Chapter 3 The Molecules of Cells

PowerPoint Lectures for
Biology: Concepts & Connections, Sixth Edition
Campbell, Reece, Taylor, Simon, and Dickey

Lecture by Richard L. Myers

Introduction: *Got Lactose?*

- Most of the world's population cannot digest milk-based foods
  - They are lactose intolerant, because they lack the enzyme lactase
- This illustrates the importance of biological molecules, such as lactase, to functioning living organisms

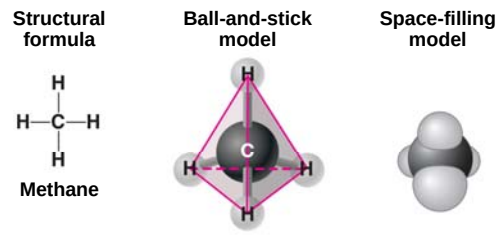
INTRODUCTION TO ORGANIC COMPOUNDS

3.1 Life's molecular diversity is based on the properties of carbon

- Diverse molecules found in cells are composed of carbon bonded to other elements
  - Carbon-based molecules are called **organic compounds**
  - By sharing electrons, carbon can bond to four other atoms
  - By doing so, it can branch in up to four directions

3.1 Life's molecular diversity is based on the properties of carbon

- Methane (CH_4) is one of the simplest organic compounds
  - Four covalent bonds link four hydrogen atoms to the carbon atom
  - Each of the four lines in the formula for methane represents a pair of shared electrons



The four single bonds of carbon point to the corners of a tetrahedron.

3.1 Life's molecular diversity is based on the properties of carbon

- Methane and other compounds composed of only carbon and hydrogen are called **hydrocarbons**
  - Carbon, with attached hydrogens, can bond together in chains of various lengths

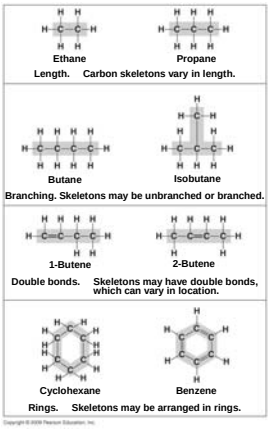
3.1 Life's molecular diversity is based on the properties of carbon

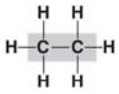
- A chain of carbon atoms is called a **carbon skeleton**
  - Carbon skeletons can be branched or unbranched
  - Therefore, different compounds with the same molecular formula can be produced
    - These structures are called **isomers**

PLAY Animation: L-Dopa

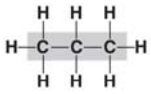
PLAY Animation: Carbon Skeletons

PLAY Animation: Isomers



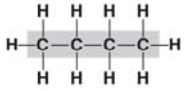


Ethane

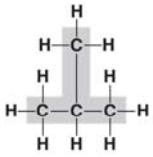


Propane

Length. Carbon skeletons vary in length.

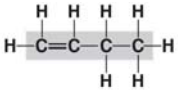


Butane

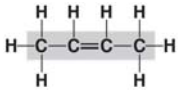


Isobutane

Branching. Skeletons may be unbranched or branched.



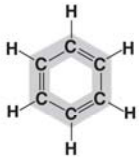
1-Butene



2-Butene

Double bonds. Skeletons may have double bonds, which can vary in location.

Cyclohexane



Benzene

Rings. Skeletons may be arranged in rings.

3.2 Characteristic chemical groups help determine the properties of organic compounds

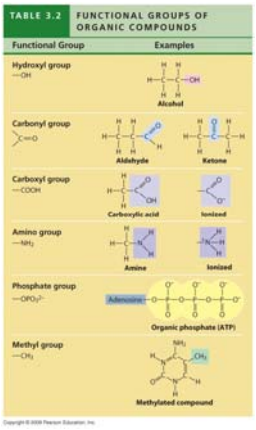
- An organic compound has unique properties that depend upon
  - The size and shape of the molecule and
  - The groups of atoms (functional groups) attached to it
- A **functional group** affects a biological molecule's function in a characteristic way

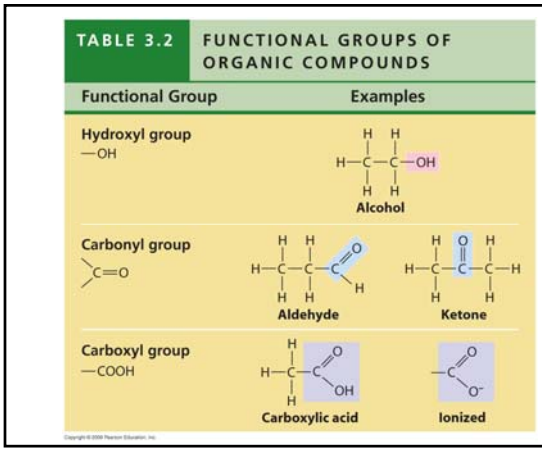
3.2 Characteristic chemical groups help determine the properties of organic compounds

