The Structure and Function of Macromolecules: Carbohydrates, Lipids & Phospholipids

NATIONAL MATH + SCIENCE INITIATIVE

The FOUR Classes of Large Biomolecules

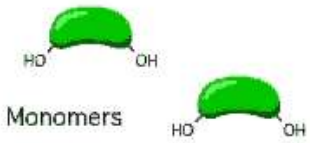
- All living things are made up of four classes of large biological molecules:
  - Carbohydrates
  - Lipids
  - Protein
  - Nucleic Acids
- **Macromolecules** are large molecules composed of thousands of *covalently* bonded atoms
- Molecular structure and function are inseparable

The FOUR Classes of Large Biomolecules

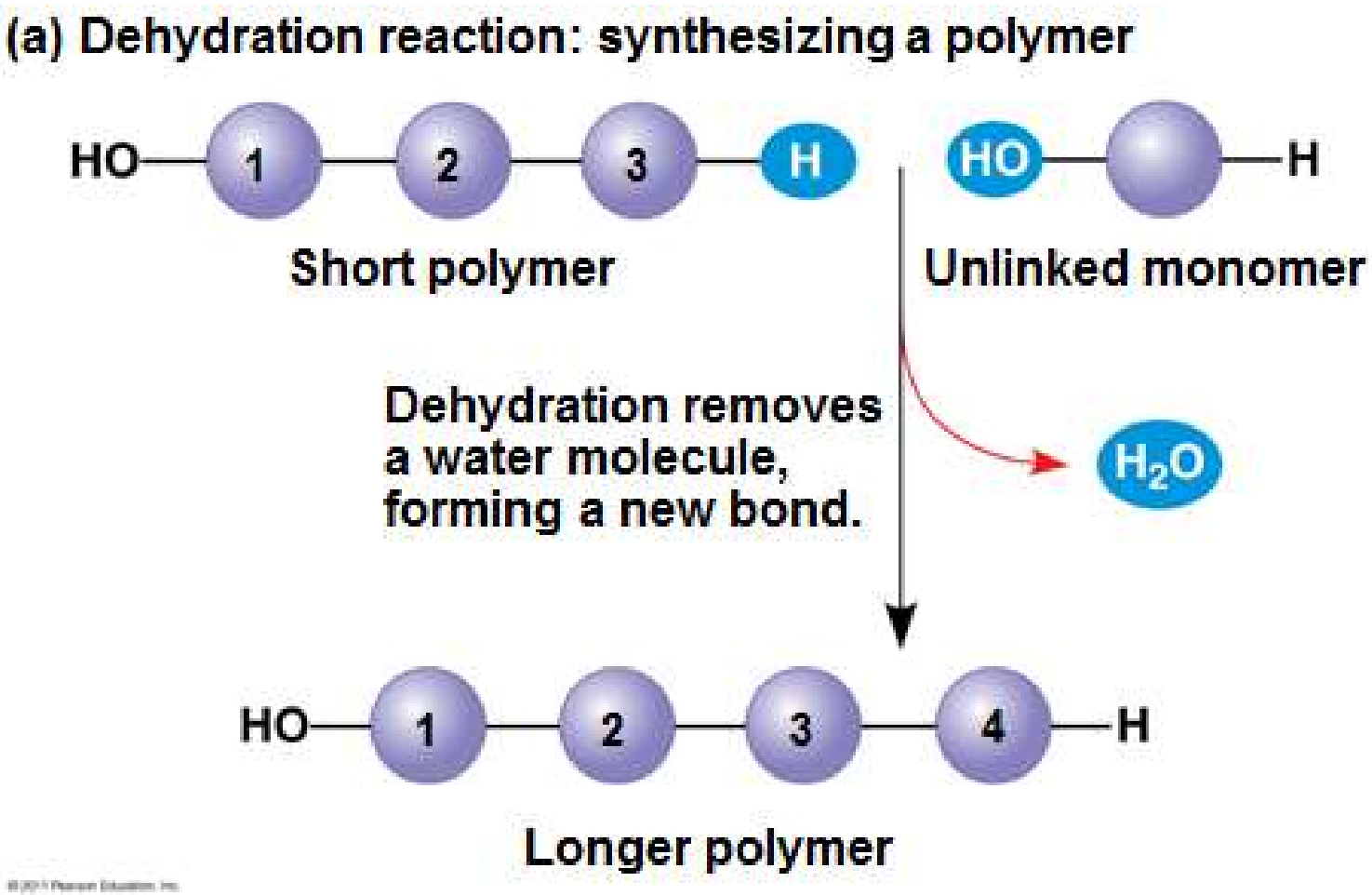
- **Macromolecules are polymers, built from monomers**
- A **polymer** is a long molecule consisting of many similar building blocks
- These small building-block molecules are called **monomers**
- Three of the four classes of life's organic molecules are polymers
  - Carbohydrates
  - Proteins
  - Nucleic acids

The synthesis and breakdown of polymers

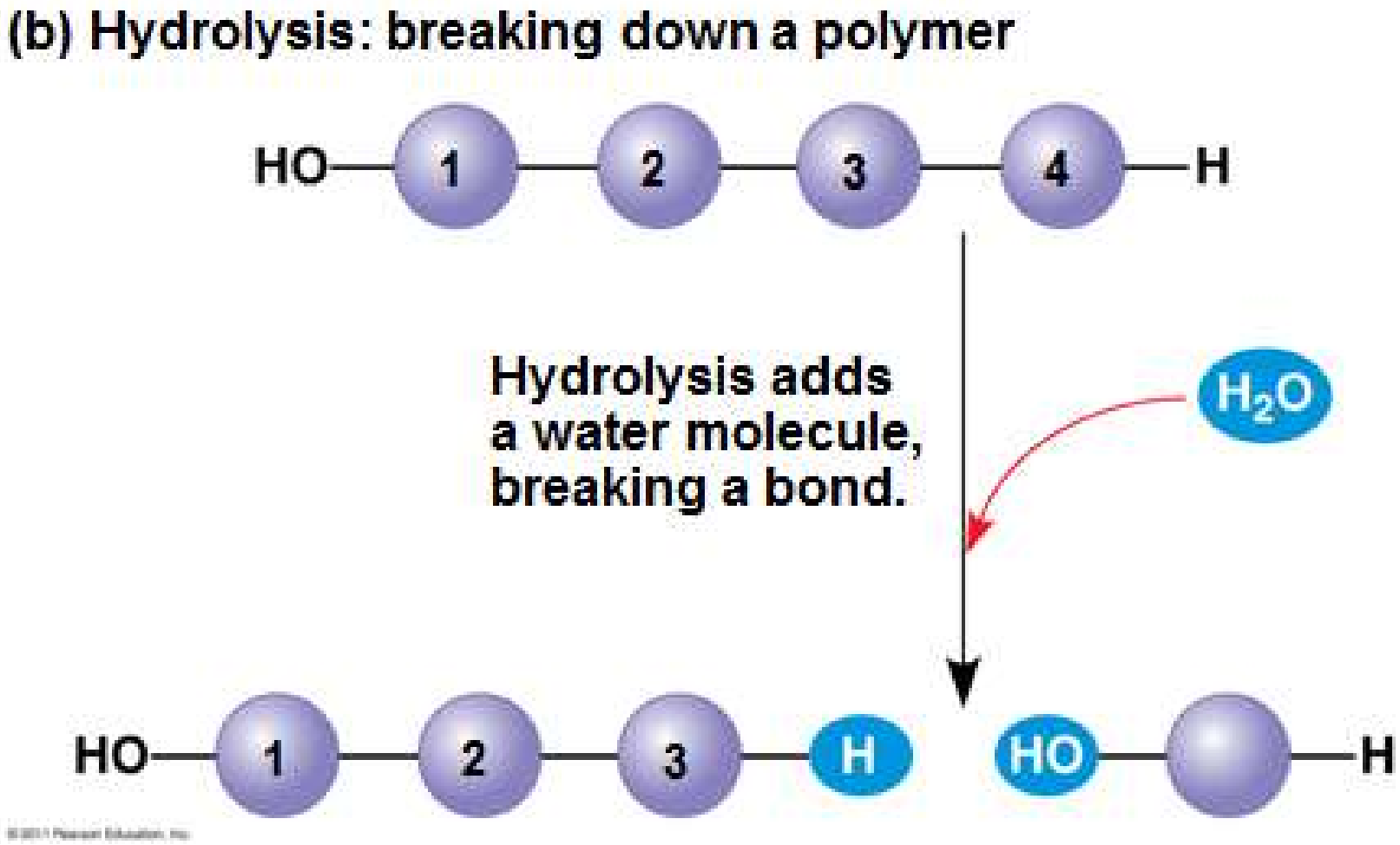
- A **dehydration reaction** occurs when two monomers bond together through the loss of a water molecule
- Polymers are disassembled to monomers by **hydrolysis**, a reaction that is essentially the reverse of the dehydration reaction



