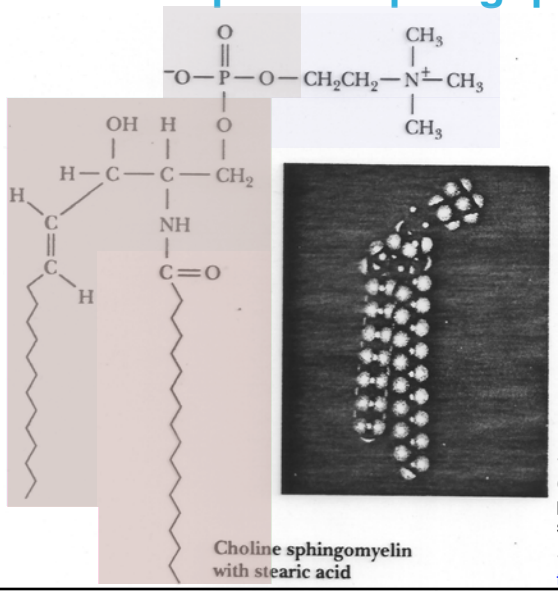
Lipids: Membrane Lipids

Sphingophospholipids



Lipids: Membrane Lipids

Examples of Sphingophospholipids



Sphingosine (C18)

Ceramide

Sphingomyelin

Choline Sphingomyelin

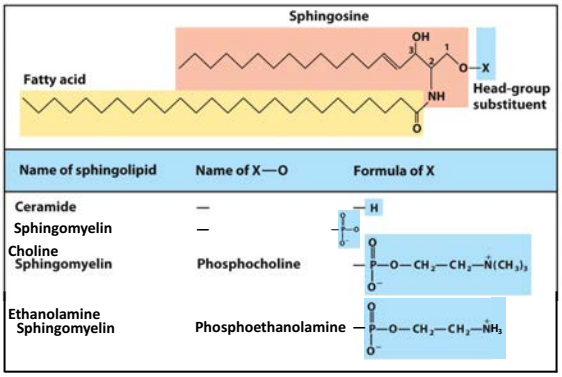
- The backbone of sphingolipids is NOT glycerol.
- The backbone of sphingolipids is a long-chain amino alcohol sphingosine.
- A fatty acid is joined to sphingosine via an amide linkage, rather than an ester linkage as usually seen in other lipids (hence the name) = ceramide.
- A polar phosphate group is connected to ceramide by a phospho-ester linkage = sphingomyelin.
- A polar alcohol is connected by another phospho-ester linkage = Choline sphingomyelin or Ethanolamine sphingomyelin

•Choline Sphingomyelin = Ceramide (sphingosine + amide-linked fatty acid) + phosphocholine attached to the C1-alcohol of sphingosine

•Sphingomyelin is abundant in myelin sheath that surrounds some nerve cells in animals.

Lipids: Membrane Lipids

Sphingophospholipids



Name of sphingolipid	Name of X—O	Formula of X
Ceramide	—	—H
Sphingomyelin	—	$-\overset{O}{\overset{\|}{P}}(O^-)-O$
Choline Sphingomyelin	Phosphocholine	$-\overset{O}{\overset{\|}{P}}(O^-)-O-CH_2-CH_2-\overset{+}{N}(CH_3)_3$
Ethanolamine Sphingomyelin	Phosphoethanolamine	$-\overset{O}{\overset{\|}{P}}(O^-)-O-CH_2-CH_2-\overset{+}{N}H_3$