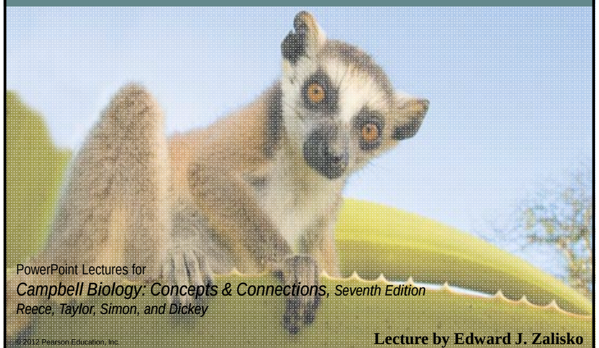
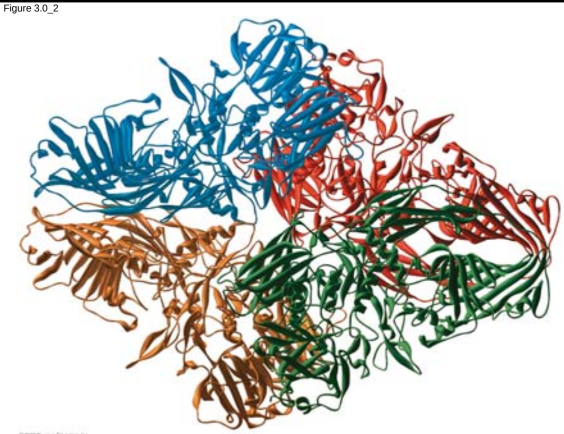
Chapter 3 The Molecules of Cells



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

Lecture by Edward J. Zalisko

Figure 3.0_2



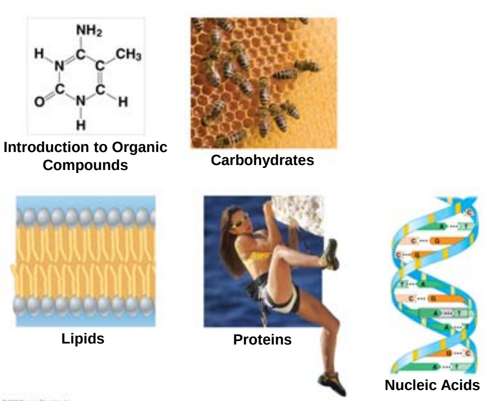
Introduction

- Most of the world's population cannot digest milk-based foods.
  - These people are lactose intolerant, because they lack the enzyme lactase.
  - This illustrates the importance of biological molecules, such as lactase, in the daily functions of living organisms.

INTRODUCTION TO ORGANIC COMPOUNDS

Figure 3.0_1

Chapter 3: Big Ideas



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 carbons and
  - atoms of other elements.
- Carbon-based molecules are called **organic compounds.**

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

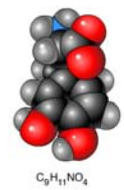
- By sharing electrons, carbon can
  - bond to four other atoms and
  - branch in up to four directions.
- Methane (CH_4) is one of the simplest organic compounds.
  - Four covalent bonds link four hydrogen atoms to the carbon atom.
  - Each of the four lines in the formula for methane represents a pair of shared electrons.

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

- A **carbon skeleton** is a chain of carbon atoms that can be
  - branched or
  - unbranched.
- Compounds with the same formula but different structural arrangements are call **isomers.**

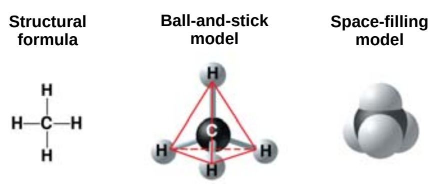
3.1 Life's molecular diversity is based on the properties of carbon

- 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.

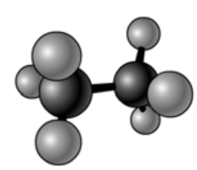


Animation: L-Dopa
Right click on animation / Click play

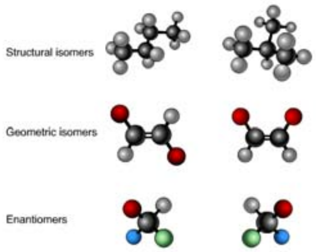
Figure 3.1A



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



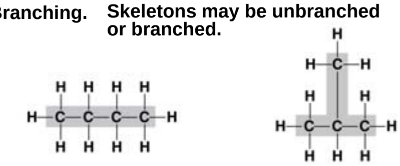
Animation: Carbon Skeletons
Right click on animation / Click play



