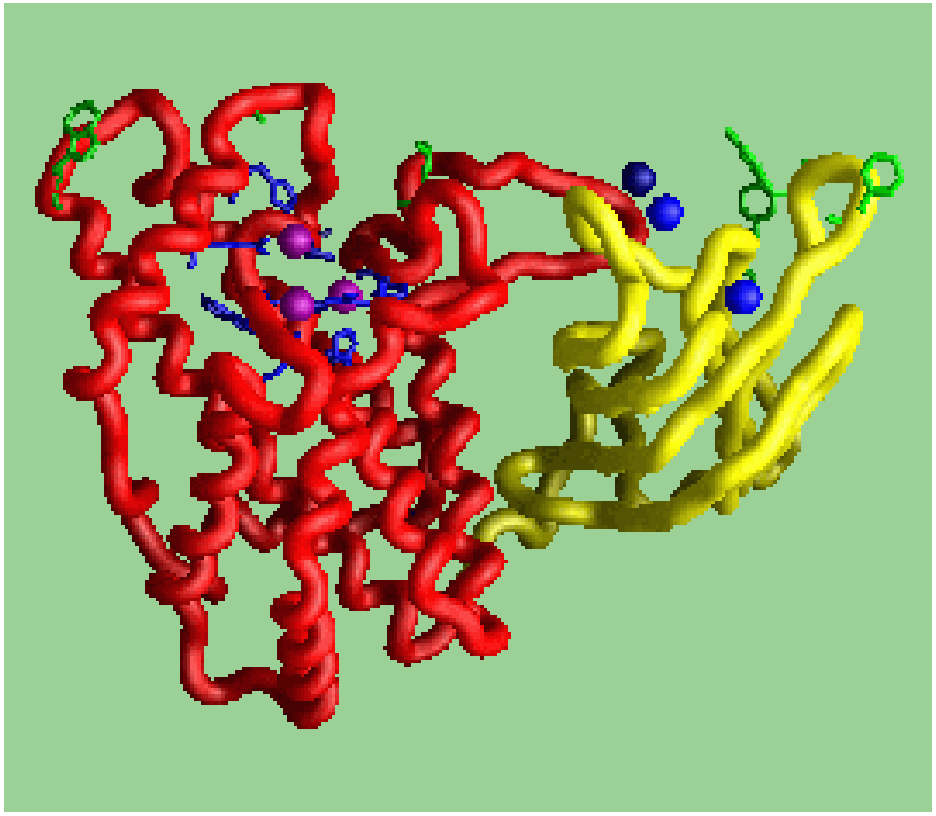
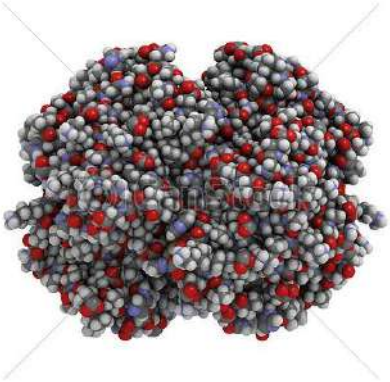
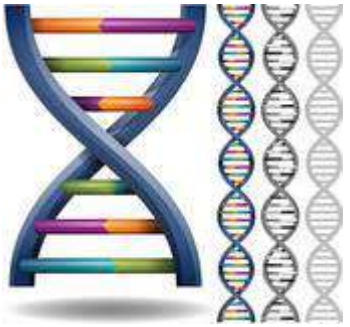
Chapter 5: The Structure and Function of Macromolecules



5.1 - Overview: The Molecules of Life

- Within cells, small organic molecules are joined together to form larger molecules
- Macromolecules are large molecules composed of thousands of covalently connected atoms



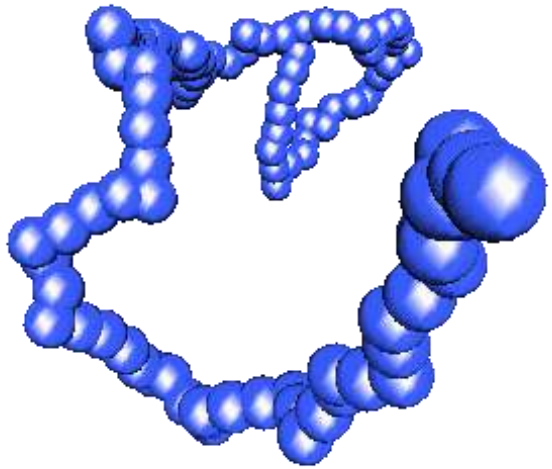


Polymer Principles

- **POLYMER**: large molecule consisting of many identical or similar subunits connected together

- **MONOMER**: subunit or building block molecule of a polymer

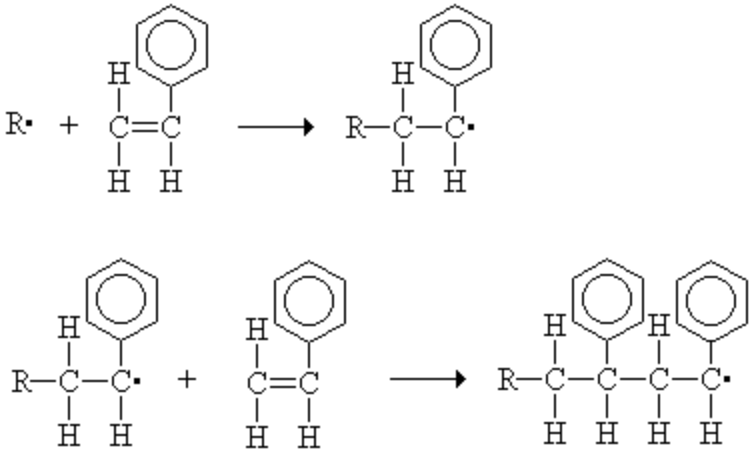
- **MACROMOLECULE**: large organic polymer
  *Examples: carbohydrates, lipids, proteins, nucleic acids



The Diversity of Polymers

- Each cell has thousands of different kinds of macromolecules
- Macromolecules vary among cells of an organism, vary more within a species, and vary even more between species
- An immense variety of polymers can be built from a small set of monomers
- Despite this great diversity, molecular structure & function can be grouped into 4 main categories (carbs, lipids, proteins, nucleic acids)

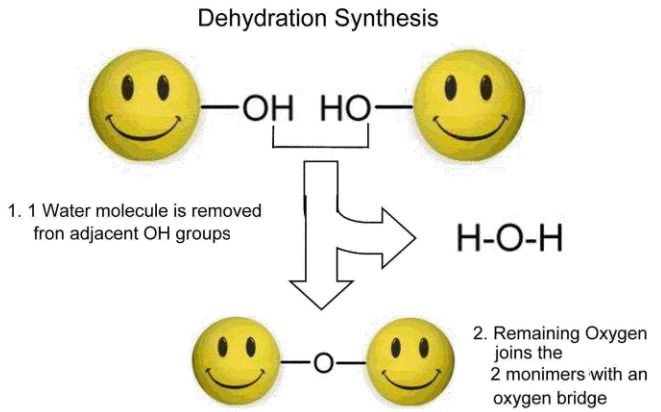
- **<u>POLYMERIZATION REACTIONS</u>**: chemical reactions that link 2 or more small molecules (<u>monomers</u>) to form larger molecules (<u>polymers</u>) with **<u>repeating structural units</u>**

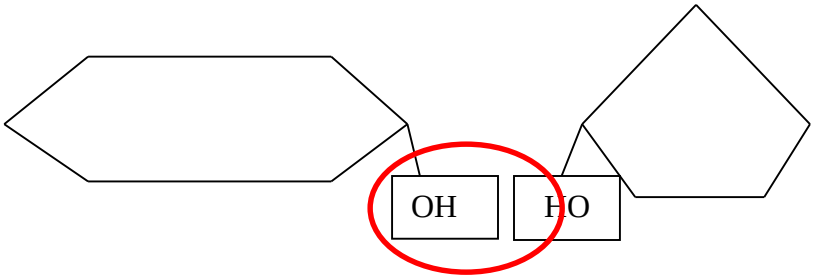


- **DEHYDRATION SYNTHESIS REACTIONS (a.k.a. condensation):** polymerization reactions during which monomers are covalently linked, producing the net removal of a water molecule for each covalent linkage

  *process that requires energy

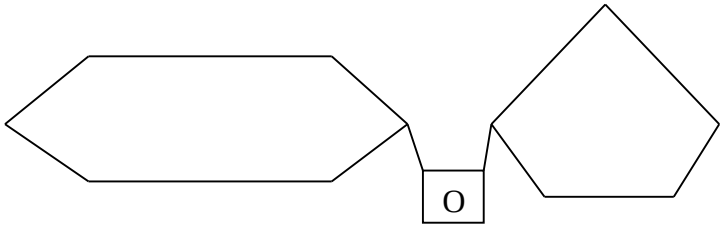
  *process that requires biological catalysts (enzymes)





Glucose $C_6H_{12}O_6$

Fructose $C_6H_{12}O_6$



H_2O

Sucrose $C_{12}H_{22}O_{11}$

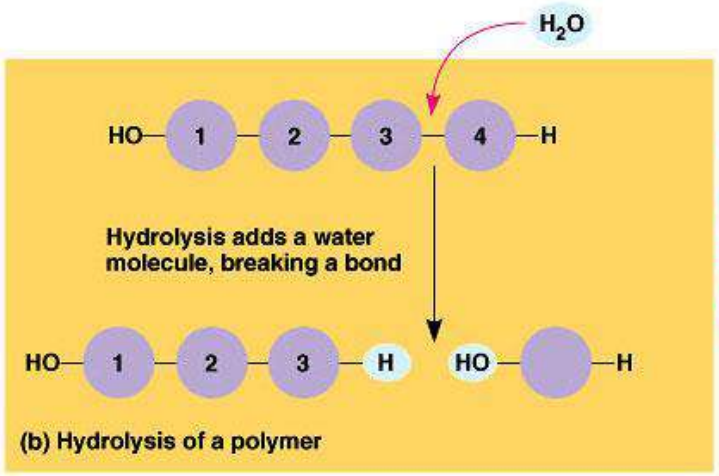
Water

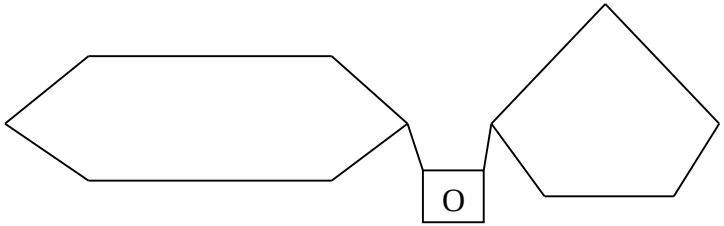
- **HYDROLYSIS**: reaction process that breaks covalent bonds between monomers by the addition of water molecules

  *process releases energy

  *requires biological catalysts (enzymes)

