Chapter 4
Lipids
<table>
<thead>
<tr>
<th>Topic</th>
<th>No of Weeks</th>
<th>Lectures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lipids:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Definition, function, fatty acids, classification:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- <strong>simple lipids</strong>: structure and function (TAG, waxes)</td>
<td>1.33</td>
<td>16-19</td>
</tr>
<tr>
<td>- <strong>compound lipids</strong>: structure and function (phospholipids, sphingolipids)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- <strong>derived lipids</strong>: structure and function (cholesterol, bile acids)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lipoproteins, micelle, membrane structure.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Glycerophospholipids (classifications, types &amp; function)</strong></td>
<td>1.33</td>
<td>20-23</td>
</tr>
<tr>
<td>Sphingolipids (classifications, types &amp; function)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triglycerides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steroids (structure, properties &amp; functions; cholesterol, terpenes, vitamins &amp; steroid hormones)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lipoproteins</strong></td>
<td>0.66</td>
<td>24-25</td>
</tr>
<tr>
<td><strong>Introduction to biomembranes and adipocytes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assembly of lipid molecules (membrane and adipose tissue)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluid mosaic model and types of membrane proteins</td>
<td>1</td>
<td>26-28</td>
</tr>
<tr>
<td><strong>Fat storage &amp; mobilization in adipose tissue</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Introduction to lipid metabolism</strong></td>
<td>0.33</td>
<td>29</td>
</tr>
</tbody>
</table>
Lipids are esters of fatty acids and alcohol. The lipids are a heterogeneous group of compounds, including:
- fats,
- oils,
- waxes,
- steroids, and
- related compounds which are related more by their physical than by their chemical properties.
- Although the term *lipid* is sometimes used as a synonym for fats, fats are a subgroup of lipids called *triglycerides*.

Lipids have the common property of being:
1. relatively insoluble in water and
2. soluble in nonpolar solvents such as ether and chloroform.

Lipids are hydrophobic small molecules; this character allows them to form structures such as vesicles or membranes.

What is the difference between micelle, liposome and bilayer lipid sheet?
Triglycerides

Triglycerides Are Esters of Glycerol and Fatty Acids

Glycerol "backbone" is a water-soluble alcohol

Fatty Acids are chains of carbon atoms with a methyl (-CH₃) group at one end and a carboxylic acid (-COOH) group at the other

Structures linked by ester bonds (R-COOR') and water is released
Lipids of Physiologic Significance

1. They are important dietary constituents as they are high source of energy (9.3 cal/g)
2. It presents in all living organisms, animals, plants, bacteria, etc
3. Animal lipids are more energetic and more saturated than plant lipids
4. They are source of the fat-soluble vitamins
5. They provide body with the essential fatty acids contained in the fat of natural foods.
6. Fat is stored in adipose tissue, where it also serves as a thermal insulator in the subcutaneous tissues and around certain organs.
7. Nonpolar lipids act as electrical insulators, allowing rapid propagation of depolarization waves along myelinated nerves.
8. Phospholipids and sterols are major structural elements of biological membranes.
9. Other lipids, although present in relatively small quantities, play crucial roles as:
   - enzyme cofactors,
   - electron carriers,
   - Light absorbing
   - pigments,
   - hydrophobic anchors for proteins,
   - “chaperones” to help membrane proteins fold,
   - Emulsifying agents in the digestive tract,
   - hormones, and
   - intracellular messengers.
LIPIDS ARE CLASSIFIED AS SIMPLE OR COMPLEX

1- Simple lipids: Esters of fatty acids with various alcohols.
   a. Fats: Esters of fatty acids with glycerol (trihydroxylic alcohol).
      Oils are fats in the liquid state.
   b. Waxes: Esters of fatty acids with longer chain monohydroxylic alcohol.

2- Complex lipids: Esters of fatty acids containing additional groups besides the alcohol and the fatty acid.
   a. Phospholipids: Lipids containing a phosphoric acid residue. They frequently have nitrogen containing bases and other substituents, eg, in glycerophospholipids the alcohol is glycerol and in sphingophospholipids the alcohol is sphingosine.
   b. Glycolipids (glycosphingolipids): Lipids containing a fatty acid, sphingosine, and carbohydrate.
c. **Other complex lipids:** Lipids such as sulfolipids and aminolipids. Lipoproteins may also be placed in this category.

