

Introduction to Organic Chemistry

CHEM 108

Credit hrs.: (3+1)

King Saud University

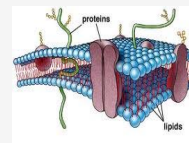
College of Science, Chemistry Department

CHAPTER 9: Lipids

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Lipids

- **Lipids** are biological molecules that are insoluble in water but soluble in nonpolar solvents (nonpolar).
- The word **lipid** comes from the Greek lipos, which means "fat."
- **Lipids** are the waxy, greasy, or oily compounds found in plants and animals.
 - wax coating that protects plants
 - used as energy storage
 - structural components (cell membranes)
 - insulation against cold



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Classification of Lipids

Lipids are divided into:

Saponifiable (Hydrolyzable) lipids

- They contain esters,
- They can undergo saponification
(hydrolysis under basic conditions)

Simple lipids

contain two components
(fatty acid and an alcohol)

Triglycerides
(Fats & oils)

Waxes

Complex lipids

contain more than two components
(fatty acids, an alcohol, and other components)

phosphoglycerides

Sphingolipids.

Nonsaponifiable (Nonhydrolyzable) lipids

- They do not contain ester groups,
- They cannot be saponified
(cannot be cleaved into smaller molecules by aqueous hydrolysis)

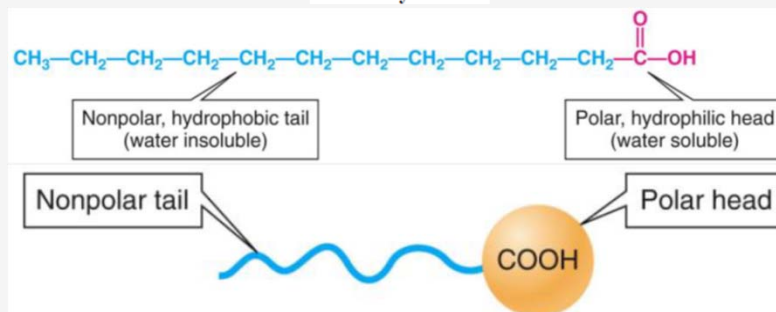
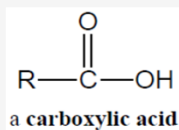
steroids

prostaglandins

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Fatty Acids

- o **Fatty acids** are long-chain unbranched carbon attached to a carboxyl group (-COOH).

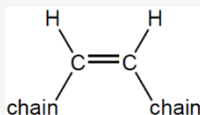


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Fatty Acids

Characteristics of Fatty Acids:

- They usually have **straight chains** (no branches) that are about **10 to 20 carbon atoms** in length.
- They usually have an **even number of carbon atoms** (counting the carboxyl carbon).
- **The carbon chains may be;**
 - **saturated** (all single bonds) or
 - **unsaturated** (containing double bonds).
- i.e. **Functional groups** are only the **carboxyl group** and the **double bonds**.
- The double bonds are usually in **cis configurations**:



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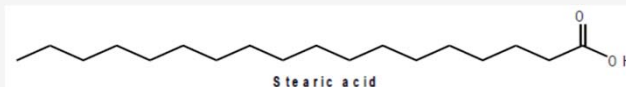
Fatty Acids

Saturated and Unsaturated Fatty Acids

- **Saturated fatty acids** have no double bonds in their long hydrocarbon chains.

Stearic acid: $\text{CH}_3(\text{CH}_2)_{16}\text{COOH}$

Stearic Acid
(m.p. 71°C)



They are solids at room temperature.

Stearic acid is found in palm oil, which is frequently used in handmade soap.