  *Example: **digestion**

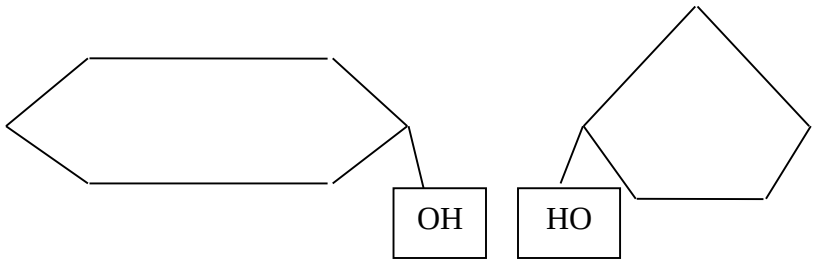




Sucrose $C_{12}H_{22}O_{11}$

H_2O

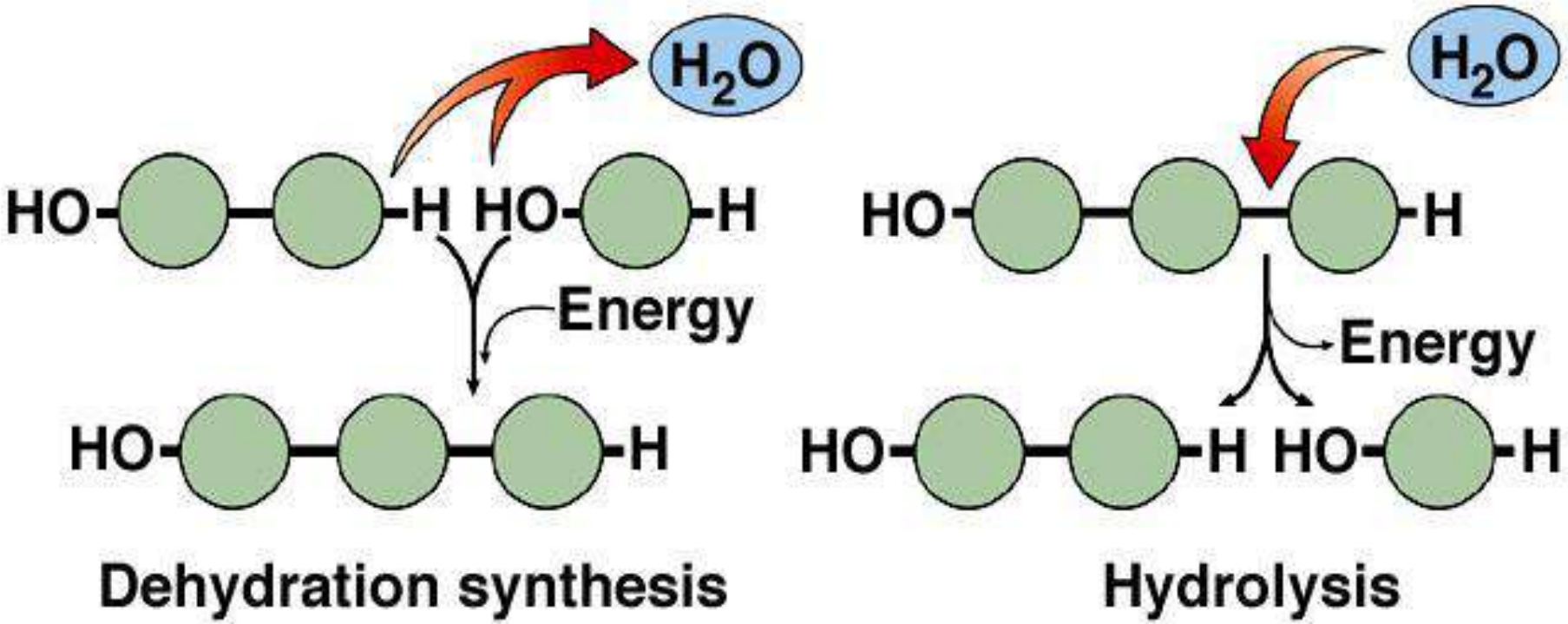
Water

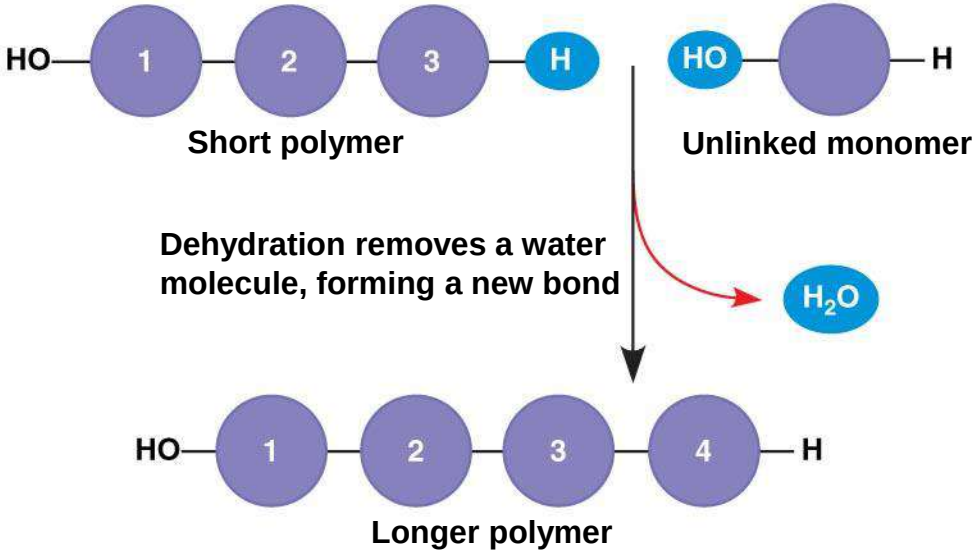


Glucose $C_6H_{12}O_6$

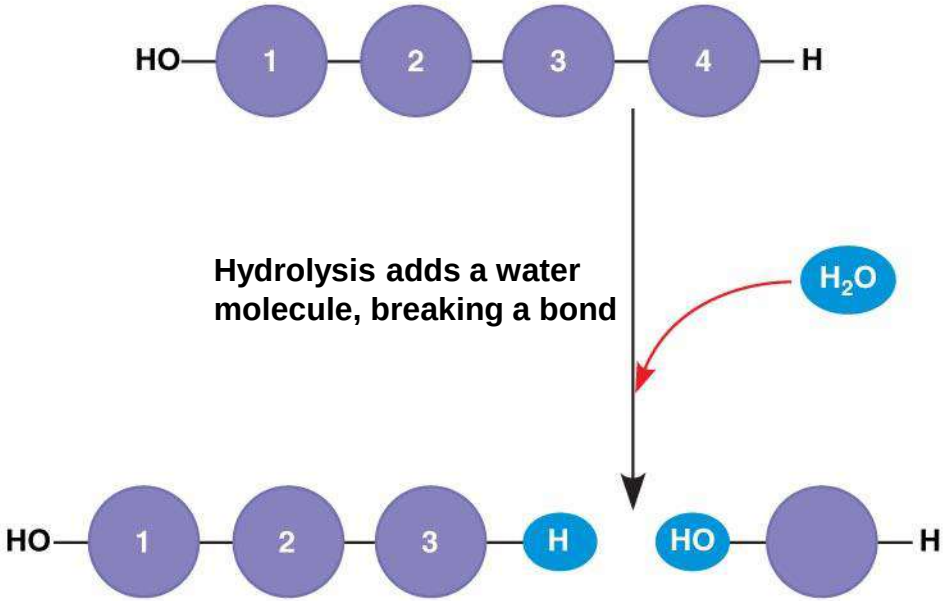
Fructose $C_6H_{12}O_6$

Dehydration and Hydrolysis

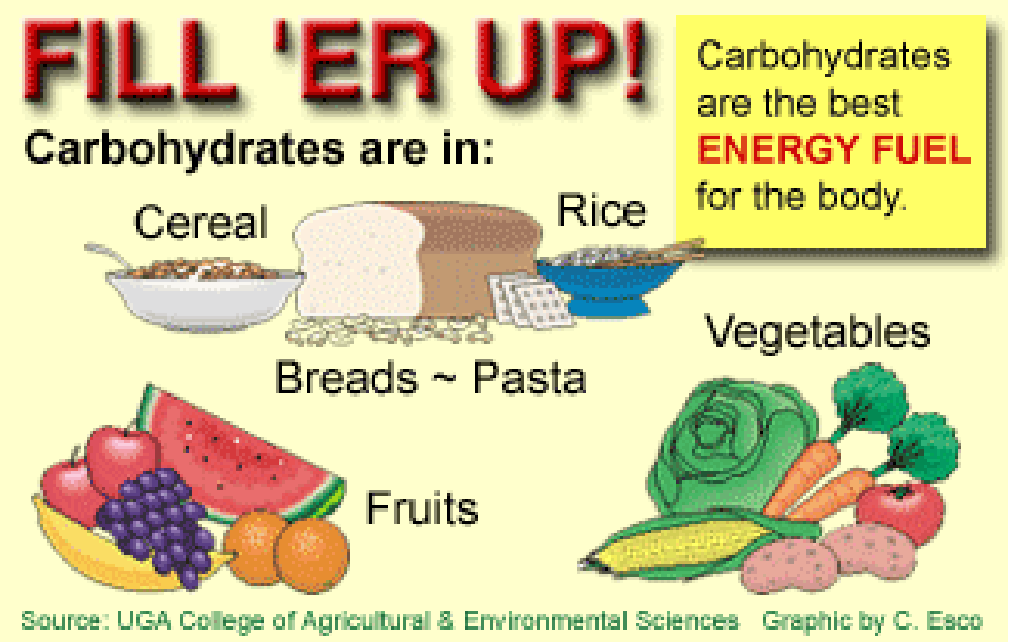




(a) Dehydration reaction in the synthesis of a polymer



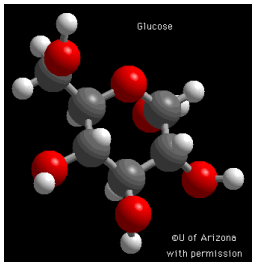
(b) Hydrolysis of a polymer



Carbohydrates

5.2 – Carbohydrates

- carbohydrates include: **sugars** & **polymers of sugars**
- carbs include:

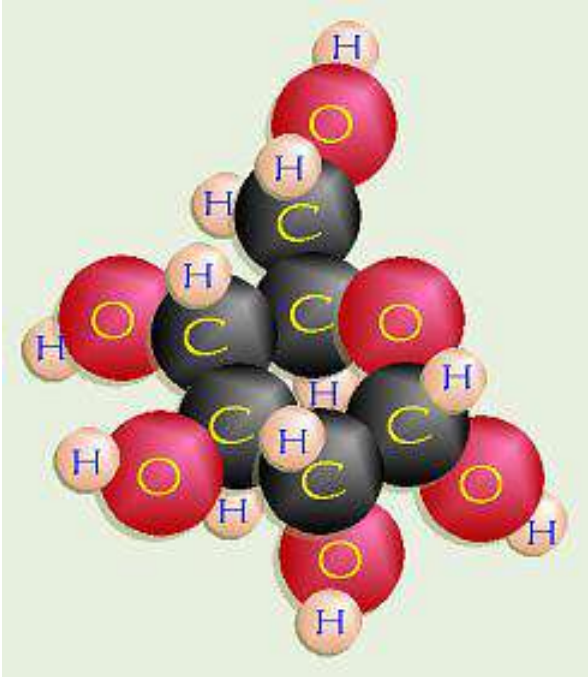


-**monosaccharides** (single sugars)

-**disaccharides** (double sugars)

-**polysaccharides** (long chains of mono.)

Monosaccharides = single sugars



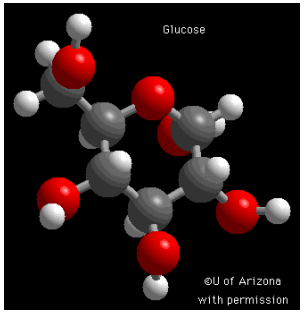
- are major nutrients for cells
- **GLUCOSE** is most common
- store energy in their chemical bonds which is harvested by cellular respiration

  *examples:

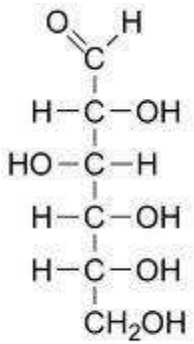
  glucose, ribose, galactose

~OSE

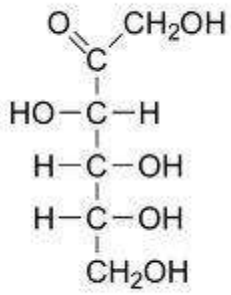
Simple Sugars:



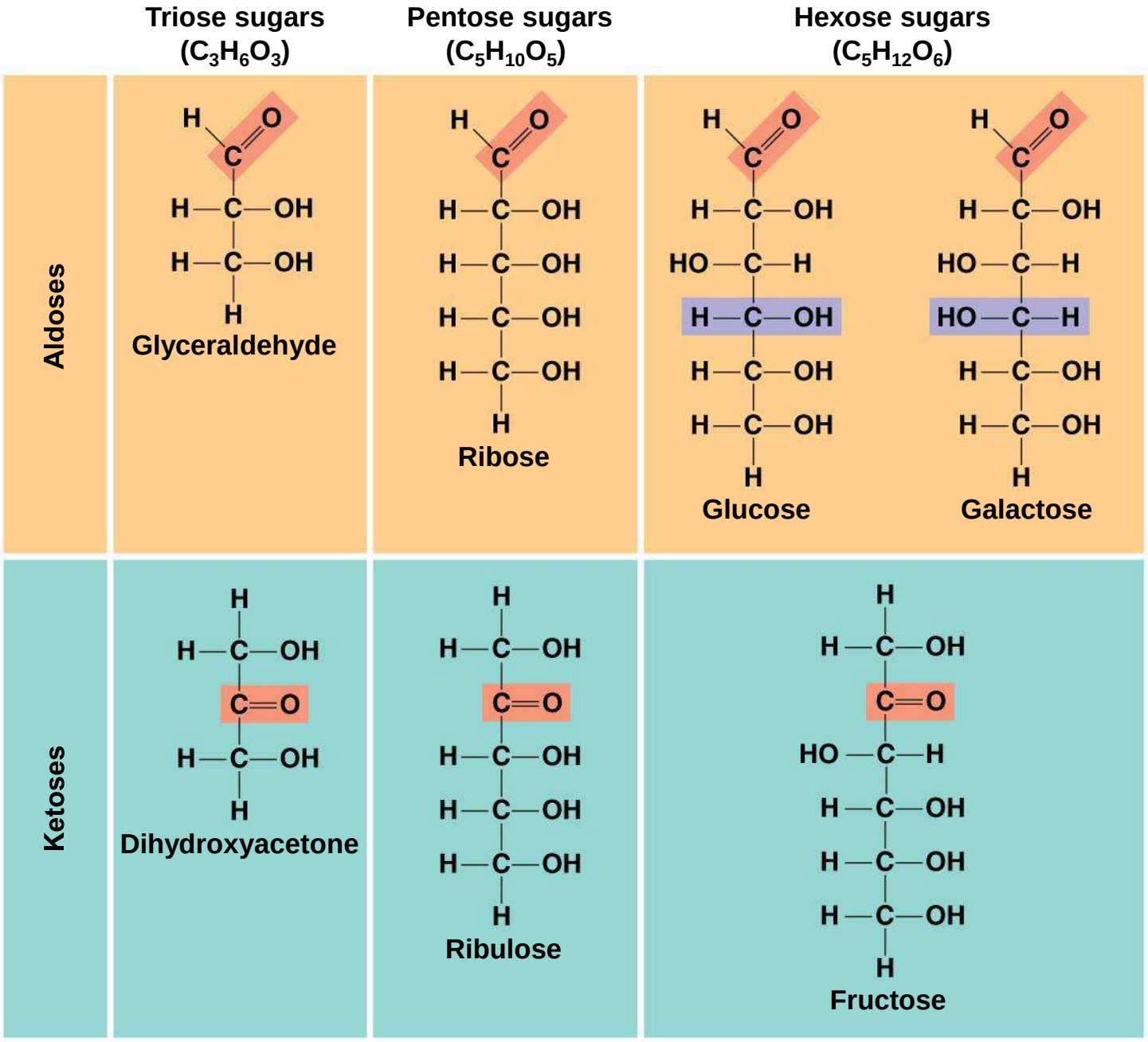
- Monosaccharides have molecular formulas that are usually multiples of **CH_2O**
- Functional groups on a sugar: **carbonyl (C=O),** and multiple **hydroxyl groups (-OH)**
- Monosaccharides are classified by location of the carbonyl group and by number of carbons in the carbon skeleton



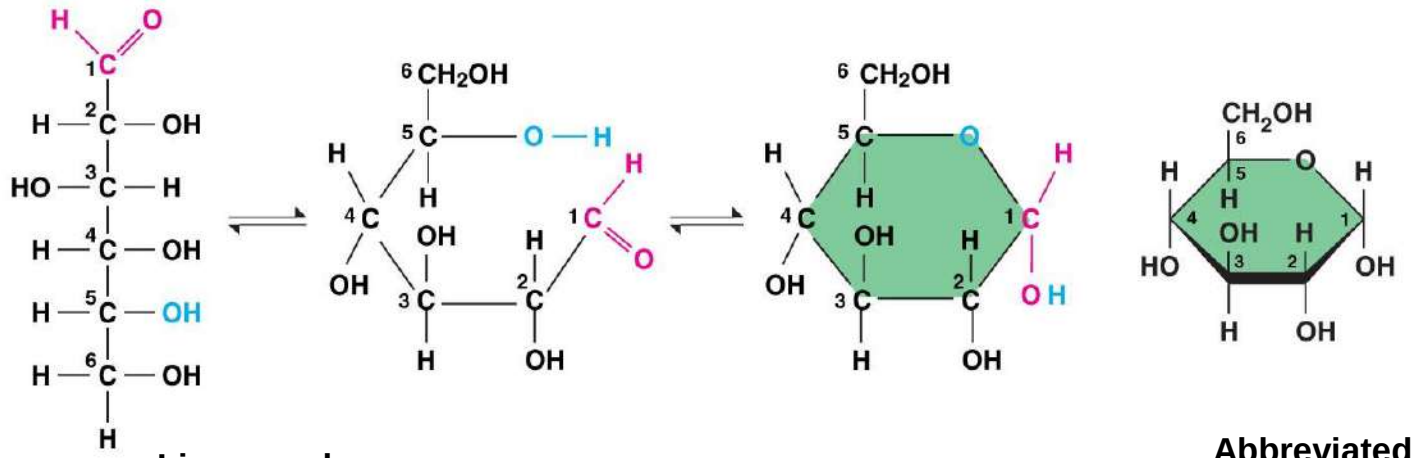
glucose



fructose

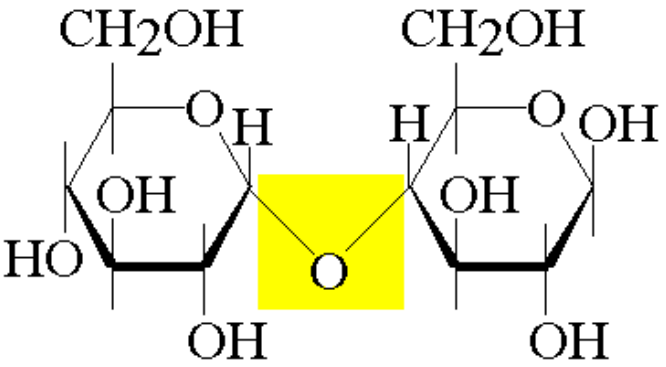


- Monosaccharides serve as a major fuel for cells and as raw material for building molecules
- Though often drawn as a linear skeleton, in aqueous solutions they form rings