Animation: Isomers
Right click on animation / Click play

Figure 3.1B_2

Branching. **Skeletons may be unbranched or branched.**



Butane **Isobutane**

Figure 3.1B

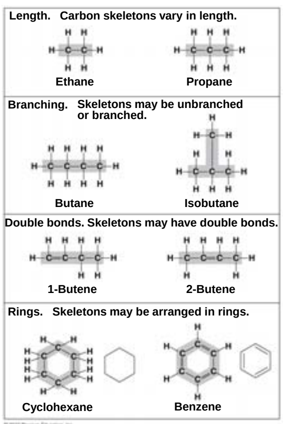


Figure 3.1B_3

Double bonds. **Skeletons may have double bonds.**

1-Butene **2-Butene**

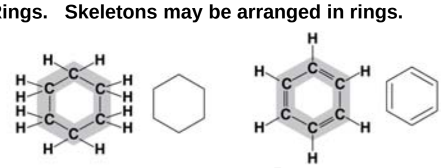
Figure 3.1B_1

Length. **Carbon skeletons vary in length.**

Ethane **Propane**

Figure 3.1B_4

Rings. **Skeletons may be arranged in rings.**

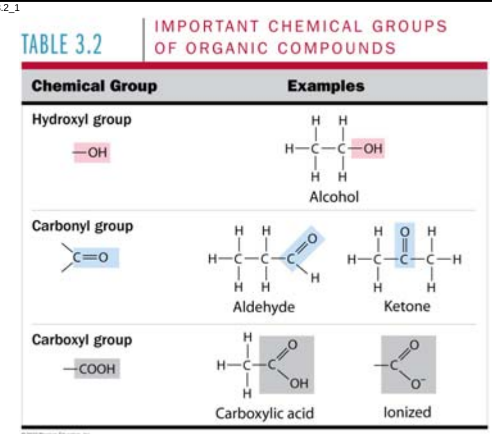


Cyclohexane **Benzene**

3.2 A few chemical groups are key to the functioning of biological molecules

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

Table 3.2_1



3.2 A few chemical groups are key to the functioning of biological molecules

- 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, and
  - **phosphate group**—consists of a phosphorus atom bonded to four oxygen atoms.

Table 3.2_2

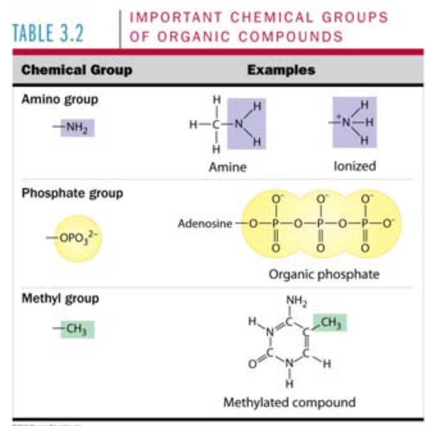
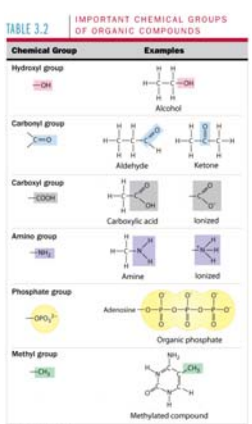


Table 3.2



3.2 A few chemical groups are key to the functioning of biological molecules

- 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.

Figure 3.2

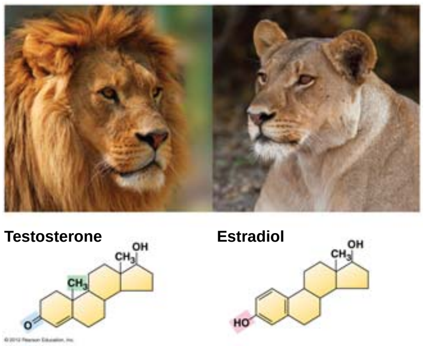
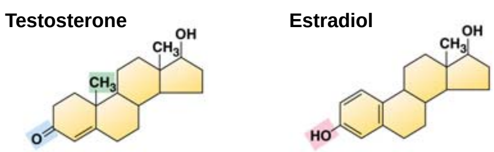


Figure 3.2_3

Figure 3.2_1



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

- There are four classes of molecules important to organisms:
  - carbohydrates,
  - proteins,
  - lipids, and
  - nucleic acids.

Figure 3.2_2

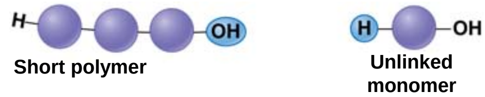
3.3 Cells make a huge number of large molecules from a limited set of small molecules

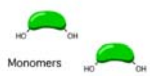
- The four classes of biological molecules contain very large molecules.
  - They are often called **macromolecules** because of their large size.
  - They are also called **polymers** because they are made from identical building blocks strung together.
  - The building blocks of polymers are called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

3.3 Cells make a huge number of large molecules from a limited 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.

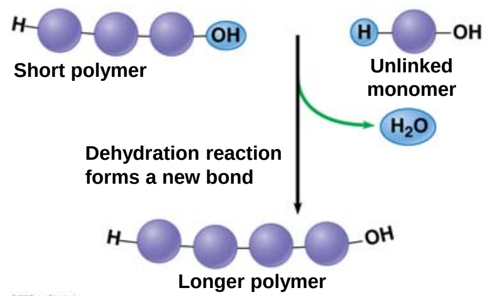
Figure 3.3A_s1





Animation: Polymers
Right click on animation / Click play

Figure 3.3A_s2



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

- A cell makes a large number of polymers from a small group of monomers. For example,
  - 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.

