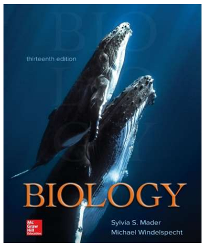


Biology

Sylvia S. Mader
Michael Windelspecht

Chapter 3
The Chemistry of
Organic Molecules
Lecture Outline

See separate FlexArt PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes.

Outline

3.1 Organic Molecules

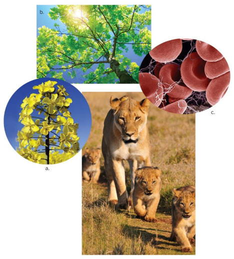
Organic molecules contain both carbon and hydrogen atoms.

Four classes of organic molecules (**biomolecules**) exist in living organisms:

- **Carbohydrates**
- **Lipids**
- **Proteins**
- **Nucleic acids**

Functions of the four biomolecules in the cell are diverse.

Inorganic versus Organic Molecules (2)



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Jump to Inorganic versus Organic Molecules (2) Long Description

The Carbon Atom

The carbon atom is small, with only 6 electrons: two in the first shell and four in the outer shell.

Carbon can form four covalent bonds.

- Bonds with carbon, nitrogen, hydrogen, oxygen, phosphorus and sulfur.
- The C-C bond is very stable.
- Long carbon chains, hydrocarbons, can be formed.
- Besides single bonds, double bonds, triple bonds, and ring structures are also possible.
- Branches may also form at any carbon atom, making complex carbon chains.

The Carbon Skeleton and Functional Groups

The carbon chain of an organic molecule is called its skeleton or backbone.

Functional groups are clusters of specific atoms bonded to the carbon skeleton with characteristic structures and functions.

- Functional groups determine the chemical reactivity and polarity of organic molecules.
- Example: Replacement of an H by -OH in the 2-carbon hydrocarbon ethane turns it into ethanol, and from hydrophobic to hydrophilic.

Inorganic versus Organic Molecules (1)

Table 3.1 Functional Groups

Group	Structure	Compound	Significance
Hydroxyl	$R-OH$	Alcohol as in ethanol	Polar, forms hydrogen bond Present in sugars, some amino acids
Carbonyl	$R-CHO$	Aldehyde as in formaldehyde	Polar Present in sugars
	$R-CO-R$	Ketone as in acetone	Polar Present in sugars
Carboxyl (acidic)	$R-COOH$	Carboxylic acid as in acetic acid	Polar, acidic Present in fatty acids, amino acids
Amino	$R-NH_2$	Amine as in tryptophan	Polar, basic, forms hydrogen bonds Present in amino acids
Sulfhydryl	$R-SH$	Thiol as in ethanethiol	Forms disulfide bonds Present in some amino acids
Phosphate	$R-O-PO(OH)_2$	Organic phosphate as in phosphorylated molecules	Polar, acidic Present in nucleotides, phospholipids

R = remainder of molecule

The Biomolecules of Cells (1)

Carbohydrates, lipids, proteins, and nucleic acids are called **biomolecules**.

- Usually consist of many repeating units
  - Each repeating unit is called a **monomer**.
  - A molecule composed of monomers is called a **polymer** (many parts).
    - Example: amino acids (monomer) are joined together to form a protein (polymer)
  - Lipids are not polymers because they contain two different types of subunits.

The Biomolecules of Cells (2)

Table 3.2 Biomolecules

Category	Subunits (monomers)	Polymer
Carbohydrates*	Monosaccharide	Polysaccharide
Lipids	Glycerol and fatty acids	N/A
Proteins*	Amino acids	Polypeptide
Nucleic acids*	Nucleotide	DNA, RNA

*form polymers

Synthesis and Degradation (1)

Special molecules called enzymes are required for cells to carry out dehydration synthesis and hydrolysis reactions.

- An **enzyme** is a molecule that speeds up a chemical reaction.
  - Enzymes are not consumed in the reaction.
  - Enzymes are not changed by the reaction.
  - Enzymes are catalysts.