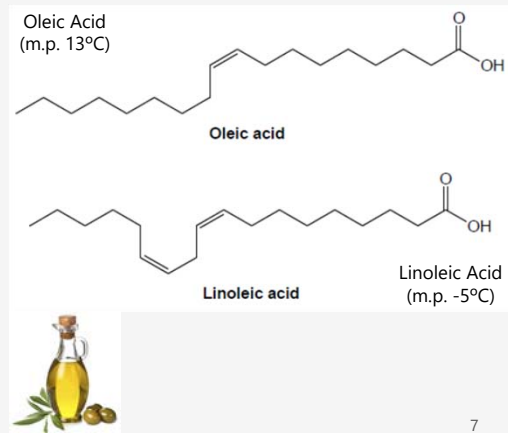


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Fatty Acids

Saturated and Unsaturated Fatty Acids

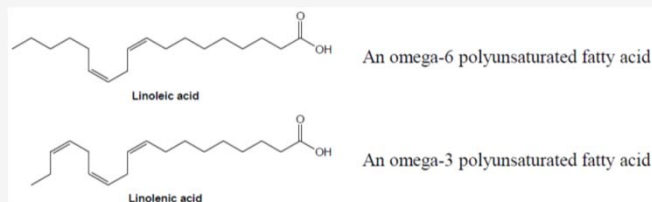
- **Unsaturated fatty acids** have 1 or more double bonds (generally *cis*) in their long hydrocarbon chains.
 - **Oleic acid** (*one double bond*), and
 - **Linoleic acid** (*two double bonds*)
 - All have **18 carbons** in the chain, but their melting points are different
- **Oleic acid** is derived mainly from "olive" oil, sesame oil, Sunflower, shea butter, coconut oil, ... etc.
- **Linoleic acid** is found in soybean oil



Fatty Acids

Essential Fatty Acids

- Most of the fatty acids we need can be synthesized in the body.
- Two fatty acids, *linoleic acid* and *linolenic acid*, both polyunsaturated fatty acids with 18-carbon chains, cannot be synthesized in the body and must be obtained from the diet.
- **These are essential fatty acids.**
- Both are found in plant and fish oils.
- In the body, they are used to produce hormone-like substances that regulate blood pressure, blood clotting, blood lipid levels, the immune response, and inflammatory reactions.



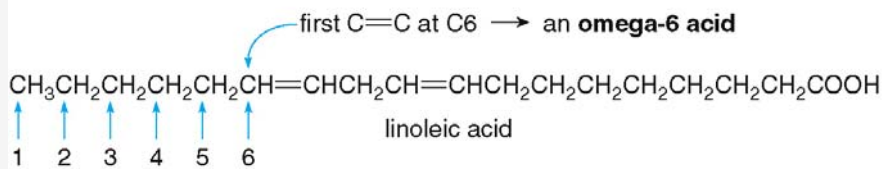
Fatty Acids

Essential Fatty Acids

- o All fatty acids that bear the "omega" label are unsaturated, containing one or more double bonds.

Omega-n acids n: the position of the first double bond

Linoleic acid is called an **omega-6 acid**, because of the position of the first C=C in the nonpolar chain.

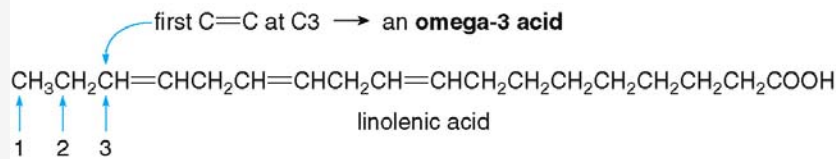


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Fatty Acids

Essential Fatty Acids

Linolenic acid is called an **omega-3 acid**, because of the position of the first C=C in the nonpolar chain.



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Fatty Acids

Some Important Fatty Acids

#C's	Name	Formula	MP	Common Sources
Saturated				
14	Myristic acid	$\text{CH}_3(\text{CH}_2)_{12}\text{COOH}$	54°C	Butterfat, coconut oil, nutmeg oil
16	Palmitic acid	$\text{CH}_3(\text{CH}_2)_{14}\text{COOH}$	63°C	Lard, beef fat, butterfat, cottonseed oil
18	Stearic acid	$\text{CH}_3(\text{CH}_2)_{16}\text{COOH}$	70°C	Lard, beef fat, butterfat, cottonseed oil
20	Arachidic acid	$\text{CH}_3(\text{CH}_2)_{18}\text{COOH}$	76°C	Peanut oil
Monounsaturated				
16	Palmitoleic acid	$\text{CH}_3(\text{CH}_2)_5\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$	-1°C	Cod liver oil, butterfat
18	Oleic acid	$\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$	13°C	Lard, beef fat, olive oil, peanut oil
Polyunsaturated				
18	Linoleic acid	$\text{CH}_3(\text{CH}_2)_4(\text{CH}=\text{CHCH}_2)_2(\text{CH}_2)_6\text{COOH}$	-5°C	Cottonseed oil, soybean oil, corn oil, linseed oil
18	Linolenic acid	$\text{CH}_3\text{CH}_2(\text{CH}=\text{CHCH}_2)_3(\text{CH}_2)_6\text{COOH}$	-11°C	Linseed oil, corn oil
20	Arachidonic acid	$\text{CH}_3(\text{CH}_2)_4(\text{CH}=\text{CHCH}_2)_4(\text{CH}_2)_2\text{COOH}$	-50°C	Corn oil, linseed oil, animal tissues
20	Eicosapentaenoic acid	$\text{CH}_3\text{CH}_2(\text{CH}=\text{CHCH}_2)_5(\text{CH}_2)_2\text{COOH}$		Fish oil, seafoods
22	Docosahexaenoic acid	$\text{CH}_3\text{CH}_2(\text{CH}=\text{CHCH}_2)_6\text{CH}_2\text{COOH}$		Fish oil, seafoods