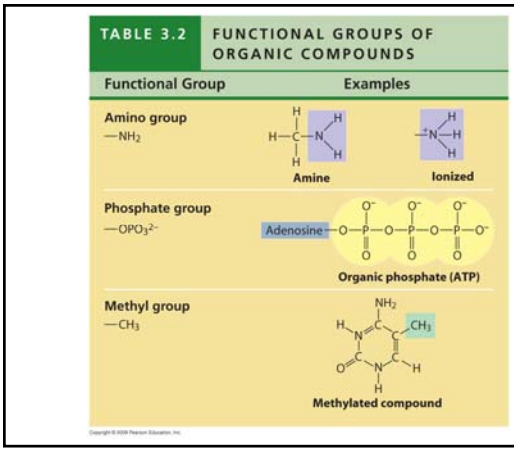
- Compounds containing functional groups are **hydrophilic** (water-loving)
  - This means that they are soluble in water, which is a necessary prerequisite for their roles in water-based life

3.2 Characteristic chemical groups help determine the properties of organic compounds

- The functional groups are
  - **Hydroxyl group**—consists of a hydrogen bonded to an oxygen
  - **Carbonyl group**—a carbon linked by a double bond to an oxygen atom
  - **Carboxyl group**—consists of a carbon double-bonded to both an oxygen and a hydroxyl group
  - **Amino group**—composed of a nitrogen bonded to two hydrogen atoms and the carbon skeleton
  - **Phosphate group**—consists of a phosphorus atom bonded to four oxygen atoms

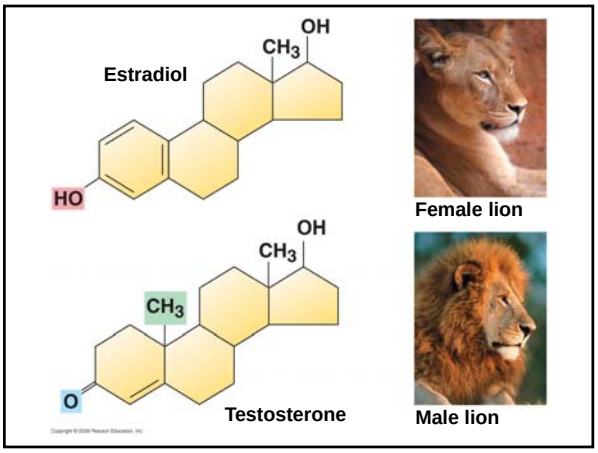


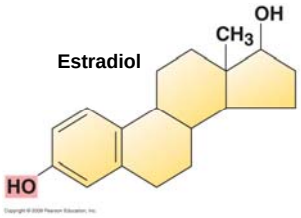




3.2 Characteristic chemical groups help determine the properties of organic compounds

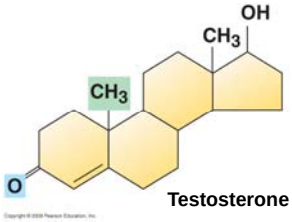
- An example of similar compounds that differ only in functional groups is sex hormones
  - Male and female sex hormones differ only in functional groups
  - The differences cause varied molecular actions
  - The result is distinguishable features of males and females





Estradiol

Female lion



Testosterone

Male lion

3.3 Cells make a huge number of large molecules from a small set of small molecules

- There are four classes of biological molecules
  - Carbohydrates
  - Proteins
  - Lipids
  - Nucleic acids

3.3 Cells make a huge number of large molecules from a small set of small molecules

- The four classes of biological molecules contain very large molecules
  - They are often called **macromolecules** because of their large size
  - They are also called **polymers** because they are made from identical building blocks strung together
  - The building blocks are called **monomers**

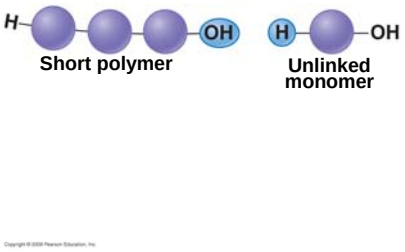
3.3 Cells make a huge number of large molecules from a small set of small molecules

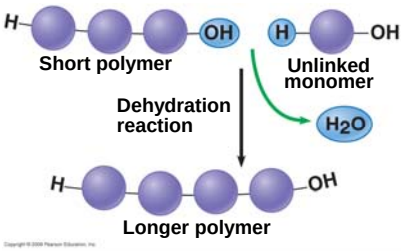
- A cell makes a large number of polymers from a small group of monomers
  - Proteins are made from only 20 different amino acids, and DNA is built from just four kinds of nucleotides
- The monomers used to make polymers are universal

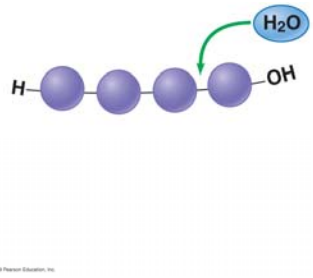
3.3 Cells make a huge number of large molecules from a small set of small molecules

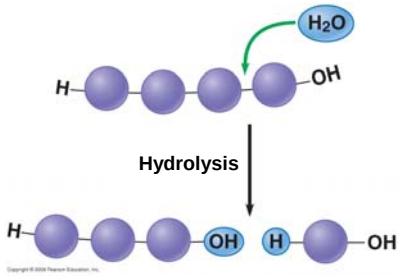
- Monomers are linked together to form polymers through **dehydration reactions**, which remove water
- Polymers are broken apart by **hydrolysis**, the addition of water
- All biological reactions of this sort are mediated by **enzymes**, which speed up chemical reactions in cells