Figure 3.3B_s1

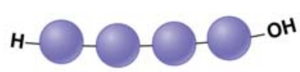


Figure 3.3B_s2

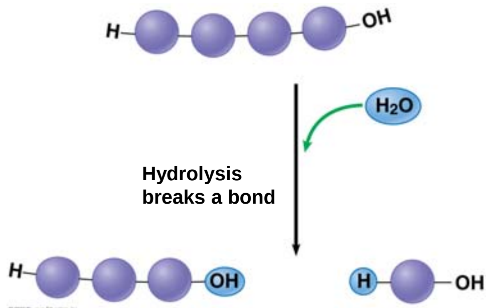


Figure 3.4A

CARBOHYDRATES

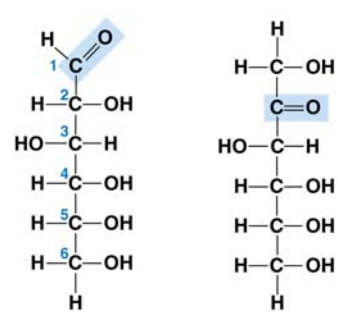
3.4 Monosaccharides are the simplest carbohydrates

- 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 and
  - used as raw materials to manufacture other organic molecules.

3.4 Monosaccharides are the simplest carbohydrates

- **Carbohydrates** range from small sugar molecules (monomers) to large polysaccharides.
- Sugar monomers are **monosaccharides**, such as those found in honey,
  - glucose, and
  - fructose.
- Monosaccharides can be hooked together to form
  - more complex sugars and
  - polysaccharides.

Figure 3.4B



Glucose (an aldose)

Fructose (a ketose)

3.4 Monosaccharides are the simplest carbohydrates

- Many monosaccharides form rings.
- The ring diagram may be
  - abbreviated by not showing the carbon atoms at the corners of the ring and
  - drawn with different thicknesses for the bonds, to indicate that the ring is a relatively flat structure with attached atoms extending above and below it.

Animation: Disaccharides
Right click on animation / Click play

Figure 3.4C

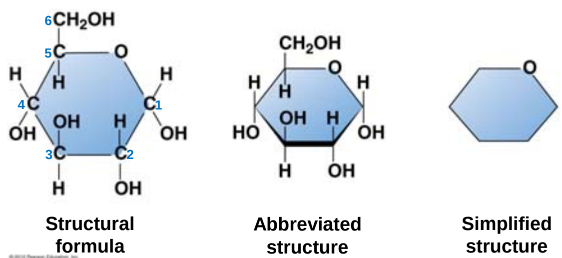
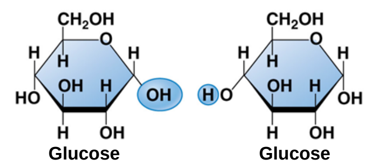


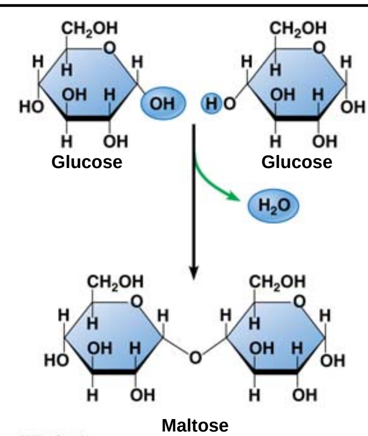
Figure 3.5_s1



3.5 Two monosaccharides are linked to form a disaccharide

- Two monosaccharides (monomers) can bond to form a **disaccharide** in a dehydration reaction.
- The disaccharide sucrose is formed by combining
  - a glucose monomer and
  - a fructose monomer.
- The disaccharide maltose is formed from two glucose monomers.

Figure 3.5_s2



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

- Sodas or fruit drinks probably contain high-fructose corn syrup (HFCS).
- Fructose is sweeter than glucose.
- To make HFCS, glucose atoms are rearranged to make the glucose isomer, fructose.

3.7 Polysaccharides are long chains of sugar units

- **Polysaccharides** are
  - macromolecules and
  - polymers composed of thousands of monosaccharides.
- Polysaccharides may function as
  - storage molecules or
  - structural compounds.

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

- High-fructose corn syrup (HFCS) is
  - used to sweeten many beverages and
  - may be associated with weight gain.
- Good health is promoted by
  - a diverse diet of proteins, fats, vitamins, minerals, and complex carbohydrates and
  - exercise.

3.7 Polysaccharides are long chains of sugar units

- **Starch** is
  - a polysaccharide,
  - composed of glucose monomers, and
  - used by plants for energy storage.
- **Glycogen** is
  - a polysaccharide,
  - composed of glucose monomers, and
  - used by animals for energy storage.

