

Fundamentals of Organic Chemistry

CHEM 108

King Saud University

College of Science, Chemistry Department

Lipids



Family of biomolecules.

- They are **not defined** by a particular functional group, thus they have a **variety** of structures and functions.



- They are soluble in organic solvents but not in water (nonpolar).

- They contain many nonpolar C—C and C—H bonds and few polar bonds resulting in their water insolubility.



Lipids with fatty acids

Waxes

Fats and oils (triglycerides)

Phospholipids

Sphingolipids

Lipids without fatty acids

Steroids

Lipids



1. **Simple lipids:** (Waxes, Fats & Oils) → Store energy, insulation (fat cells)
2. **Complex lipids** (Glycerophospholipids) → Cell membrane
3. **Steroid** (Cholesterol & steroid hormones) → Chemical messenger
(find in nerve fibers and hormones) Cell membrane
4. **Eicosanoids** → Pain, fever, inflammation

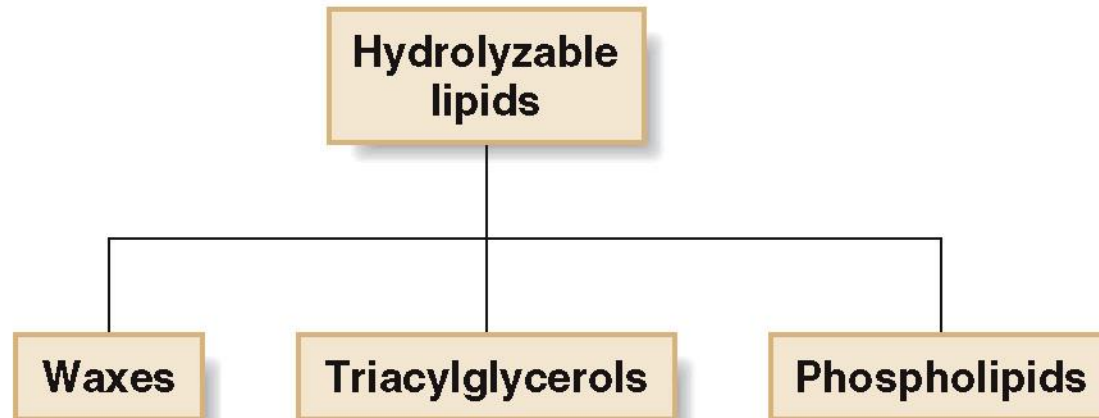
Controls cell growth, Controls the regulation of hormones,
Have an important role in the sense of pain

Lipids



Lipids can be categorized as:

1. **Hydrolyzable** lipids can be converted into small molecules by aqueous hydrolysis.

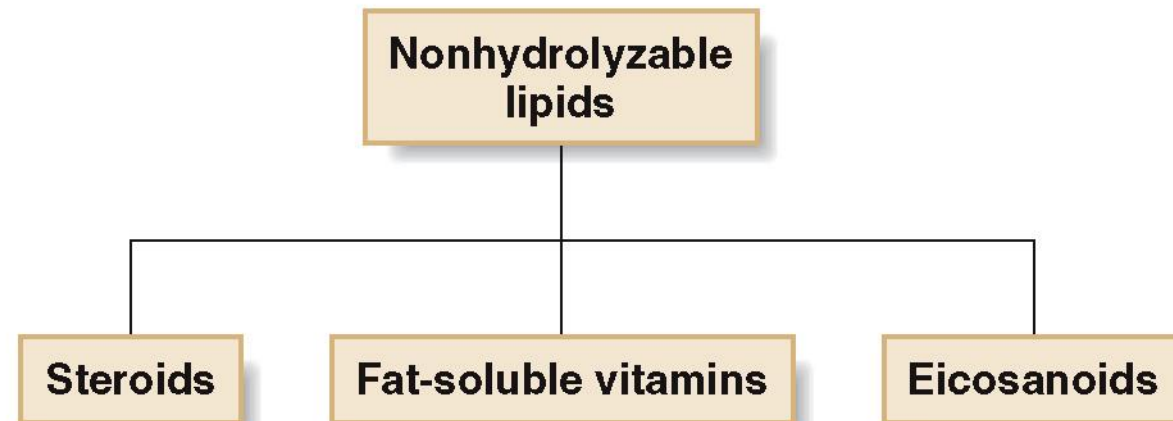


Lipids

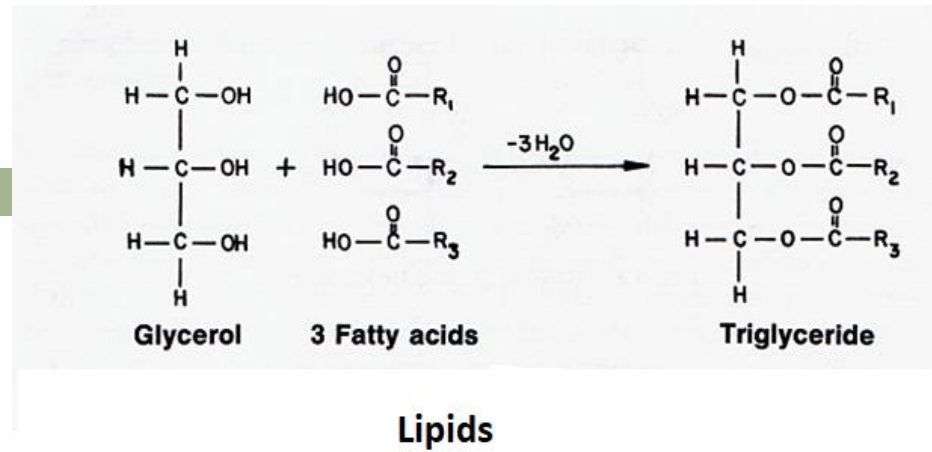


Lipids can be categorized as:

2. **Nonhydrolyzable** lipids cannot be cleaved into smaller molecules by aqueous hydrolysis.



Lipids

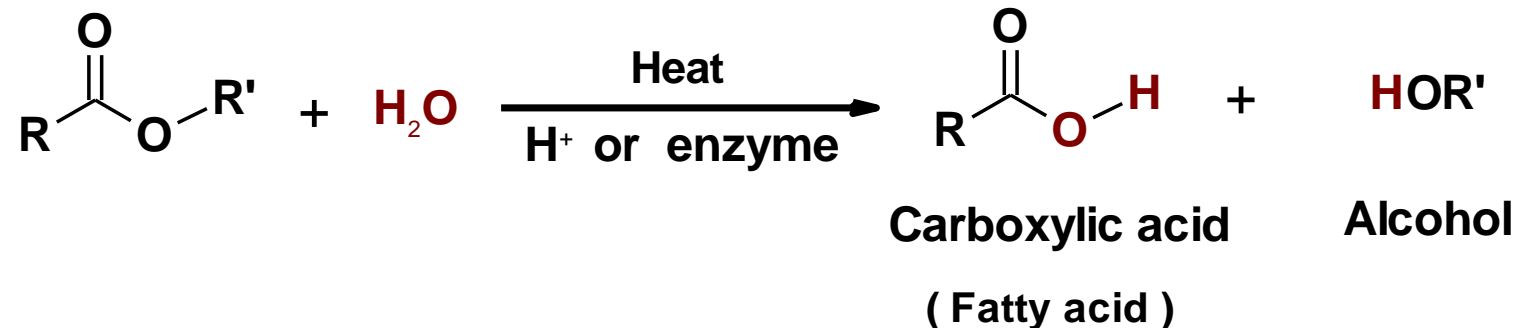


Hydrolysis

Most hydrolyzable lipids contain an ester.