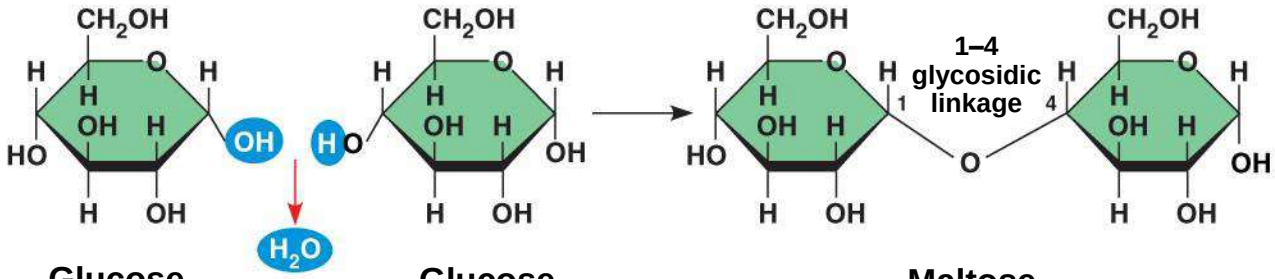
2 monosaccharides joined together = **a DISACCHARIDE**

- A disaccharide is formed when a dehydration reaction joins two monosaccharides
- This covalent bond is called a **GLYCOSIDIC LINKAGE**

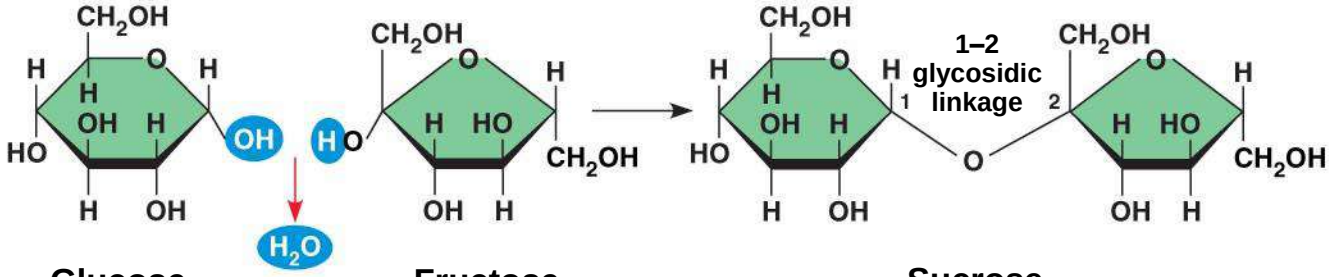


1-4 glycosidic linkage

(a) Dehydration reaction in the synthesis of maltose

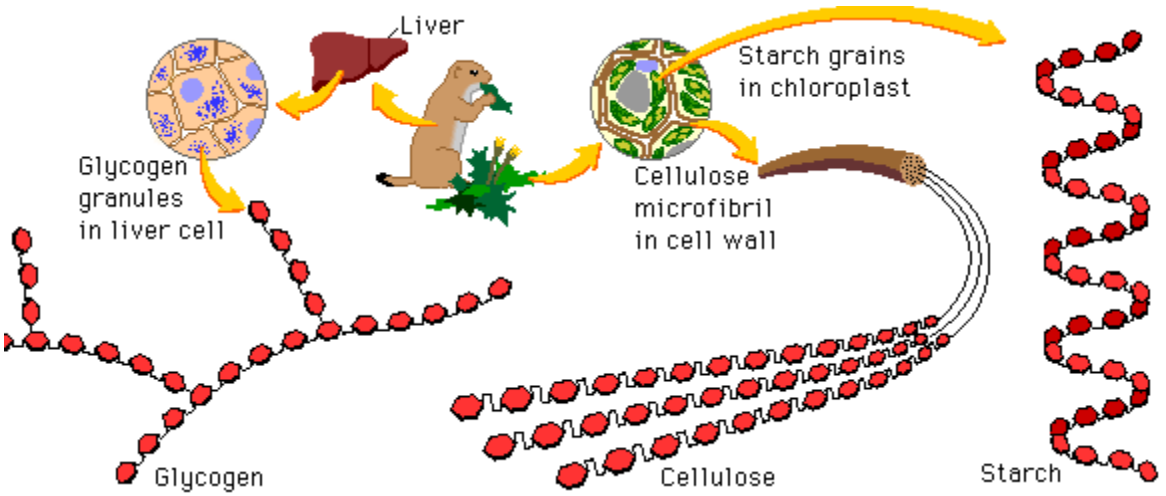


(b) Dehydration reaction in the synthesis of sucrose



POLYSACCHARIDES

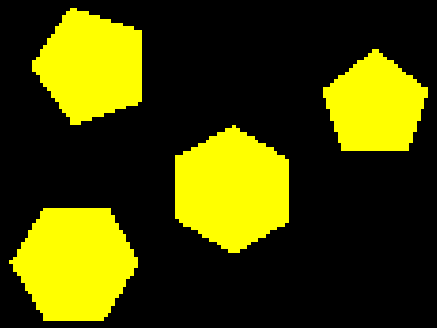
- Polysaccharides, the polymers of sugars, have storage and structural roles
- The structure and function of a polysaccharide are determined by its sugar monomers and the positions of glycosidic linkages



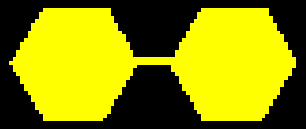
Polysaccharides = hundreds or thousands of monosaccharides

- formed by linking monomers in enzyme-mediated **DEHYDRATION SYNTHESIS REACTIONS**.

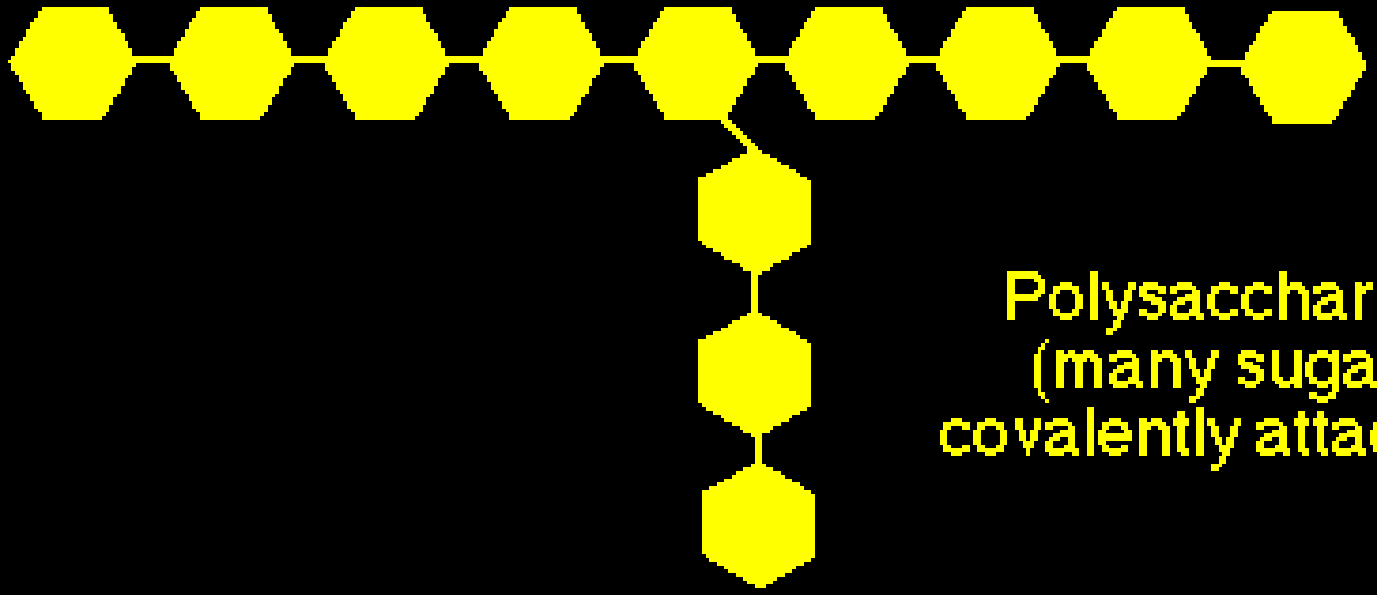
- Monomers held together by covalent bonds called **GLYCOSIDIC LINKAGES.**



Monosaccharides (simple sugars)

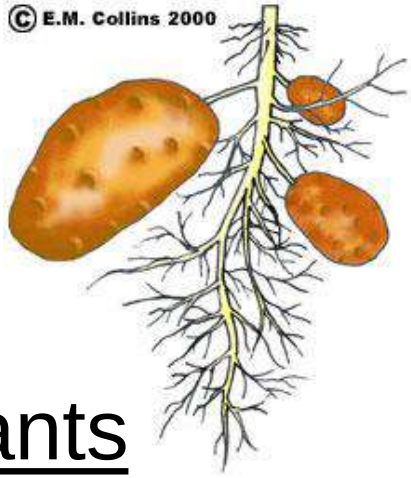


Disaccharide (two sugars covalently attached)

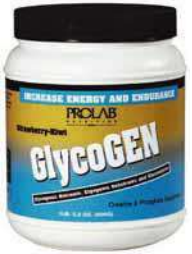


Polysaccharide (many sugars covalently attached)

Examples of energy storage polysaccharides:



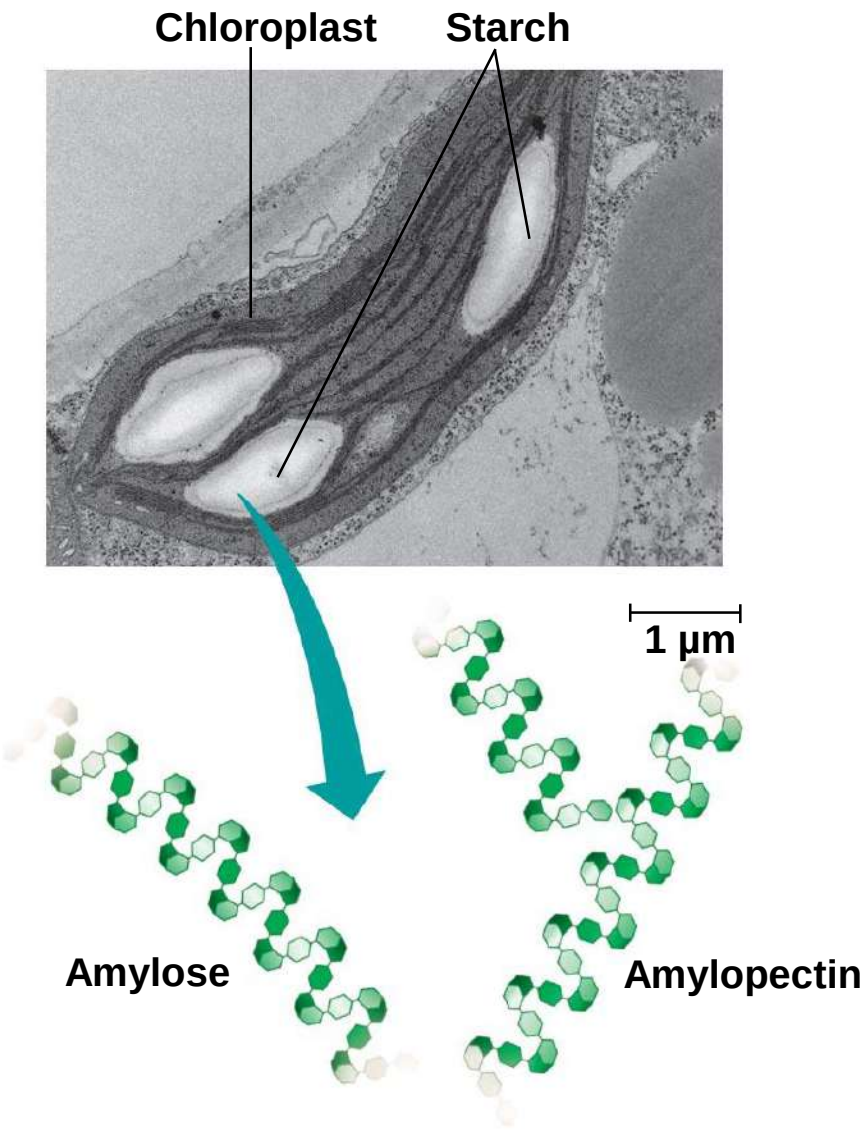
- **STARCH**= glucose polymer in plants stored as granules within plastids



- **GLYCOGEN**= glucose polymer in animals stored in skeletal muscles and liver of humans & other vertebrates

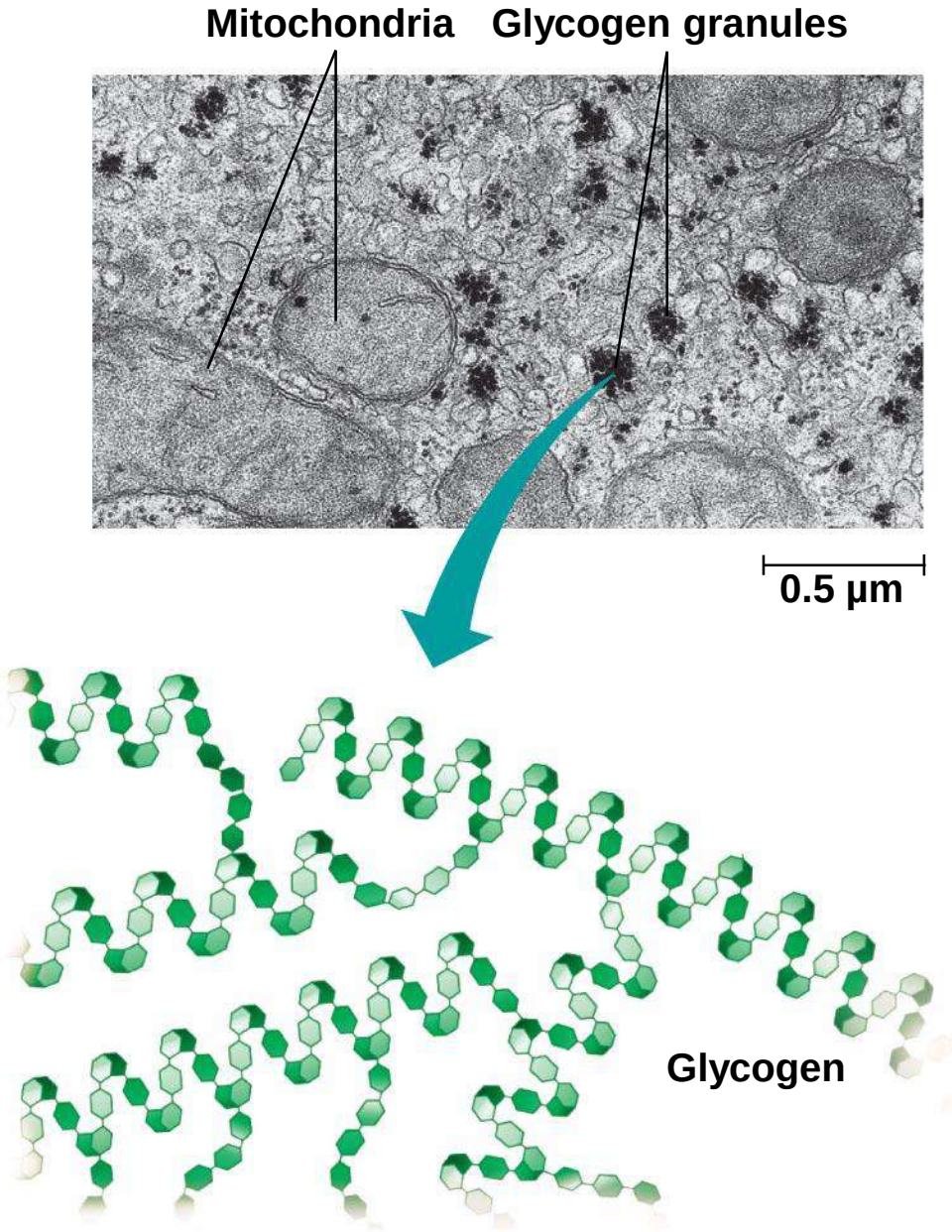
Storage Polysaccharides

- **STARCH**, a storage polysaccharide of plants, consists entirely of glucose monomers
- Plants store surplus starch as granules within chloroplasts and other plastids

