Learning Outcomes: Macromolecules

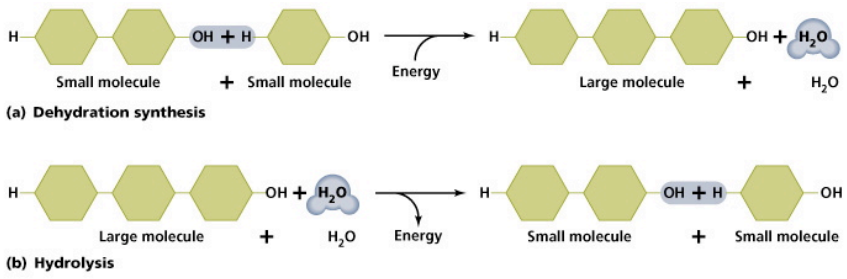
- List and describe the four major classes of molecules
- Describe the formation of a glycosidic linkage and distinguish between monosaccharides, disaccharides, and polysaccharides
- Distinguish between saturated and unsaturated fats and between *cis* and *trans* fat molecules
- Describe the four levels of protein structure
- Distinguish between the following pairs: pyrimidine and purine, nucleotide and nucleoside, ribose and deoxyribose, the 5′ end and 3′ end of a nucleotide

Overview: The Molecules of Life

- All living things are made up of four classes of large biological molecules: carbohydrates, lipids, proteins, and nucleic acids
- **Macromolecules** are large molecules composed of thousands of covalently connected atoms
- Molecular structure and function are inseparable
- 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

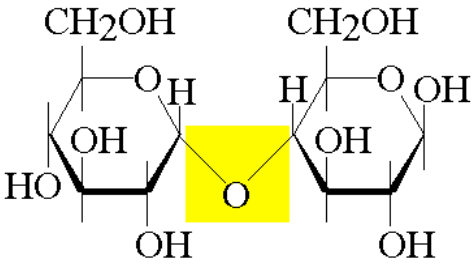
- A **condensation reaction** or more specifically a **dehydration reaction** occurs when two monomers bond together through the loss of a water molecule
- **Enzymes** are macromolecules that speed up the dehydration process
- Polymers are disassembled to monomers by **hydrolysis**, a reaction that is essentially the reverse of the dehydration reaction



Concept: Carbohydrates serve as fuel and building material

- **Carbohydrates** include sugars and the polymers of sugars
- The simplest carbohydrates are monosaccharides $(CH_2O)_n$, or single sugars

that are classified by
  - The location of the carbonyl group (as aldose or ketose)
  - The number of carbons in the carbon skeleton
- Carbohydrate macromolecules are polysaccharides, polymers composed of many sugar building blocks
- A **disaccharide** is formed when a dehydration reaction joins two monosaccharides
- This covalent bond is called a **glycosidic linkage**

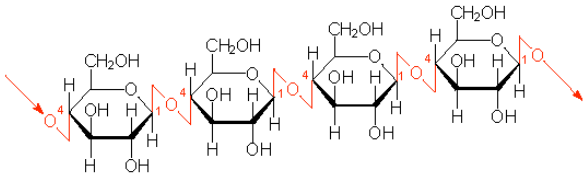


1-4 glycosidic linkage

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

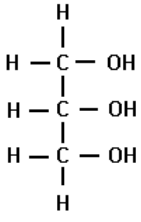
  - Polymers with α glucose are helical (starch and glycogen have α linkages)
  - Polymers with β glucose are straight (cellulose has β linkages)
  - In straight structures, H atoms on one strand can bond with OH groups on other strands
  - Parallel cellulose molecules held together this way are grouped into microfibrils, which form strong building materials for plants



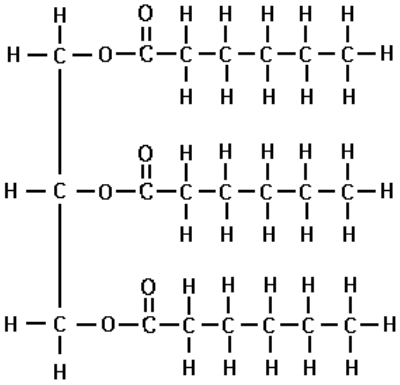
cellulose

Concept: 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
- Lipids are hydrophobic because they consist mostly of hydrocarbons, which form nonpolar covalent bonds
- The most biologically important lipids are fats, phospholipids, and steroids
- A diet rich in saturated fats may contribute to cardiovascular disease through plaque deposits