3.2 Carbohydrates

Functions:

- Energy source
- Provide building material (structural role)

Contain carbon, hydrogen, and oxygen atoms in a 1:2:1 ratio

Varieties: monosaccharides, disaccharides, and polysaccharides

Monosaccharides

A **monosaccharide** is a single sugar molecule.

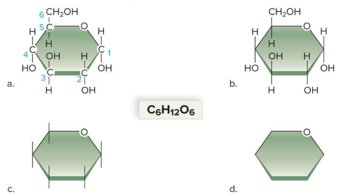
It is also called a simple sugar.

It has a backbone of 3 to 7 carbon atoms.

Examples:

- Glucose (blood sugar), fructose (fruit sugar), and galactose
  - **Hexoses** – six carbon atoms
- Ribose and deoxyribose (sugars contained in nucleotides, the monomer of DNA)
  - **Pentoses** – five carbon atoms

Glucose



$C_6H_{12}O_6$

Jump to Glucose Long Description

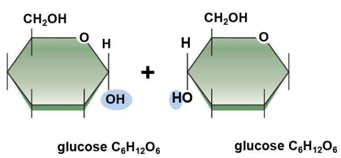
Disaccharides

A **disaccharide** contains two monosaccharides joined together by dehydration synthesis.

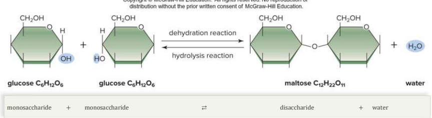
Examples:

- Lactose (milk sugar) is composed of galactose and glucose.
- Sucrose (table sugar) is composed of glucose and fructose.
- Maltose is composed of two glucose molecules.
- Lactose intolerant individuals lack the enzyme lactase which breaks down lactose into galactose and glucose.

Synthesis and Degradation of Maltose (1)



Synthesis and Degradation of Maltose (3)



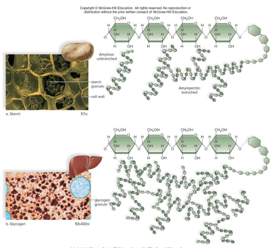
Polysaccharides: Energy-Storage and Structural Molecules (1)

A **polysaccharide** is a polymer of monosaccharides.

Examples:

- **Starch** provides energy storage in plants.
- **Glycogen** provides energy storage in animals.
- **Cellulose** is found in the cell walls of plants.
  - Most abundant organic molecule on earth
  - Animals are unable to digest cellulose.
- **Chitin** is found in the cell walls of fungi and in the exoskeleton of some animals.
- **Peptidoglycan** is found in the cell walls of bacteria.
  - Monomers contain an amino acid chain.

Polysaccharides: Energy-Storage and Structural Molecules (2)



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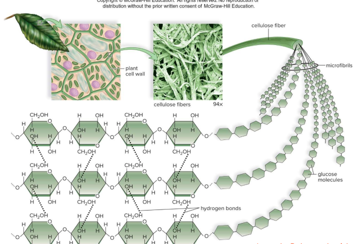
Jump to Polysaccharides: Energy-Storage and Structural Molecules (2) Long Description

Polysaccharides: Energy-Storage and Structural Molecules (3)



Jump to Polysaccharides: Energy-Storage and Structural Molecules (3) Long Description

3.3 Lipids (1)

Varied in structure

Large, nonpolar molecules that are insoluble in water

Functions:

- Long-term energy storage
- Structural components
- Heat retention
- Cell communication and regulation
- Protection

Varieties: fats, oils, phospholipids, steroids, waxes

3.3 Lipids (2)

Table 3.3 Lipids

Type	Functions	Human Uses
Fats	Long-term energy storage and insulation in animals	Butter, lard
Oils	Long-term energy storage in plants and their seeds	Cooking oils
Phospholipids	Component of plasma membrane	Food additive
Steroids	Component of plasma membrane (cholesterol), Sex hormones	Medicines
Waxes	Protection, prevention of water loss (cuticle of plant surfaces), beeswax earwax	Candles, polishes

Triglycerides: Long-Term Energy Storage (1)

Also called **fats** and **oils**

Functions: long-term energy storage and insulation

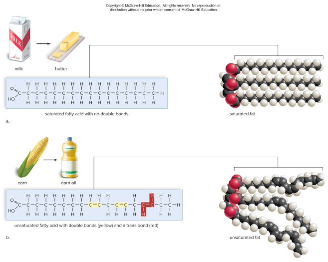
Consist of one glycerol molecule linked to three fatty acids by dehydration synthesis

Triglycerides: Long-Term Energy Storage (2)

Fatty acids may be either **unsaturated** or **saturated**.