PLAY Animation: Polymers









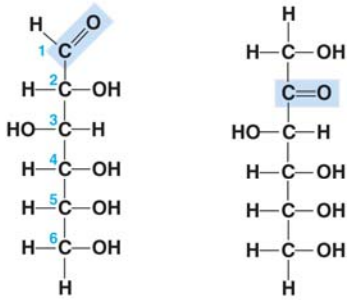
CARBOHYDRATES

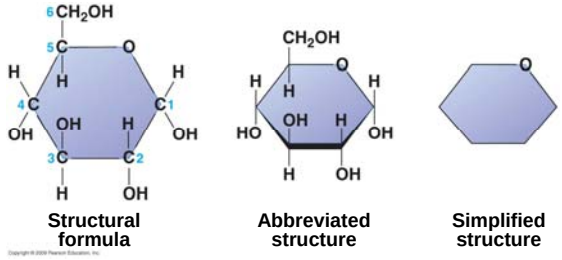
3.4 Monosaccharides are the simplest carbohydrates

- Carbohydrates range from small sugar molecules (monomers) to large polysaccharides
  - Sugar monomers are **monosaccharides**, such as glucose and fructose
  - These can be hooked together to form the polysaccharides

3.4 Monosaccharides are the simplest carbohydrates

- The carbon skeletons of monosaccharides vary in length
  - Glucose and fructose are six carbons long
  - Others have three to seven carbon atoms
- Monosaccharides are the main fuels for cellular work
  - Monosaccharides are also used as raw materials to manufacture other organic molecules

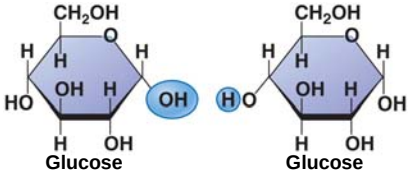


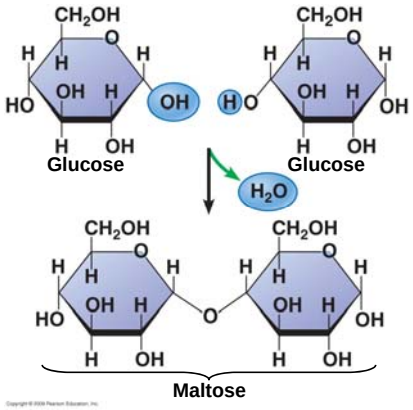


3.5 Cells link two single sugars to form disaccharides

- Two monosaccharides (monomers) can bond to form a **disaccharide** in a dehydration reaction
  - An example is a glucose monomer bonding to a fructose monomer to form sucrose, a common disaccharide

PLAY Animation: Disaccharides





3.6 CONNECTION: What is high-fructose corn syrup and is it to blame for obesity?

- When you drink a soda, you are probably consuming a sweetener called high-fructose corn syrup (HFCS)
- Because fructose is sweeter than glucose, glucose atoms produced from starch are rearranged to make the glucose isomer, fructose
  - This is used to sweeten sodas
  - So, if you overconsume sweeteners as well as fat and do not exercise, you may experience weight gain

3.7 Polysaccharides are long chains of sugar units

- **Polysaccharides** are polymers of monosaccharides
  - They can function in the cell as a storage molecule or as a structural compound

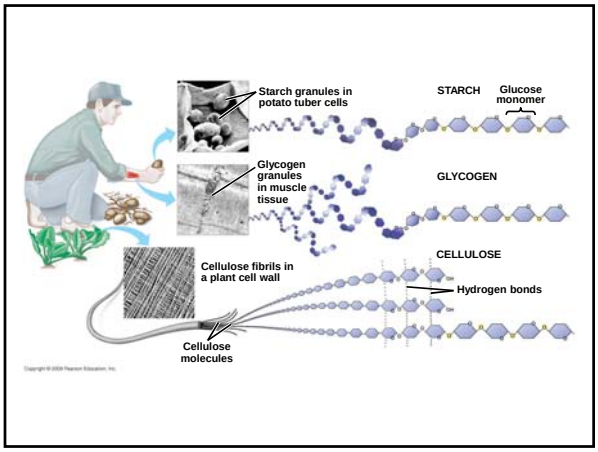
3.7 Polysaccharides are long chains of sugar units

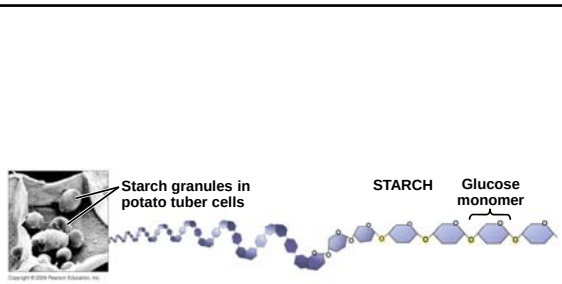
- **Starch** is a storage polysaccharide composed of glucose monomers and found in plants
- **Glycogen** is a storage polysaccharide composed of glucose, which is hydrolyzed by animals when glucose is needed
- **Cellulose** is a polymer of glucose that forms plant cell walls
- **Chitin** is a polysaccharide used by insects and crustaceans to build an exoskeleton

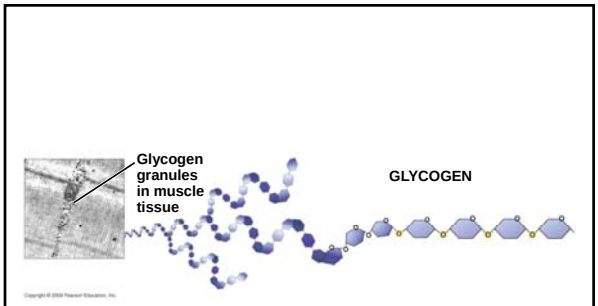
3.7 Polysaccharides are long chains of sugar units