Dehydration Synthesis



Hydrolysis


(b) Hydrolysis: breaking down a polymer
HO
1
2
3
4
H
Hydrolysis adds a water molecule, breaking a bond.
H_2O
HO
1
2
3
H
HO
H

The Diversity of Polymers

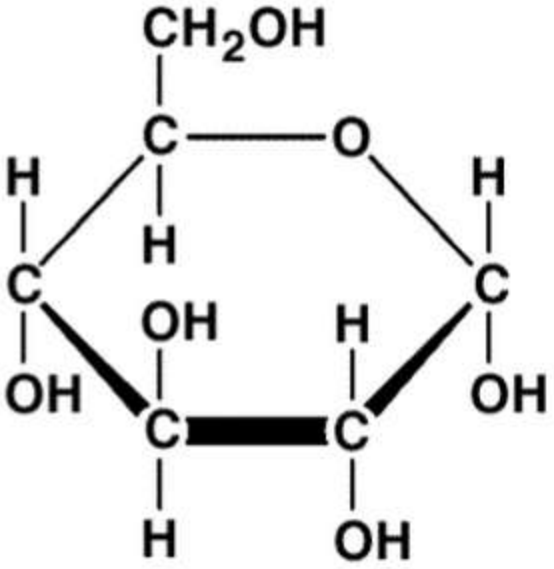
- Each cell has thousands of different macromolecules
- Macromolecules vary among cells of an organism, vary more within a species, and vary even more between species
- An immense variety of polymers can be built from a small set of monomers

Carbohydrates Serve as Fuel & Building Material

- **Carbohydrates** include sugars and the polymers of sugars
- The simplest carbohydrates are *monosaccharides*, or single sugars
- Carbohydrate macromolecules are *polysaccharides*, polymers composed of many sugar building blocks

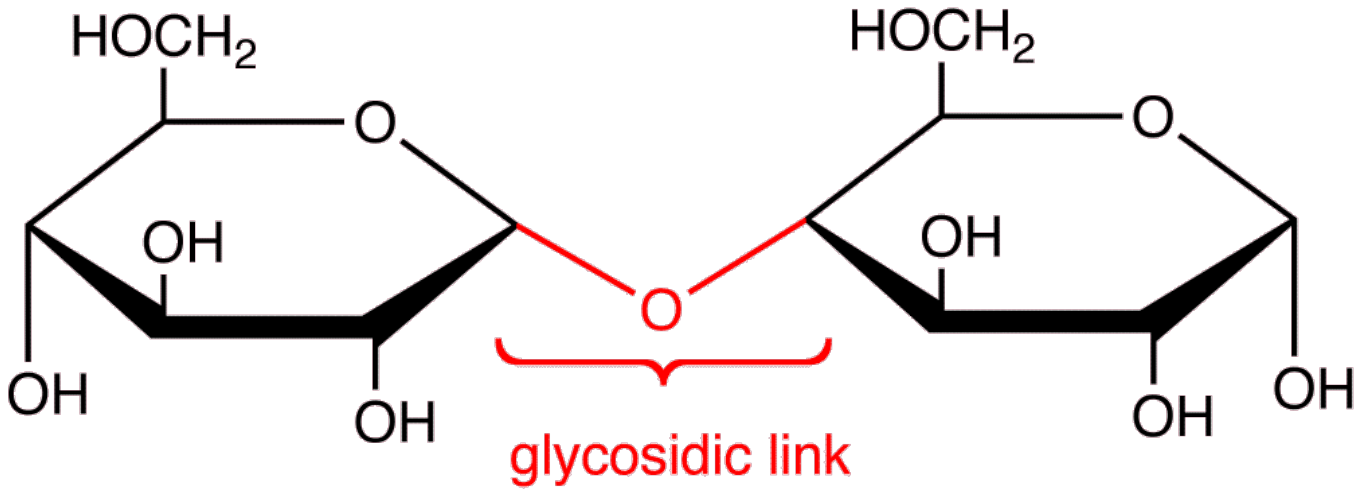
Sugars: Monosaccharides

- **Monosaccharides** have molecular formulas that are usually multiples of CH_2O
- Glucose ($C_6H_{12}O_6$) is the most common monosaccharide
- Monosaccharides are classified by
  - The location of the carbonyl group
  - The number of carbons in the carbon skeleton

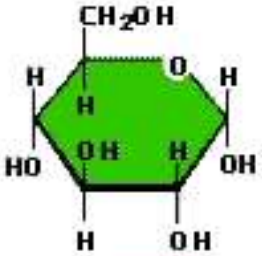


Sugars: Disaccharides

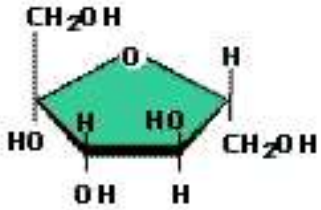
- A **disaccharide** is formed when a dehydration reaction joins two monosaccharides
- This covalent bond is called a **glycosidic linkage**