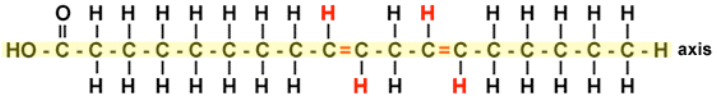


Glycerol

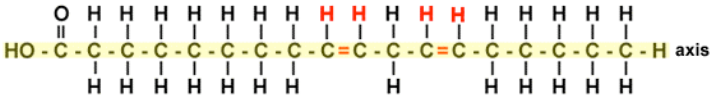

Triglyceride-Saturated

- Hydrogenation is the process of converting unsaturated fats to saturated fats by adding hydrogen
- Hydrogenating vegetable oils also creates unsaturated fats with *trans* double

bonds
- These *trans* fats may contribute more than saturated fats to 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

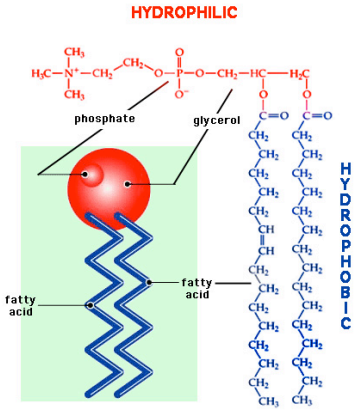


linoleic acid: *trans* configuration (*trans* isomer)

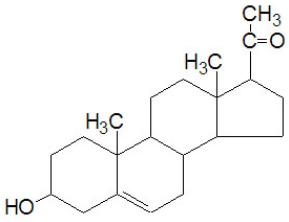


linoleic acid: *cis* configuration (*cis* isomer)

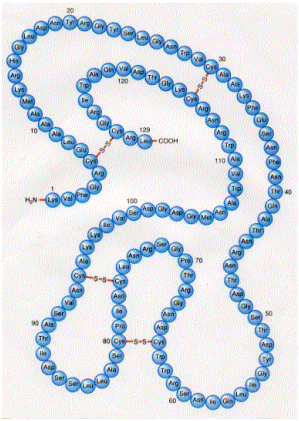
Phospholipids
- In a **phospholipid**, two fatty acids and a phosphate group are attached to glycerol
- The two fatty acid tails are hydrophobic, but the phosphate group and its attachments form a hydrophilic head
- When phospholipids are added to water, they self-assemble into a bilayer, with the hydrophobic 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



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



Concept: Proteins have many structures, resulting in a wide range of functions



Enzymes are a type of protein that acts as a **catalyst** to speed up chemical reactions

Polypeptides are made up of amino acids

- **Polypeptides** are polymers built from the same set of 20 amino acids
- **Amino acids** are organic molecules with carboxyl and amino groups
- Amino acids differ in their properties due to differing side chains, called R groups
- A **protein** consists of one or more polypeptides

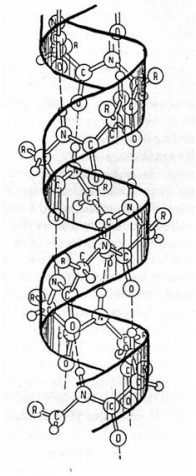
Protein Structure and Function

- A functional protein consists of one or more polypeptides twisted, folded, and coiled into a unique shape

Four Levels of Protein Structure

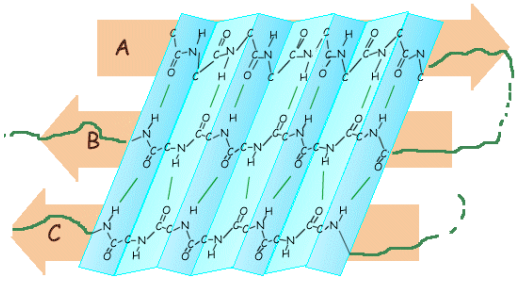
- The primary structure of a protein is its unique sequence of amino acids
- Secondary structure, found in most proteins, consists of coils and folds in the polypeptide chain
- Tertiary structure is determined by interactions among various side chains (R groups)
- Quaternary structure results when a protein consists of multiple polypeptide chains

