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

(a) Dehydration reaction: synthesizing a polymer

Short polymer

Dehydration removes a water molecule, forming a new bond.

Unlinked monomer

Longer polymer
Hydrolysis

(b) Hydrolysis: breaking down a polymer

Hydrolysis adds a water molecule, breaking a bond.
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
Monosaccharides have molecular formulas that are usually multiples of CH$_2$O

Glucose (C$_6$H$_{12}$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**.

![glycosidic bond diagram]
Disaccharides

Glucose

Fructose

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Synthesizing Maltose & Sucrose

(a) Dehydration reaction in the synthesis of maltose

(b) Dehydration reaction in the synthesis of sucrose
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 (bacteria, protozoans) 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 surgical 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.
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!
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.
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.

![Diagram of linoleic acid: trans configuration (trans isomer) and cis configuration (cis isomer).](image)
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.
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

(a) Structural formula
(b) Space-filling model
(c) Phospholipid symbol

- **Hydrophilic head**
  - Choline
  - Phosphate
  - Glycerol

- **Hydrophobic tails**
  - Fatty acids
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.