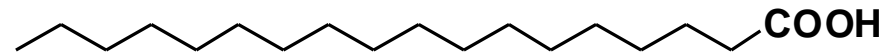
Hydrolysis: reaction with water.

(breaking a bond and adding the elements of water)



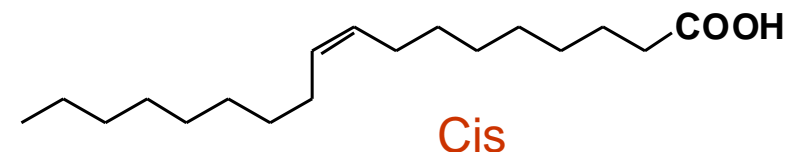
Fatty acids

Hydrolyzable lipids are derived from **fatty acids**.

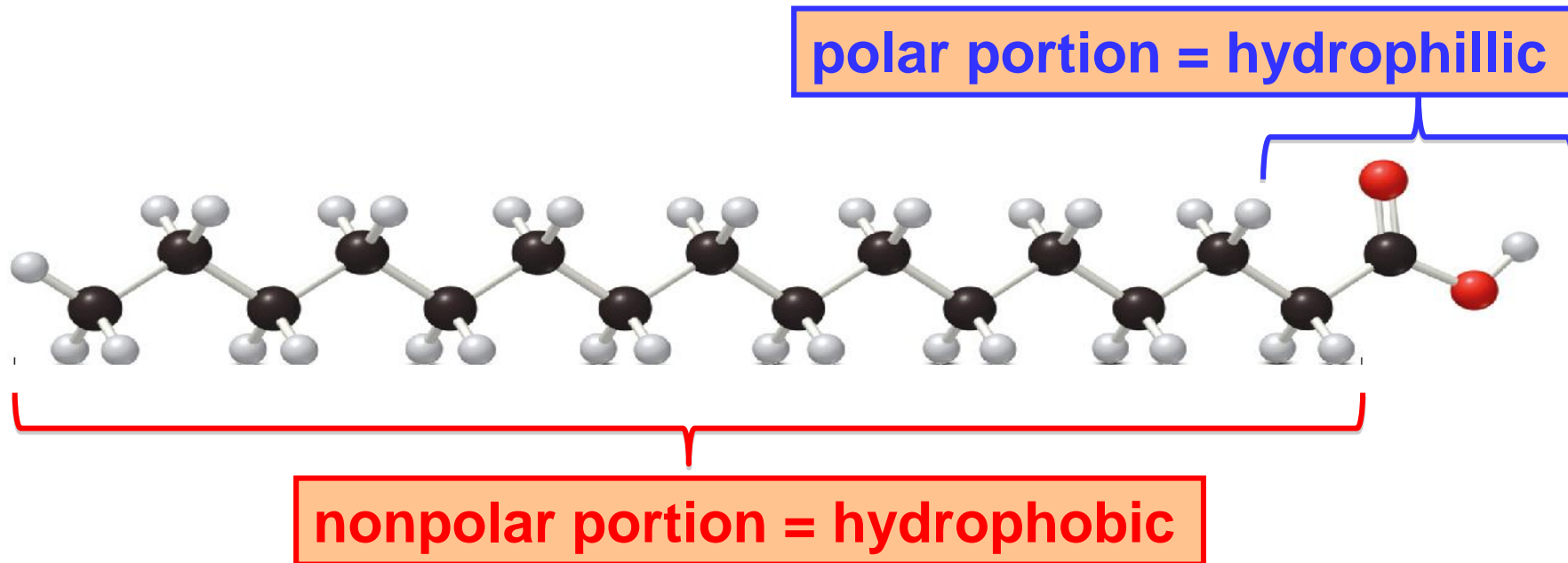


Fatty acids are:

- Long-chain unbranched carbon attached to a carboxyl group (-COOH).
- Typically 12-20 carbon atoms.
- They have an even number of C atoms.
- May be saturated or unsaturated
- Insoluble in water.



Fatty acids

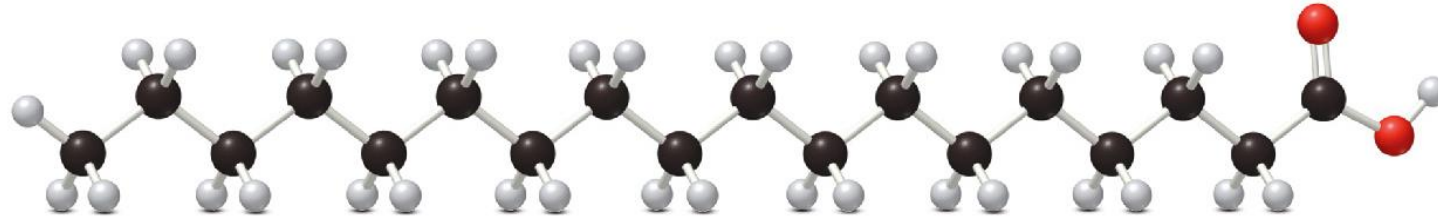


Hydrophobic portion is much bigger than hydrophilic portion. \longrightarrow Insoluble in water

Saturated and unsaturated Fatty acids

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

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



They are solids at room temperature.

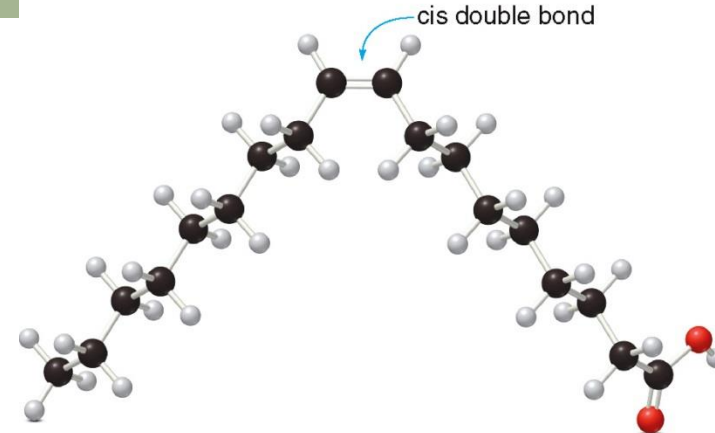
Packed together → Maximum London dispersion forces



Saturated and unsaturated Fatty acids

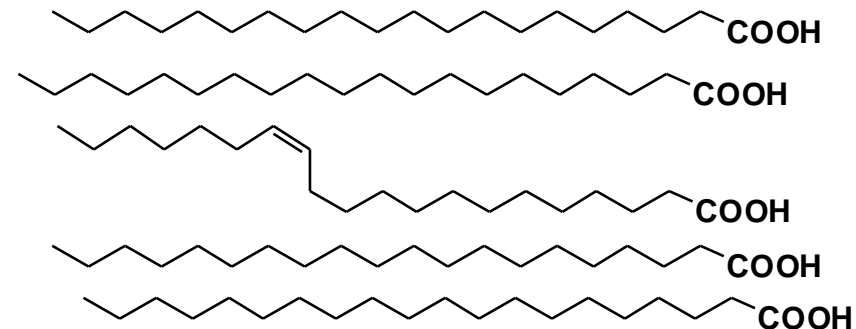
Unsaturated fatty acids have 1 or more double bonds (generally cis) in their long hydrocarbon chains.