Disaccharides

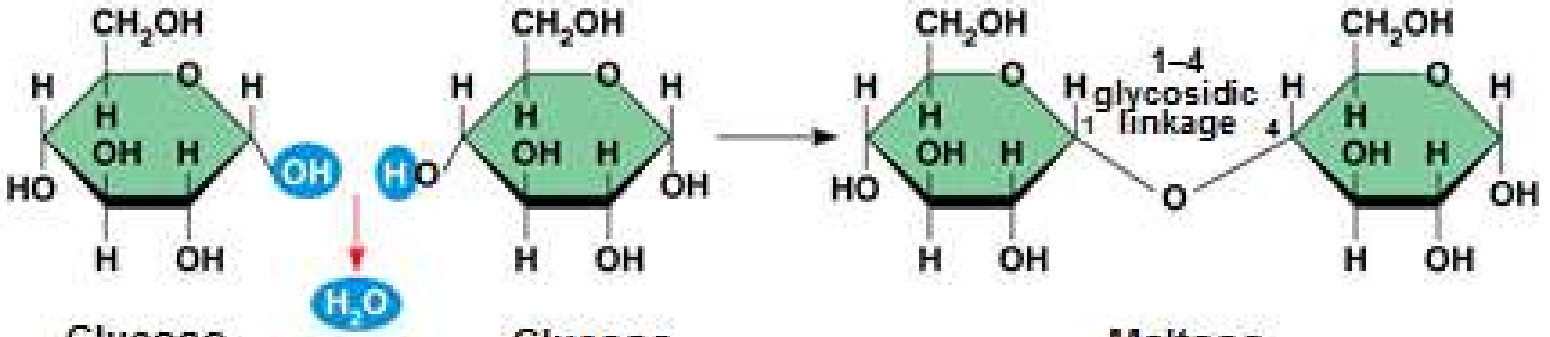


Glucose

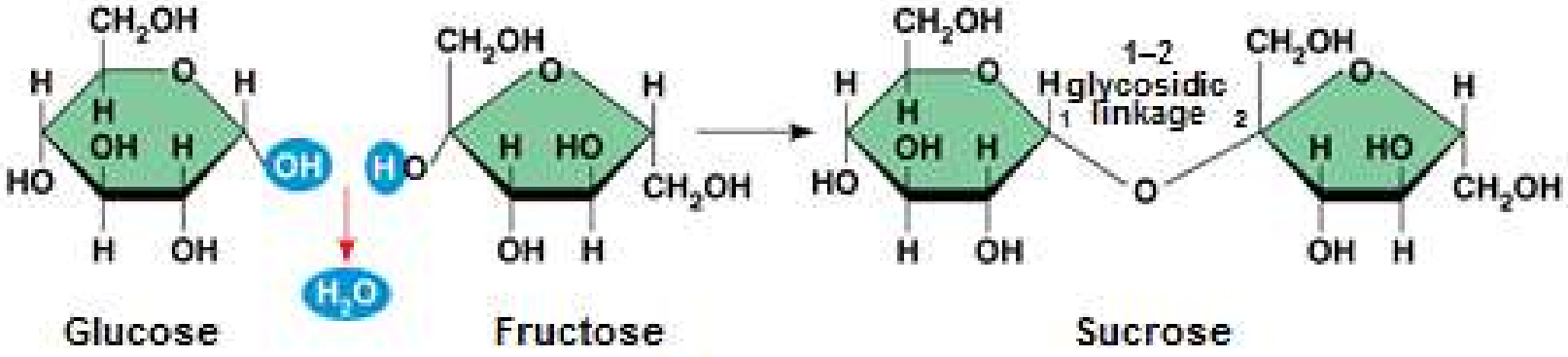


Fructose

Synthesizing Maltose & Sucrose



(a) Dehydration reaction in the synthesis of maltose



(b) Dehydration reaction in the synthesis of sucrose

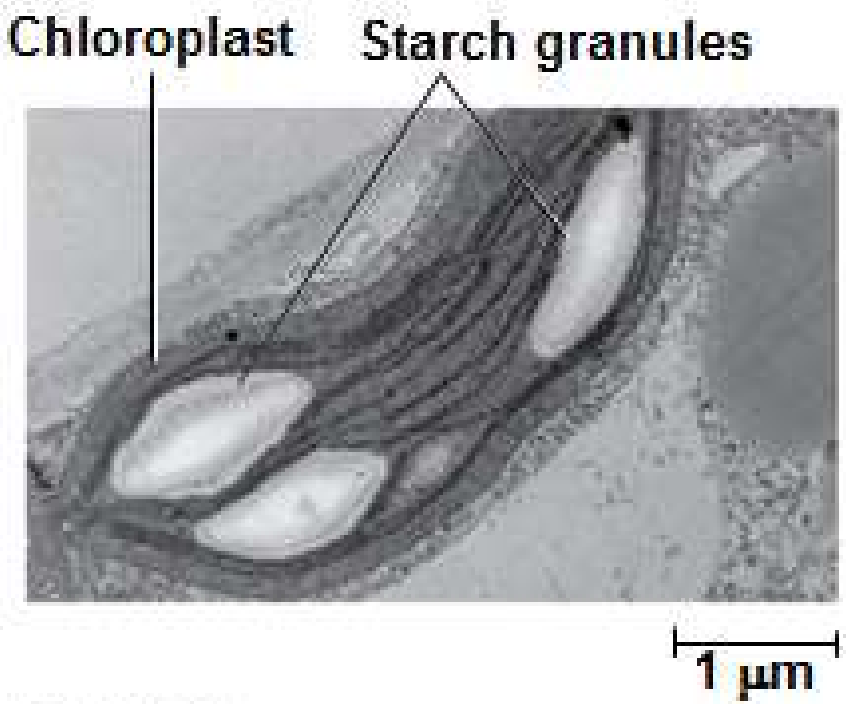
Polysaccharides

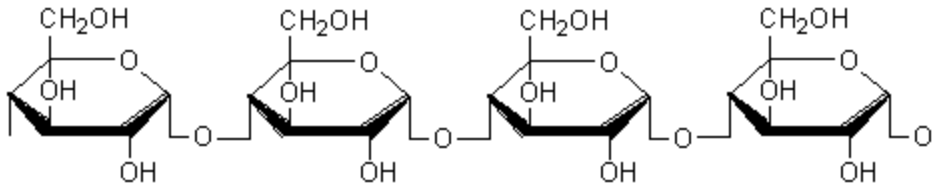
- **Polysaccharides**, the polymers of sugars, have storage and structural roles

- The structure and function of a polysaccharide are determined by its sugar monomers and the positions of glycosidic linkages

Types of Polysaccharides: Storage

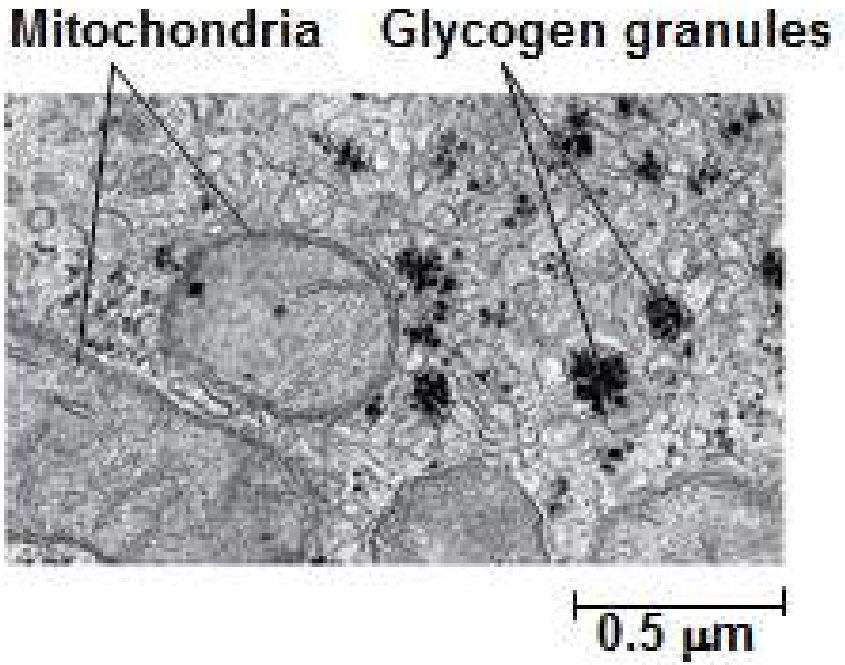
- **Starch**, a storage polysaccharide of plants, consists entirely of glucose monomers
- Plants store surplus starch as granules within chloroplasts and other plastids
- The simplest form of starch is amylose