- **Primary structure**, the sequence of amino acids in a protein, is like the order of letters in a long word
- Primary structure is determined by inherited genetic information



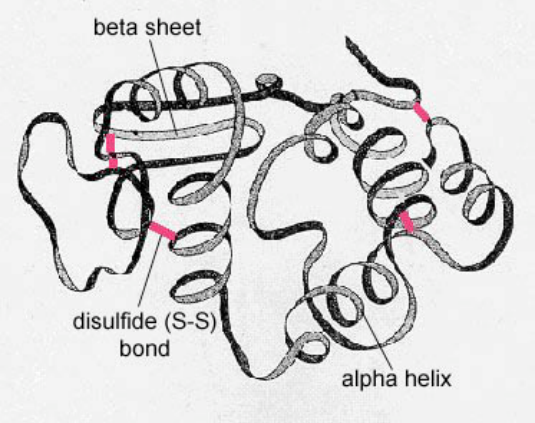
The coils and folds of **secondary structure** result from hydrogen bonds between repeating constituents of the polypeptide backbone

- Typical secondary structures are a coil called an α **helix** and a folded structure called a β **pleated sheet**



Tertiary structure is determined by interactions between R groups, rather than interactions between backbone constituents

- These interactions between R groups include hydrogen bonds, ionic bonds, **hydrophobic interactions**, and van der Waals interactions
- Strong covalent bonds called **disulfide bridges** may reinforce the protein's structure



Quaternary structure results when two or more polypeptide chains form one macromolecule

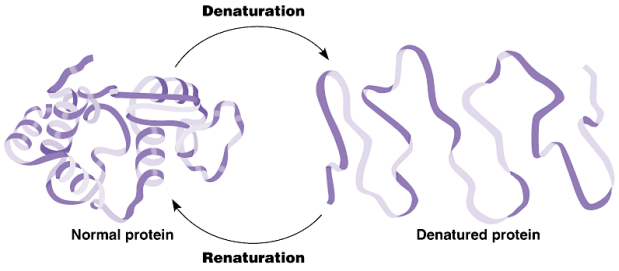
- Collagen is a fibrous protein consisting of three polypeptides coiled like a rope
- Hemoglobin is a globular protein consisting of four polypeptides: two alpha and two beta chains

Sickle-Cell Disease: A Change in Primary Structure

- A slight change in primary structure can affect a protein's structure and ability to function
- Sickle-cell disease, an inherited blood disorder, results from a single amino acid substitution in the protein hemoglobin

What Determines Protein Structure?

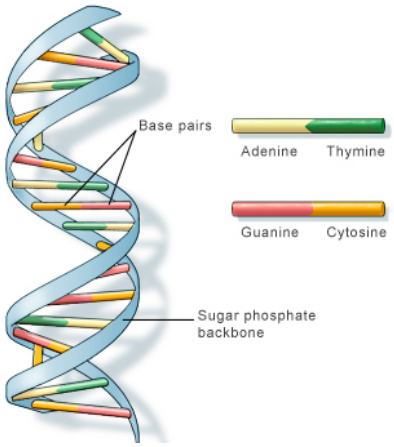
- In addition to primary structure, physical and chemical conditions can affect structure
- Alterations in pH, salt concentration, temperature, or other environmental factors can cause a protein to unravel



- This loss of a protein's native structure is called **denaturation -** A denatured protein is biologically inactive

Concept: Nucleic acids store and transmit hereditary information

- The amino acid sequence of a polypeptide is programmed by a unit of inheritance called a **gene**
- Genes are made of DNA, a **nucleic acid**
- There are two types of nucleic acids:
  - **Deoxyribonucleic acid (DNA)**
  - **Ribonucleic acid (RNA)**
- DNA provides directions for its own replication
- DNA directs synthesis of messenger RNA (mRNA) and, through mRNA, controls protein synthesis
- Protein synthesis occurs in ribosomes