Oleic acid: $\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$



They are liquids at room temperature.

They can not pack together → London dispersion forces ↓



Fatty acids



- The human body is capable of synthesizing most fatty acids from carbohydrates or other fatty acids.
- Humans do not synthesize sufficient amounts of fatty acids that have more than one double bond.
- More than one double bond fatty acids are called **essential fatty acids** and they must be provided by the diet.

Linoleic acid

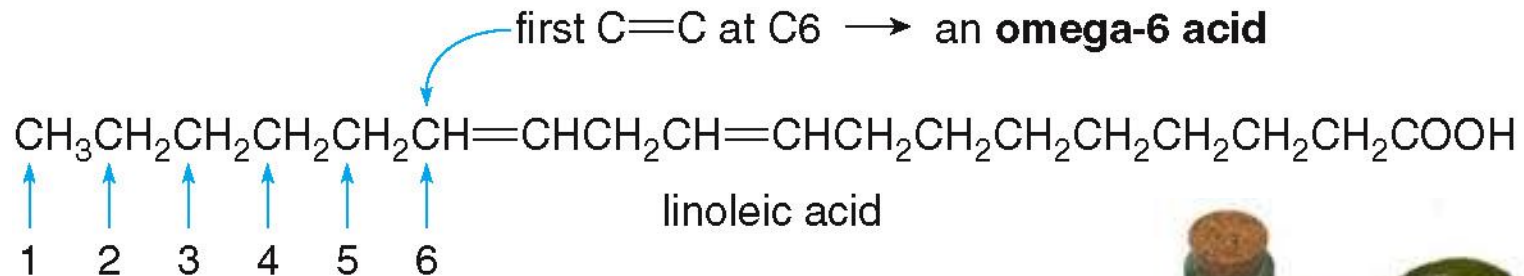
linolenic acid

Essential Fatty acids

Omega-n acids

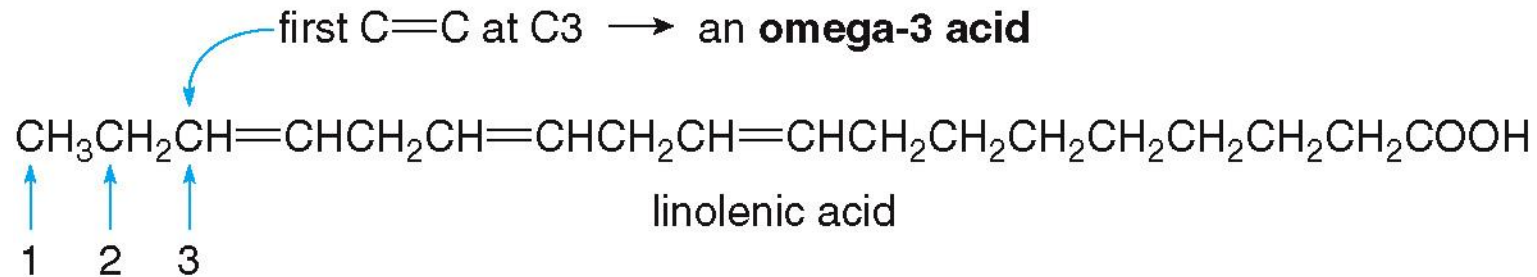
n: the position of the first double bond

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

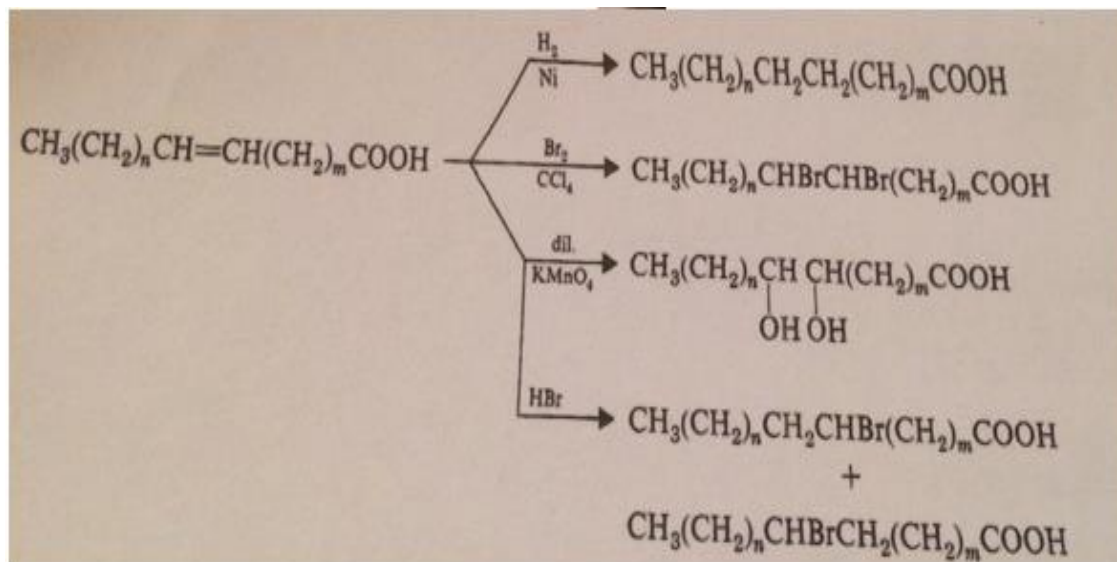
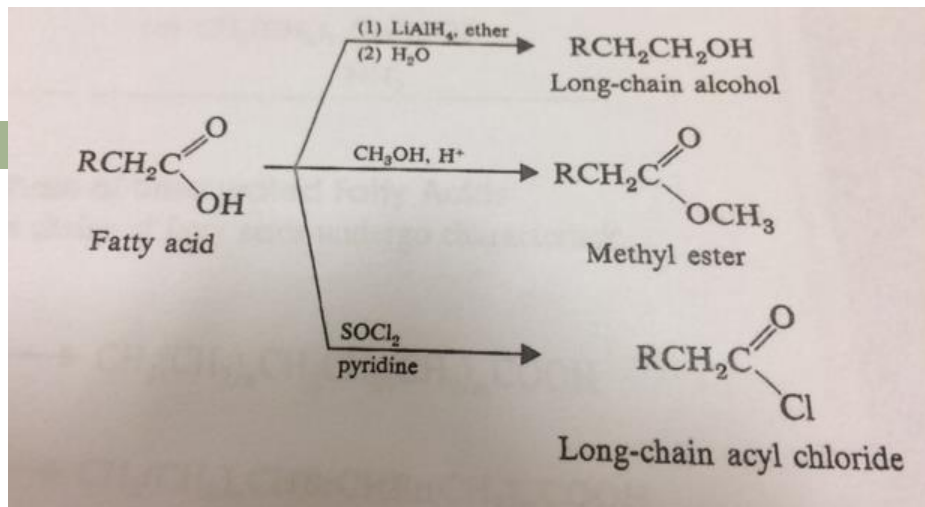