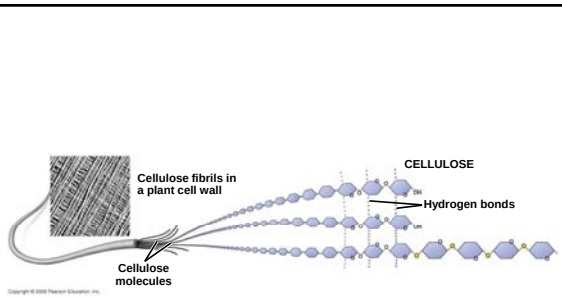
- Polysaccharides are hydrophilic (water-loving)
  - Cotton fibers, such as those in bath towels, are water absorbent

PLAY Animation: Polysaccharides









LIPIDS

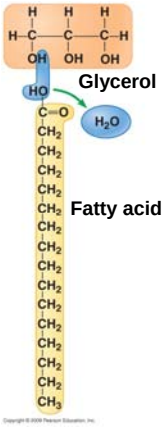
3.8 Fats are lipids that are mostly energy-storage molecules

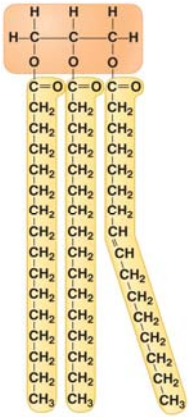
- **Lipids** are water insoluble (**hydrophobic**, or water fearing) compounds that are important in energy storage
  - They contain twice as much energy as a polysaccharide
- **Fats** are lipids made from glycerol and fatty acids

3.8 Fats are lipids that are mostly energy-storage molecules

- Fatty acids link to glycerol by a dehydration reaction
  - A fat contains one glycerol linked to three fatty acids
  - Fats are often called triglycerides because of their structure

PLAY Animation: Fats



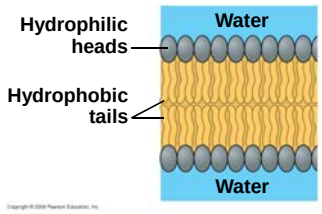


3.8 Fats are lipids that are mostly energy-storage molecules

- Some fatty acids contain double bonds
  - This causes kinks or bends in the carbon chain because the maximum number of hydrogen atoms cannot bond to the carbons at the double bond
  - These compounds are called **unsaturated fats** because they have fewer than the maximum number of hydrogens
    - Fats with the maximum number of hydrogens are called **saturated fats**

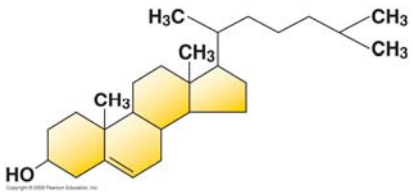
3.9 Phospholipids and steroids are important lipids with a variety of functions

- **Phospholipids** are structurally similar to fats and are an important component of all cells
  - For example, they are a major part of cell membranes, in which they cluster into a bilayer of phospholipids
  - The hydrophilic heads are in contact with the water of the environment and the internal part of the cell
  - The hydrophobic tails band in the center of the bilayer



3.9 Phospholipids and steroids are important lipids with a variety of functions

- **Steroids** are lipids composed of fused ring structures
  - **Cholesterol** is an example of a steroid that plays a significant role in the structure of the cell membrane
  - In addition, cholesterol is the compound from which we synthesize sex hormones



3.10 CONNECTION: Anabolic steroids pose health risks

- **Anabolic steroids** are synthetic variants of testosterone that can cause a buildup of muscle and bone mass
  - They can be sold as prescription drugs and used to treat certain diseases
  - They may also be abused with serious consequences, such as liver damage that can lead to cancer

PROTEINS

3.11 Proteins are essential to the structures and functions of life

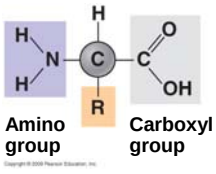
- A **protein** is a polymer built from various combinations of 20 amino acid monomers
  - Proteins have unique structures that are directly related to their functions
  - **Enzymes**, proteins that serve as metabolic catalysts, regulate the chemical reactions within cells

3.11 Proteins are essential to the structures and functions of life

- **Structural** proteins provide associations between body parts and **contractile** proteins are found within muscle
- **Defensive** proteins include antibodies of the immune system, and **signal** proteins are best exemplified by the hormones
- **Receptor** proteins serve as antenna for outside signals, and **transport** proteins carry oxygen

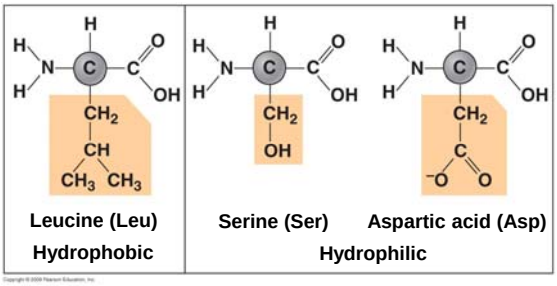
3.12 Proteins are made from amino acids linked by peptide bonds

- **Amino acids**, the building blocks of proteins, have an amino group and a carboxyl group
  - Both of these are covalently bonded to a central carbon atom
  - Also bonded to the central carbon is a hydrogen atom and some other chemical group symbolized by R