Figure 3.6

3.7 Polysaccharides are long chains of sugar units

- **Cellulose**
  - is a polymer of glucose and
  - forms plant cell walls.
- **Chitin** is
  - a polysaccharide and
  - used by insects and crustaceans to build an exoskeleton.

Figure 3.7

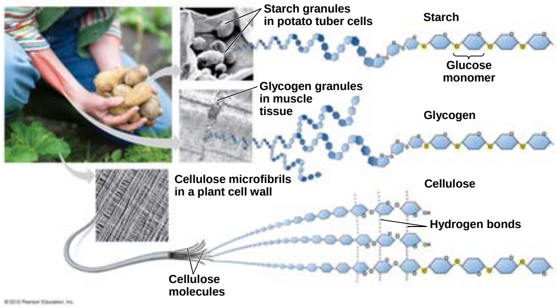


Figure 3.7_3

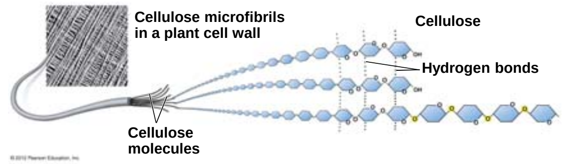


Figure 3.7_1

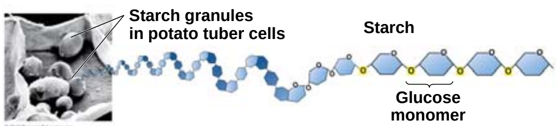
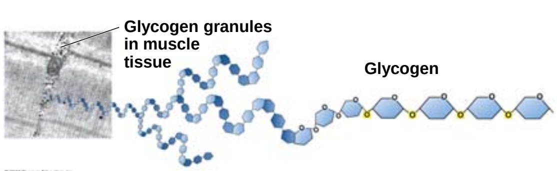


Figure 3.7_4

Figure 3.7_2



3.7 Polysaccharides are long chains of sugar units

- Polysaccharides are usually hydrophilic (water-loving).
- Bath towels are
  - often made of cotton, which is mostly cellulose, and
  - water absorbent.

Animation: Polysaccharides
Right click on animation / Click play

Figure 3.8A

LIPIDS

3.8 Fats are lipids that are mostly energy-storage molecules

- Lipids differ from carbohydrates, proteins, and nucleic acids in that they are
  - not huge molecules and
  - not built from monomers.
- Lipids vary a great deal in
  - structure and
  - function.

3.8 Fats are lipids that are mostly energy-storage molecules

- **Lipids**
  - are water insoluble (**hydrophobic**, or water-fearing) compounds,
  - are important in long-term energy storage,
  - contain twice as much energy as a polysaccharide, and
  - consist mainly of carbon and hydrogen atoms linked by nonpolar covalent bonds.

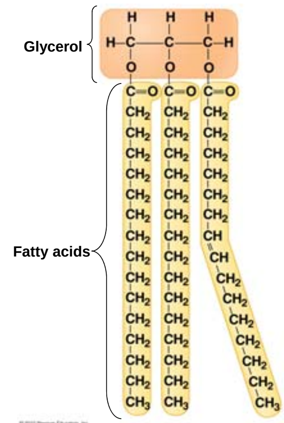
3.8 Fats are lipids that are mostly energy-storage molecules

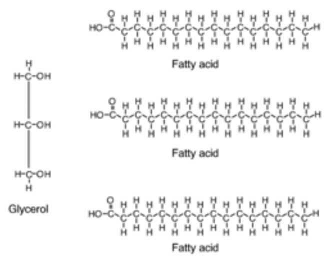
- We will consider three types of lipids:
  - fats,
  - phospholipids, and
  - steroids.
- A **fat** is a large lipid made from two kinds of smaller molecules,
  - glycerol and
  - fatty acids.

3.8 Fats are lipids that are mostly energy-storage molecules

- A fatty acid can 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.

Figure 3.8C



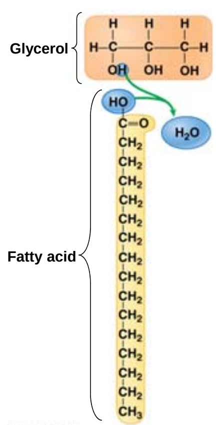


Animation: Fats
Right click on animation / Click play

3.8 Fats are lipids that are mostly energy-storage molecules

- Some fatty acids contain one or more double bonds, forming **unsaturated fatty acids** that
  - have one fewer hydrogen atom on each carbon of the double bond,
  - cause kinks or bends in the carbon chain, and
  - prevent them from packing together tightly and solidifying at room temperature.
- Fats with the maximum number of hydrogens are called **saturated fatty acids.**

Figure 3.8B



3.8 Fats are lipids that are mostly energy-storage molecules

- Unsaturated fats include corn and olive oils.
- Most animal fats are saturated fats.
- Hydrogenated vegetable oils are unsaturated fats that have been converted to saturated fats by adding hydrogen.
- This hydrogenation creates **trans fats** associated with health risks.