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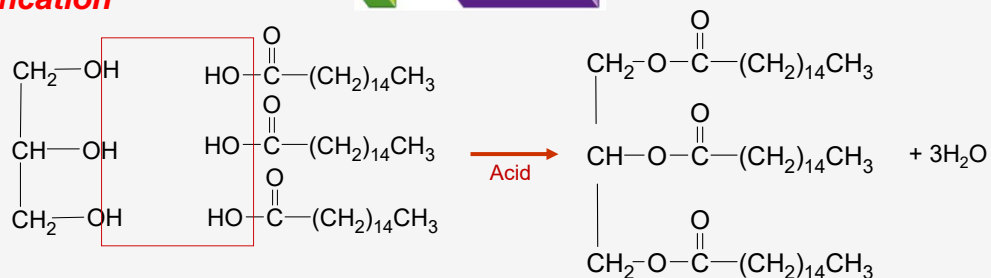
Triglycerides

Simple lipids

- Animal fats and vegetable oils are esters composed of three molecules of a fatty acid connected to a glycerol molecule, producing a structure called a *triglyceride* or a *triacylglycerol*:



Esterification

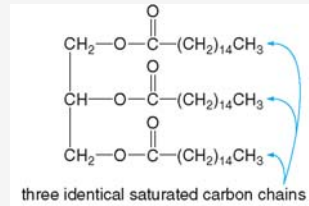


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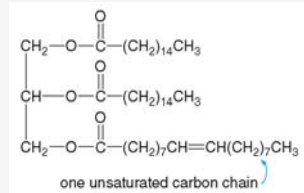
Triglycerides

Simple lipids

- **Simple triacylglycerols** have three **identical** fatty acid side chains.



- **Mixed triacylglycerols** have two or three **different** fatty acids.

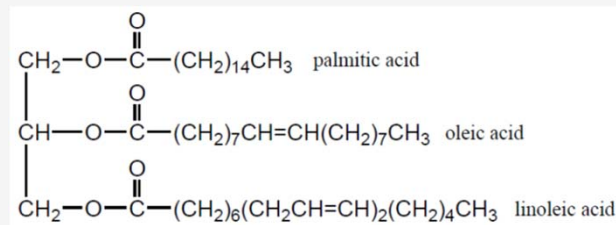


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Fats & oils

Simple lipids

- The fatty acids in a triglyceride molecule are usually not all the same;
- **Natural triglycerides** are often mixtures of different triglyceride molecules.



Fats are



- triglycerides that are solids at room temp.
- usually derived from animals
- mostly saturated fatty acids



Oils are

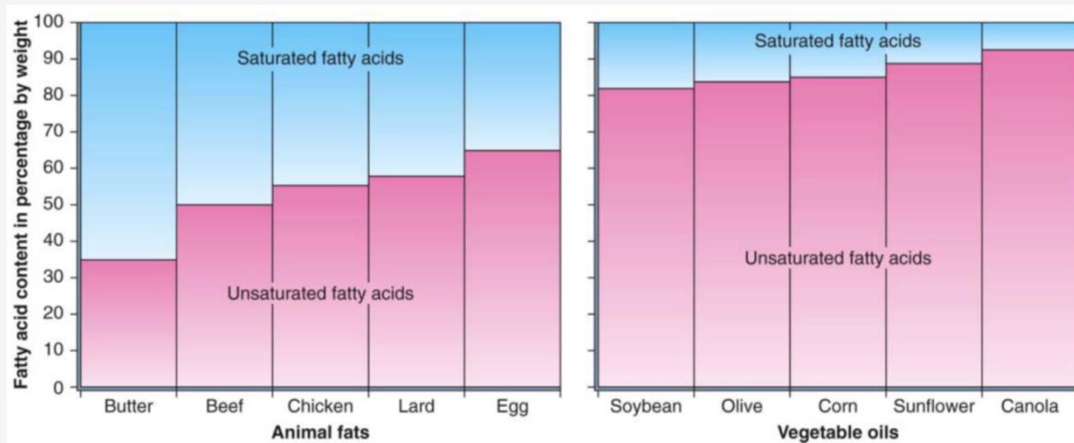
- triglycerides that are liquids at room temp.
- usually derived from plants or fish
- mostly unsaturated fatty acids

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Fats & oils

Simple lipids

A comparison of saturated and unsaturated fatty acids in some foods.