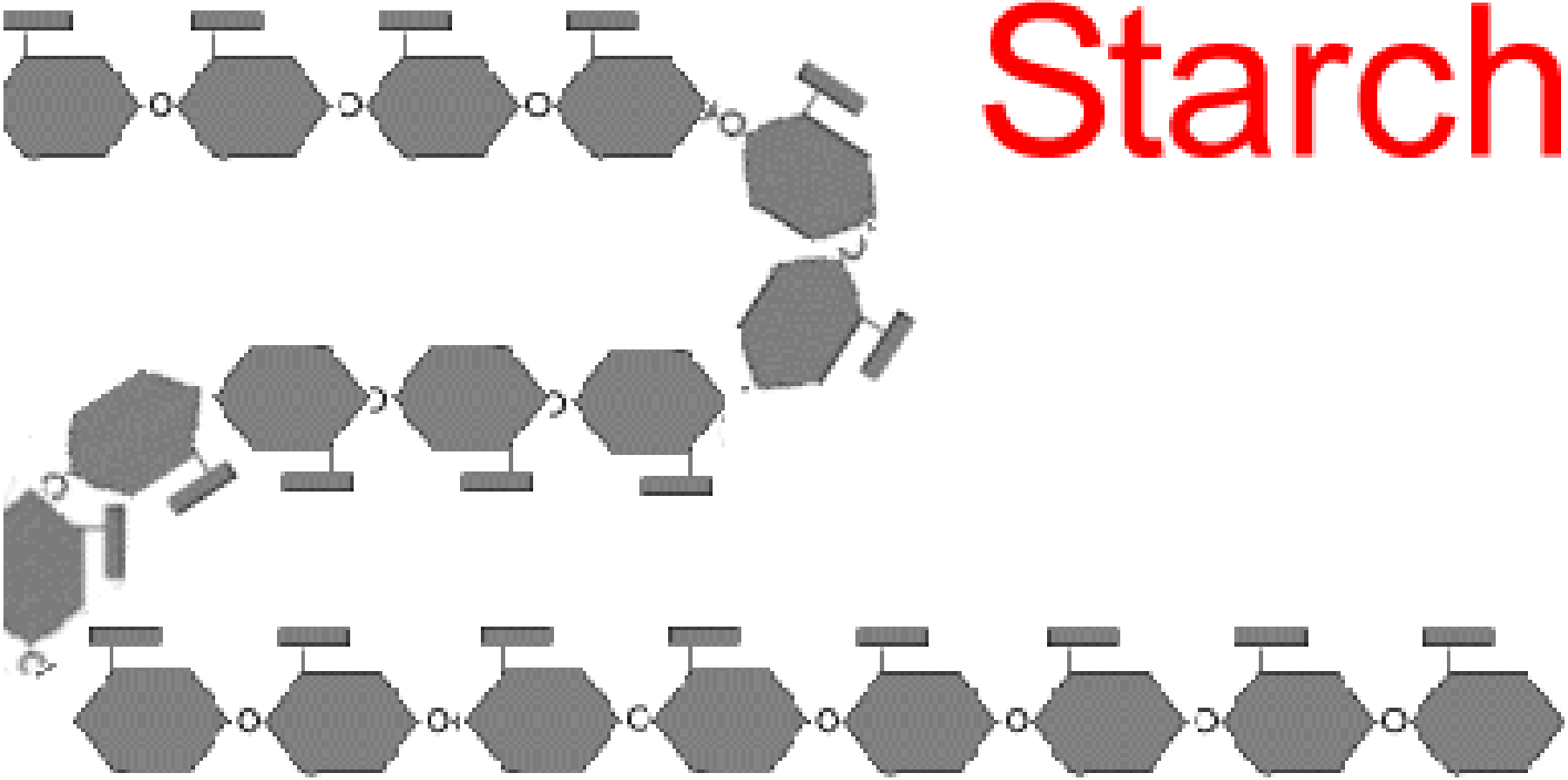


(a) Starch: a plant polysaccharide

- **GLYCOGEN** is a storage polysaccharide in animals
- Humans and other vertebrates store glycogen mainly in liver and muscle cells



(b) **Glycogen: an animal polysaccharide**

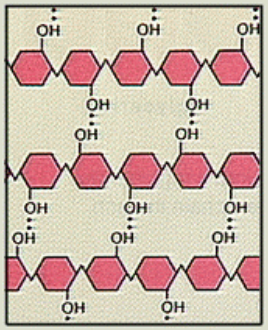


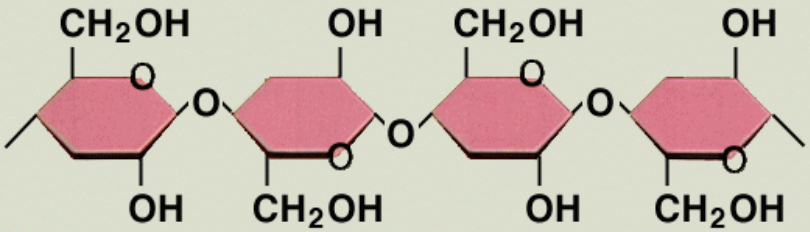
Starch

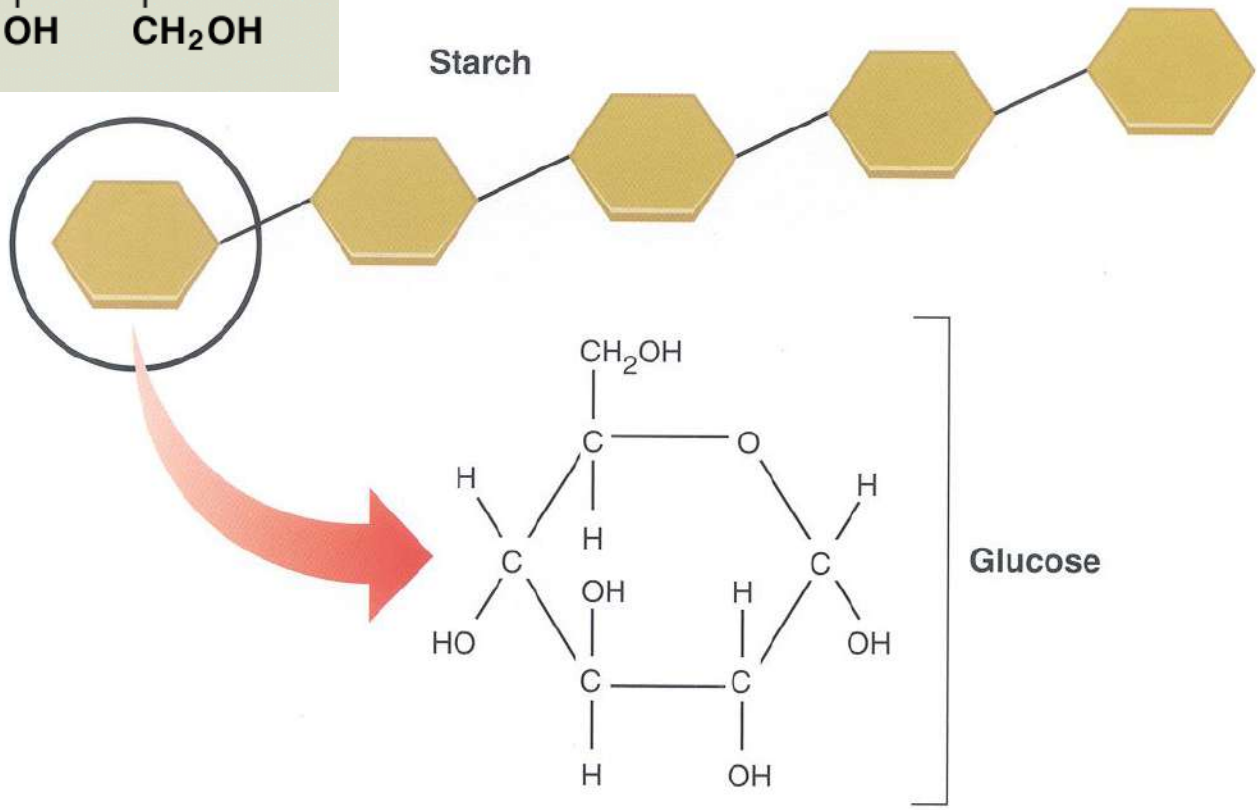
Examples of structural support polysaccharides:

- **CELLULOSE** = major structural component of plant cell walls that cannot be digested by most organisms because of missing enzyme

Cellulose

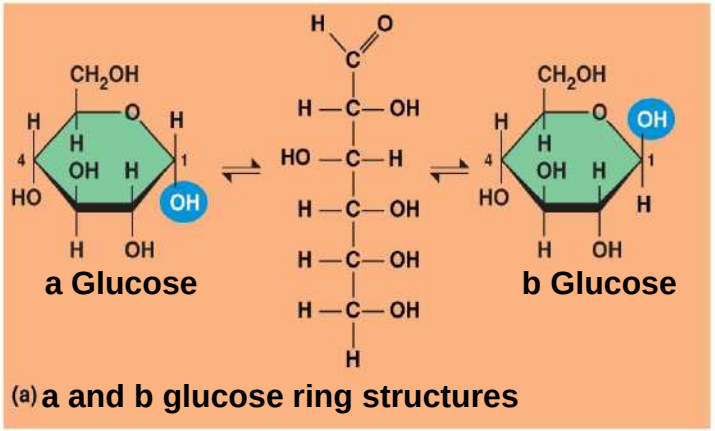



CH2OH
OH
CH2OH
OH
O
O
O
O
O
O
OH
CH2OH
OH
CH2OH

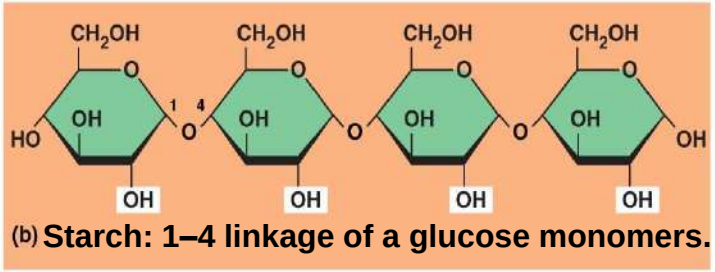

Starch
CH2OH
C
O
H
H
C
C
H
OH
H
HO
OH
C
C
H
OH
Glucose

Structural Polysaccharides

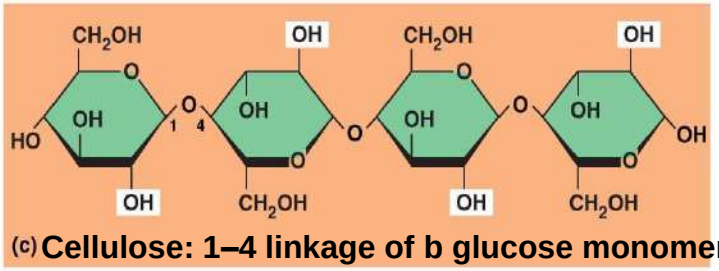
- Like starch, cellulose is a polymer of glucose, **but the glycosidic linkages differ**



(a) a and b glucose ring structures

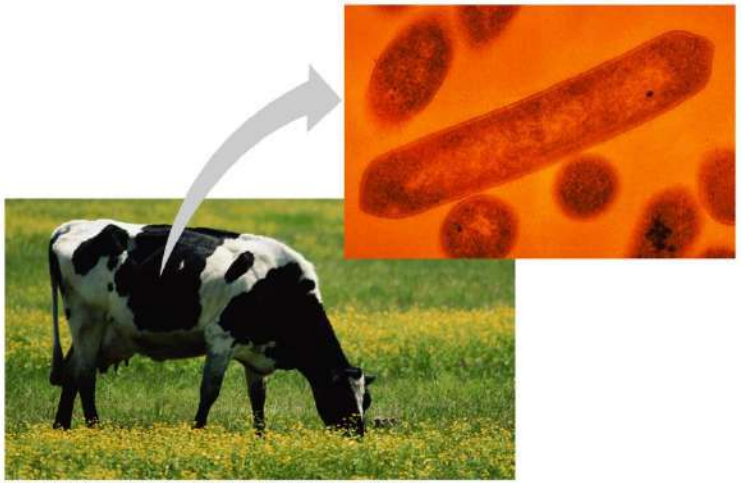


(b) Starch: 1–4 linkage of a glucose monomers.

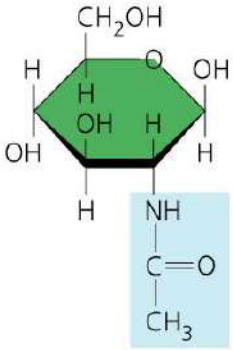


(c) Cellulose: 1–4 linkage of b glucose monomers.

- Enzymes that digest starch by hydrolyzing alpha linkages can't hydrolyze beta linkages in cellulose
- Cellulose in human food passes through the digestive tract as **insoluble fiber**
- Some microbes use enzymes to digest cellulose
- Many herbivores, from cows to termites, have symbiotic relationships with these microbes



- **CHITIN**, another structural polysaccharide, is found many places:
  - In the exoskeleton of arthropods
  - In the cell walls of many fungi
  - Used as surgical thread



(a) The structure of chitin.

(b) Chitin forms the exoskeleton of arthropods. This cicada is molting, shedding its old exoskeleton and emerging in adult form.

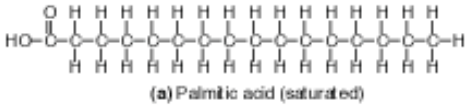
(c) Chitin is used to make a strong and flexible surgical thread that decomposes after the wound or incision heals.


Lipids!!