3. **Precursor and derived lipids:** These include fatty acids, glycerol, steroids, other alcohols, fatty aldehydes, and ketone bodies, hydrocarbons, lipid-soluble vitamins, and hormones.

Triacylglycerols, and cholesteryl esters are termed **neutral lipids** because they are uncharged.
Fatty acids are aliphatic carboxylic acids

Fatty acids are long hydrocarbon chain preceded by carboxyl group.
- i.e. They are carboxylic acids with hydrocarbon chains.

i.e. it has small polar, hydrophilic end (the carboxy-end) and long nonpolar, hydrophobic end (the 4-36 hydrocarbon tail).
So, the overall of fatty acids is insoluble in water.
They occur mainly as esters in natural fats and oils.
They are transported in the blood as free fatty acids (unesterified form).
Fatty acids that occur in natural fats are usually straight-chain derivatives (unbranched) containing an even number of carbon atoms.
A few branched-chain fatty acids have also been isolated from both plant and animal sources.
The chain may be saturated (containing no double bonds) or unsaturated (containing one or more double bonds).
Carboxylic group

Saturated Fatty Acid

Unsaturated Fatty Acid

Long hydrocarbon chain
Fatty Acids Are Named After Corresponding Hydrocarbons

The most frequently used systematic nomenclature names the fatty acid after the hydrocarbon with the same number and arrangement of carbon atoms, with -oic being substituted for the final -e (Genevan system).

*Saturated fatty acids* are those containing single covalent bonds between carbon atoms \([\text{CH}_3-(\text{CH}_2)_n-\text{COOH}]\)

Their name is composed from the Latin number of the carbons end in -anoic, eg, octanoic acid,

*Unsaturated acids* are those containing at least one double bond between carbon atoms

Their name end in -enoic, eg, octadecenoic acid (oleic acid).

Carbon atoms are numbered from the carboxyl carbon (carbon No. 1). The carbon atoms adjacent to the carboxyl carbon (Numbers. 2, 3, and 4) are also known as the \(\alpha\), \(\beta\), and \(\gamma\) carbons, respectively, and the terminal methyl carbon is known as the \(\omega\) or n-carbon.
Nomenclature of fatty acids

Every fatty acids can be named by three ways:
1- Commercial name
2- Chemical name
3- Simplified code name

1- Commercial name
The name does not reflect the number of carbon atoms or the level of saturation
Example, palmetic, stearic, oleic, arachidonic, linoleic, linolenic, etc.
2- Chemical name

- The systematic name for a fatty acid is derived from the name of its parent hydrocarbon by the substitution of *oic* (+an or en) for the final *e*.

  i.e. The Latin number of carbon atoms + suffix
  - In saturated fatty acids the suffix is *anoic*
  - In the unsaturated fatty acids the suffix is *enoic*

*Examples*
- Palmetric acid contains 16 carbons and is saturated.
  Its name is **Hexadec anoic**

- Stearic acid contains 18 carbons and saturated.
  Its name is **Octadec anoic**
In the unsaturated fatty acids more details are required to indicated the position and number of double bonds

- Site of the double bond + Latin number of the carbon atoms + number of double bonds + the suffix enoic

**Linoleic acid**
It is unsaturated fatty acid.
It contains 18 carbon atoms, 2 double bonds between C9,10 and C12,13 9,12 –octadeca di enoic

**Linolenic acid**
18 carbon atoms, 3 double bonds between C6,7; C9,10 and C12,13 6,9,12 –octadeca tri enoic
3- The simplified code name

A simplified nomenclature specifies the chain length and number of double bonds, separated by a colon;

Example,

Palmetic is 16-carbon saturated fatty acid. It is abbreviated 16:0,

Oleic is 18-carbon acid, with one double bond, is 18:1.

The positions of any double bonds are specified by superscript numbers following Δ (delta)

**Examples:**

- Palmetic: C16:0
- Stearic: C18:0
- Linoleic: C18:2 Δ\(^{9,12}\)
- Linolenic: C18:3 Δ\(^{6,9,12}\)
ω9 indicates a double bond on the ninth carbon counting from the ω- carbon.