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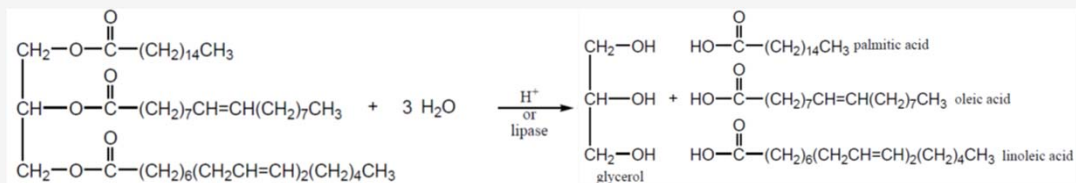
Fats & oils

Simple lipids

Chemical Properties of Fats and Oils

Hydrolysis of Triglycerides

Triglycerides can be broken apart with water and an acid catalyst (*hydrolysis*), or by digestive enzymes called lipases:



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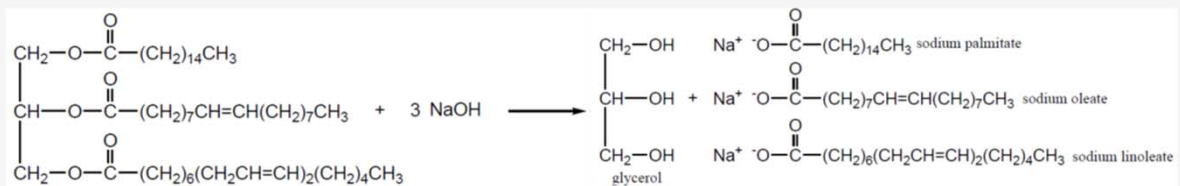
Fats & oils

Simple lipids

Chemical Properties of Fats and Oils

Saponification of Triglycerides (Basic Hydrolysis)

Triglycerides react with strong bases (NaOH or KOH) to form the carboxylate salts of the fatty acids, called soaps:



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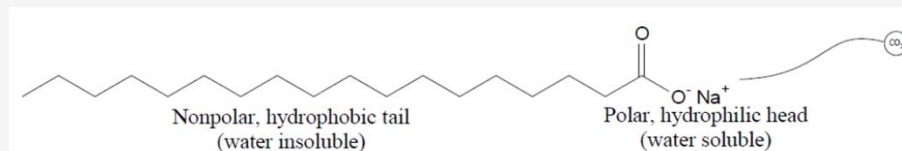
Fats & oils

Simple lipids

Chemical Properties of Fats and Oils

Soaps

- NaOH produces a "hard" soap, commonly found in bar soaps;
- KOH produces a "soft" soap, such as those in shaving creams and liquid soaps.
- These salts combine two solubility characteristics:
 - a long, nonpolar, water-insoluble (*hydrophobic*) hydrocarbon "tail."
 - a charged, water-soluble (*hydrophilic*) "head."



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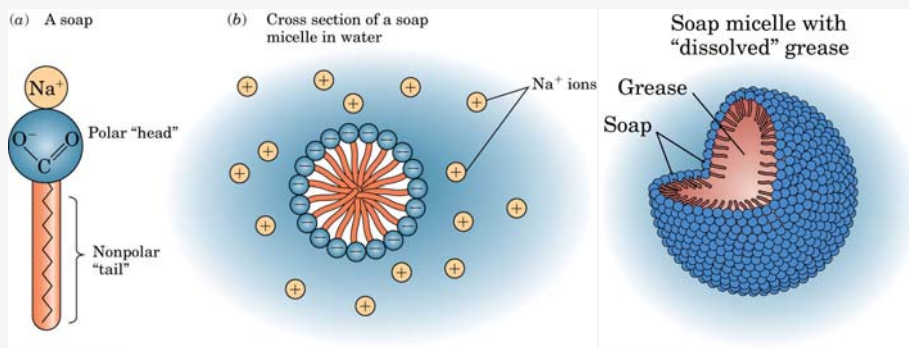
Fats & oils

Simple lipids

Chemical Properties of Fats and Oils

Soaps

In water, the "tails" become tangled, leaving the charged heads sticking out into the solution, forming a structure called a **micelle**.