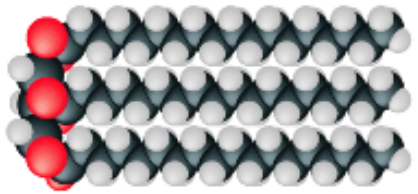
5.3 - LIPIDS:

- **Lipids** are the one class of large biological molecules that *do not form polymers*
- The unifying feature of lipids is having little or no affinity for water (**hydrophobic**)
- Lipids are hydrophobic because they consist mostly of hydrocarbons, which form nonpolar covalent bonds

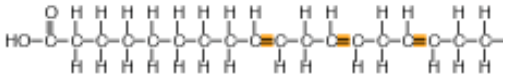
LIPIDS



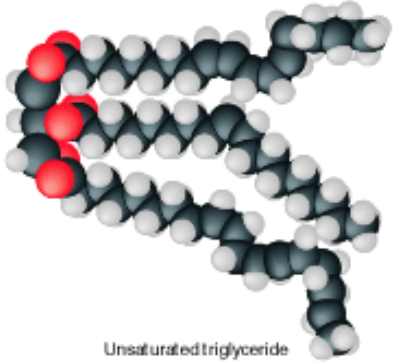
(a) Palmitic acid (saturated)



Saturated triglyceride



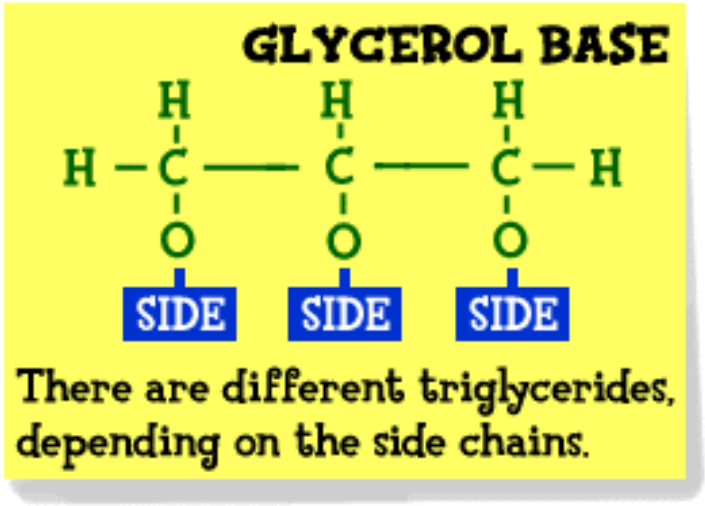
(b) Linolenic acid (polyunsaturated)



Unsaturated triglyceride

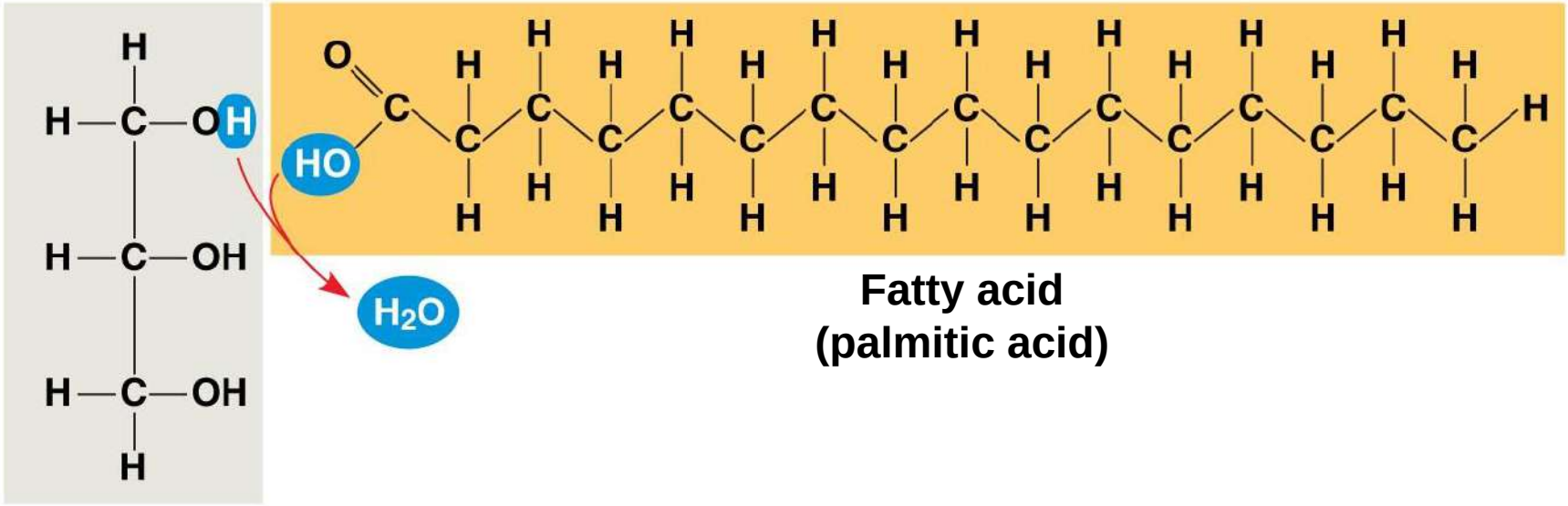
- insoluble in water
- include:
  1. **Fats**
  2. **Phospholipids**
  3. **Steroids**

1. FATS



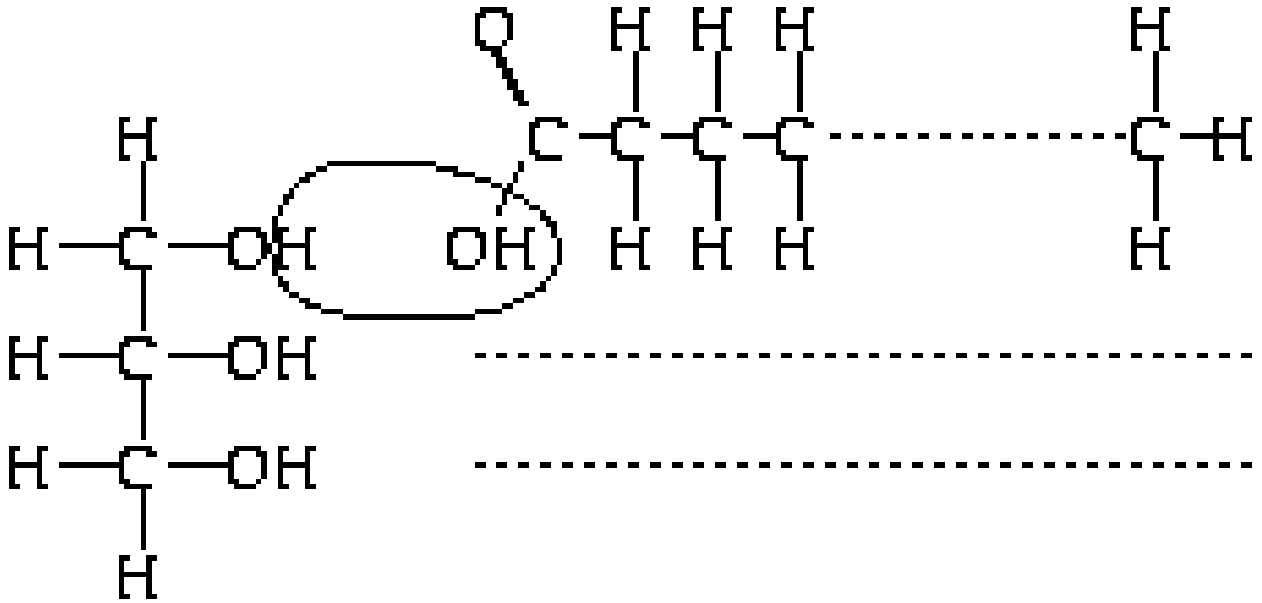
- composed of:
  - **glycerol** (3-carbon alcohol)
  - **fatty acid** (contains carboxylic acid; long hydrocarbon chain or “tail”)

    **the nonpolar C-H bonds make the chain hydrophobic and insoluble in water

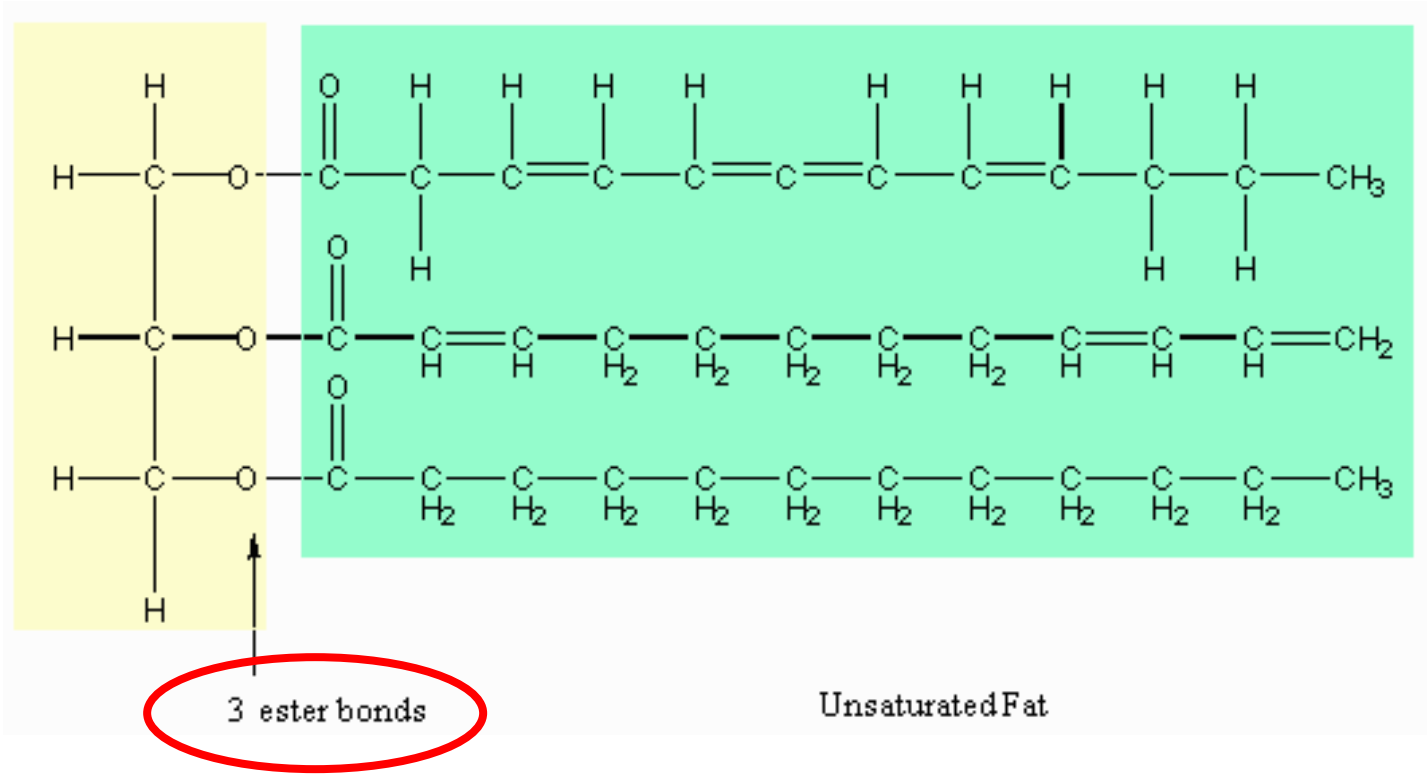


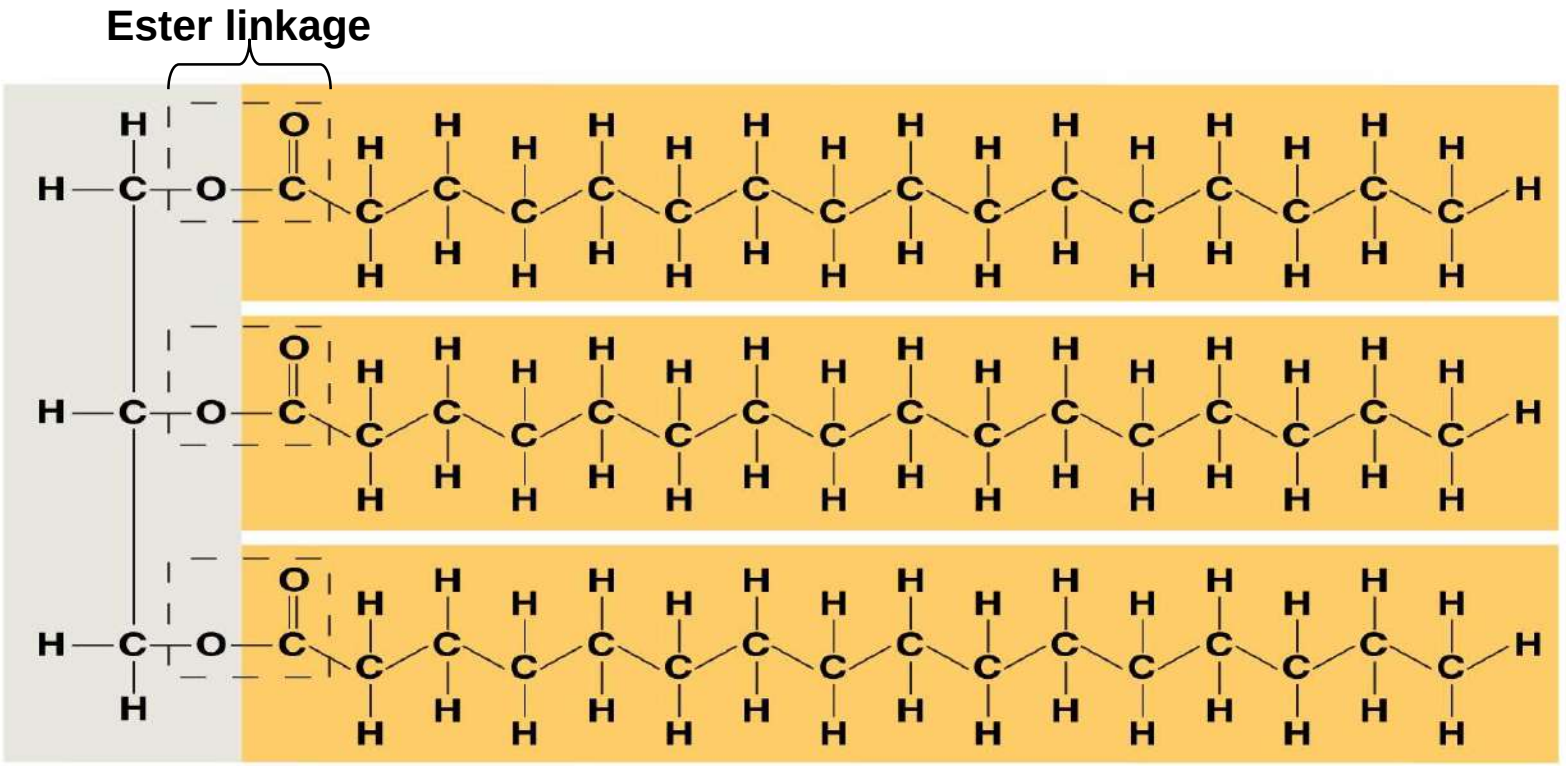
(a) Dehydration reaction in the synthesis of a fat

- during formation of a fat, enzyme-catalyzed dehydration synthesis reactions link glycerol to fatty acids by **<u>ESTER LINKAGES</u>** (bond between a hydroxyl group and a carboxyl group)



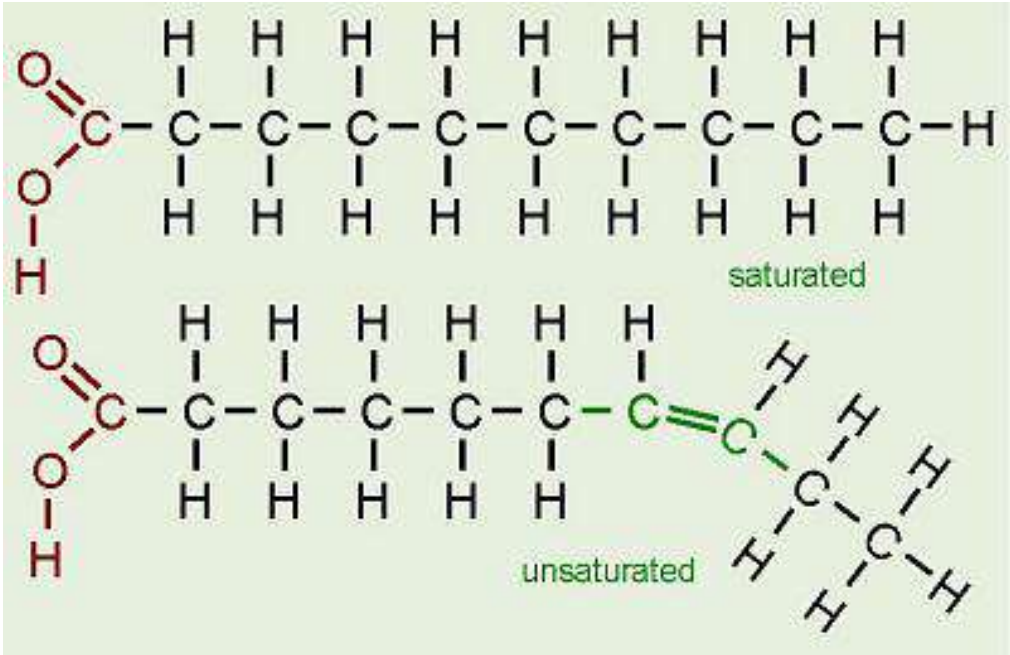
- Each of glycerol's 3 hydroxyl groups can bond to a fatty acid by an ester linkage producing a fat. (resulting in triacylglycerol, or a **triglyceride**)