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

- **Phospholipids** are
  - structurally similar to fats and
  - the major component of all cells.
- Phospholipids are structurally similar to fats.
  - Fats contain three fatty acids attached to glycerol.
  - Phospholipids contain two fatty acids attached to glycerol.

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

- Phospholipids 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.

Figure 3.9A-B

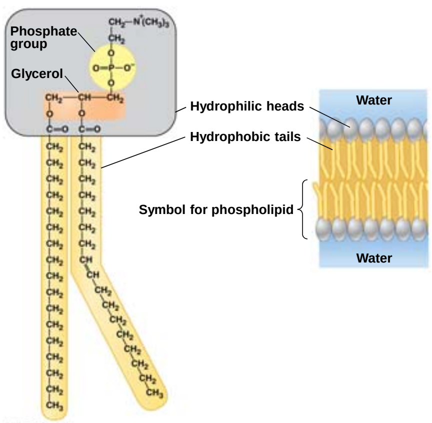


Figure 3.9B

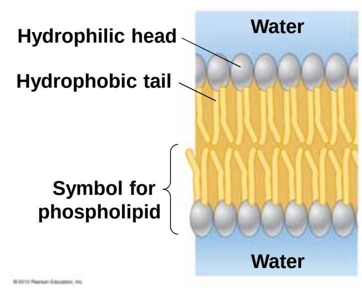
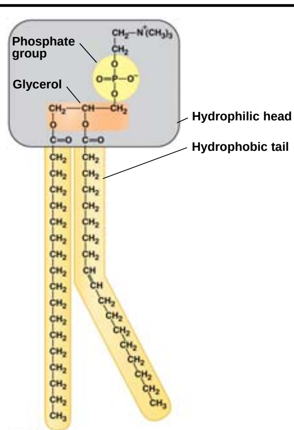


Figure 3.9A



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

- **Steroids** are lipids in which the carbon skeleton contains four fused rings.
- **Cholesterol** is a
  - common component in animal cell membranes and
  - starting material for making steroids, including sex hormones.

Figure 3.9C

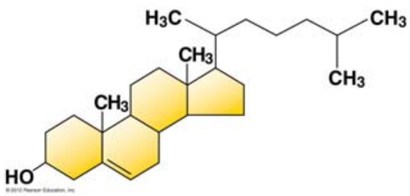


Figure 3.10

3.10 CONNECTION: Anabolic steroids pose health risks

- **Anabolic steroids**
  - are synthetic variants of testosterone,
  - can cause a buildup of muscle and bone mass, and
  - are often prescribed to treat general anemia and some diseases that destroy body muscle.

PROTEINS

3.10 CONNECTION: Anabolic steroids pose health risks

- Anabolic steroids are abused by some athletes with serious consequences, including
  - violent mood swings,
  - depression,
  - liver damage,
  - cancer,
  - high cholesterol, and
  - high blood pressure.

3.11 Proteins are made from amino acids linked by peptide bonds

- Proteins are
  - involved in nearly every dynamic function in your body and
  - very diverse, with tens of thousands of different proteins, each with a specific structure and function, in the human body.
- Proteins are composed of differing arrangements of a common set of just 20 amino acid monomers.

3.11 Proteins are made from amino acids linked by peptide bonds

- **Amino acids** have
  - an amino group and
  - a carboxyl group (which makes it an acid).
- Also bonded to the central carbon is
  - a hydrogen atom and
  - a chemical group symbolized by R, which determines the specific properties of each of the 20 amino acids used to make proteins.

Figure 3.11B

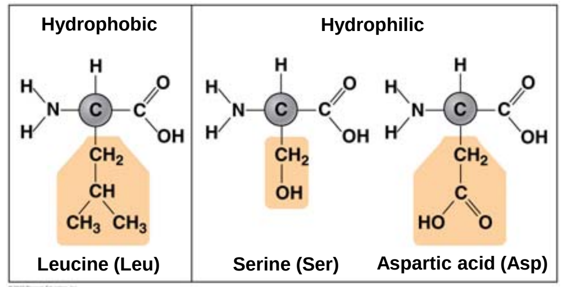
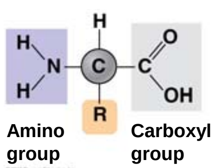


Figure 3.11A



3.11 Proteins are made from amino acids linked by peptide bonds

- Amino acid monomers are linked together
  - in a dehydration reaction,
  - joining carboxyl group of one amino acid to the amino group of the next amino acid, and
  - creating a **peptide bond.**
- Additional amino acids can be added by the same process to create a chain of amino acids called a **polypeptide**.

3.11 Proteins are made from amino acids linked by peptide bonds

- Amino acids are classified as either
  - hydrophobic or
  - hydrophilic.