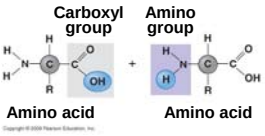
3.12 Proteins are made from amino acids linked by peptide bonds

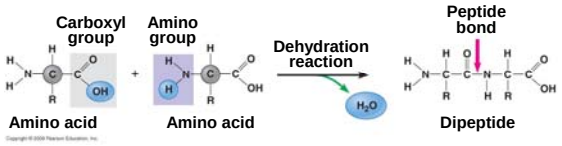
- Amino acids are classified as hydrophobic or hydrophilic
  - Some amino acids have a nonpolar R group and are hydrophobic
  - Others have a polar R group and are hydrophilic, which means they easily dissolve in aqueous solutions



3.12 Proteins are made from amino acids linked by peptide bonds

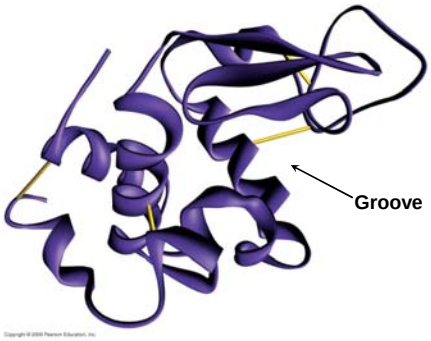
- Amino acid monomers are linked together to form polymeric proteins
  - This is accomplished by an enzyme-mediated dehydration reaction
  - This links the carboxyl group of one amino acid to the amino group of the next amino acid
    - The covalent linkage resulting is called a **peptide bond**

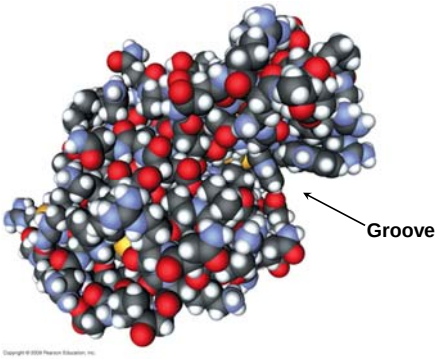




3.13 A protein's specific shape determines its function

- A polypeptide chain contains hundreds or thousands of amino acids linked by peptide bonds
  - The amino acid sequence causes the polypeptide to assume a particular shape
  - The shape of a protein determines its specific function





3.13 A protein's specific shape determines its function

- If for some reason a protein's shape is altered, it can no longer function
  - **Denaturation** will cause polypeptide chains to unravel and lose their shape and, thus, their function
  - Proteins can be denatured by changes in salt concentration and pH

3.14 A protein's shape depends on four levels of structure

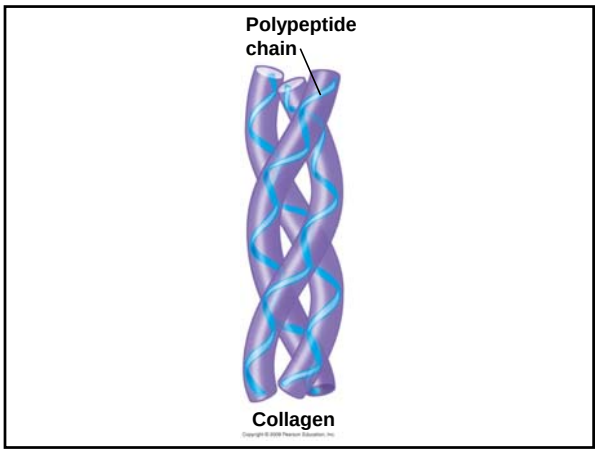
- A protein can have four levels of structure
  - Primary structure
  - Secondary structure
  - Tertiary structure
  - Quaternary structure

3.14 A protein's shape depends on four levels of structure

- The **primary structure** of a protein is its unique amino acid sequence
  - The correct amino acid sequence is determined by the cell's genetic information
  - The slightest change in this sequence affects the protein's ability to function

3.14 A protein's shape depends on four levels of structure

- Protein **secondary structure** results from coiling or folding of the polypeptide
  - Coiling results in a helical structure called an alpha helix
  - Folding may lead to a structure called a pleated sheet
    - Coiling and folding result from hydrogen bonding between certain areas of the polypeptide chain



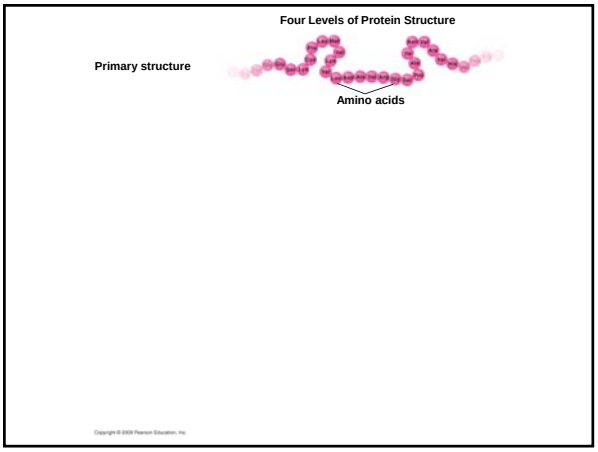
3.14 A protein's shape depends on four levels of structure