(b) Fat molecule (triacylglycerol)

- Fatty acids vary in length (number of carbons) and in the number and locations of double bonds



Saturated ***vs.*** Unsaturated Fats

SATURATED FAT	UNSATURATED FAT
◆ no C-C double bonds in fatty acid tail ◆ carbon skeleton bonded to max. # of hydrogens ◆ usually solid at room temp. ◆ most animal fats ◆ e.g., bacon grease, lard, butter	

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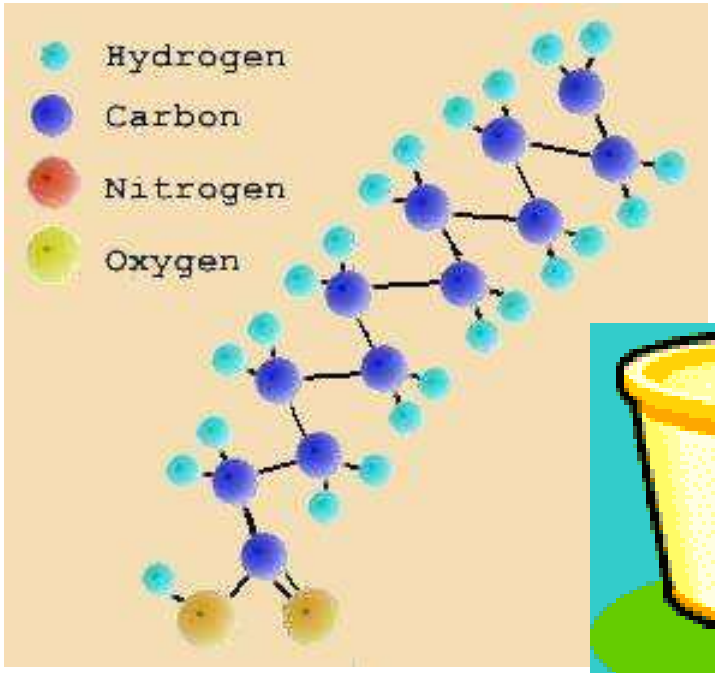
◆ no C-C double bonds in fatty acid tail ◆ carbon skeleton bonded to max. # of hydrogens ◆ usually solid at room temp. ◆ most animal fats ◆ e.g., bacon grease, lard, butter	◆ one or more C-C double bonds in fatty acid tail ◆ tail kinks at each C=C, so molecules do not pack closely enough to solidify ◆ usually a liquid at room temp. ◆ most plant fats ◆ e.g., corn, peanut, olive oils



Nutrition Facts

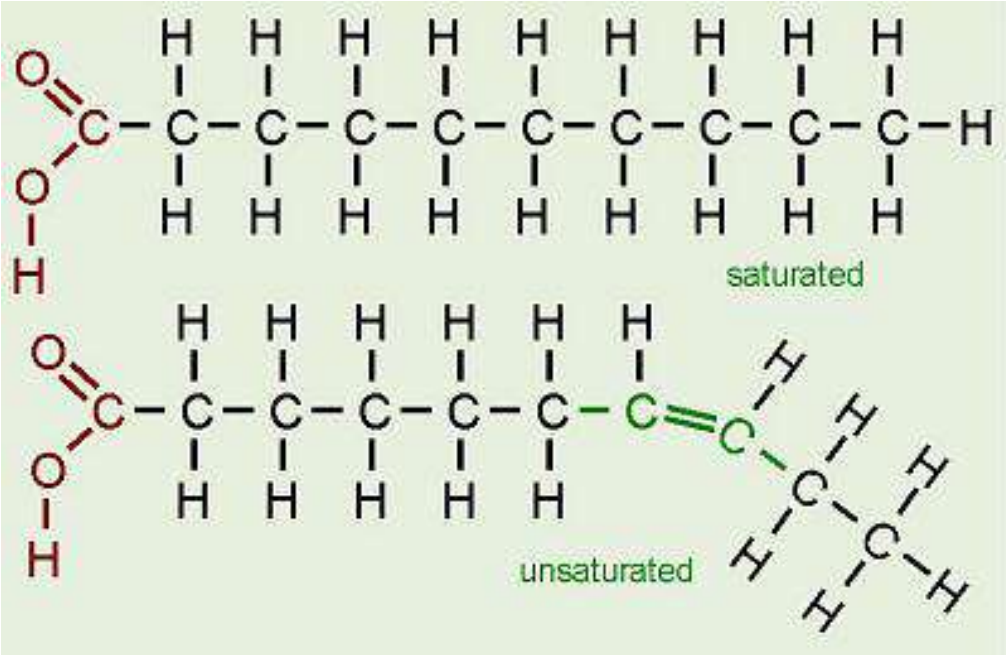
Serving Size 1/2 cup (114g)
Servings Per Container about 4

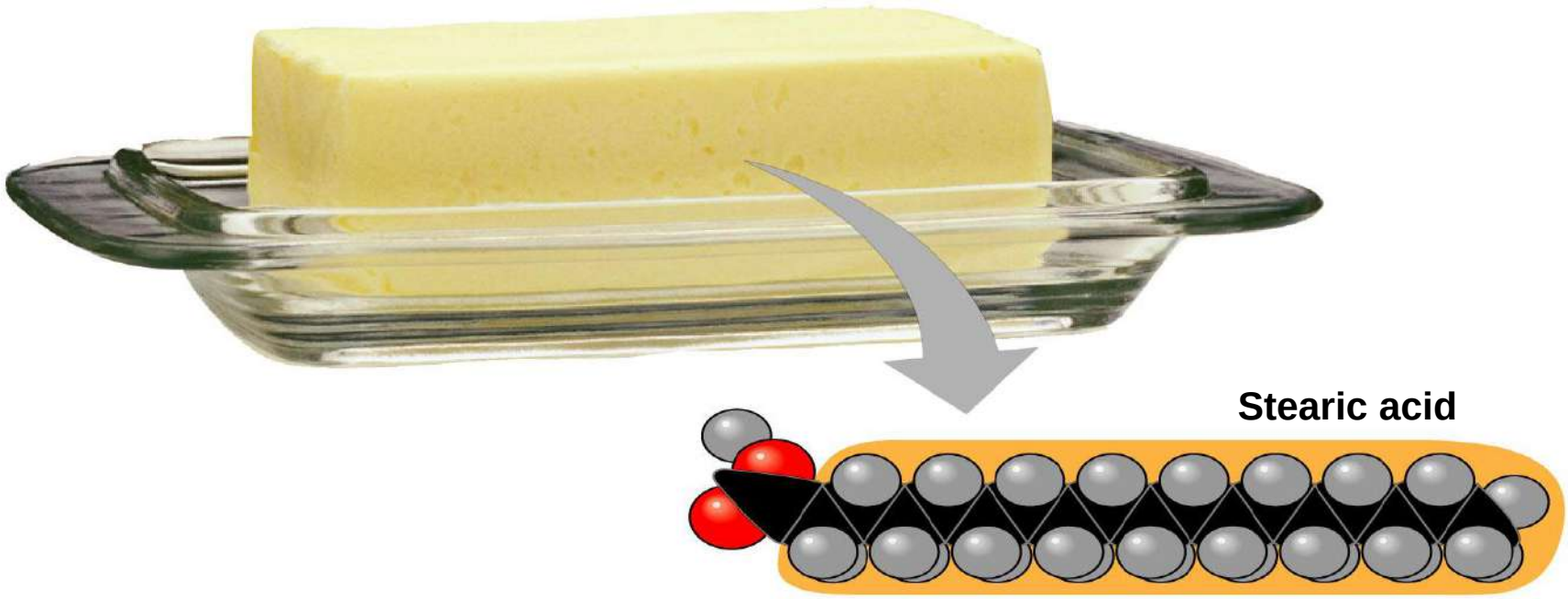
Amount Per Serving

Calories 90	Calories from Fat 30
	% Daily Value
Total Fat 3g	5%
Saturated Fat 0g	0%
Cholesterol 0mg	0%
Sodium 300mg	13%
Total Carbohydrate 13g	4%
Dietary Fiber 3g	12%
Sugars 3g	
Protein 3g	

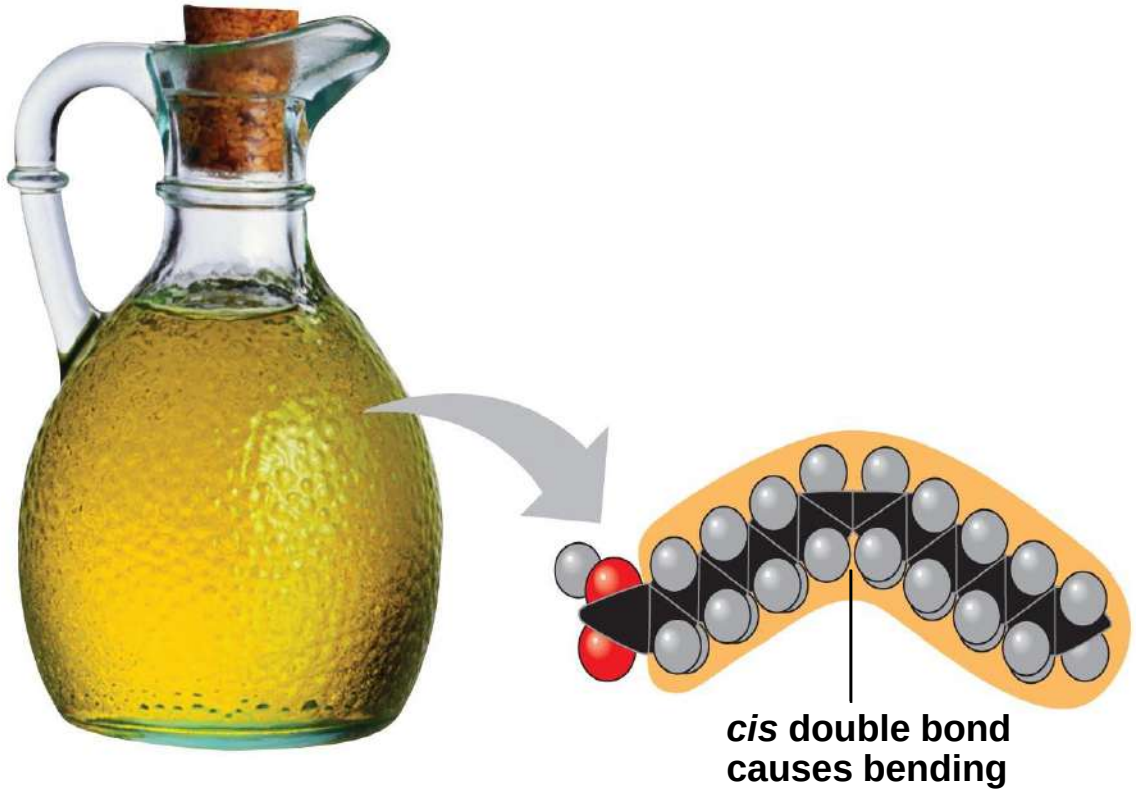
Vitamin A 80% • Vitamin C	60%
Calcium 4% • Iron	10%

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs.





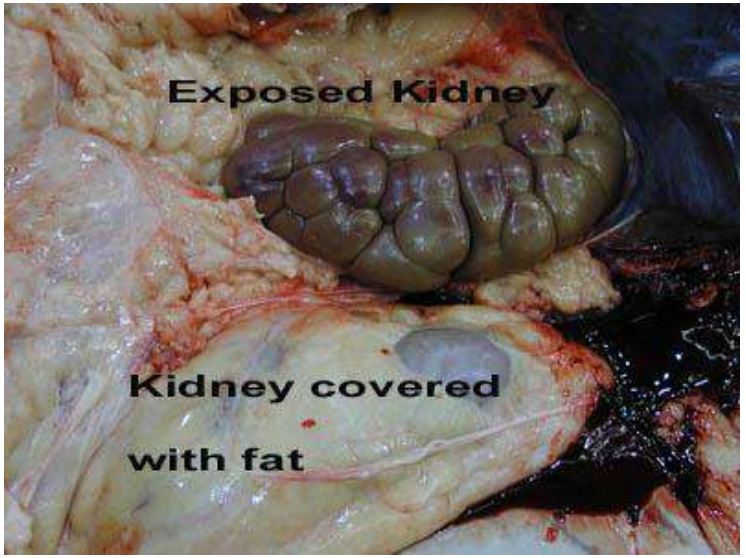
(a) Saturated fat and fatty acid.



(b) Unsaturated fat and fatty acid.

Functions of Fats

- energy storage (1 g of fat stores 2x as much energy as 1 g of carbohydrate)
- cushions vital organs in mammals (e.g. kidney)