Figure 3.11C_s1

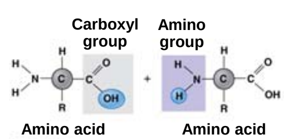


Figure 3.11C_s2

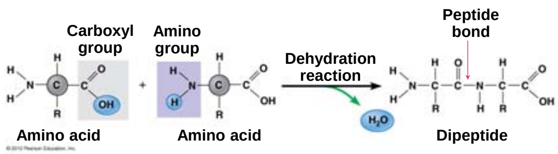


Figure 3.12A

3.12 A protein's specific shape determines its function

- Probably the most important role for proteins is as **enzymes**, proteins that
  - serve as metabolic catalysts and
  - regulate the chemical reactions within cells.

3.12 A protein's specific shape determines its function

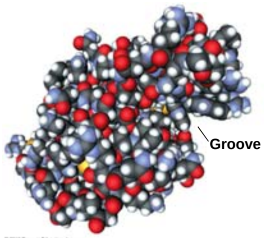
- A polypeptide chain contains hundreds or thousands of amino acids linked by peptide bonds.
- The amino acid sequence causes the polypeptide to assume a particular shape.
- The shape of a protein determines its specific function.

3.12 A protein's specific shape determines its function

- Other proteins are also important.
  - **Structural** proteins provide associations between body parts.
  - **Contractile** proteins are found within muscle.
  - **Defensive** proteins include antibodies of the immune system.
  - **Signal** proteins are best exemplified by hormones and other chemical messengers.
  - **Receptor** proteins transmit signals into cells.
  - **Transport** proteins carry oxygen.
  - **Storage** proteins serve as a source of amino acids for developing embryos.

Figure 3.12B

Figure 3.12C



3.13 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 may affect the protein's ability to function.

3.12 A protein's specific shape determines its function

- If a protein's shape is altered, it can no longer function.
- In the process of **denaturation,** a polypeptide chain
  - unravels,
  - loses its shape, and
  - loses its function.
- Proteins can be denatured by changes in salt concentration, pH, or by high heat.

3.13 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.
  - A certain kind of folding leads to a structure called a pleated sheet, which dominates some fibrous proteins such as those used in spider webs.
  - Coiling and folding are maintained by regularly spaced hydrogen bonds between hydrogen atoms and oxygen atoms along the backbone of the polypeptide chain.

3.13 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**

Figure 3.13_1

Figure 3.13_2

Animation: Protein Structure Introduction
Right click on animation / Click play

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

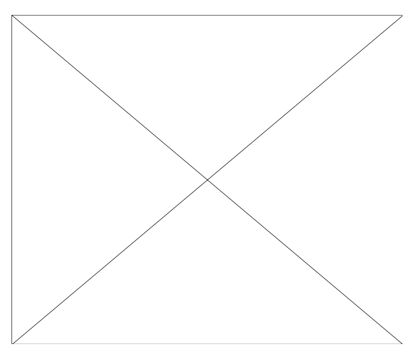
- The overall three-dimensional shape of a polypeptide is called its **tertiary structure.**
  - Tertiary structure generally results from interactions between the R groups of the various amino acids.
  - Disulfide bridges may further strengthen the protein's shape.

Animation: Primary Protein Structure
Right click on animation / Click play

3.13 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.
  - Collagen's triple helix gives great strength to connective tissue, bone, tendons, and ligaments.

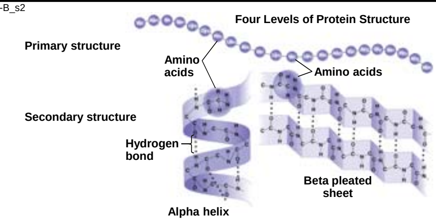
PLAY Animation: Protein Structure Introduction
PLAY Animation: Primary Protein Structure
PLAY Animation: Secondary Protein Structure
PLAY Animation: Tertiary Protein Structure
PLAY Animation: Quaternary Protein Structure