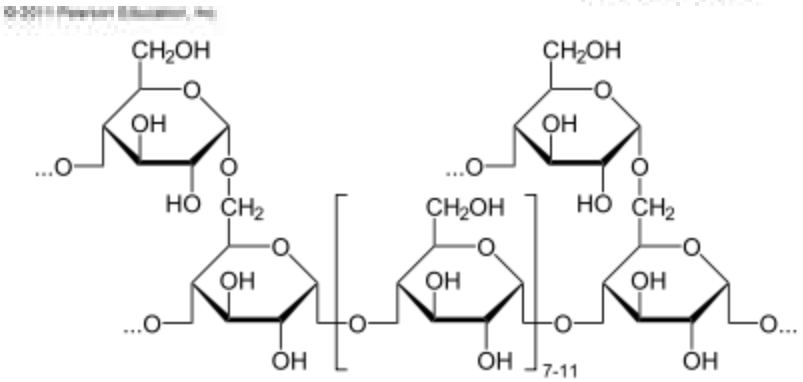




Types of Polysaccharides: Storage

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

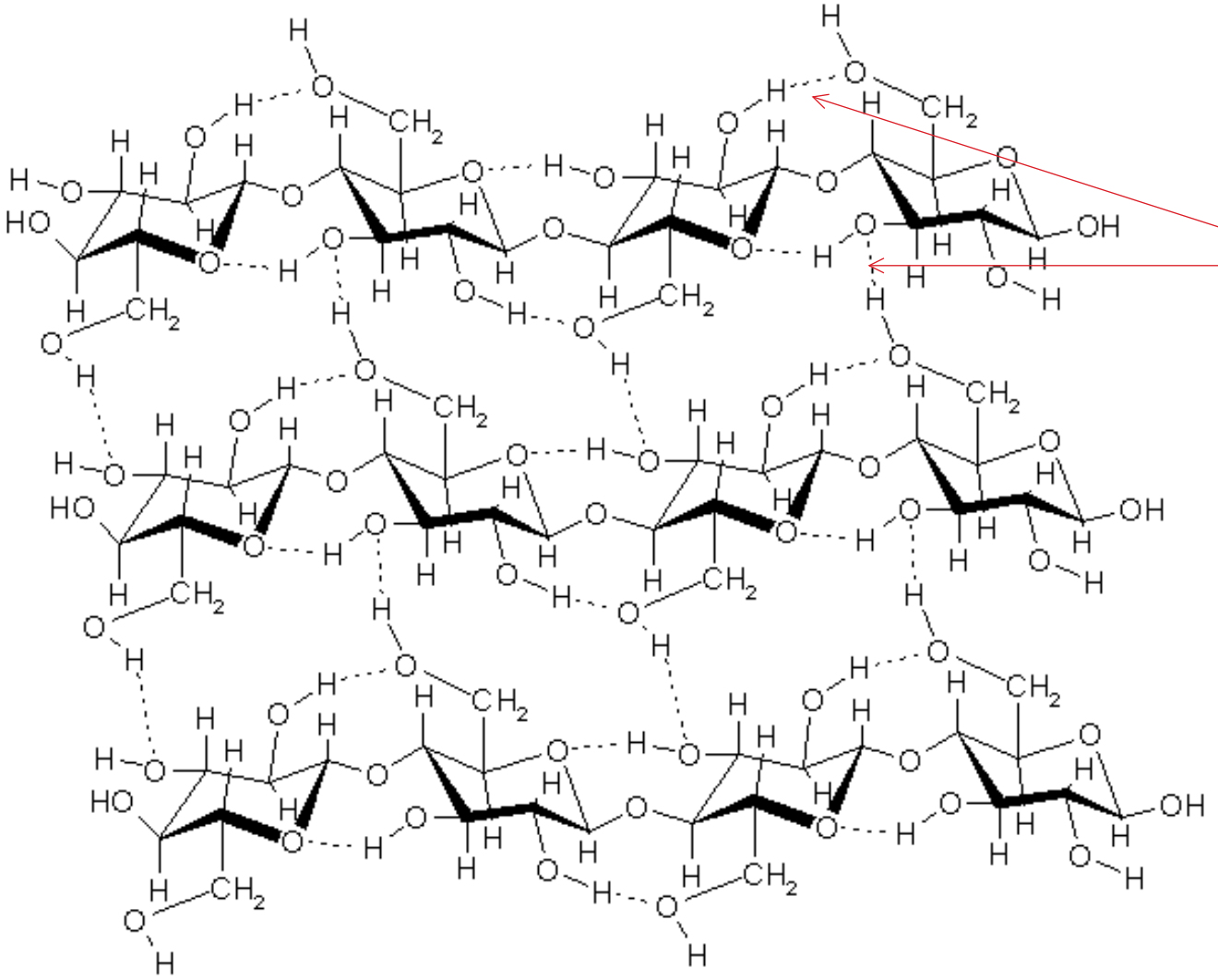




Types of Polysaccharides: Structural

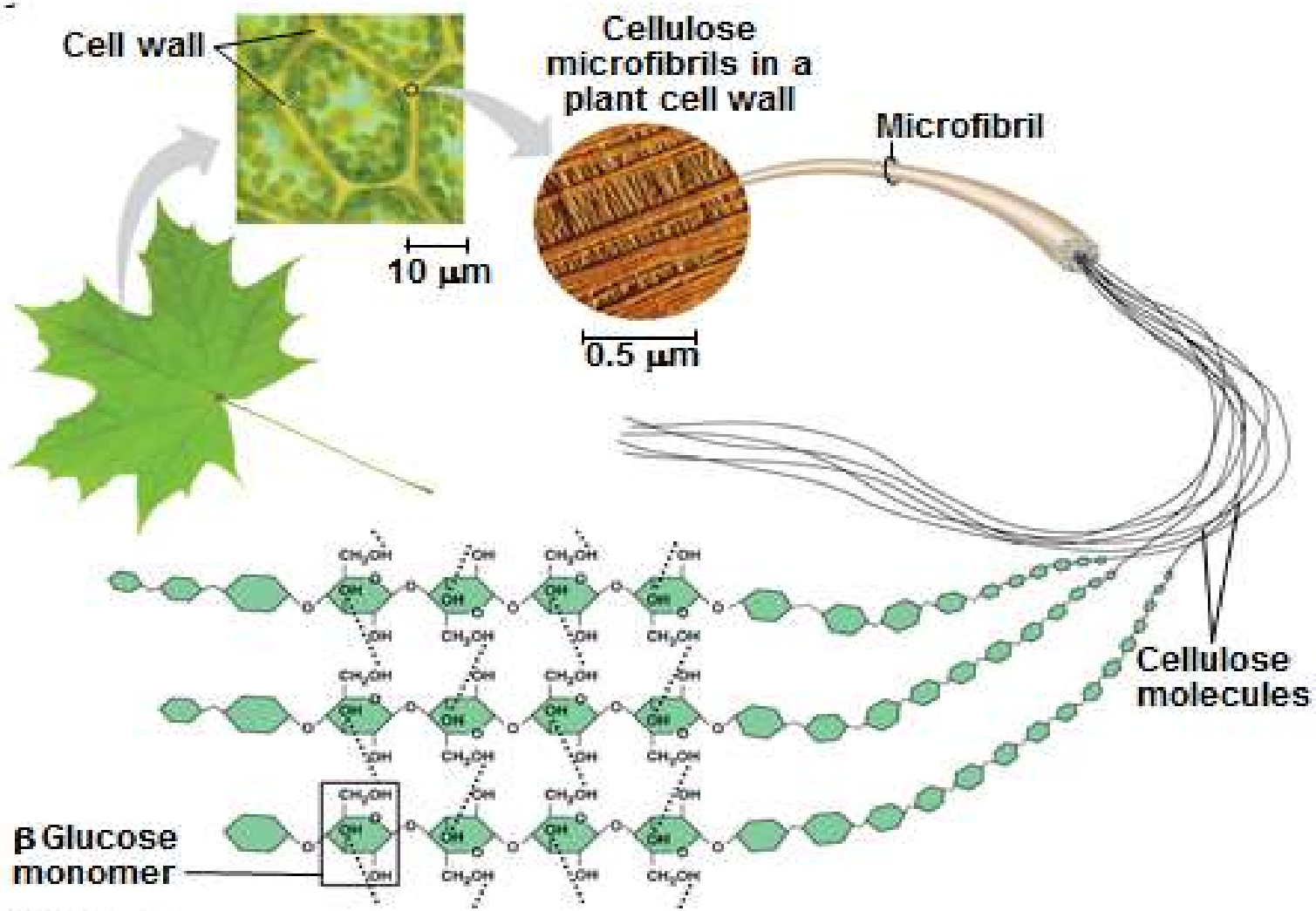
- The polysaccharide **cellulose** is a major component of the tough wall of plant cells
- Like starch, cellulose is a polymer of glucose, but the glycosidic linkages differ
- The difference is based on two ring forms for glucose: alpha (α) and beta (β)

Cellulose: A termite's best friend!