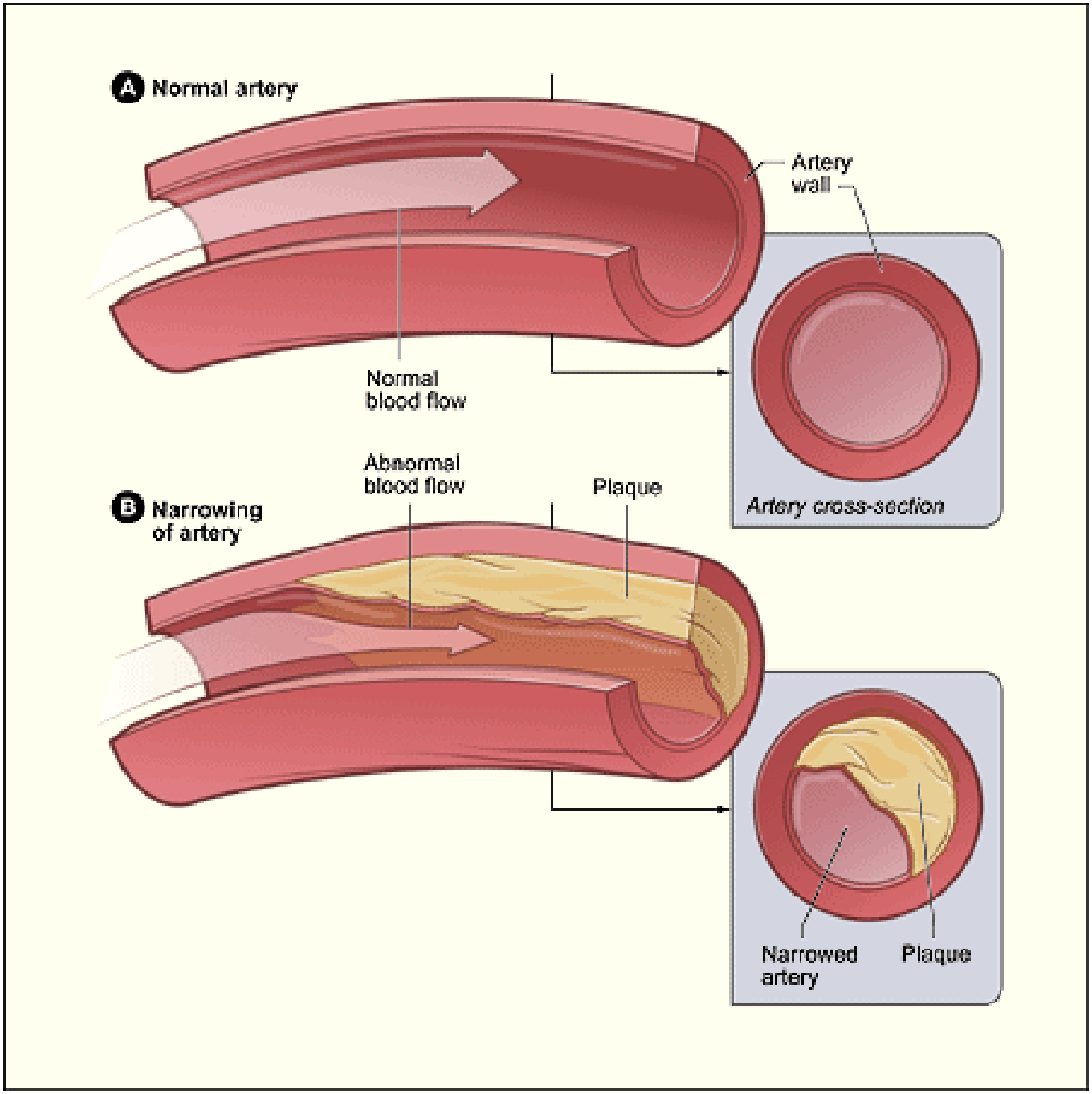


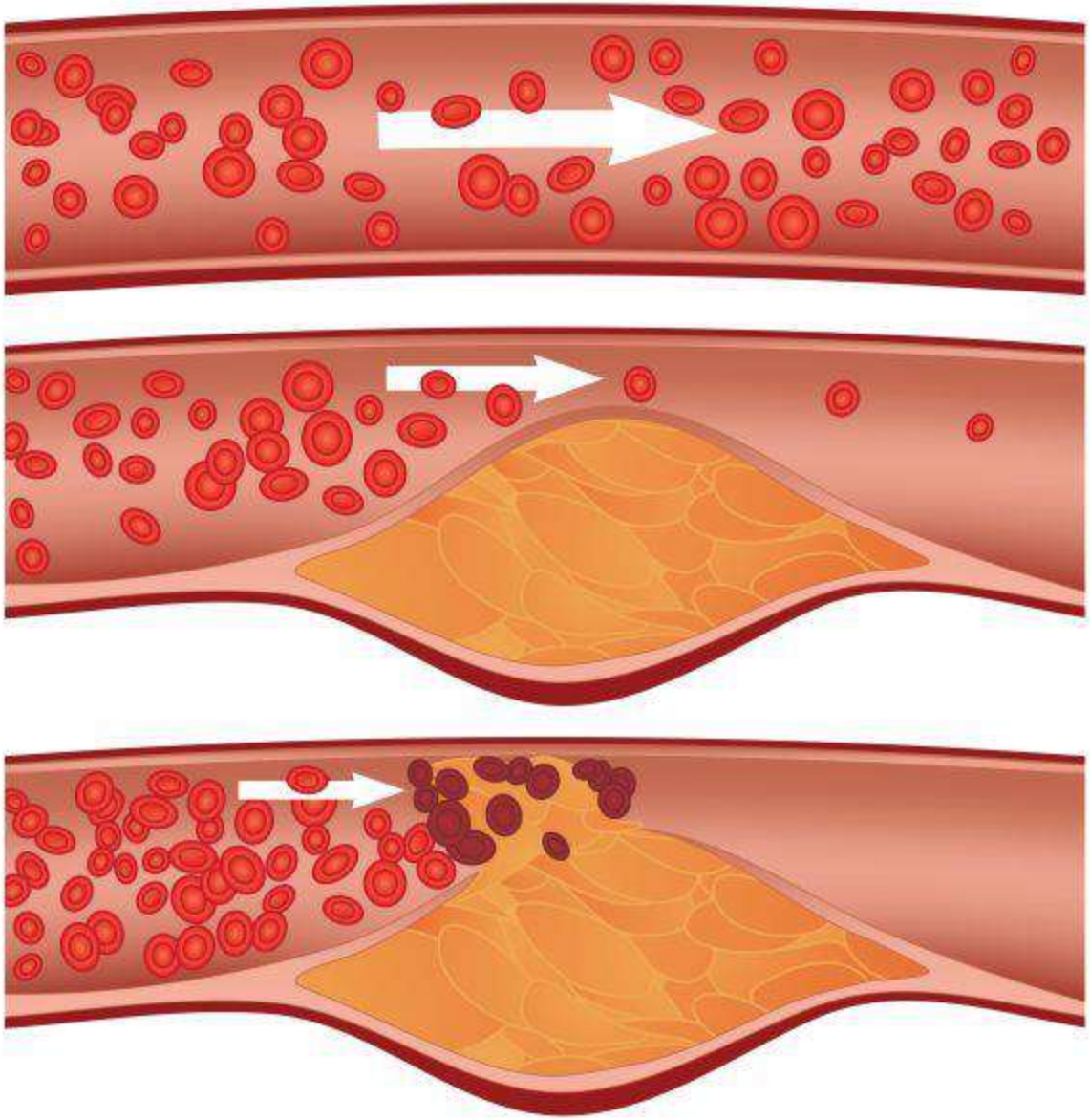
- insulates against heat loss (e.g. whales, seals)

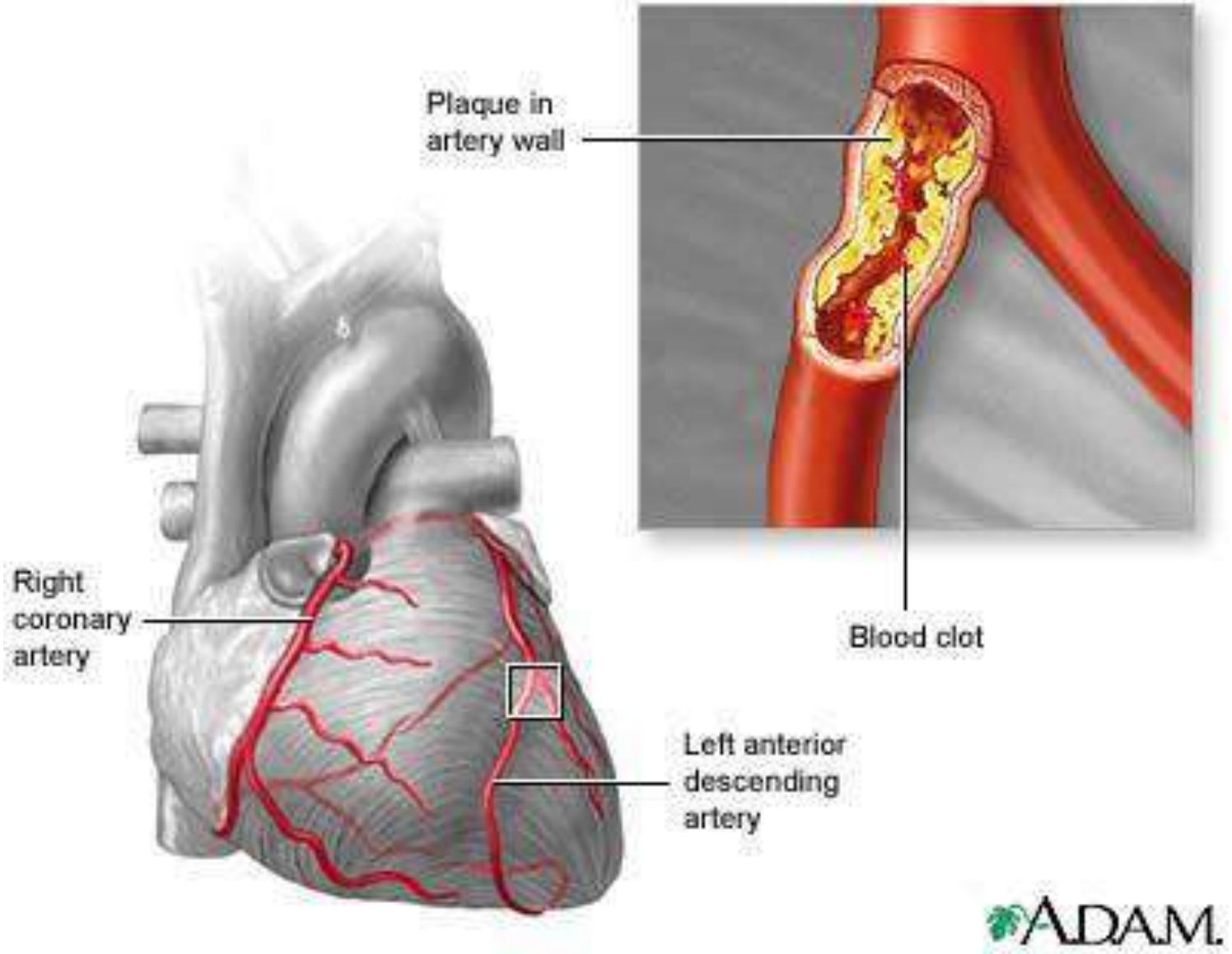
What if too much fat in the diet…?

- a diet rich in saturated fats in one factor that contributes to cardiovascular disease known as atherosclerosis

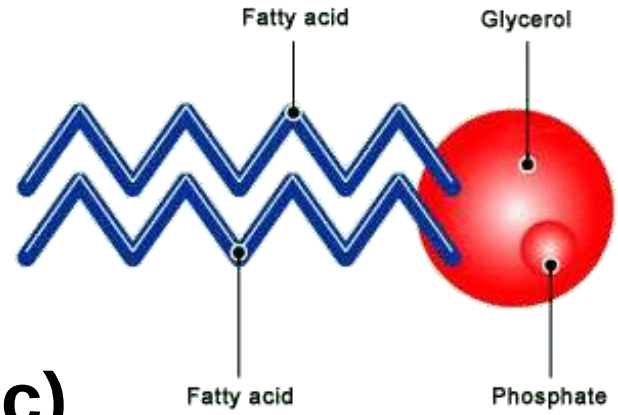
- **atherosclerosis:** plaque deposits develop within walls of blood vessels, causing inward bulges that impede blood flow


A Normal artery
Artery wall
Normal blood flow
Artery cross-section
Abnormal blood flow
Plaque
B Narrowing of artery
Narrowed artery
Plaque