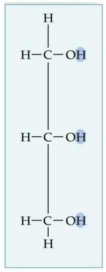
- **Unsaturated** – one or more double bonds between carbons
  - Tend to be liquid at room temperature
    - Example: plant oils
    - Can have chemical groups on the same (cis) or opposite (trans) side of the double bond
- **Saturated** – no double bonds between carbons
  - Tend to be solid at room temperature
    - Examples: butter, lard
- **Trans** – a triglyceride with at least one bond in a trans configuration

Triglycerides: Long-Term Energy Storage (3)



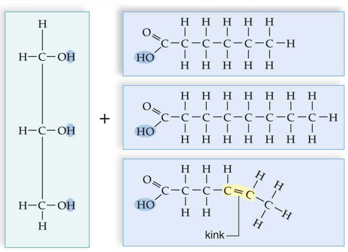
Jump to Triglycerides: Long-Term Energy Storage (3) Long Description

Triglycerides: Long-Term Energy Storage (4)



glycerol

Triglycerides: Long-Term Energy Storage (5)



glycerol

3 fatty acids

Phospholipids: Membrane Components

The structure is similar to triglycerides.

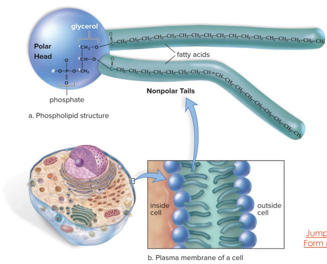
- It consists of one glycerol molecule linked to two fatty acids and a modified phosphate group.
  - The **fatty acids** (tails) are **nonpolar** and **hydrophobic**.
  - The modified **phosphate group** (head) is **polar** and **hydrophilic**.

Function: forms plasma membranes of cells.

In water, phospholipids aggregate to form a lipid bilayer (double layer).

- Polar phosphate heads are oriented towards the water.
- Nonpolar fatty acid tails are oriented away from water.
  - Nonpolar fatty acid tails form a hydrophobic core.
  - Kinks in the tails keep the plasma membrane fluid across a range of temperatures.

Phospholipids Form Membranes



Jump to Phospholipids Form Membranes Long Description

Steroids: Four Fused Carbon Rings

They are composed of four fused carbon rings.

- Various functional groups attached to the carbon skeleton

Functions: component of animal cell membrane, regulation

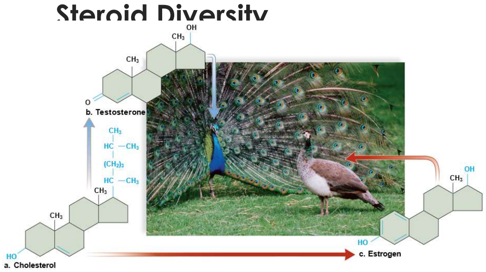
Examples: cholesterol, testosterone, estrogen

- Testosterone and estrogen are sex hormones differing only in the functional groups attached to the same carbon skeleton.

Cholesterol is the precursor molecule for several other steroids.

Cholesterol can also contribute to circulatory disorders.

Steroid Diversity

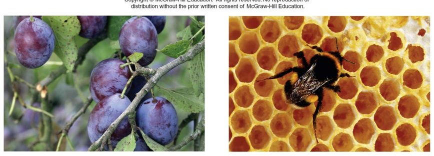


Jump to Steroid Diversity Long Description

Waxes (1)

- Long-chain fatty acids connected to carbon chains containing alcohol functional groups
- Solid at room temperature
- Waterproof
- Resistant to degradation
- Function: protection
- Examples: earwax (contains cerumen), plant cuticle, beeswax

Waxes (2)



a. b.