Note the H-bonds

Such Elegance!



Polysaccharide
Random Acts of Biology

- **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 in the exoskeleton of arthropods (crunch!)
- **Chitin** also provides structural support for the cell walls of many fungi

Who knew?

▲ Chitin forms the exoskeleton of arthropods.

▲ Chitin is used to make a strong and flexible surgica thread that decomposes after the wound or incision heals.

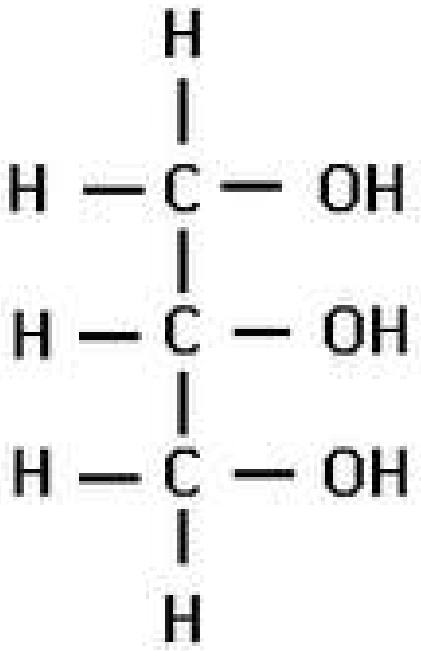
Lipids Are Hydrophobic

Lipids are a diverse group of hydrophobic molecules

- **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 (water fearing)
- Lipids are hydrophobic because they consist mostly of hydrocarbons, which form *nonpolar covalent bonds*
- The most biologically important lipids are fats, phospholipids, and steroids

Fats: Start with a Simple Little Glycerol Molecule

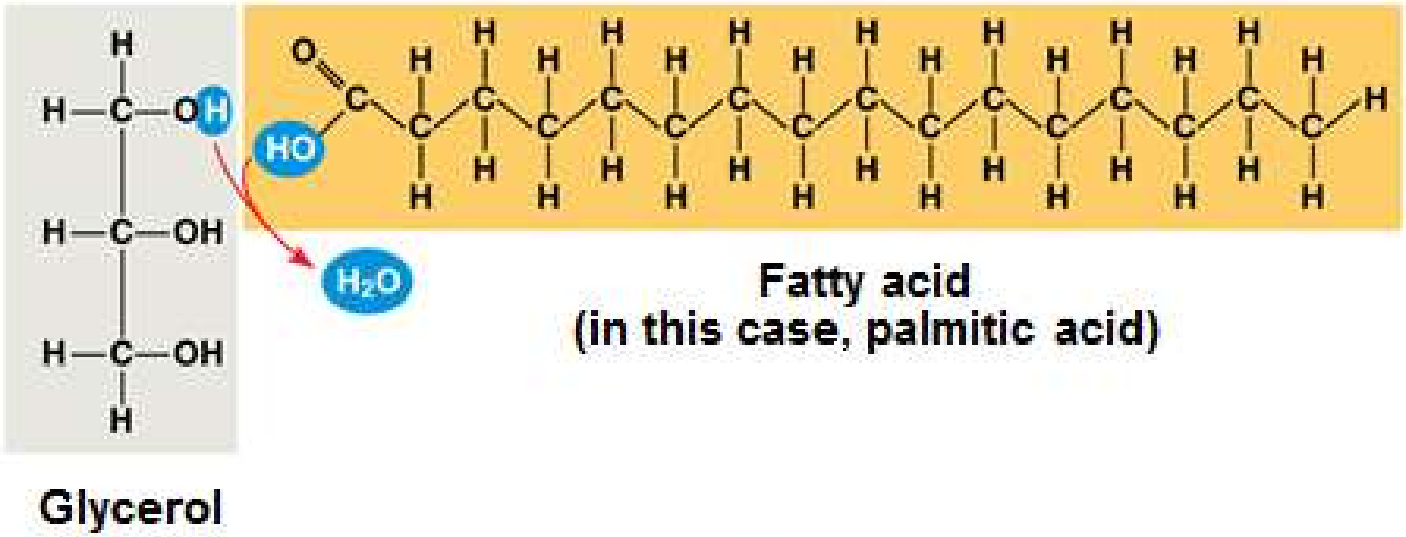
- **Fats** are constructed from two types of smaller molecules: glycerol and fatty acids
- Glycerol is a three-carbon alcohol with a hydroxyl group attached to each carbon
- A **fatty acid** consists of a carboxyl group attached to a long carbon skeleton



Glycerol

Dehydration Rxn 1: Add a Fatty Acid

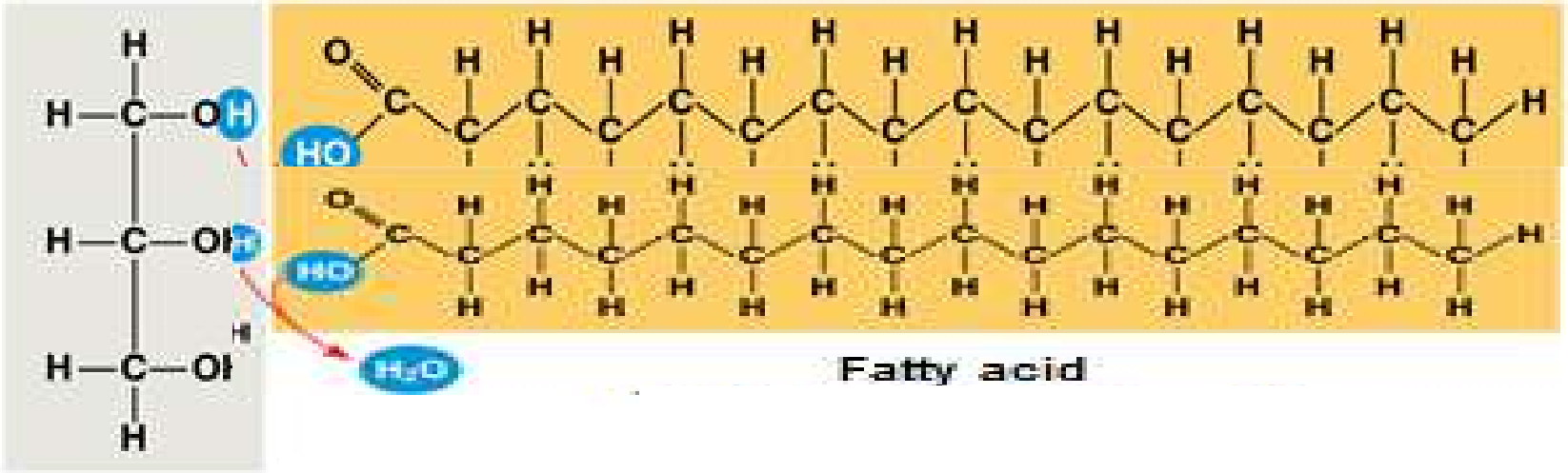
- **Next,** add a "fatty acid" through a dehydration synthesis reaction
- What makes it an acid? The C double bond O, single bond OH!