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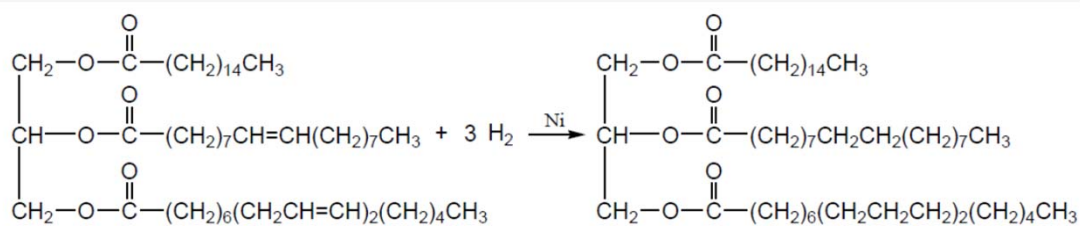
Fats & oils

Simple lipids

Chemical Properties of Fats and Oils

Hydrogenation

- Alkenes are converted into alkanes with hydrogen gas (H₂) and a catalyst (Pt, Ni, or some other metal).
- This process is used to convert unsaturated vegetable oils, which are liquids at room temp., to saturated fats, which are solids at room temp.

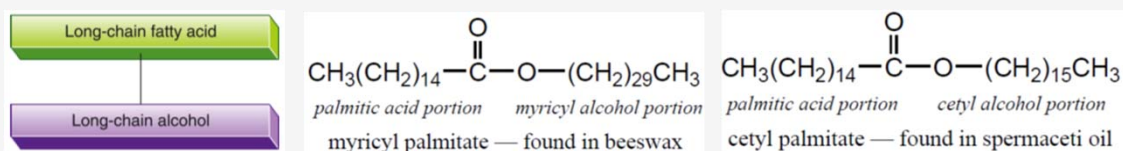


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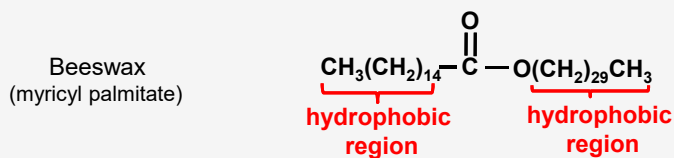
Waxes

Simple lipids

Waxes are simple lipids contain a fatty acid joined to a long-chain (12-32 carbons) alcohol:



Because of their long nonpolar C chains, waxes are very hydrophobic.



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Waxes

Simple lipids

- **Waxes** are insoluble in water, and not as easily hydrolyzed as fats and oils.
- **Waxes** often occur in nature as protective coatings on feathers, fur, skin, leaves, and fruits.
- **Waxes** are used commercially to make cosmetics, candles, ointments, and protective polishes.

Beeswax



Lanolin from wool



lotions

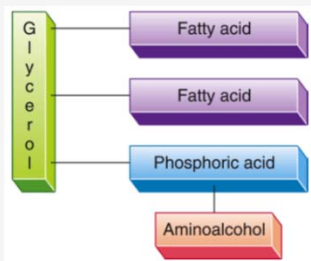
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Phospholipids

Complex lipids

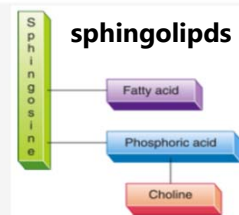
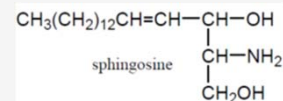
- **Phospholipids** are lipids that contain a P atom.
- There are two common types:

Phosphoglycerol



Sphingolipids

Sphingolipids are complex lipids that contain sphingosine instead of glycerol.



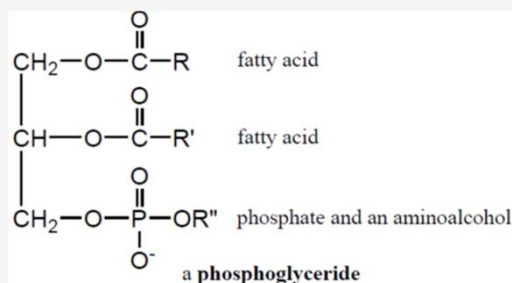
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Phospholipids

Complex lipids

Phosphoglycerols

- **Phosphoglycerols** are complex lipids that are *major components of cell membranes*.
- Structurally, they resemble a triacylglycerol, except the third fatty acid has been replaced with a **phosphodiester bonded to an alcohol**.



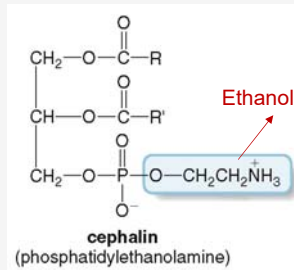
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Phospholipids

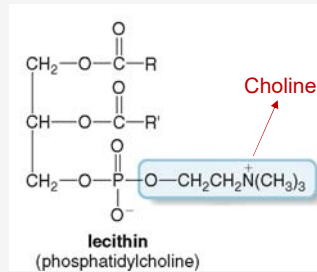
Complex lipids

Phosphoglycerols

- There are two types of phosphoglycerols;



- Cephalins** are found in most cell membranes,
- They are particularly abundant in brain tissue.
- They are also found in blood platelets, and play a role in blood clotting.