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Jump to Waxes (2) Long Description

3.4 Proteins

Proteins are polymers of **amino acids** linked together by **peptide bonds**.

- A peptide bond is a covalent bond between amino acids.
- As much as 50% of the dry weight of most cells consists of proteins.
- Several hundred thousand have been identified.

Two or more amino acids joined together are called **peptides**.

- Long chains of amino acids joined together are called **polypeptides**.

A **protein** is a polypeptide that has folded into a particular shape, which is essential for its proper functioning.

Functions of Proteins

Metabolism

- Most enzymes are proteins that act as catalysts to accelerate chemical reactions within cells.

Support

- Some proteins have a structural function, for example, keratin and collagen.

Transport

- Membrane channel and carrier proteins regulate what substances enter and exit cells. Hemoglobin protein transports oxygen to tissues and cells.

Defense

- Antibodies are proteins of our immune system that bind to antigens and prevent them from destroying cells.

Regulation

- Hormones are regulatory proteins that influence the metabolism of cells.

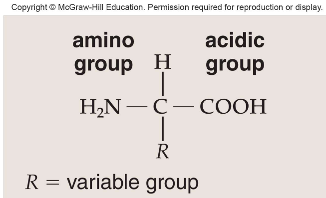
Motion

- Microtubules move cell components to different locations. Actin and myosin contractile proteins allow muscles to contract.

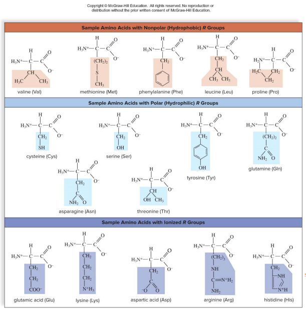
Amino Acids: Protein Monomers (1)

There are 20 different common amino acids.

Amino acids differ by their *R*, or variable groups, which range in complexity.



Amino Acids: Protein Monomers (2)



Jump to Amino Acids: Protein Monomers (2) Long Description

Shapes of Proteins and Levels of Protein Structure

Proteins cannot function properly unless they fold into their proper shape.

- When a protein loses it proper shape, it said to be **denatured**.
  - Exposure of proteins to certain chemicals, a change in pH, or high temperature can disrupt protein structure.

Proteins can have up to four levels of structure:

- **Primary**
- **Secondary**
- **Tertiary**
- **Quaternary**

Four Levels of Protein Structure (1)

Primary level

- Primary level is the linear sequence of amino acids.
- Hundreds of thousands of different polypeptides can be built from just 20 amino acids.
- Changing the sequence of amino acids can produce different proteins.

Secondary level

- Secondary level is characterized by the presence of alpha helices and beta (pleated) sheets held in place with hydrogen bonds.

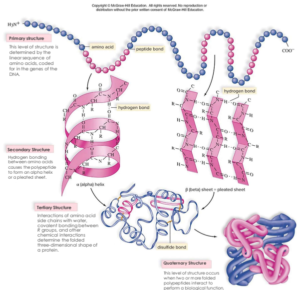
Tertiary level

- Tertiary level is the overall three-dimensional shape of a polypeptide.
- It is stabilized by the presence of hydrophobic interactions, hydrogen, ionic, and covalent bonding.

Quaternary level

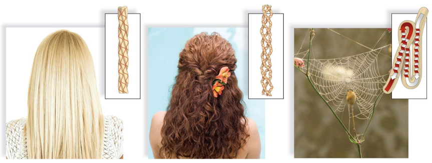
- Quaternary level consists of more than one polypeptide.

Four Levels of Protein Structure (2)



Jump to Four Levels of Protein Structure (2) Long Description

Examples of Fibrous Proteins



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Jump to Examples of Fibrous Proteins Long Description

The Importance of Protein Folding and Protein-Folding Diseases

Prions are misfolded proteins that have been implicated in a group of fatal brain diseases known as TSEs.

- Mad cow disease is one example of a TSE.
- Prions are believed to cause other proteins to fold the wrong way.

3.5 Nucleic Acids

Nucleic acids are polymers of **nucleotides**.