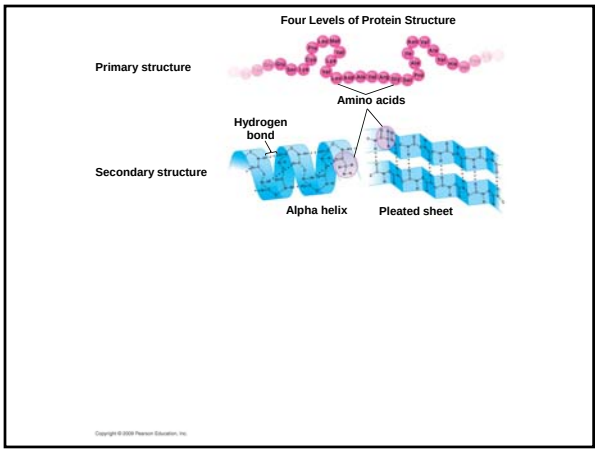
- The overall three-dimensional shape of a protein is called its **tertiary structure**
  - Tertiary structure generally results from interactions between the R groups of the various amino acids
  - Disulfide bridges are covalent bonds that further strengthen the protein's shape

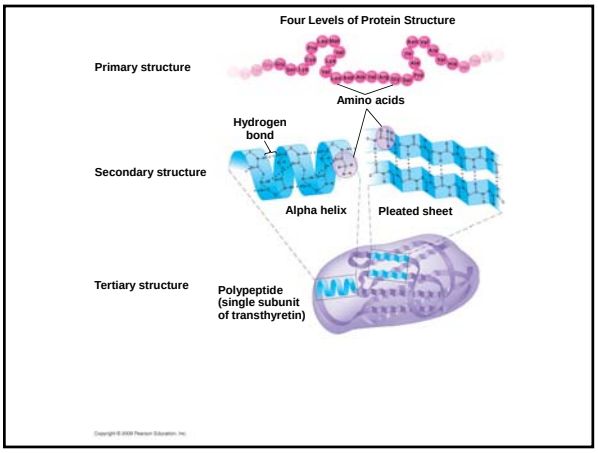
3.14 A protein's shape depends on four levels of structure

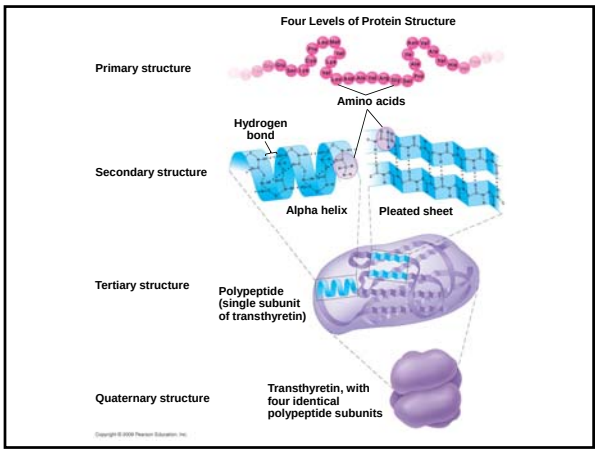
- Two or more polypeptide chains (subunits) associate providing **quaternary structure**
  - Collagen is an example of a protein with quaternary structure
  - Its triple helix gives great strength to connective tissue, bone, tendons, and ligaments

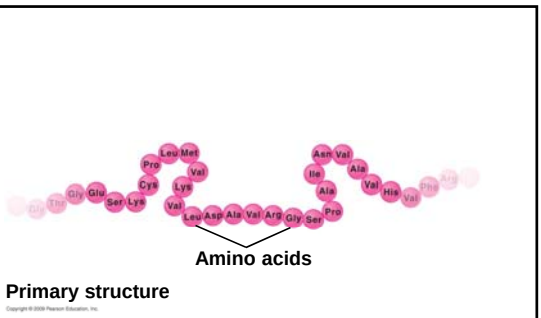
PLAY Animation: Protein Structure Introduction
PLAY Animation: Primary Protein Structure
PLAY Animation: Secondary Protein Structure
PLAY Animation: Tertiary Protein Structure
PLAY Animation: Quaternary Protein Structure