In animals, additional double bonds are introduced only between the existing double bond (e.g., ω9, ω6, or ω3) and the carboxyl carbon, leading to three series of fatty acids known as the ω9, ω6, and ω3 families, respectively.

Oleic acid. n – 9 is equivalent to ω9.
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 \textit{n-} indicates the “normal” unbranched structure. For instance, “dodecanoic” simply indicates 12 carbon atoms, which could be arranged in a variety of branched forms; “\textit{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 \textit{cis}.

### TABLE 10–1

**Some Naturally Occurring Fatty Acids: Structure, Properties, and Nomenclature**

<table>
<thead>
<tr>
<th>Carbon skeleton</th>
<th>Structure*</th>
<th>Systematic name †</th>
<th>Common name (derivation)</th>
<th>Melting point (°C)</th>
<th>Solubility at 30°C (mg/g solvent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:0</td>
<td>CH₃(CH₂)₁₀COOH</td>
<td>\textit{n-}Dodecanoic acid</td>
<td>Lauric acid (Latin \textit{laurus}, “laurel plant”)</td>
<td>44.2</td>
<td>0.063</td>
</tr>
<tr>
<td>14:0</td>
<td>CH₃(CH₂)₁₂COOH</td>
<td>\textit{n-}Tetradecanoic acid</td>
<td>Myristic acid (Latin \textit{Myristica}, nutmeg genus)</td>
<td>53.9</td>
<td>0.024</td>
</tr>
<tr>
<td>16:0</td>
<td>CH₃(CH₂)₁₄COOH</td>
<td>\textit{n-}Hexadecanoic acid</td>
<td>Palmitic acid (Latin \textit{palma}, “palm tree”)</td>
<td>63.1</td>
<td>0.0083</td>
</tr>
<tr>
<td>18:0</td>
<td>CH₃(CH₂)₁₆COOH</td>
<td>\textit{n-}Octadecanoic acid</td>
<td>Stearic acid (Greek \textit{stear}, “hard fat”)</td>
<td>69.6</td>
<td>0.0034</td>
</tr>
<tr>
<td>20:0</td>
<td>CH₃(CH₂)₁₈COOH</td>
<td>\textit{n-}Eicosanoic acid</td>
<td>Arachidic acid (Latin \textit{Arachis}, legume genus)</td>
<td>76.5</td>
<td></td>
</tr>
<tr>
<td>24:0</td>
<td>CH₃(CH₂)₂₂COOH</td>
<td>\textit{n-}Tetracosanoic acid</td>
<td>Lignoceric acid (Latin \textit{lignum}, “wood” + \textit{cera},“wax”)</td>
<td>86.0</td>
<td></td>
</tr>
<tr>
<td>16:1(Δ⁹)</td>
<td>CH₃(CH₂)₅CH＝CH(CH₂)₁₀COOH</td>
<td>\textit{cis-}9-Hexadecenoic acid</td>
<td>Palmitoleic acid</td>
<td>1 to −0.5</td>
<td></td>
</tr>
<tr>
<td>18:1(Δ⁹)</td>
<td>CH₃(CH₂)₇CH＝CH(CH₂)₁₀COOH</td>
<td>\textit{cis-}9-Octadecenoic acid</td>
<td>Oleic acid (Latin \textit{oleum}, “oil”)</td>
<td>13.4</td>
<td></td>
</tr>
<tr>
<td>18:2(Δ⁹,₁₂)</td>
<td>CH₃(CH₂)₄CH＝CHCH₂CH＝CH(CH₂)₂COOH</td>
<td>\textit{cis-},\textit{cis-}9,12-Octadecadienoic acid</td>
<td>Linoleic acid (Greek \textit{linon}, “flax”)</td>
<td>1–5</td>
<td></td>
</tr>
<tr>
<td>18:3(Δ⁹,₁₂,₁₅)</td>
<td>CH₃CH₂CH＝CHCH₂CH＝CHCH₂CH＝CH(CH₂)₂COOH</td>
<td>\textit{cis-},\textit{cis-},\textit{cis-}9,12,15-Octadecatrienoic acid</td>
<td>\textit{α}-Linolenic acid</td>
<td>−11</td>
<td></td>
</tr>
<tr>
<td>20:4(Δ⁵,₈,₁₁,₁₄)</td>
<td>CH₃(CH₂)₄CH＝CHCH₂CH＝CHCH₂CH＝CHCH₂CH＝CH(CH₂)₃COOH</td>
<td>\textit{cis-},\textit{cis-},\textit{cis-},\textit{cis-}5,8,11,14-Eicosatetraenoic acid</td>
<td>Arachidonic acid</td>
<td>−49.5</td>
<td></td>
</tr>
</tbody>
</table>