(a) One of three dehydration reactions in the synthesis of a fat

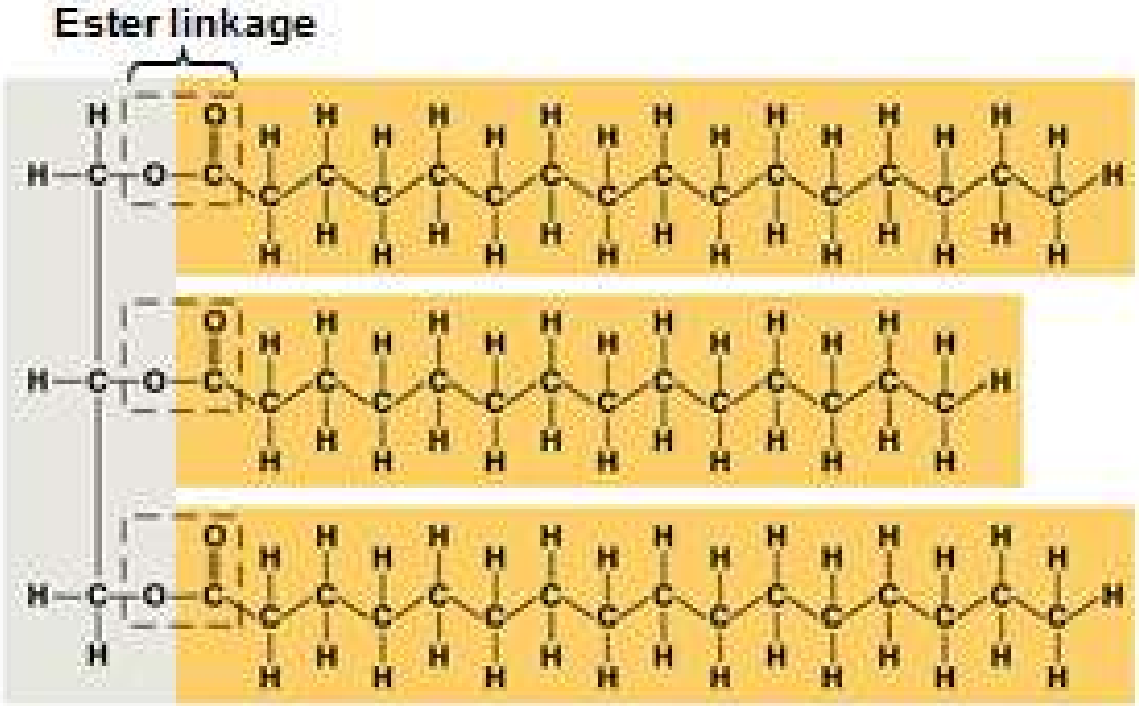
Dehydration Rxn 2!!

- **Next,** add a SECOND "fatty acid" through a dehydration synthesis reaction



Dehydration Reaction THREE!!!

- The joining of the C of the fatty acid to the O of the hydroxyl group of the glycerol is called an **ester linkage**.



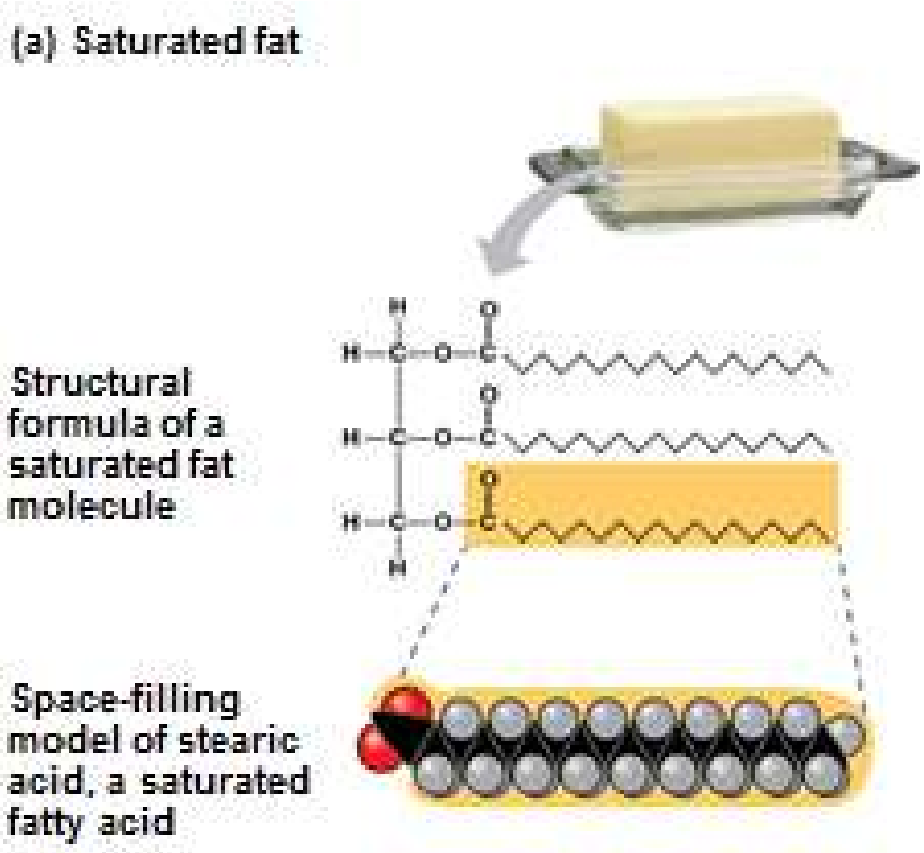
(b) Fat molecule (triacylglycerol)

Fats Are Insoluble In Aqueous Environments

- Fats separate from water because water molecules form hydrogen bonds with each other and exclude the fats
- In a fat, three fatty acids are joined to glycerol by an ester linkage, creating a **triacylglycerol**, or triglyceride

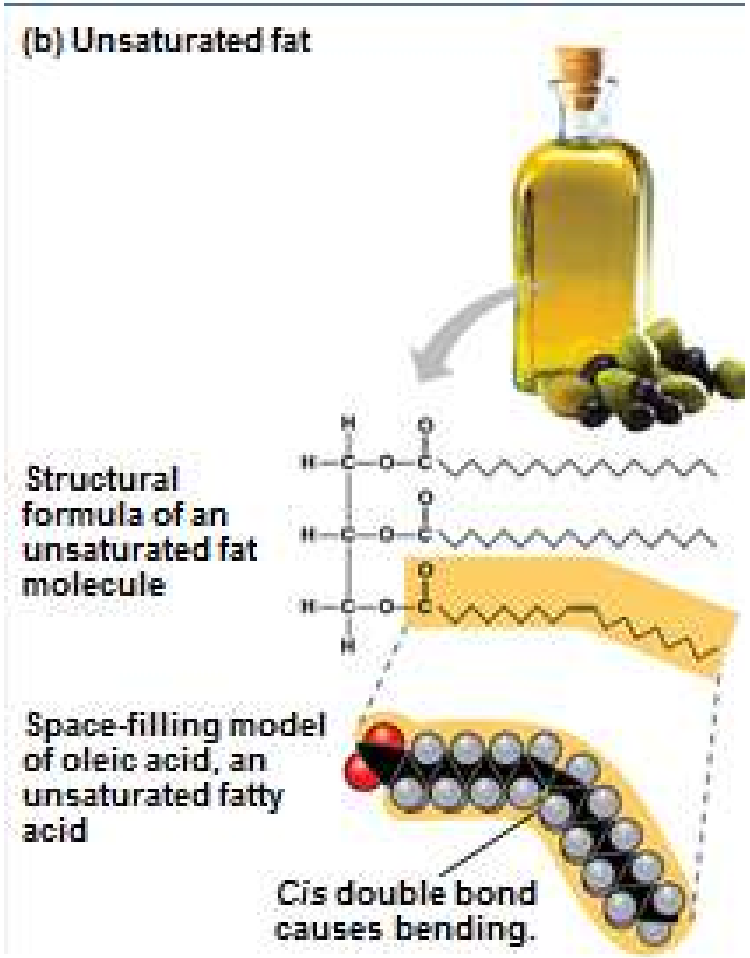
Saturated or Unsaturated?