Animation: Secondary Protein Structure
Right click on animation / Click play

Animation: Tertiary Protein Structure
Right click on animation / Click play

Figure 3.13A-B_s2



Animation: Quaternary Protein Structure
Right click on animation / Click play

Figure 3.13A-C_s3

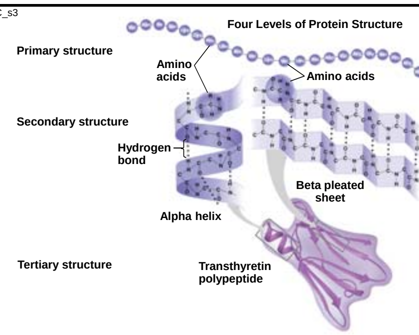


Figure 3.13A_s1

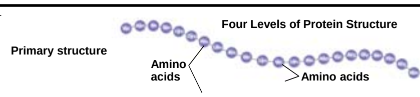


Figure 3.13A-D_s4

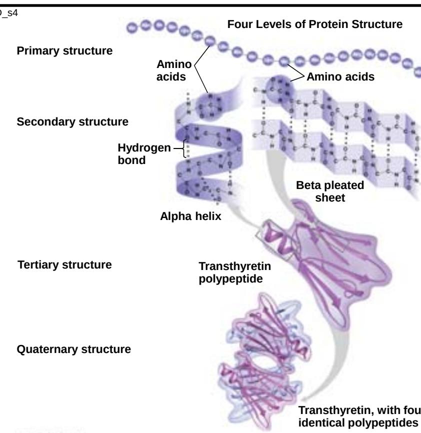


Figure 3.13A

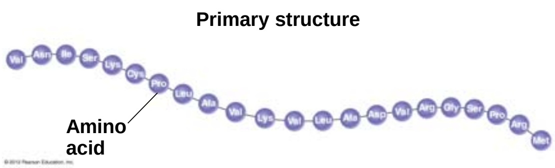


Figure 3.13D

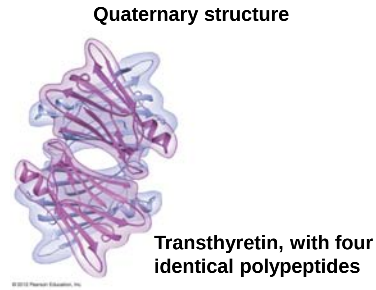
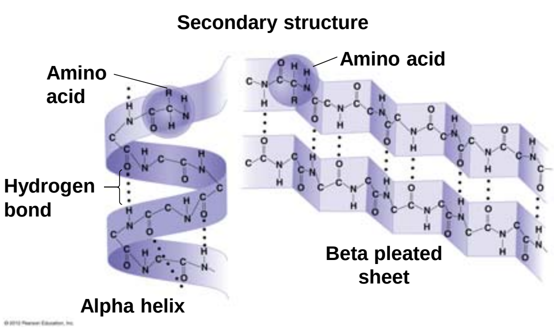
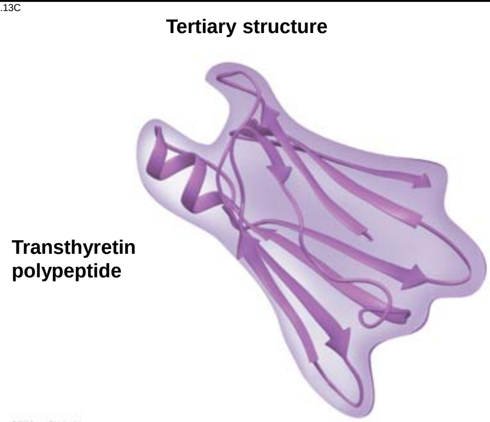


Figure 3.13B



NUCLEIC ACIDS

Figure 3.13C



3.14 DNA and RNA are the two types of nucleic acids

- The amino acid sequence of a polypeptide is programmed by a discrete unit of inheritance known as a **gene**.
- Genes consist of **DNA**(**deoxyribonucleic acid**), a type of **nucleic acid**.
- DNA is inherited from an organism's parents.
- DNA provides directions for its own replication.
- DNA programs a cell's activities by directing the synthesis of proteins.

3.14 DNA and RNA are the two types of nucleic acids

- DNA does not build proteins directly.
- DNA works through an intermediary, **ribonucleic acid (RNA)**.
  - DNA is transcribed into RNA.
  - RNA is translated into proteins.

Figure 3.14_s1

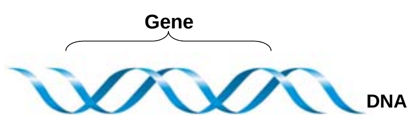


Figure 3.14_s2

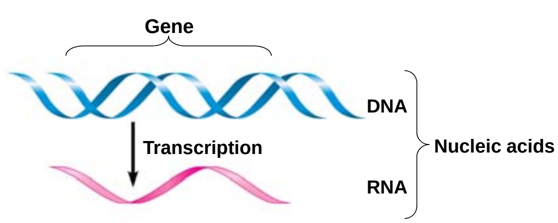
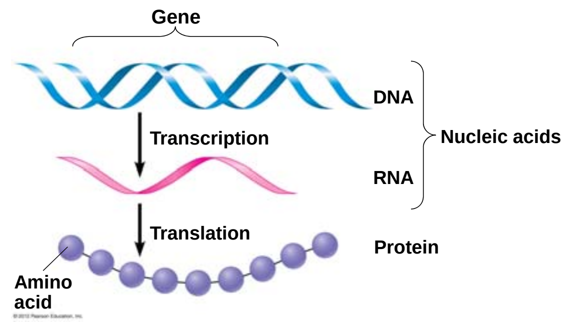


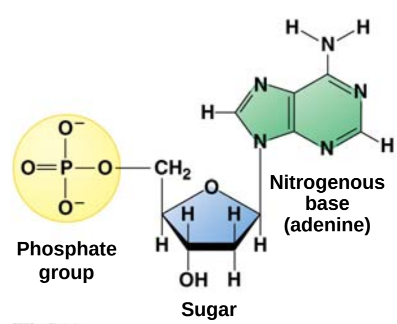
Figure 3.14_s3



3.15 Nucleic acids are 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, and
  - a nitrogenous base.

Figure 3.15A



3.15 Nucleic acids are 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).

3.15 Nucleic acids are 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.

3.15 Nucleic acids are 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,
  - by dehydration reactions, and
  - by producing a repeating sugar-phosphate backbone with protruding nitrogenous bases.