---

Principles of Biochemistry 4ed - Lehninger
**Saturated fatty acids.**

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Number of C Atoms</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic</td>
<td>2</td>
<td>Major end product of carbohydrate fermentation by rumen organisms¹</td>
</tr>
<tr>
<td>Propionic</td>
<td>3</td>
<td>An end product of carbohydrate fermentation by rumen organisms¹</td>
</tr>
<tr>
<td>Butyric</td>
<td>4</td>
<td>In certain fats in small amounts (especially butter). An end product of carbohydrate fermentation by rumen organisms¹</td>
</tr>
<tr>
<td>Valeric</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Caproic</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Lauric</td>
<td>12</td>
<td>Spermaceti, cinnamon, palm kernel, coconut oils, laurels, butter</td>
</tr>
<tr>
<td>Myristic</td>
<td>14</td>
<td>Nutmeg, palm kernel, coconut oils, myrtles, butter</td>
</tr>
<tr>
<td>Palmitic</td>
<td>16</td>
<td>Common in all animal and plant fats</td>
</tr>
<tr>
<td>Stearic</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>
Unsaturated Fatty Acids Contain One or More Double Bonds

Fatty acids may be further subdivided as follows:

(1) **Monounsaturated** (monoethenoid, monoenoic) acids, containing one double bond.

(2) **Polyunsaturated** (polyethenoid, polyenoic) acids, containing two or more double bonds.

(3) **Eicosanoids**: These compounds, derived from eicosa- (20-carbon) polyenoic fatty acids, comprise the prostanoids, leukotrienes (LTs), and lipoxins (LXs). Prostanoids include prostaglandins (PGs), prostacyclins (PGIs), and thromboxanes (TXs).
Features of unsaturated fatty acids

- It is NOT closely packed, more fluid, has lower melting point, and are liquid at room temperature.

- **Trans vs Cis Unsaturated Fatty Acids**
  - Trans = pack more regularly than cis, so higher melting point,
    - Formed by partial dehydrogenation of unsaturated fatty acids; higher melting points
  - Cis = packs more loosely than trans, so lower melting point

- Details????
## Unsaturated fatty acids of physiologic and nutritional significance

<table>
<thead>
<tr>
<th>Number of C Atoms and Number and Position of Double Bonds</th>
<th>Family</th>
<th>Common Name</th>
<th>Systematic Name</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>16:1,9</td>
<td>ω7</td>
<td>Palmitoleic</td>
<td>cis-9-Hexadecenoic</td>
<td>In nearly all fats.</td>
</tr>
<tr>
<td>18:1,9</td>
<td>ω9</td>
<td>Oleic</td>
<td>cis-9-Octadecenoic</td>
<td>Possibly the most common fatty acid in natural fats.</td>
</tr>
<tr>
<td>18:1,9</td>
<td>ω9</td>
<td>Elaidic</td>
<td>trans-9-Octadecenoic</td>
<td>Hydrogenated and ruminant fats.</td>
</tr>
<tr>
<td>18:2,9,12</td>
<td>ω6</td>
<td>Linoleic</td>
<td>all-cis-9,12-Octadecadienoic</td>
<td>Corn, peanut, cottonseed, soybean, and many plant oils.</td>
</tr>
<tr>
<td>18:3,6,9,12</td>
<td>ω6</td>
<td>γ-Linolenic</td>
<td>all-cis-6,9,12-Octadecatrienoic</td>
<td>Some plants, e.g., oil of evening primrose, borage oil; minor fatty acid in animals.</td>
</tr>
<tr>
<td>18:3,9,12,15</td>
<td>ω3</td>
<td>α-Linolenic</td>
<td>all-cis-9,12,15-Octadecatrienoic</td>
<td>Frequently found with linoleic acid but particularly in linseed oil.</td>
</tr>
<tr>
<td>20:4,5,8,11,14</td>
<td>ω6</td>
<td>Arachidonic</td>
<td>all-cis-5,8,11,14-Eicosatetraenoic</td>
<td>Found in animal fats and in peanut oil; important component of phospholipids in animals.</td>
</tr>
<tr>
<td>20:5,5,8,11,14,17</td>
<td>ω3</td>
<td>Timnodonic</td>
<td>all-cis-5,8,11,14,17-Eicosapentaenoic</td>
<td>Important component of fish oils, e.g., cod liver, mackerel, menhaden, salmon oils.</td>
</tr>
<tr>
<td>22:6,4,7,10,13,16,19</td>
<td>ω3</td>
<td>Cervonic</td>
<td>all-cis-4,7,10,13,16,19-Docosahexaenoic</td>
<td>Fish oils, phospholipids in brain.</td>
</tr>
</tbody>
</table>
Eicosanoids