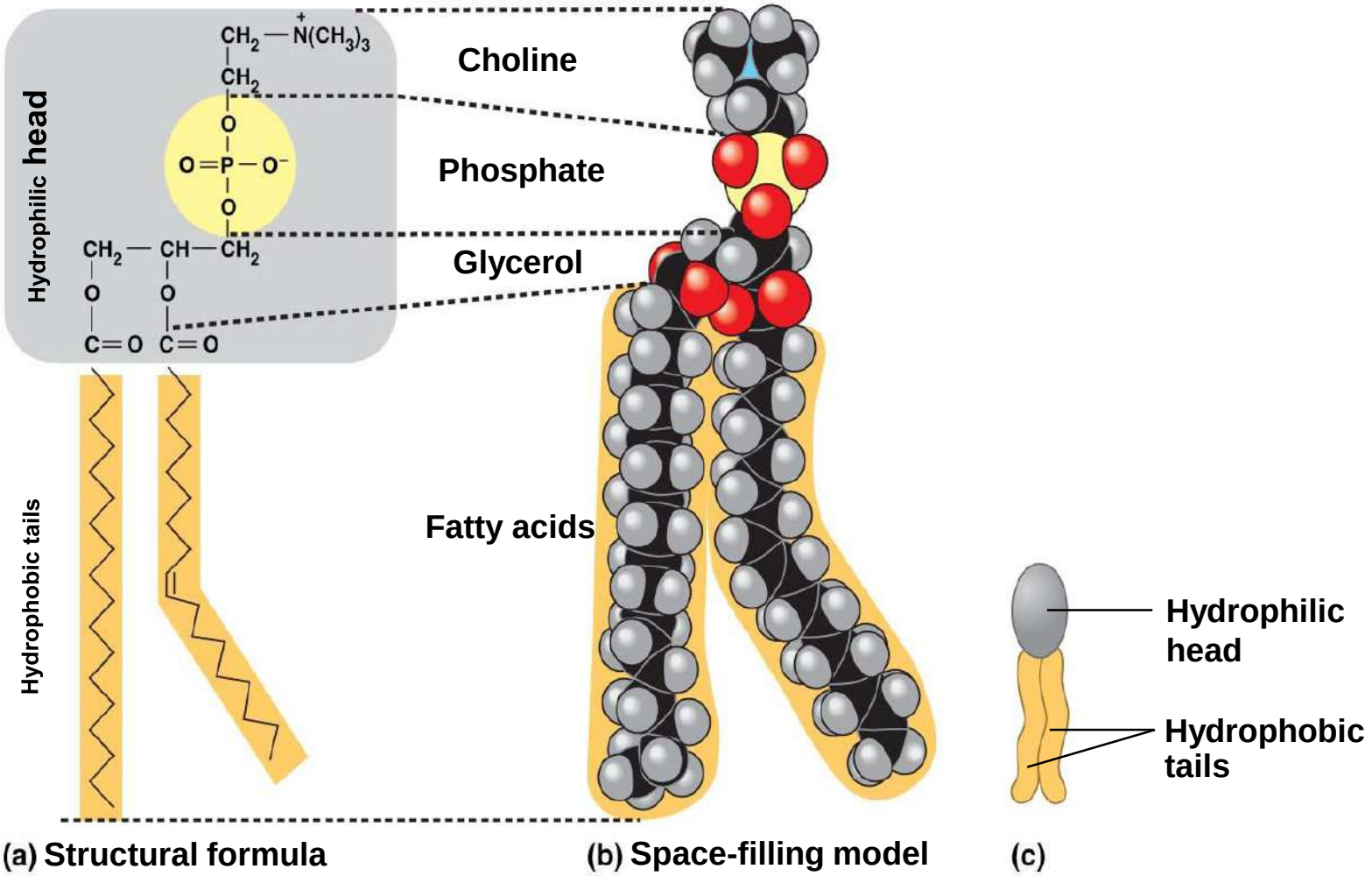


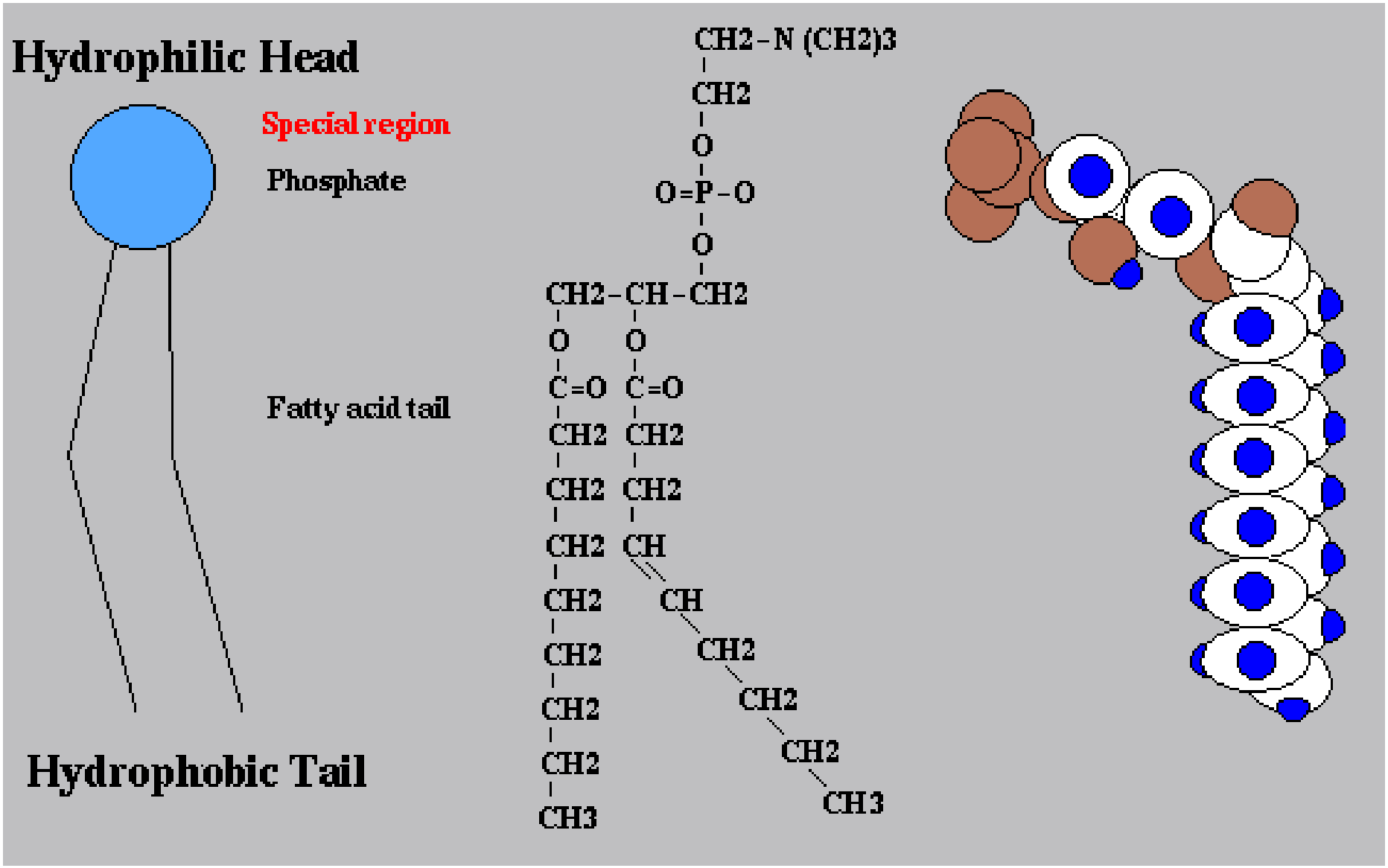

Plaque in artery wall
Blood clot
Right coronary artery
Left anterior descending artery
A.D.A.M.

2. PHOSPHOLIPIDS

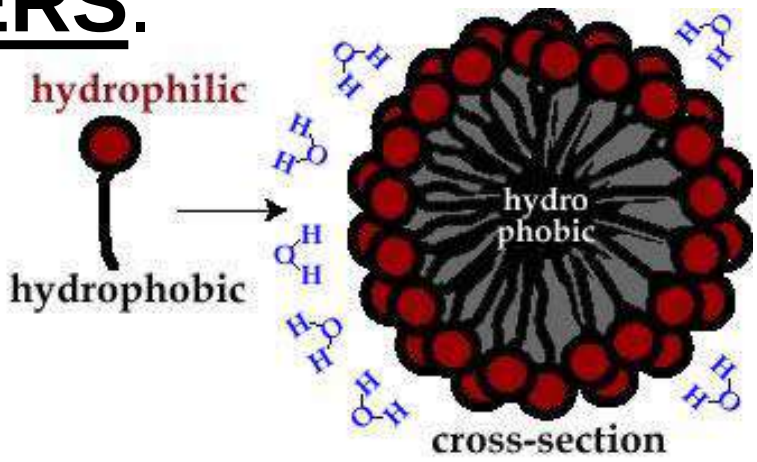


- Composed of:
  - **glycerol**
  - **2 fatty acids (hydrophobic)**
  - **a phosphate group (hydrophilic)**
- show ambivalent behavior towards water (tails are hydrophobic and heads are hydrophilic)

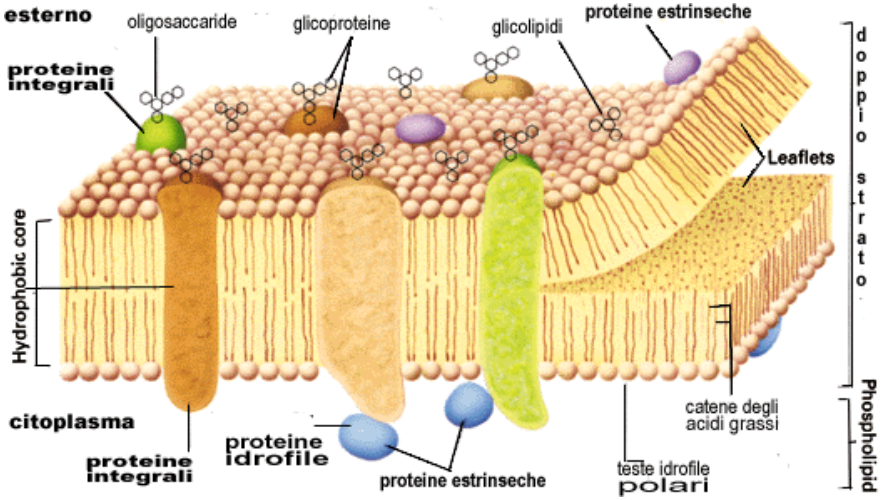


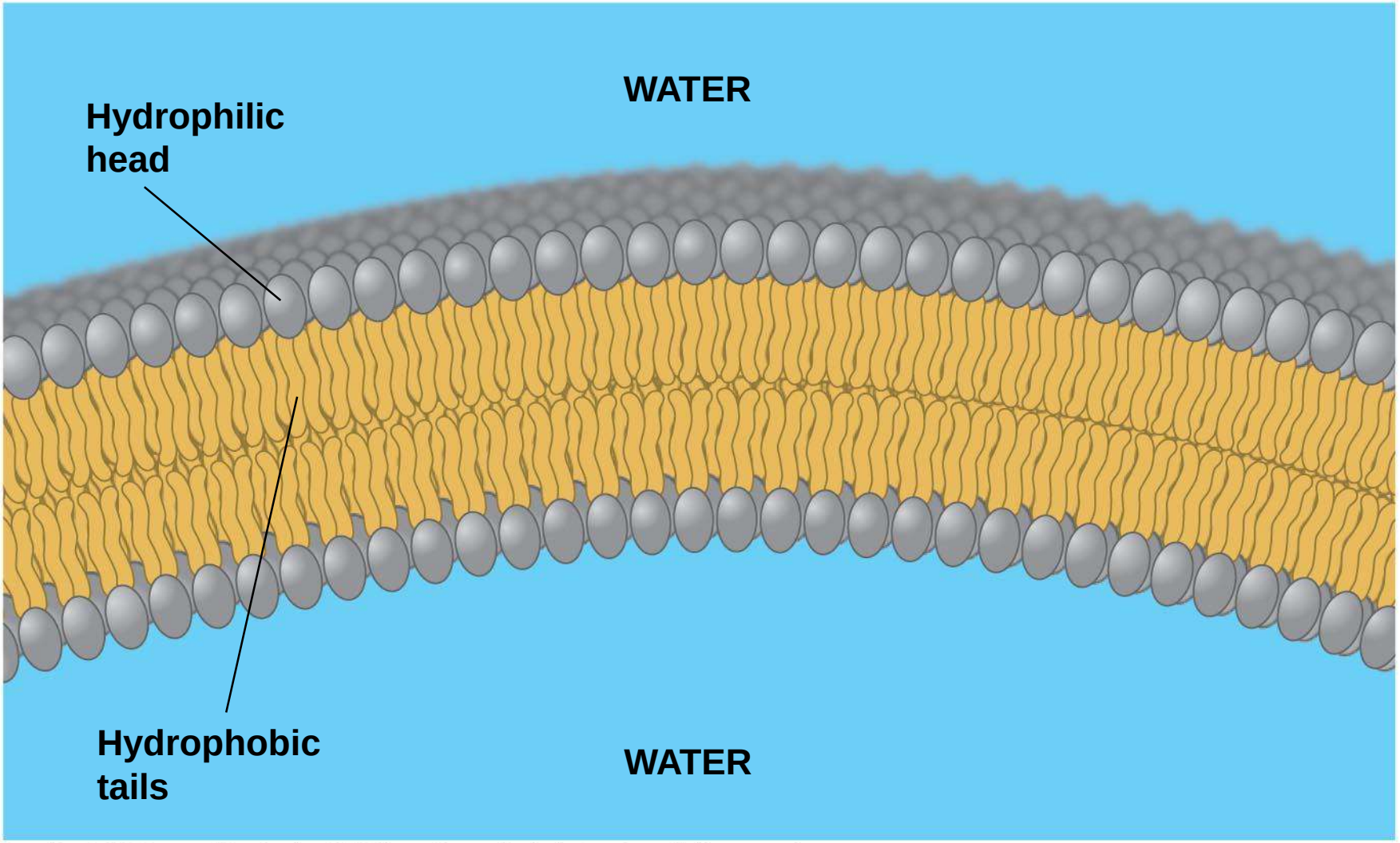

Hydrophilic Head
Special region
Phosphate
Fatty acid tail
Hydrophobic Tail
CH2-N (CH2)3
CH2
O
O=P-O
O
CH2-CH-CH2
O O
C=O C=O
CH2 CH2
CH2 CH2
CH2 CH
CH
CH2
CH2
CH2
CH2
CH2
CH3

- in water, will spontaneously self-assemble into double-layered structures called **BILAYERS**.



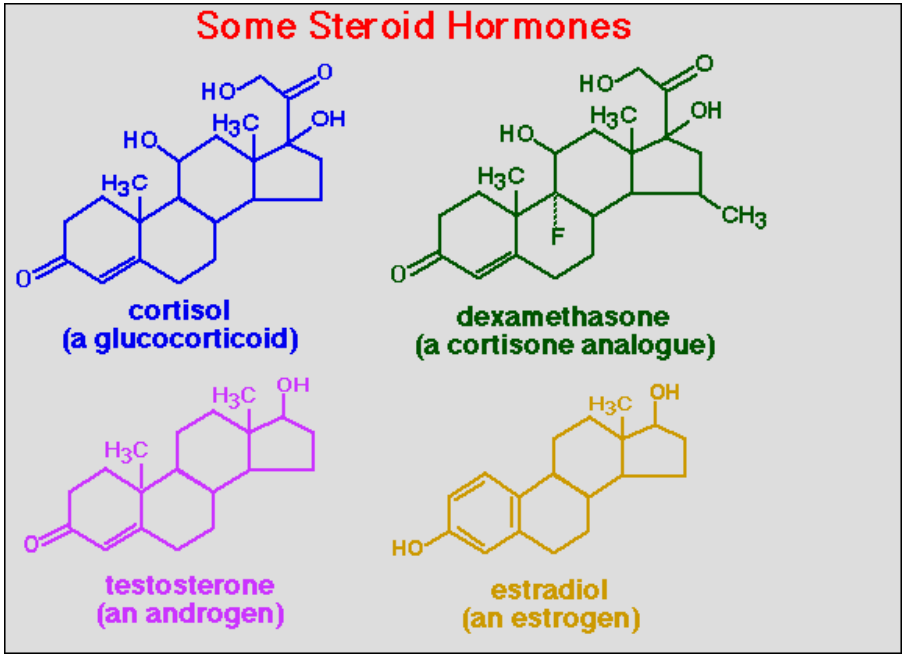
- major constituents of cell membranes



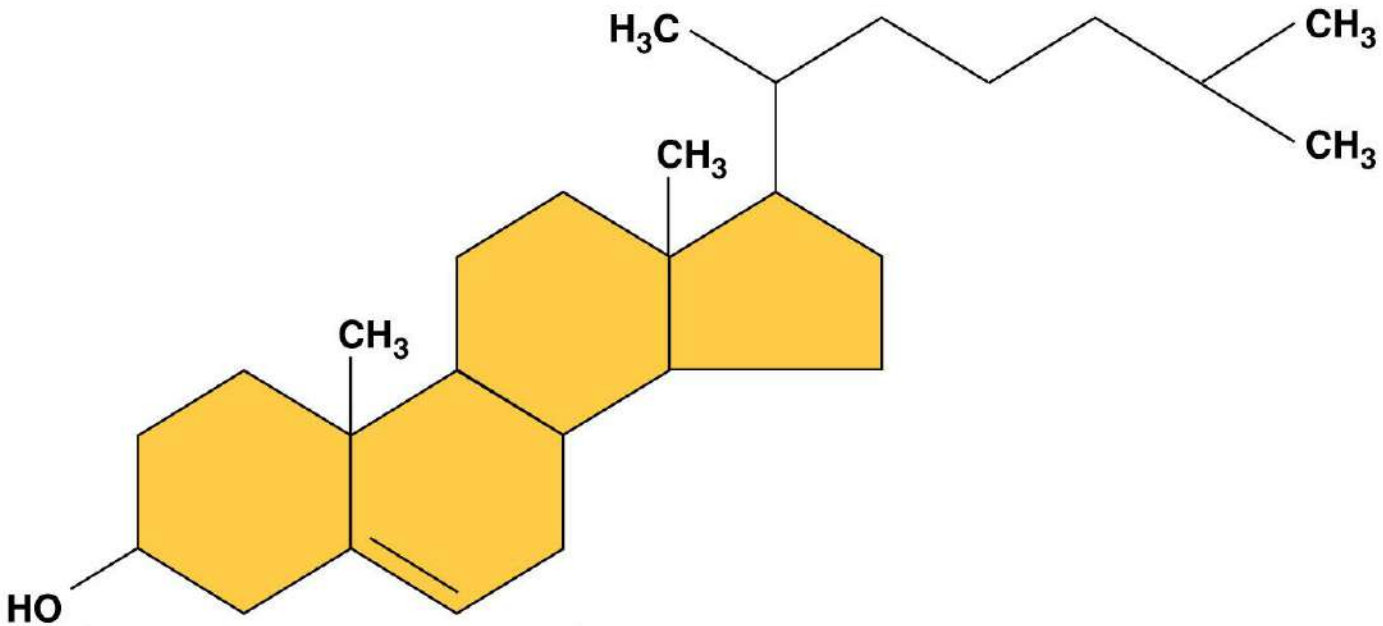


3. STEROIDS

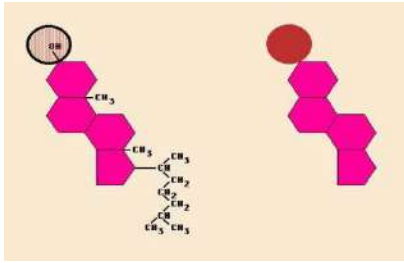
- Composed of:
  - 4 fused carbon rings w/various functional groups attached
- structurally, not similar to other lipids, but since they are hydrophobic, they are categorized as lipids.



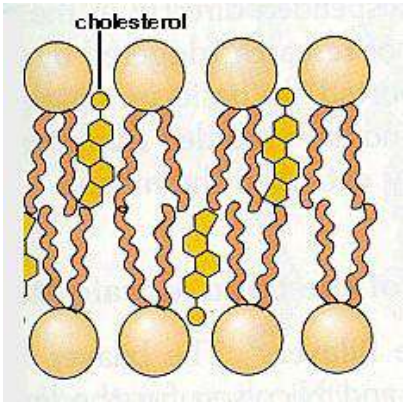
- Example: **CHOLESTEROL**



Cholesterol…



- is precursor to many other steroids (including <u>sex hormones</u> in vertebrates)
- common component of cell membranes



Cholesterol…

- can contribute to atherosclerosis (if have too much)