Figure 3.15C

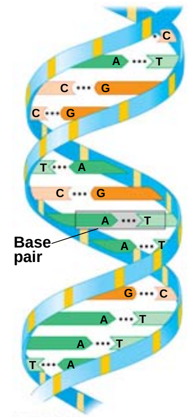
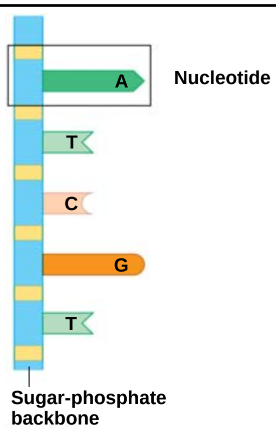


Figure 3.15B



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

- The majority of people
  - stop producing the enzyme lactase in early childhood and
  - do not easily digest the milk sugar lactose.
- Lactose tolerance represents a
  - relatively recent mutation in the human genome and
  - survival advantage for human cultures with milk and dairy products available year-round.

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

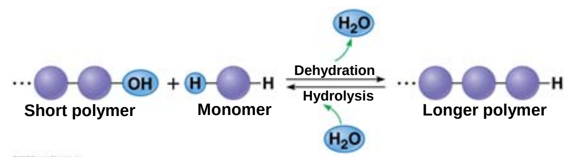
- Researchers identified three mutations that keep the lactase gene permanently turned on.
- The mutations appear to have occurred
  - about 7,000 years ago and
  - at the same time as the domestication of cattle in these regions.

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.
8. Explain how lactose tolerance has evolved in humans.

Figure 3.16

Figure 3.UN01



You should now be able to

1. Describe 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.

Figure 3.UN02

Figure 3.UN03

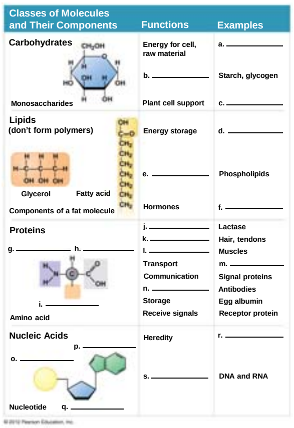


Figure 3.UN04

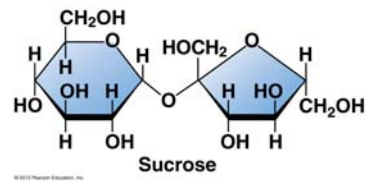


Figure 3.UN03_1

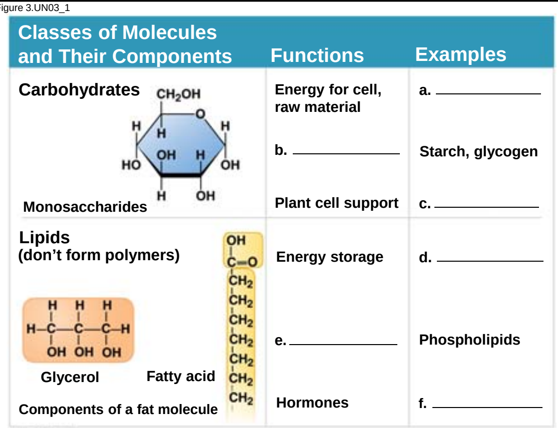


Figure 3.UN05

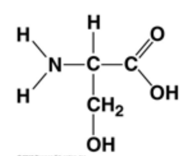


Figure 3.UN03_2

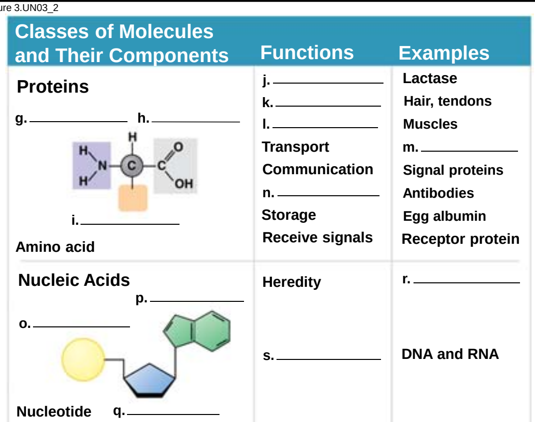


Figure 3.UN06