Essential Fatty acids

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

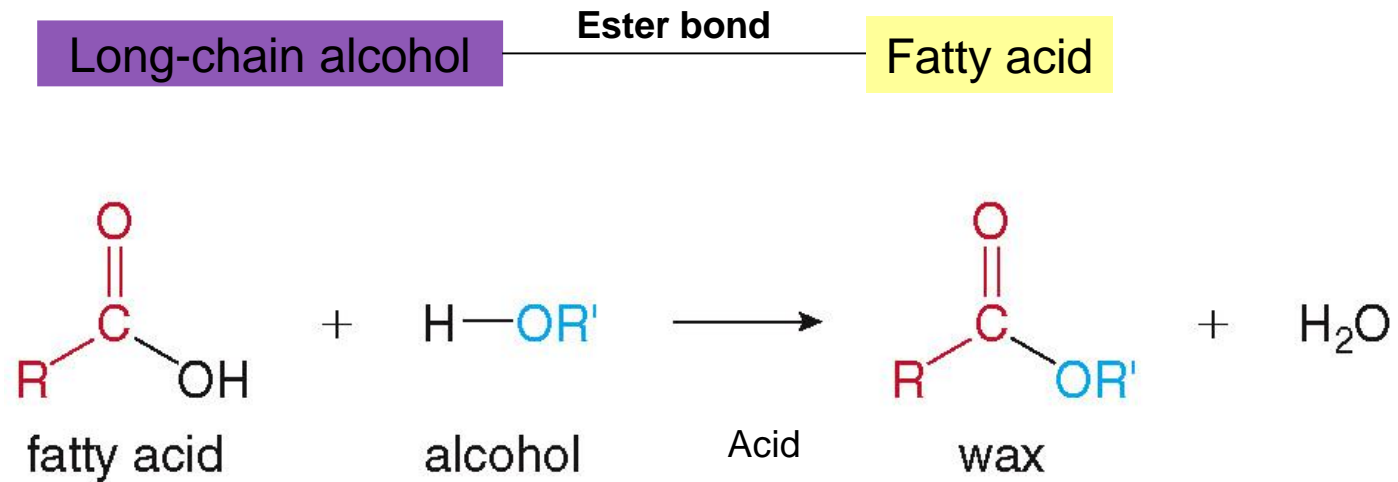


Reactions of alkenyl chain of unsaturated fatty acids



Waxes

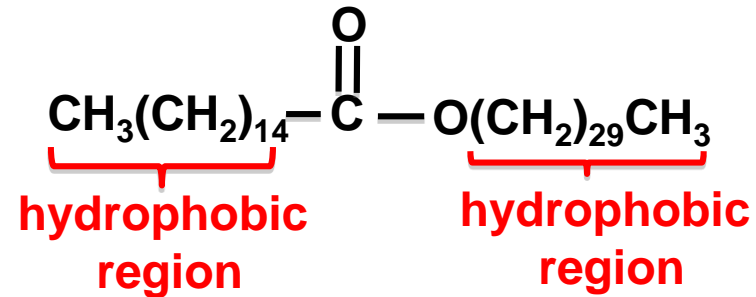
Wax is an ester of saturated fatty acid and long chain alcohol.



Waxes

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

Beeswax
(myricyl palmitate)



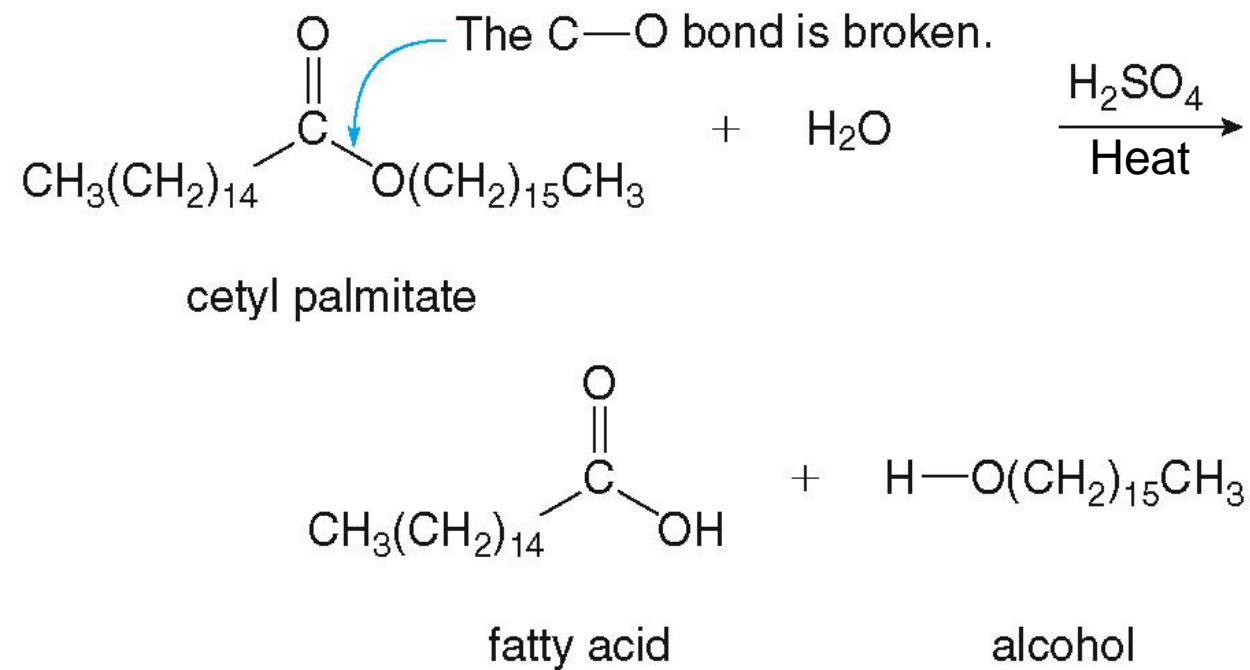
They form **protective coatings**:

- In plants, they help prevent loss of water and damage from pests.
- In humans and animals, provide waterproof coating on skin and fur.



Waxes

Hydrolysis reaction: like other esters, waxes are hydrolyzed.