- Lecithin** can act as an emulsifying agent:
 - important structural component of cell membranes.
 - play a role in the transport of lipids in the blood stream.
 - Commercially, lecithin extracted from soybeans is used as an emulsifying agent in margarine and candies to provide a smooth texture.

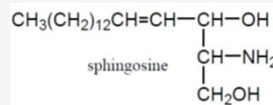
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Phospholipids

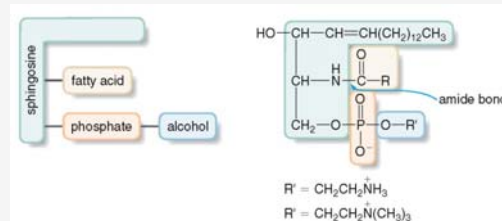
Complex lipids

Sphingomyelins

They do not contain a glycerol backbone, they have a sphingosine backbone instead.



They **do not contain an ester**; their single fatty acid is bonded to the backbone by an **amide bond**.



Sphingomyelins are found brain and nerve tissue, and in the myelin sheath that protects nerves.

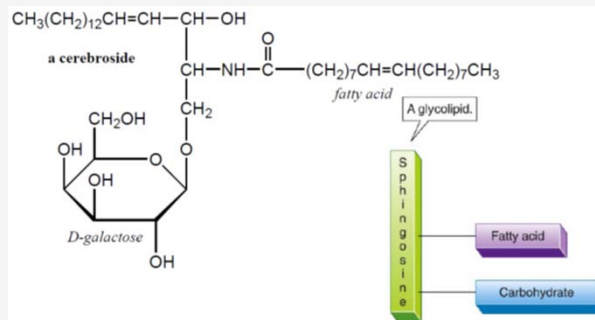
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Phospholipids

Complex lipids

Glycolipids

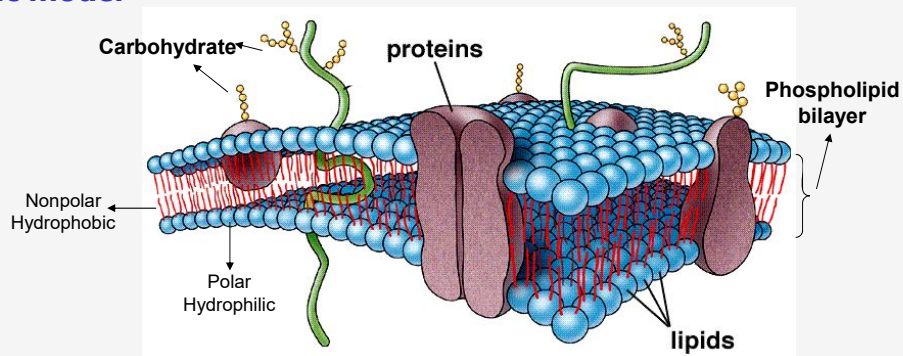
- **Glycolipids** are sphingolipids that contain carbohydrates (usually monosaccharides).
- They are also referred to as *cerebrosides* because of their abundance in brain tissue.



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Cell Membrane

Fluid mosaic model



The cell membrane as being composed of a lipid bilayer, in which the nonpolar tails of lipids point towards the "interior" of the bilayer, leaving the polar, hydrophilic portions pointing outwards.

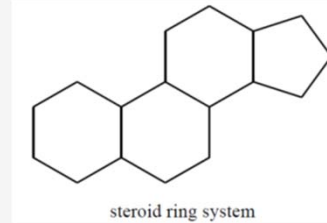
Semipermeable: selected nutrients can enter and waste products can leave.

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Steroids

Nonsaponifiable (Nonhydrolyzable) lipids

- **Steroids** are classified as lipids because they are soluble in nonpolar solvents.
- They are nonsaponifiable because the components are not held together by ester linkages.
- The basic steroid structure contains four fused rings:



- **Steroids** have nucleus which is 4 carbon rings.
attached groups that make the different types of compounds.
no fatty acids.

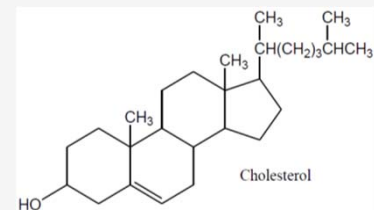
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Steroids

Nonsaponifiable (Nonhydrolyzable) lipids

Cholesterol

- **Cholesterol** is the most abundant steroid in the body.
- It is an essential component of cell membranes, and is a precursor for other steroids, such as the bile salts, sex hormones, vitamin D, and the adrenocorticoid hormones.
- There is apparently a correlation between high levels of cholesterol in the blood and atherosclerosis.