- Fats made from **saturated** fatty acids are called saturated fats, and are solid at room temperature
- Most animal fats are saturated (lard)
- **Saturated fatty acids** have the maximum number of hydrogen atoms possible and *no double bonds*



Saturated or Unsaturated?

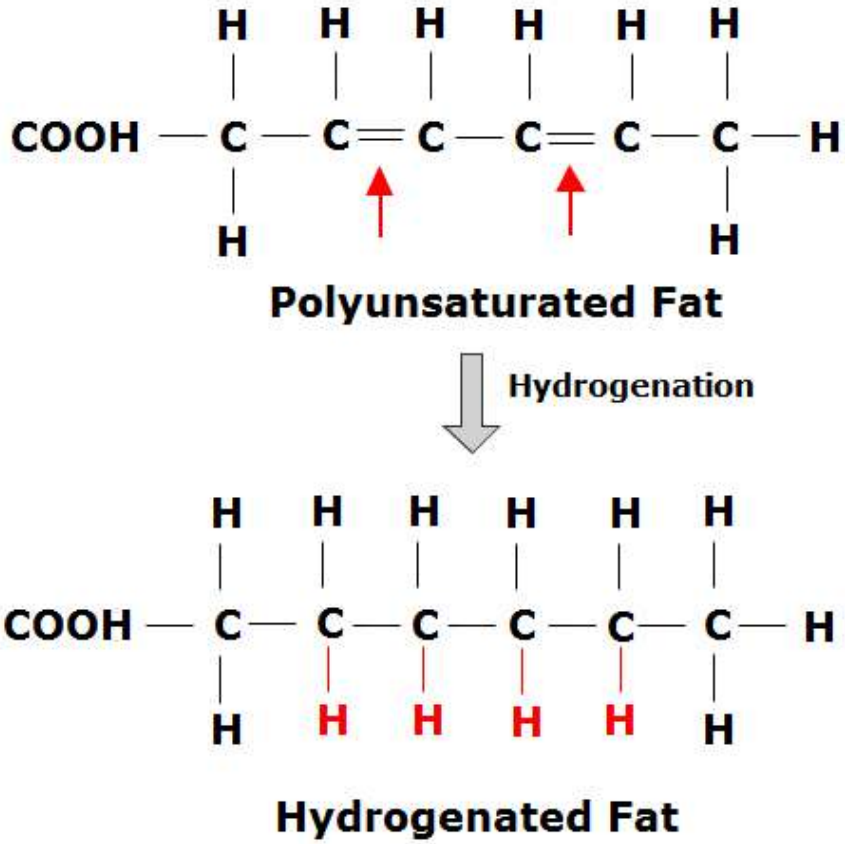
- Fats made from unsaturated fatty acids are called unsaturated fats or oils, and are liquid at room temperature
- Plant fats and fish fats are usually unsaturated
- **Unsaturated fatty acids** have *one or more double bonds*



Saturated or Unsaturated?

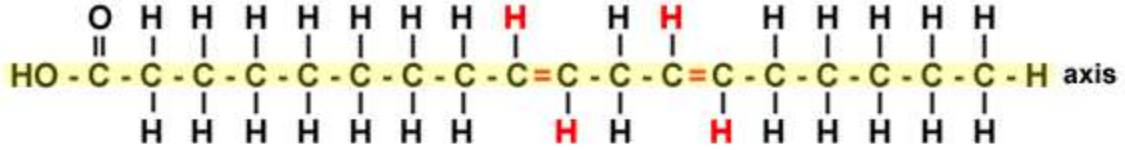
- A diet rich in saturated fats may contribute to cardiovascular disease through plaque deposits

- **Hydrogenation** is the process of converting unsaturated fats to saturated fats by adding hydrogen

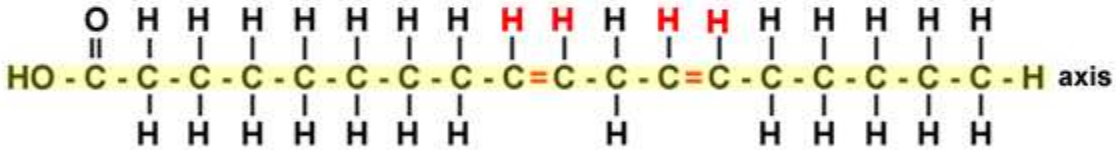


What's a Trans fat?

- **Hydrogenating** vegetable oils also creates unsaturated fats with *trans* double bonds
- **These *trans* fats may contribute more than saturated fats to cardiovascular disease**



linoleic acid: *trans* configuration (*trans* isomer)



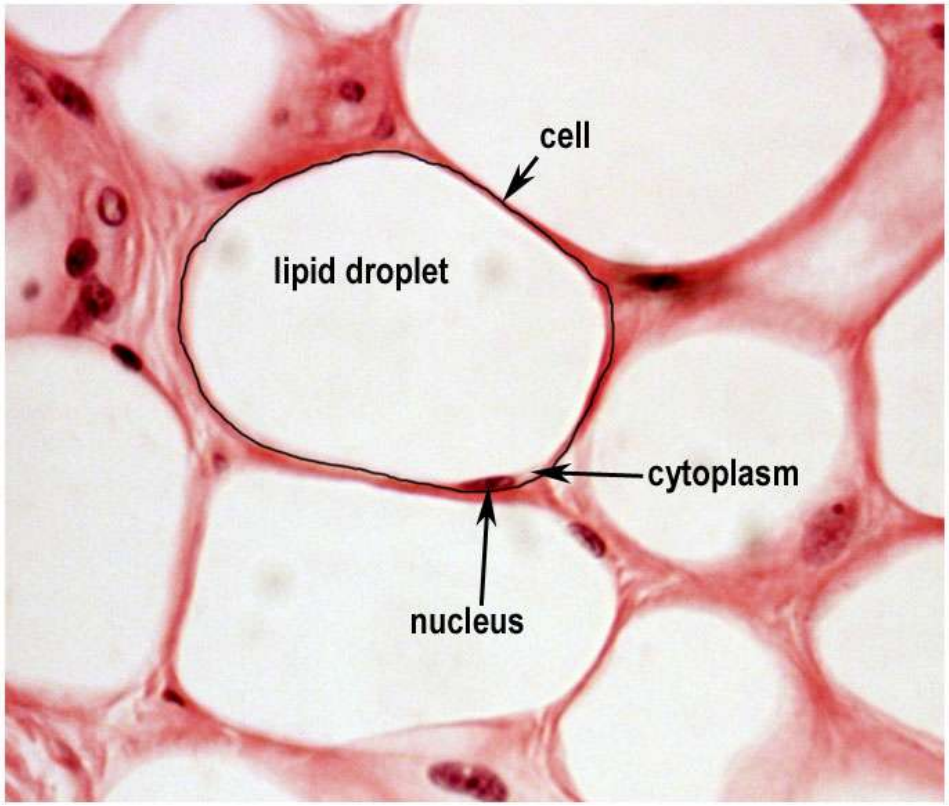
linoleic acid: *cis* configuration (*cis* isomer)

Saturated or Unsaturated?