Triacylglycerols (Triglycerides)

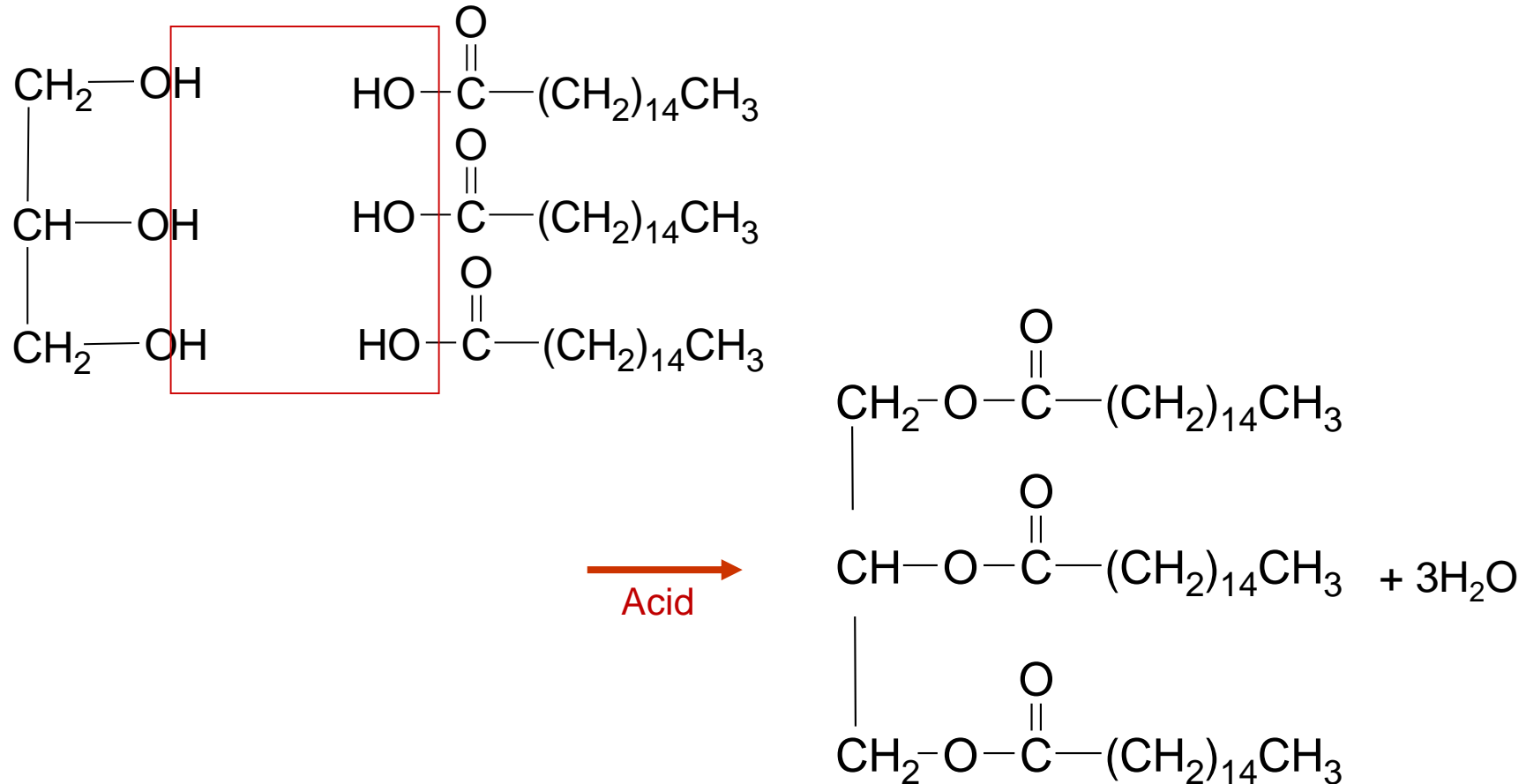
Triacylglycerols are:

- Fats and oils (are stored in the body).
- Triesters of glycerol.
- Produced by Fischer esterification.
- Formed when the hydroxyl groups of glycerol react with the carboxyl groups of fatty acids.

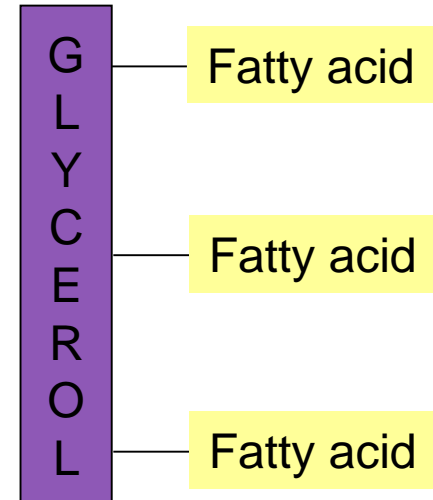
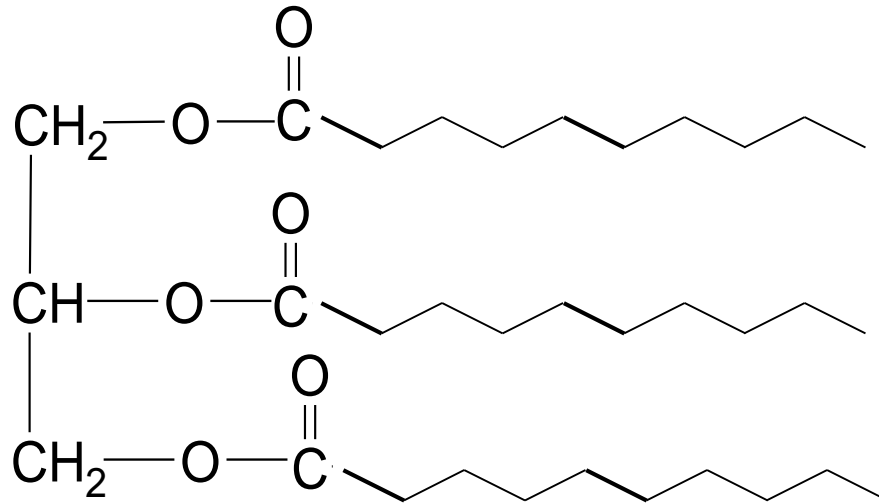
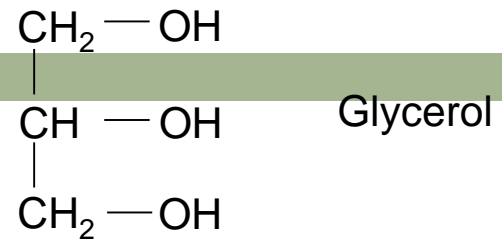


Esterification

glycerol + three fatty acids \rightarrow triacylglycerol



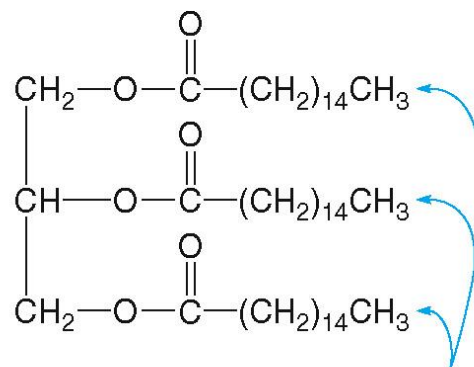
Triacylglycerols (Triglycerides)



Produced by **esterification** of glycerol (a trihydroxyl alcohol).