Cholesterol is obtained from meats, milk, and eggs.

Cholesterol is synthesized in the liver from fats, carbohydrates and proteins.

No cholesterol in vegetable and plants.

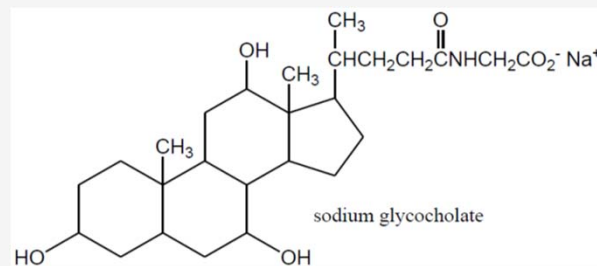
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Steroids

Nonsaponifiable (Nonhydrolyzable) lipids

Bile Salts

- **Bile** is a yellowish brown or green fluid produced in the liver and stored in the gall bladder.
- **Bile salts** act like soaps and other emulsifiers: they contain both polar and nonpolar regions, helping to break fats in foods into smaller pieces, allowing them to be hydrolyzed more easily.



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Steroids

Nonsaponifiable (Nonhydrolyzable) lipids

Steroid Hormones

- **A hormone** is a molecule that is synthesized in one part of an organism, which then elicits a response at a different site.
- **Two types of steroids hormones:**

1. Sex hormones

Estrogens & progestins in **females**

Androgens in **males**

2. Adrenal Cortical Steroids

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Steroids

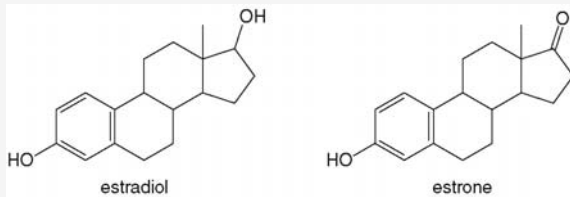
Nonsaponifiable (Nonhydrolyzable) lipids

Steroid Hormones

Female Sex Hormones

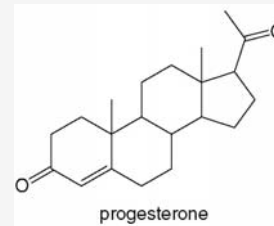
Estrogens

The estrogens **estradiol** and **estrone** control development of secondary sex characteristics, *regulate the menstrual cycle*, and are made in the ovaries.



Progestins

The progestin **progesterone** is called the “pregnancy hormone”; it is responsible for the *preparation of the uterus for implantation of a fertilized egg*.



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Steroids

Nonsaponifiable (Nonhydrolyzable) lipids

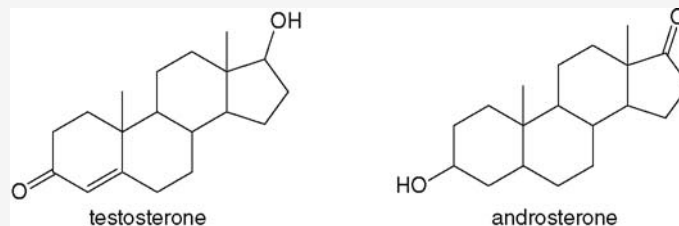
Steroid Hormones

Male Sex Hormones

Androgens

Testosterone and **Androsterone** are androgens made in the testes.

They control the development of secondary sex characteristics in **males**.



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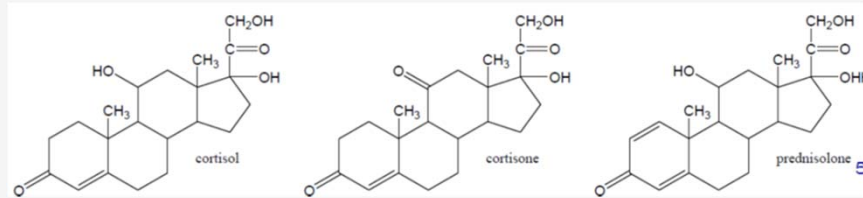
Steroids

Nonsaponifiable (Nonhydrolyzable) lipids

Steroid Hormones

Adrenocorticoid Hormones

- The **adrenocorticoid hormones** are produced in the adrenal glands (located on the top of the kidney).
- **Glucocorticoids** such as cortisol affect the metabolism of carbohydrates.
- **Cortisol and its derivatives, cortisone and prednisolone** (synthetic) are powerful anti-inflammatory drugs used to treat arthritis and asthma.