Thromboxane $A_2$ – involved in blood clot formation

Leukotriene $D_4$ – mediator of smooth-muscle contraction and provokes bronchial constriction seen in asthmatics.

Aspirin alleviates pain, fever, and inflammation by inhibiting cyclooxygenase (COX), an enzyme critical for the synthesis of Prostaglandins. (NSAID family of compounds)
Chemical and physical properties of fatty acids
Q:

- Describe the dependence of the melting point of a fatty acid upon (a) chain length and (b) unsaturation; (c) explain these dependencies in molecular terms.

Ans: All other things being equal, (a) the longer the acyl chain, the higher the melting temperature; and (b) the more unsaturation, the lower the melting temperature. (c) The melting temperature is a measure of the thermal energy needed to break the intermolecular interactions that stabilize the "solid" form of a lipid, which depends upon how well the individual lipid molecules fit into the nearly crystalline array of lipids. When a shorter acyl chain lies between two longer chains in a nearly crystalline array of lipid molecules, there is a cavity at the end of the short acyl group that allows freer motion to the neighboring acyl chains. A cis double bond introduces a "kink" into the acyl chain, so that it does not pack as easily with its straighter neighbors.
Triacylglycerols (triglycerides) are the main storage forms of fatty acids

- Glycerol is tri hydroxylic alcohol.
- The hydroxyl group of glycerol can bind with one, 2 or 3 fatty acids by ester bond to form mono, di- or tri acyl glycerol.
- They are found in the tissues.
- Triacylglycerols are nonpolar hydrophobic molecules that can be stored in specialized nonaqueous cellular compartments, mainly adipocytes.
Q:

- In cells, fatty acids are stored as triacylglycerols for energy reserves.
  (a) What is the molecule to which fatty acids are esterified to form triacylglycerols?
  (b) Define the logic behind cells storing fatty acids in esterified form.
  (a) Three fatty acids are esterified to glycerol.
  (b) Triacylglycerols are uncharged and insoluble in water. They form lipid droplets within adipocytes, which do not contribute to the osmolarity of the cytosol in those cells, and do not require any water of hydration.

Describe three functions of triacylglycerols in mammals and one function in higher plant
Triacylglycerols provide mammals with
- stored fuel,
- insulation, and
- a source of metabolic water.
In some animals, such as camels and desert rats, the oxidation of stored lipids provides water; in hibernating animals, oxidation of stored lipids generates heat to maintain body temperature

In plants, oxidation of the triacylglycerols stored in seeds provides the energy and precursors for biosynthetic processes during germination, before photosynthetic mechanisms become functional.
Phospholipids are the main lipid constituents of membranes

Phospholipids may be regarded as derivatives of phosphatidic acid, in which the phosphate is esterified with the -OH of a suitable alcohol. Phosphatidic acid is important as an intermediate in the synthesis of triacylglycerols as well as phosphoglycerols but is not found in any great quantity in tissues.

Glycerophospholipids are amphipathic molecules that can serve as structural components of membranes, which have hydrophilic and hydrophobic regions.
**Phosphatidic acid and its derivatives.**
The $O^-$ shown shaded in phosphatidic acid is substituted by the substituents shown to form:

(A) 3-phosphatidylcholine,
(B) 3-phosphatidylethanolamine,
(C) 3-phosphatidylserine
(D) 3-phosphatidylinositol,
(E) cardiolipin (diphosphatidylglycerol).
Phosphatidylcholines (Lecithins), Phosphatidylethanolamine (cephalin) and phosphatidylserine Occur in Cell Membranes

Phosphatidylcholines (Lecithins), are the most abundant phospholipids of the cell membrane and represent a large proportion of the body's store of choline.