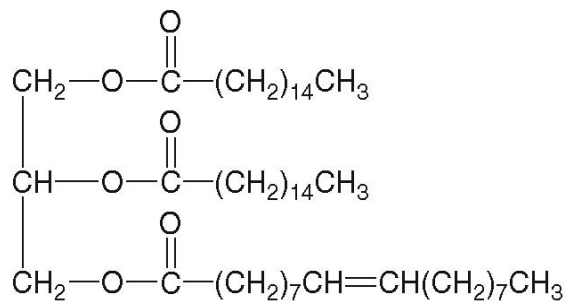
Triacylglycerols (Triglycerides)

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



three identical saturated carbon chains

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



one unsaturated carbon chain

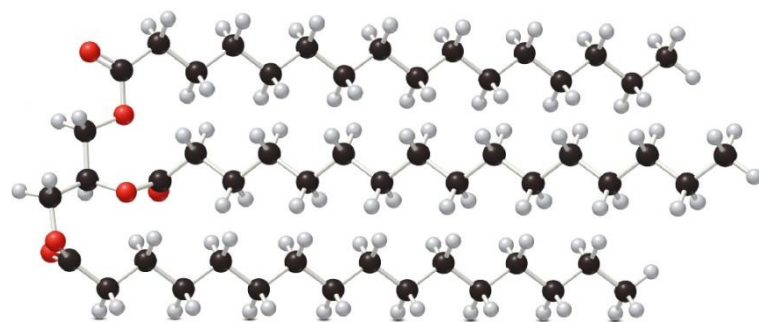
Triacylglycerols (Triglycerides)

Saturated triacylglycerols contain only saturated fatty acids.

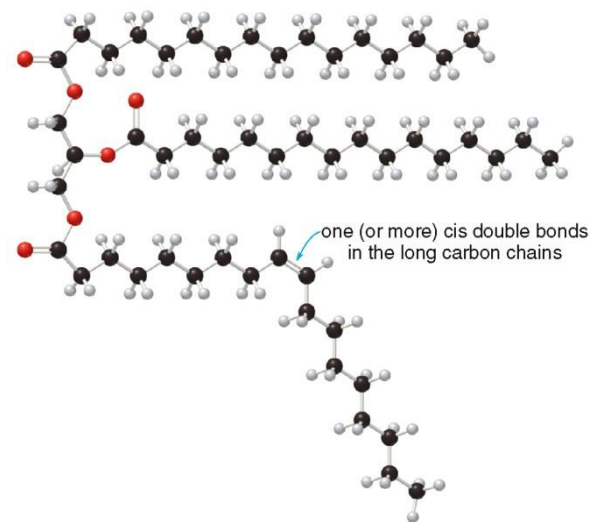
Monounsaturated triacylglycerols have 1 C=C bond.

Polyunsaturated triacylglycerols have many C=C bonds.

Increasing the number of double bonds in the fatty acid chain **decreases** the melting point of the triacylglycerol.



a saturated triacylglycerol



Triacylglycerols (Triglycerides)

Fat: is a triacylglycerol that is solid at room temperature.

Made by more saturated fatty acids (**Saturated triacylglycerols**).

Meat, milk, butter and cheese (**animal sources**).



Oil: is a triacylglycerol that is liquid at room temperature.

Made by more unsaturated fatty acids (**Unsaturated triacylglycerols**).

Corn, cotton seed, safflower and sunflower (**plant sources**).



Both are colorless, odorless, and tasteless.

Fat & Health



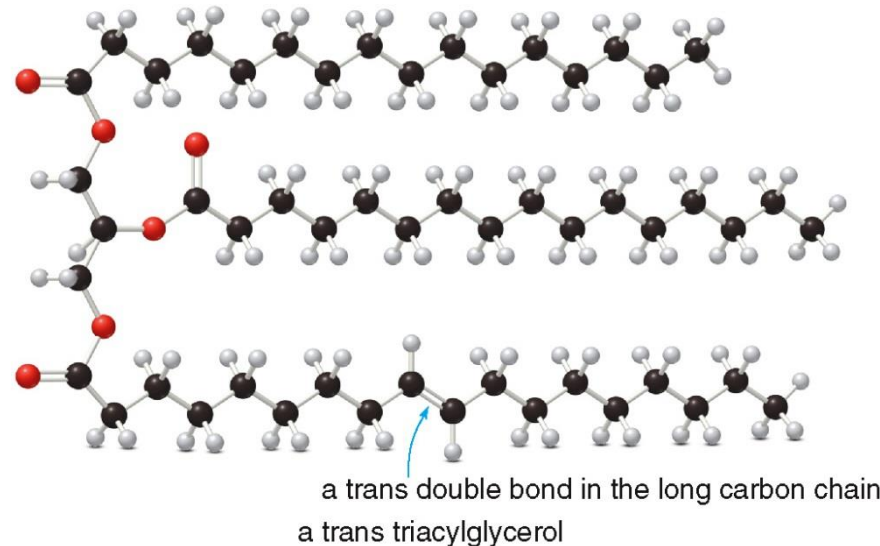
- **Fats** are used to build cell membranes, insulate the body, and store energy for later use.
- It is recommended that **no more than 20-35%** of a person's caloric intake should come from lipids.
- A high intake of **saturated triacylglycerols** is linked to heart disease.
- Saturated fats stimulate **cholesterol** synthesis in the liver, which can lead to **cholesterol plaques** building up inside arteries.
- The result is high blood pressure, **heart attack**, and even **stroke**.
- Unlike other vegetable oils, oils from palm and coconut trees are very high in saturated fats.

Fat & Health

- **Unsaturated triacylglycerols** (omega-3 fatty acids from fish) lower the risk of heart disease by decreasing the level of cholesterol in the blood.

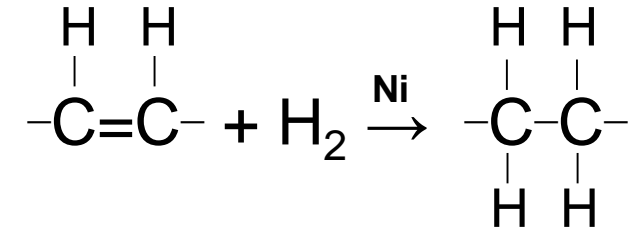
- However, if the double bond of the unsaturated triacylglycerol is **trans**, the beneficial effect is lost.

- **Trans fats**, which are primarily **synthesized** instead of naturally occurring, act like saturated fats and **increase the cholesterol levels** in the blood.