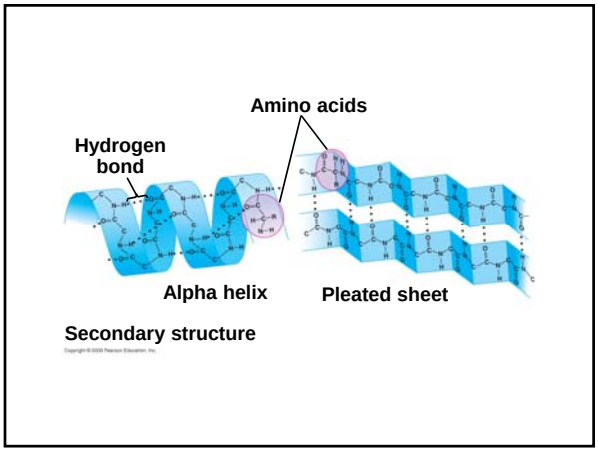


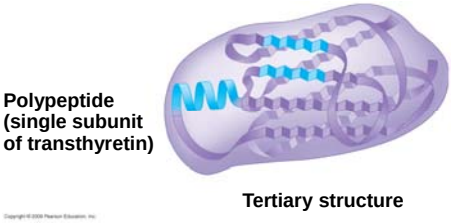


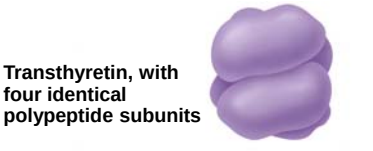






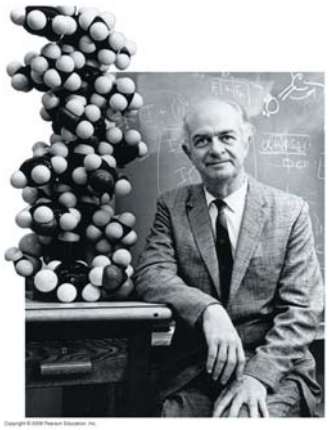






3.15 TALKING ABOUT SCIENCE: Linus Pauling contributed to our understanding of the chemistry of life

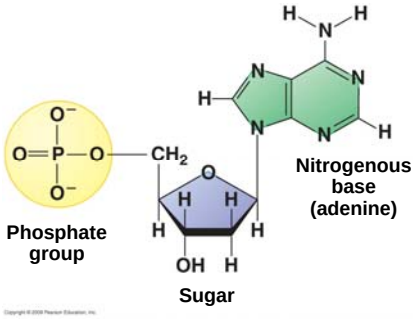
- After winning a Nobel Prize in Chemistry, Pauling spent considerable time studying biological molecules
  - He discovered an oxygen attachment to hemoglobin as well as the cause of sickle-cell disease
  - Pauling also discovered the alpha helix and pleated sheet of proteins



NUCLEIC ACIDS

3.16 Nucleic acids are information-rich polymers of nucleotides

- **DNA** (**deoxyribonucleic acid**) and **RNA** (**ribonucleic acid**) are composed of monomers called **nucleotides**
  - Nucleotides have three parts
    - A five-carbon sugar called ribose in RNA and deoxyribose in DNA
    - A phosphate group
    - A nitrogenous base

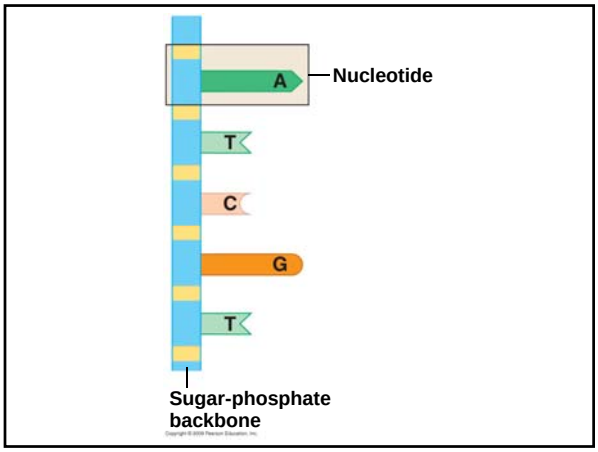


3.16 Nucleic acids are information-rich polymers of nucleotides

- DNA nitrogenous bases are adenine (A), thymine (T), cytosine (C), and guanine (G)
  - RNA also has A, C, and G, but instead of T, it has uracil (U)

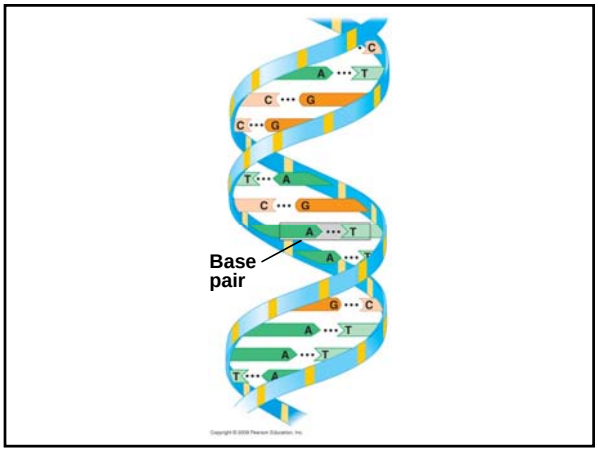
3.16 Nucleic acids are information-rich polymers of nucleotides

- A nucleic acid polymer, a polynucleotide, forms from the nucleotide monomers when the phosphate of one nucleotide bonds to the sugar of the next nucleotide
  - The result is a repeating sugar-phosphate backbone with protruding nitrogenous bases



3.16 Nucleic acids are information-rich polymers of nucleotides

- Two polynucleotide strands wrap around each other to form a DNA **double helix**
  - The two strands are associated because particular bases always hydrogen bond to one another
  - A pairs with T, and C pairs with G, producing **base pairs**
- RNA is usually a single polynucleotide strand

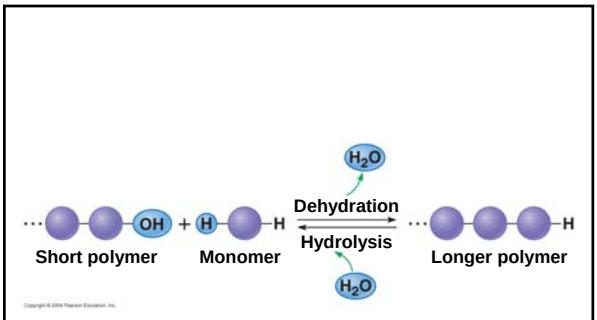


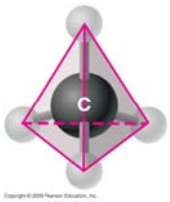
3.16 Nucleic acids are information-rich polymers of nucleotides