Choline is important in nervous transmission, as acetylcholine, and as a store of labile methyl groups.

Phosphatidyl ethanolamine (cephalin) and phosphatidylserine are also found in cell membranes and differ from phosphatidylcholine only in that ethanolamine or serine, respectively, replaces choline.
Phosphatidylinositol Is a Precursor of Second Messengers

Phosphatidylinositol 4,5-bisphosphate is an important constituent of cell membrane phospholipids.

It is glycerophospholipid and upon stimulation by a suitable hormone agonist, it is cleaved into diacylglycerol and inositol trisphosphate, both of which act as internal signals or second messengers.

Cardiolipin Is a Major Lipid of Mitochondrial Membranes

Phosphatidic acid is a precursor of phosphatidylycerol which, in turn, gives rise to cardiolipin. This phospholipid is found only in mitochondria and is essential for mitochondrial function.

Lysosphospholipids Are Intermediates in the Metabolism of Phosphoglycerols

These are phosphoacylglycerols containing only one acyl radical, eg, lysophosphatidylcholine (lysolecithin), important in the metabolism and interconversion of phospholipids.
Plasmalogens Occur in Brain & Muscle

These compounds constitute as much as 10% of the phospholipids of brain and muscle.

Structurally, the plasmalogens resemble phosphatidyl-ethanolamine but possess an *ether link* on the *sn*-1 carbon instead of the ester link found in acylglycerols. Typically, the alkyl radical is an unsaturated alcohol.
Phospholipids

**Phospholipids** in animal membranes are derived from either glycerol or sphingosine.

- **GlyceroPhosphoLipids** and called phosphoglyceroids.
  - It consists of a glycerol backbone (3-OH, 3-C alcohol), two fatty acid chains and a phosphorylated alcohol.

- **SphingoPhosphoLipids**.
  - It consists of sphingosine (complex alcohol) and a fatty acid.

- The fatty acid chain usually contain even number of C atom, between 14-24. the 16 and 18 are most common.
- Fatty acids may be saturated or unsaturated.
- The configuration of double bonds in unsaturated fatty acids is nearly always *cis*.
- The length and the degree of unsaturation of fatty acids chains affect the membrane fluidity.
GlyceroPhospholipid structure

Glycerol + R₁ saturated fatty acid + R₂ unsaturated fatty acid + phosphate
The phosphate is bound to: Choline, ethanolamine, serine, myoinositol or phosphatidylglycerol.

Phosphatidic acid
Sphingosine is *amino* alcohol that contains a long, *unsaturated* hydrocarbon chain (C\textsubscript{18}H\textsubscript{37}NO\textsubscript{2}).

Sphingosine can bind to **ONE** fatty acid through **AMIDE** bond.

It may also bind to the lateral CH\textsubscript{2}OH group to give many derivatives.
Different Derivatives of sphingosine

- Sphingosine + 1 FF $\rightarrow$ Ceramide
- Ceramide + Phosphocholine $\rightarrow$ A Sphingomyelin (Phospholipid)
- Ceramide + Phosphoethanolamine $\rightarrow$ A Sphingomyelin (Phospholipid)
- Ceramide + Sugar $\rightarrow$ A Cerebroside (Glycolipid)
- Ceramide + many Sugars $\rightarrow$ A Ganglioside (Glycolipid)
Glycerophospholipid vs sphingomyelin

**Both contain:**
- hydrophilic head composed of alcohol –phosphate and ligand that may be choline, serine or ethanolamine
- 2 Hydrophobic tails (2 FA in case of GPL and 1 FA + side group in SPL)

**They differ in:**
- Glycerophospholipids have glycerol + 2 fatty acids + Phosphate + ligand
- The bonds between glycerol and each of the two FFs are ester bond
- Sphingomyelin have sphingosine + 1 fatty acid + phosphate + ligand
- The bond between sphingosine and the FF is amide bond
Summary of membrane phospholipids:

- Phosphatidylethanolamine
- Phosphatidylserine
- Phosphatidylcholine
- Sphingomyelin