1- Hydrogenation

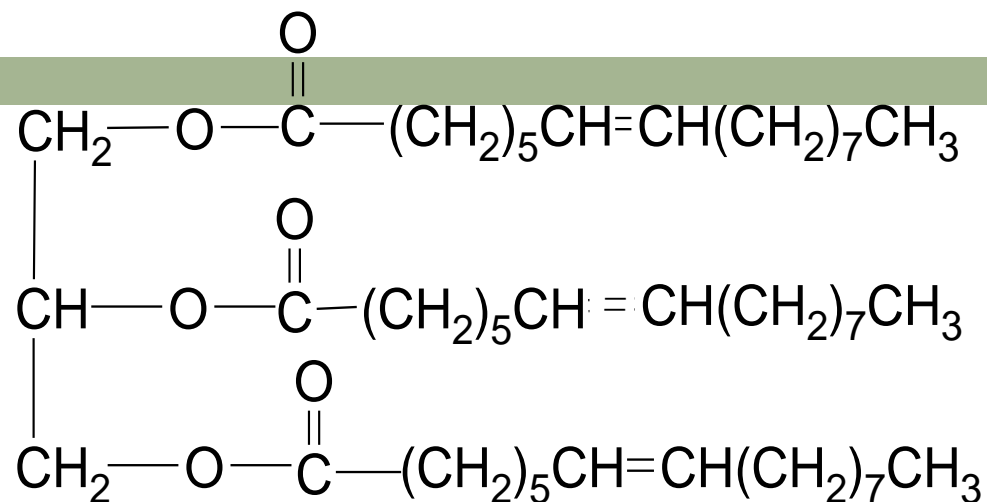
- Hydrogen adds to the double bonds of unsaturated fats (using transition metal catalyst such as Ni).



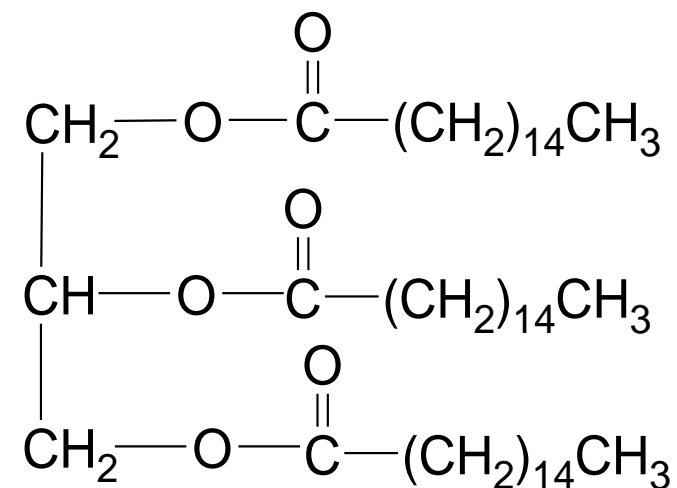
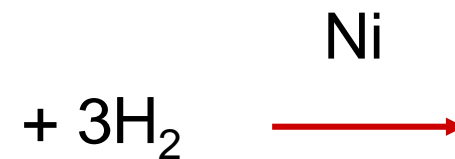
- Melting point is increased.
- Liquid oils are converted to semi-solid fats.



1- Hydrogenation



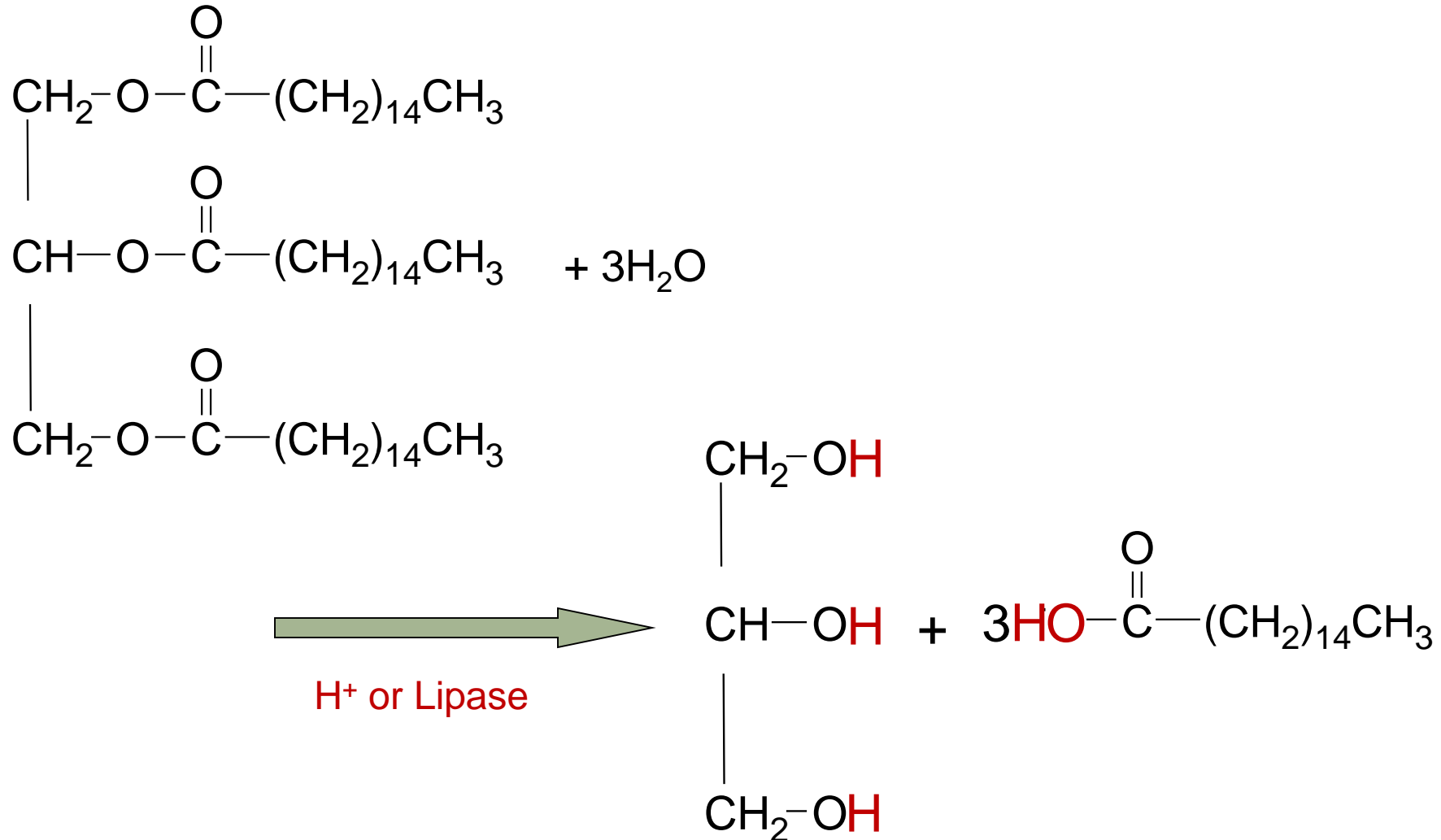
glyceryl Trioleate
(triolein)



glyceryl tristearate
(tristearin)

2- Hydrolysis

Triacylglycerols are hydrolysis (split by water) in the presence of strong acid or **lipase** (digestive enzyme).