- Certain unsaturated fatty acids are not synthesized in the human body
- These must be supplied in the diet
- These essential fatty acids include the omega-3 fatty acids, required for normal growth, and thought to provide protection against cardiovascular disease

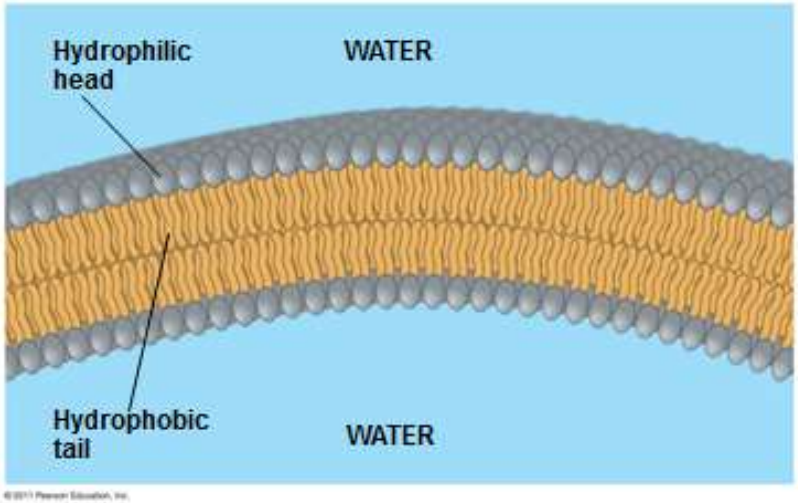
Fats: Major function is storage!

- The major function of fats is energy storage
- Humans and other mammals store their fat in adipose cells
- Adipose tissue also cushions vital organs and insulates the body

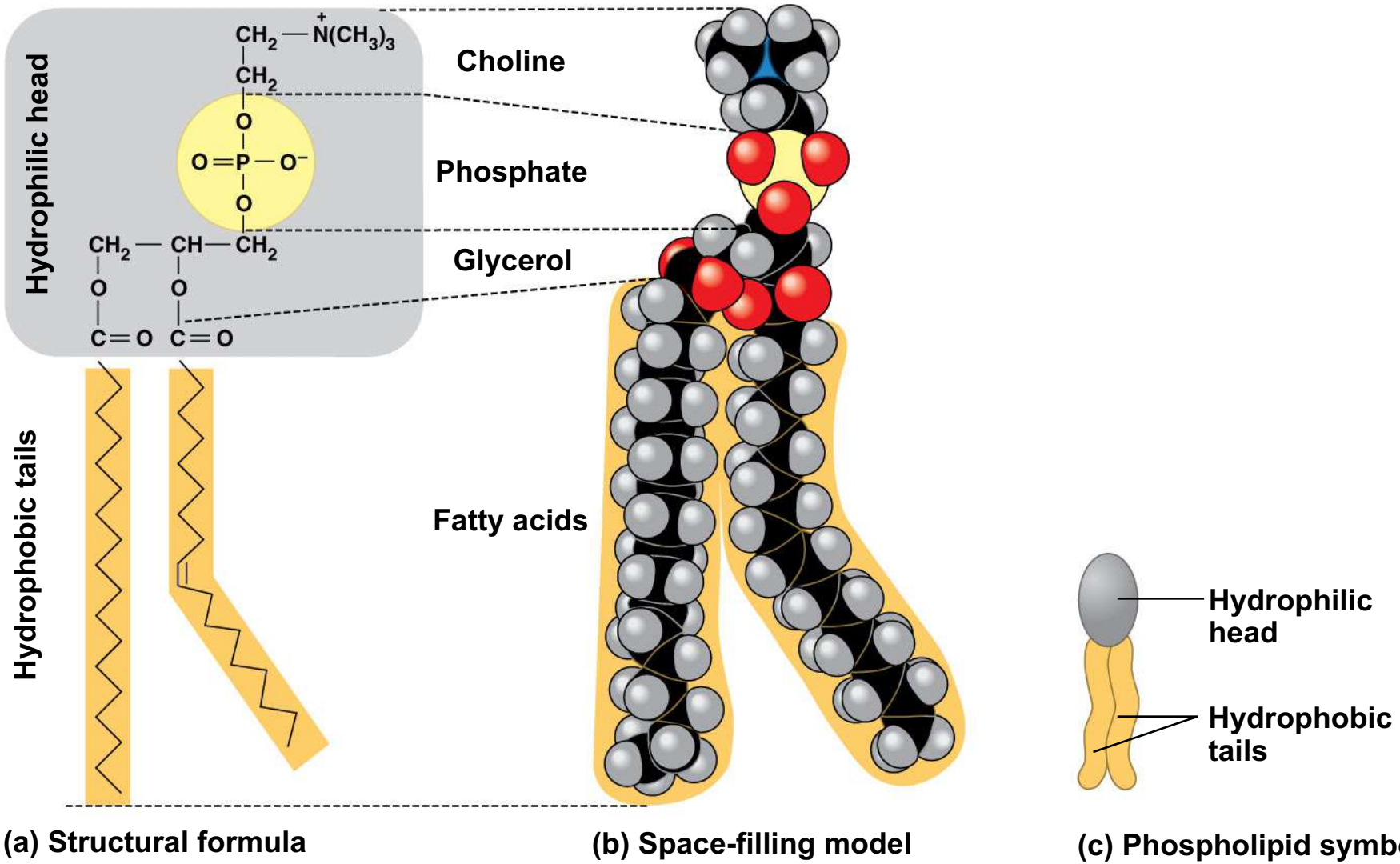


Phospholipids

- When phospholipids are added to water, they self-assemble into a bilayer, with the hydrophobic tails pointing toward the interior
- The structure of phospholipids results in a bilayer arrangement found in cell membranes
- Phospholipids are the major component of all cell membranes

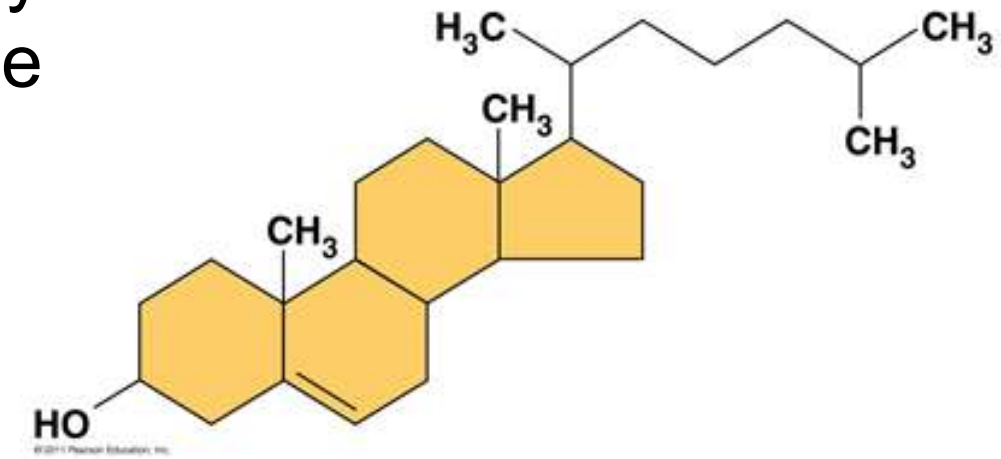


A Single Phospholipid Molecule



Steroids

- **Steroids** are lipids characterized by a carbon skeleton consisting of four fused rings
- **Cholesterol**, an important steroid, is a component in animal cell membranes
- Although cholesterol is essential in animals, high levels in the blood may contribute to cardiovascular disease



Created by:

René McCormick
National Math and Science
Dallas, TX