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Steroids

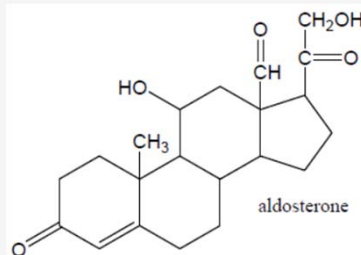
Nonsaponifiable (Nonhydrolyzable) lipids

Steroid Hormones

Adrenocorticoid Hormones

Mineralocorticoids regulate ion concentration (mainly Na^+).

Aldosterone influences the absorption of Na^+ and Cl^- in kidney tubules, thus regulating the retention of water in the body.

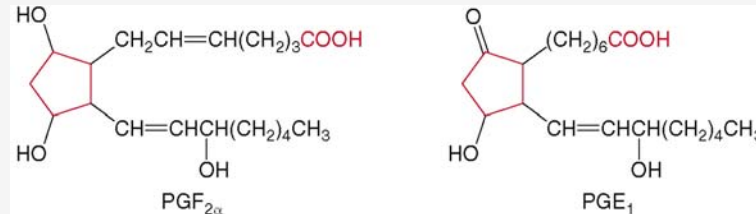


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Prostaglandins

Nonsaponifiable (Nonhydrolyzable) lipids

Prostaglandins are **carboxylic acids** that contain a **five-membered ring** and have a wide range of biological activities.



- **Prostaglandins** are responsible for **inflammation**.
- **Prostaglandins** also decrease gastric secretions, inhibit blood platelet aggregation, stimulate uterine contractions, and relax smooth muscles.
- Aspirin and ibuprofen relieve pain and inflammation by **blocking the synthesis** of these molecules.

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Vitamins

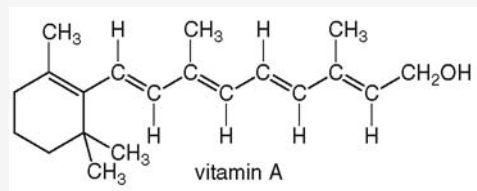
- They are organic compounds required in small quantities for normal metabolism.
- They must be obtained from the diet (our cells cannot synthesize them).
- Vitamins are either **water soluble** or **fat soluble**.
- The four fat-soluble vitamins (**A, D, E, and K**) are lipids and nonpolar.
- They are found in fruits, vegetables, fish, liver, and dairy products.
- Excess vitamins are **stored in adipose cells** to be used when needed.

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Vitamin A

Vitamins

- It is found in *liver, fish, and dairy products*, and is made from β -carotene (the orange pigment in carrots).
- It is needed for **vision** and for healthy mucous membranes.
- Vitamin A **deficiency** causes night blindness and dry eyes and skin.

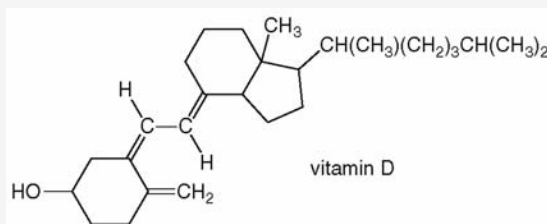


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Vitamin D

Vitamins

- **Vitamin D** can be synthesized from cholesterol.
- It can be obtained in the diet from many foods, especially **milk**, and helps regulate Ca and P metabolism.
- A **deficiency** of vitamin D causes rickets (bone malformation).

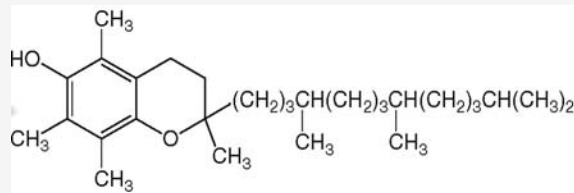


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Vitamin E

Vitamins

- o Vitamin E is an antioxidant, protecting unsaturated side chains in fatty acids from unwanted oxidation.
- o Deficiency of vitamin E causes numerous neurological problems, although it is rare.

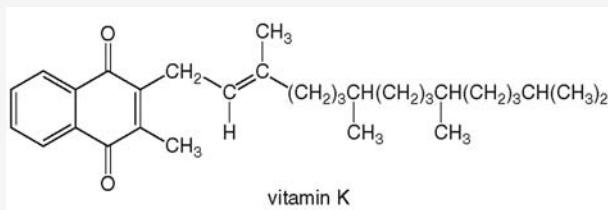


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Vitamin K

Vitamins

- o Vitamin K regulates the synthesis of clotting proteins (prothrombin), and deficiency of this leads to excessive or fatal bleeding.



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