Chapter 5

The Structure and Function of Large Biological Molecules

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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Overview: The Molecules of Life

- All living things are made up of four classes of large biological molecules: carbohydrates, lipids, proteins, and nucleic acids
- Within cells, small organic molecules are joined together to form larger molecules
- **Macromolecules** are large molecules composed of thousands of covalently connected atoms
- Molecular structure and function are inseparable

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Concept 5.1: Macromolecules are polymers, built from monomers

- A **polymer** is a long molecule consisting of many similar building blocks
- These small building-block molecules are called **monomers**
- Three of the four classes of life's organic molecules are polymers:
  - Carbohydrates
  - Proteins
  - Nucleic acids

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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

PLAY **Animation: Polymers**

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The Diversity of Polymers

- Each cell has thousands of different kinds of macromolecules
- Macromolecules vary among cells of an organism, vary more within a species, and vary even more between species
- An immense variety of polymers can be built from a small set of monomers

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Concept 5.2: Carbohydrates serve as fuel and building material

- **Carbohydrates** include sugars and the polymers of sugars
- The simplest carbohydrates are monosaccharides, or single sugars
- Carbohydrate macromolecules are polysaccharides, polymers composed of many sugar building blocks

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Sugars

- **Monosaccharides** have molecular formulas that are usually multiples of CH_2O
- Glucose ($C_6H_{12}O_6$) is the most common monosaccharide
- Monosaccharides are classified by
  - The location of the carbonyl group (as aldose or ketose)
  - The number of carbons in the carbon skeleton

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- Though often drawn as linear skeletons, in aqueous solutions many sugars form rings
- Monosaccharides serve as a major fuel for cells and as raw material for building molecules

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- A **disaccharide** is formed when a dehydration reaction joins two monosaccharides
- This covalent bond is called a **glycosidic linkage**

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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

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Storage Polysaccharides

- **Starch**, a storage polysaccharide of plants, consists entirely of glucose monomers
- Plants store surplus starch as granules within chloroplasts and other plastids

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- **Glycogen** is a storage polysaccharide in animals
- Humans and other vertebrates store glycogen mainly in liver and muscle cells

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Structural Polysaccharides

- The polysaccharide **cellulose** is a major component of the tough wall of plant cells
- Like starch, cellulose is a polymer of glucose, but the glycosidic linkages differ
- The difference is based on two ring forms for glucose: alpha (α) and beta (β)

PLAY Animation: Polysaccharides

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- Polymers with α glucose are helical
- Polymers with β glucose are straight
- 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

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- Enzymes that digest starch by hydrolyzing α linkages can’t hydrolyze β linkages in cellulose
- Cellulose in human food passes through the digestive tract as insoluble fiber
- Some microbes use enzymes to digest cellulose
- Many herbivores, from cows to termites, have symbiotic relationships with these microbes

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- **Chitin**, another structural polysaccharide, is found in the exoskeleton of arthropods
- Chitin also provides structural support for the cell walls of many fungi

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Concept 5.3: 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

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Fats

- **Fats** are constructed from two types of smaller molecules: glycerol and fatty acids
- Glycerol is a three-carbon alcohol with a hydroxyl group attached to each carbon
- A **fatty acid** consists of a carboxyl group attached to a long carbon skeleton

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- Fats separate from water because water molecules form hydrogen bonds with each other and exclude the fats
- In a fat, three fatty acids are joined to glycerol by an ester linkage, creating a **triacylglycerol**, or triglyceride

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- Fatty acids vary in length (number of carbons) and in the number and locations of double bonds
- **Saturated fatty acids** have the maximum number of hydrogen atoms possible and no double bonds
- **Unsaturated fatty acids** have one or more double bonds

PLAY Animation: Fats

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- Fats made from saturated fatty acids are called saturated fats, and are solid at room temperature
- Most animal fats are saturated
- Fats made from unsaturated fatty acids are called unsaturated fats or oils, and are liquid at room temperature
- Plant fats and fish fats are usually unsaturated

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- A diet rich in saturated fats may contribute to cardiovascular disease through plaque deposits
- Hydrogenation is the process of converting unsaturated fats to saturated fats by adding hydrogen
- Hydrogenating vegetable oils also creates unsaturated fats with *trans* double bonds
- These *trans* fats may contribute more than saturated fats to cardiovascular disease

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- 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

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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

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- 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

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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

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Concept 5.4: Proteins have many structures, resulting in a wide range of functions

- Proteins account for more than 50% of the dry mass of most cells
- Protein functions include structural support, storage, transport, cellular communications, movement, and defense against foreign substances

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- **Enzymes** are a type of protein that acts as a **catalyst** to speed up chemical reactions
- Enzymes can perform their functions repeatedly, functioning as workhorses that carry out the processes of life

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Polypeptides

- **Polypeptides** are polymers built from the same set of 20 amino acids
- A **protein** consists of one or more polypeptides

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Amino Acid Monomers

- **Amino acids** are organic molecules with carboxyl and amino groups
- Amino acids differ in their properties due to differing side chains, called R groups

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Amino Acid Polymers

- Amino acids are linked by **peptide bonds**
- A polypeptide is a polymer of amino acids
- Polypeptides range in length from a few to more than a thousand monomers
- Each polypeptide has a unique linear sequence of amino acids

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Protein Structure and Function

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

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- The sequence of amino acids determines a protein’s three-dimensional structure
- A protein’s structure determines its function

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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

PLAY Animation: Protein Structure Introduction

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- **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

PLAY Animation: Primary Protein Structure

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- 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**

PLAY Animation: Secondary Protein Structure

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- **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

PLAY Animation: Tertiary Protein Structure

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- **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

PLAY Animation: Quaternary Protein Structure

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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

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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

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Protein Folding in the Cell

- It is hard to predict a protein's structure from its primary structure
- Most proteins probably go through several states on their way to a stable structure
- **Chaperonins** are protein molecules that assist the proper folding of other proteins

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- Scientists use **X-ray crystallography** to determine a protein’s structure
- Another method is nuclear magnetic resonance (NMR) spectroscopy, which does not require protein crystallization
- Bioinformatics uses computer programs to predict protein structure from amino acid sequences

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Concept 5.5: 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**

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The Roles of Nucleic Acids

- 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

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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*

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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

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Nucleotide Polymers

- 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

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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 $5' \rightarrow 3'$ 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)

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DNA and Proteins as Tape Measures of Evolution

- The linear sequences of nucleotides in DNA molecules are passed from parents to offspring
- Two closely related species are more similar in DNA than are more distantly related species
- Molecular biology can be used to assess evolutionary kinship

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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

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You should now be able to:

1. List and describe the four major classes of molecules
2. Describe the formation of a glycosidic linkage and distinguish between monosaccharides, disaccharides, and polysaccharides
3. Distinguish between saturated and unsaturated fats and between *cis* and *trans* fat molecules
4. Describe the four levels of protein structure

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You should now be able to:

5. Distinguish between the following pairs: pyrimidine and purine, nucleotide and nucleoside, ribose and deoxyribose, the 5′ end and 3′ end of a nucleotide

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