Metabolism of triacylglycerols



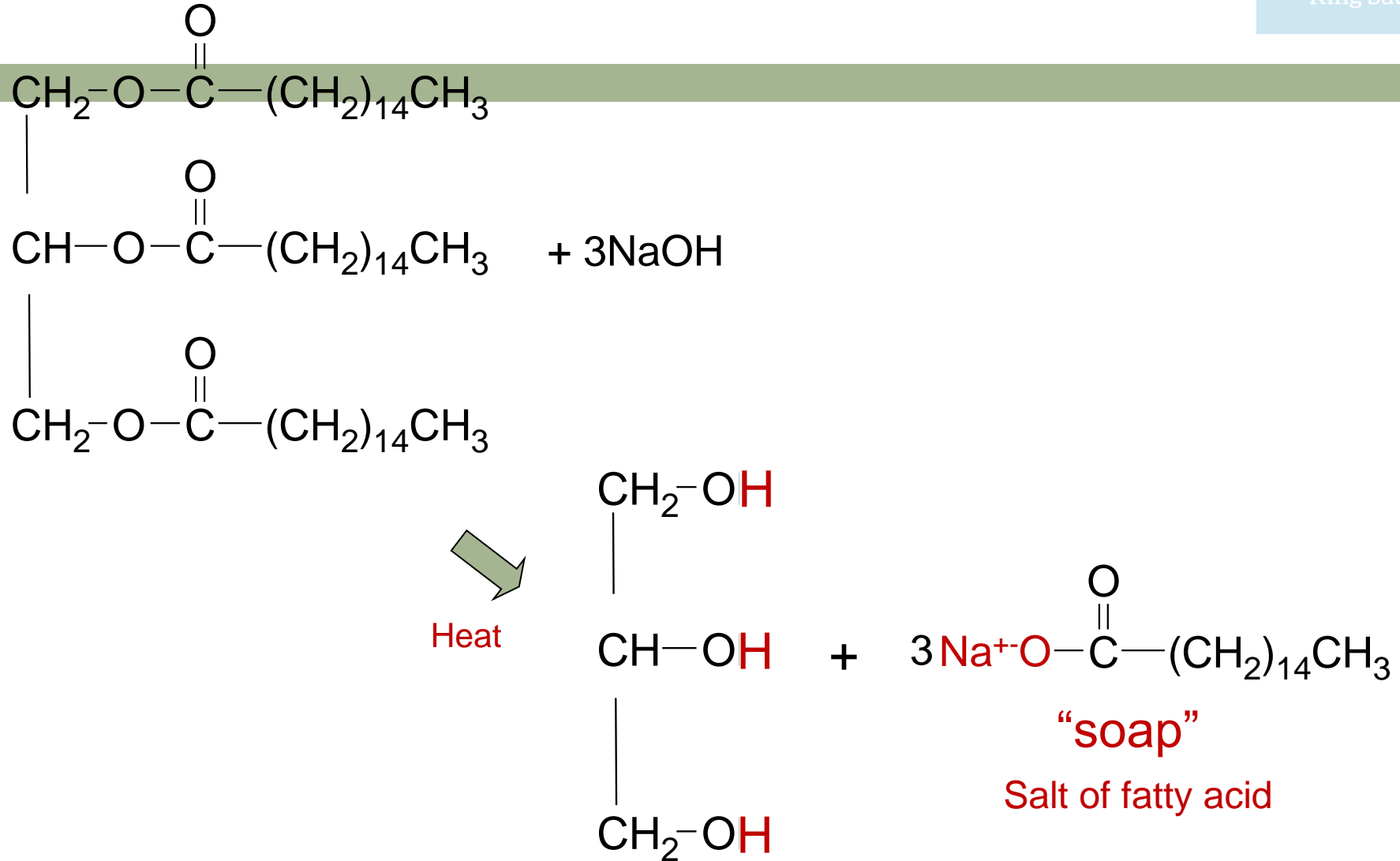
- Humans store **energy** as triacylglycerols in adipose cells below the surface of the skin, in the breast area, and surrounding internal organs.
- The number of **adipose cells** is constant; weight gained or lost causes them to **swell or shrink**, but not decrease or increase in number.
- To metabolize triacylglycerols for energy, the esters are hydrolyzed by **enzymes called lipases**.
- **Complete metabolism** of a triacylglycerol yields CO_2 , H_2O , and a great deal of energy.

3- Saponification (Basic Hydrolysis)



- Is the process of forming “soaps” (salts of fatty acids).
- Is the reaction of a fat with a strong base (NaOH).
- Splits triacylglycerols into glycerol and the salts of fatty acids.
- With KOH or the oils that are polyunsaturated gives softer soaps (liquid soaps).
- Soaps are typically made from lard (from hogs), tallow (from cows or sheep), coconut oil, or palm oil.
- All soaps work in the same way, but have **different properties** depending on the lipid source, length of C chain, and degree of unsaturation.

3- Saponification (Basic Hydrolysis)



Soaps

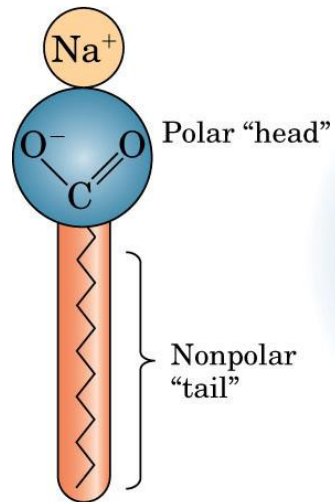
Hydrophobic part: nonpolar

Hydrophilic part: polar (remains in contact with environment)

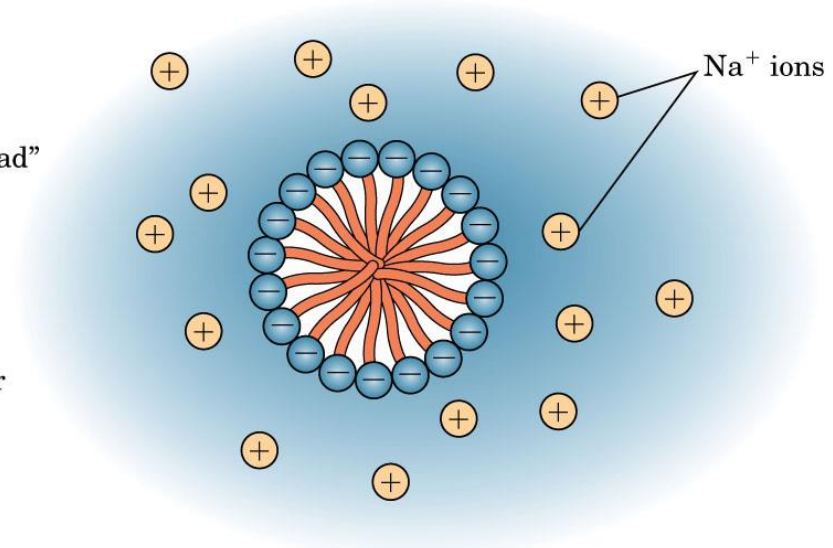


Sodium soaps

(a) A soap



(b) Cross section of a soap micelle in water



Soaps

When soap is mixed with dirt (grease, oil, and ...), soap micelles “dissolve” these nonpolar, water-insoluble molecules.

Soap micelle with
“dissolved” grease