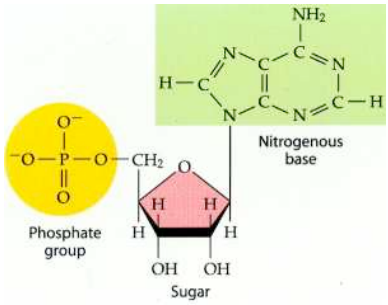


The Structure of Nucleic Acids

- Nucleic acids are polymers called **polynucleotides**
- Each polynucleotide is made of monomers called **nucleotides**
- Each nucleotide consists of a nitrogenous base, a pentose sugar, and a phosphate group
- The portion of a nucleotide without the phosphate group is called a *nucleoside*

Nucleotide Monomers

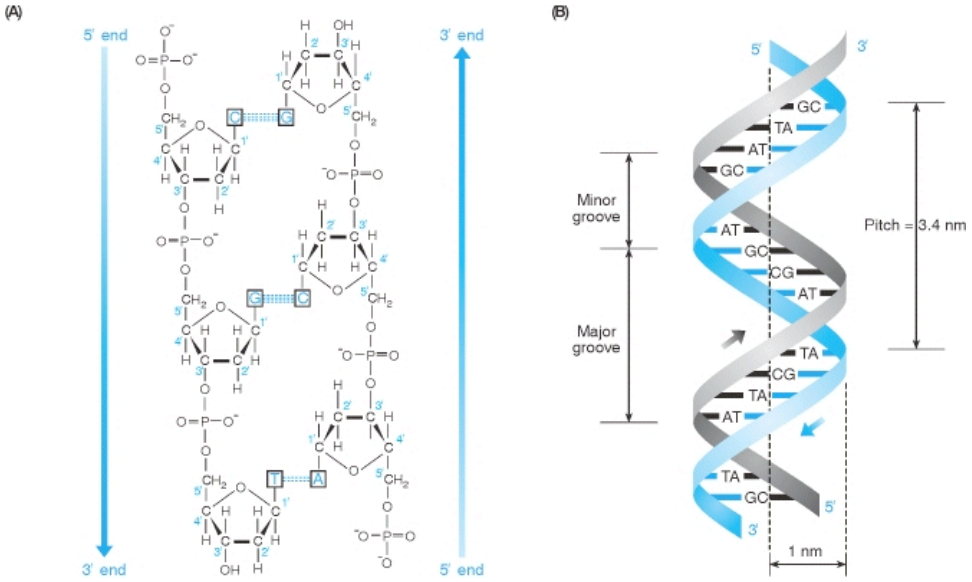
- Nucleoside = nitrogenous base + sugar
- There are two families of nitrogenous bases:
  - **Pyrimidines** (cytosine, thymine, and uracil) have a single six-membered ring
  - **Purines** (adenine and guanine) have a six-membered ring fused to a five-membered ring
- In DNA, the sugar is **deoxyribose**; in RNA, the sugar is **ribose**



- Nucleotide = nucleoside + phosphate group - Nucleotide polymers are linked together to build a polynucleotide
- Adjacent nucleotides are joined by covalent bonds that form between the –OH group on the 3′ carbon of one nucleotide and the phosphate on the 5′ carbon on the next
- These links create a backbone of sugar-phosphate units with nitrogenous bases as appendages
- The sequence of bases along a DNA or mRNA polymer is unique for each gene

The DNA Double Helix

- A DNA molecule has two polynucleotides spiraling around an imaginary axis, forming a **double helix**
- In the DNA double helix, the two backbones run in opposite 5′ → 3′ directions from each other, an arrangement referred to as **antiparallel**
- One DNA molecule includes many genes
- The nitrogenous bases in DNA pair up and form hydrogen bonds: adenine (A) always with thymine (T), and guanine (G) always with cytosine (C)



The Theme of Emergent Properties in the Chemistry of Life: *A Review*

- Higher levels of organization result in the emergence of new properties
- Organization is the key to the chemistry of life