- A particular nucleotide sequence that can instruct the formation of a polypeptide is called a **gene**
  - Most DNA molecules consist of millions of base pairs and, consequently, many genes
  - These genes, many of which are unique to the species, determine the structure of proteins and, thus, life's structures and functions

3.17 EVOLUTION CONNECTION: Lactose tolerance is a recent event in human evolution

- Mutations are alterations in bases or the sequence of bases in DNA
  - Lactose tolerance is the result of mutations
  - In many people, the gene that dictates lactose utilization is turned off in adulthood
  - Apparently, mutations occurred over time that prevented the gene from turning off
  - This is an excellent example of human evolution

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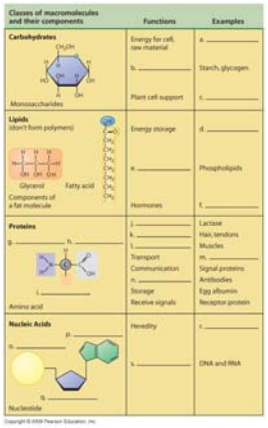
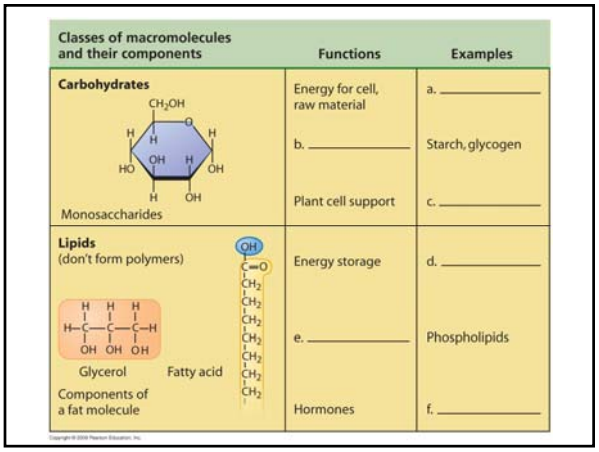

Classes of macromolecules and their components
Functions
Examples
Carbohydrates
Monosaccharides
Energy for cell, raw material
a.
b.
Starch, glycogen
Plant cell support
c.
Lipids
(don't form polymers)
Glycerol
Fatty acid
Components of a fat molecule
Energy storage
d.
e.
Phospholipids
Hormones
f.
Proteins
g.
h.
i.
Amino acid
j.
k.
l.
Transport
Communication
n.
Storage
Receive signals
Lactase
Hair, tendons
Muscles
m.
Signal proteins
Antibodies
Egg albumin
Receptor protein
Nucleic Acids
Nucleotide
p.
o.
q.
Heredity
s.
r.
DNA and RNA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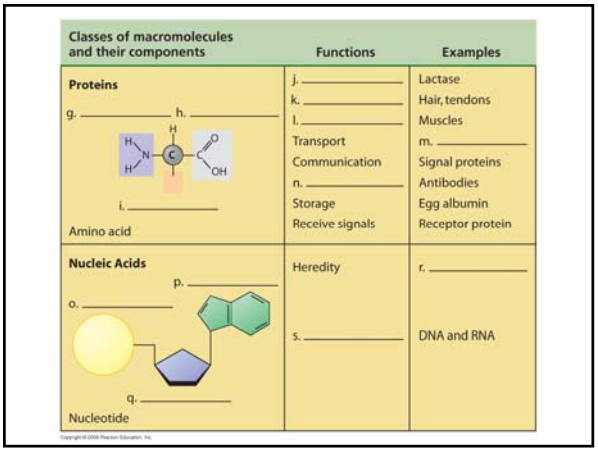
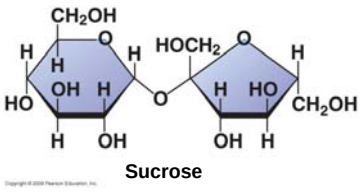
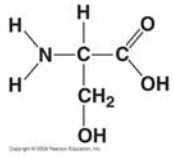
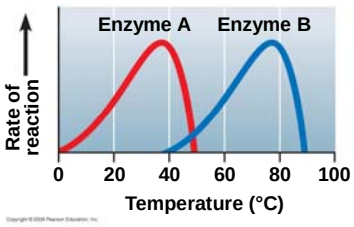
(don't form polymers)
Glycerol
Fatty acid
Components of a fat molecule
Energy storage
d.
e.
Phospholipids
Hormones
f.


Classes of macromolecules and their components
Functions
Examples
Proteins
g.
h.
i.
Amino acid
j.
k.
l.
Transport
Communication
n.
Storage
Receive signals
Lactase
Hair, tendons
Muscles
m.
Signal proteins
Antibodies
Egg albumin
Receptor protein
Nucleic Acids
Nucleotide
p.
o.
q.
Heredity
s.
r.
DNA and RNA



Sucrose





You should now be able to

1. Discuss the importance of carbon to life's molecular diversity
2. Describe the chemical groups that are important to life
3. Explain how a cell can make a variety of large molecules from a small set of molecules
4. Define monosaccharides, disaccharides, and polysaccharides and explain their functions
5. Define lipids, phospholipids, and steroids and explain their functions

You should now be able to

6. Describe the chemical structure of proteins and their importance to cells
7. Describe the chemical structure of nucleic acids and how they relate to inheritance