Two varieties of nucleic acids:

- **DNA (deoxyribonucleic acid)**
  - Genetic material that stores information for its own replication and for the sequence of amino acids in proteins
- **RNA (ribonucleic acid)**
  - Performs a wide range of functions within cells which include protein synthesis and regulation of gene expression

Structure of a Nucleotide

Each nucleotide is composed of three parts:

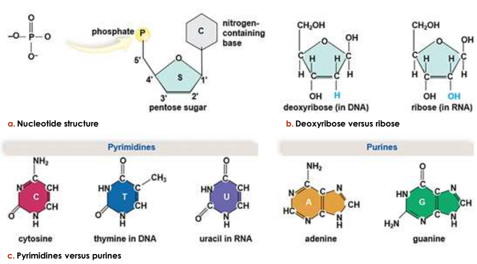
- **A phosphate group**
- **A pentose sugar**
- **A nitrogen-containing (nitrogenous) base**

There are five types of nucleotides found in nucleic acids.

- **DNA** contains **adenine**, **guanine**, **cytosine**, and **thymine**.
- **RNA** contains **adenine**, **guanine**, **cytosine**, and **uracil**.

Nucleotides are joined together by a series of dehydration synthesis reactions to form a linear molecule called a strand, which is a sequence of nucleotides.

Nucleotides (4)



Jump to Nucleotides (4) Long Description

Structure of DNA and RNA (1)

The backbone of the nucleic acid strand is composed of alternating sugar-phosphate molecules.

RNA is predominately a single-stranded molecule, whereas DNA is a double-stranded molecule.

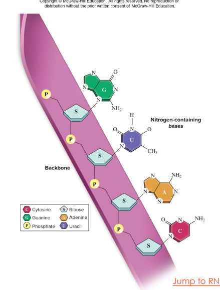
- DNA is composed of two strands held together by hydrogen bonds between the nitrogen-containing bases. The two strands twist around each other, forming a double helix.
- The nucleotides may be in any order within a strand but between strands:
  - Adenine (purine) makes hydrogen bonds with thymine (pyrimidine).
  - Cytosine (pyrimidine) makes hydrogen bonds with guanine (purine).
- The bonding between the nitrogen-containing bases in DNA is referred to as **complementary base pairing**.
  - The number of A + G (purines) always equals the number of T + C (pyrimidines).

Structure of DNA and RNA (2)

Table 3.4 DNA Structure Compared to RNA Structure

	DNA	RNA
Sugar	Deoxyribose	Ribose
Bases	Adenine, guanine, thymine, cytosine	Adenine, guanine, uracil, cytosine
Strands	Double stranded with base pairing	Single stranded
Helix	Yes	No

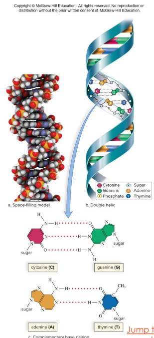
RNA Structure



Jump to RNA Structure Long Description

DNA Structure

Complementary Base Pairing in DNA



a. Space-filling model b. Double helix c. Complementary base pairing

Jump to DNA Structure Long Description

ATP (Adenosine Triphosphate)

ATP (adenosine triphosphate) is a nucleotide composed of adenine and ribose (adenosine) and three phosphates.

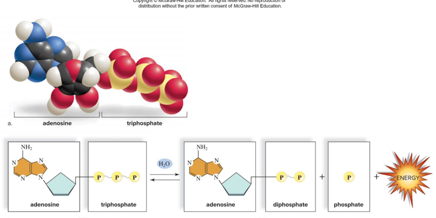
ATP is a high-energy molecule due to the presence of the last two unstable phosphate bonds, which are easily broken.

Hydrolysis of the terminal phosphate bond yields:

- The molecule ADP (adenosine diphosphate)
- An inorganic phosphate, P
- Energy to do cellular work
  - The hydrolysis of the ATP molecule can be coupled with chemically unfavorable reactions in the cell to allow the reactions to proceed.
  - Example: key steps in the synthesis of carbohydrates and proteins, and muscle contraction and nerve impulse conduction

ATP is therefore called the energy currency of the cell.

ATP



Jump to ATP Long Description