The Structure and Function of Macromolecules
Proteins & Nucleic Acids
The FOUR Classes of Large Biomolecules

• All living things are made up of four classes of large biological molecules:
  • Carbohydrates
  • Lipids
  • Protein
  • Nucleic Acids

• Macromolecules are large molecules composed of thousands of covalently bonded atoms

• Molecular structure and function are inseparable
Proteins Come In Many Varieties!

• Proteins include a diversity of 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
Enzymatic proteins

Function: Selective acceleration of chemical reactions

Example: Digestive enzymes catalyze the hydrolysis of bonds in food molecules.
Storage proteins

Function: Storage of amino acids

Examples: Casein, the protein of milk, is the major source of amino acids for baby mammals. Plants have storage proteins in their seeds. Ovalbumin is the protein of egg white, used as an amino acid source for the developing embryo.
Hormonal proteins

Function: Coordination of an organism’s activities

Example: Insulin, a hormone secreted by the pancreas, causes other tissues to take up glucose, thus regulating blood sugar concentration.
Defensive proteins

Function: Protection against disease

Example: Antibodies inactivate and help destroy viruses and bacteria.
Transport proteins

Function: Transport of substances

Examples: Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across cell membranes.
Receptor proteins

Function: Response of cell to chemical stimuli

Example: Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.
Structural proteins

Function: Support

Examples: Keratin is the protein of hair, horns, feathers, and other skin appendages. Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin proteins provide a fibrous framework in animal connective tissues.
More About Enzymes

- **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.
Amino Acids: Yet Another Monomer

- **Amino acids** are organic molecules with carboxyl and amino groups.

- Amino acids differ in their properties due to differing side chains, called R groups.
Polypeptides

- **Polypeptides** are unbranched polymers built from **20 amino acids**
- **A protein** is a biologically functional molecule that consists of one or more polypeptides
Nonpolar side chains; hydrophobic

Glycine (Gly or G)

Alanine (Ala or A)

Valine (Val or V)

Leucine (Leu or L)

Isoleucine (Ile or I)

Methionine (Met or M)

Phenylalanine (Phe or F)

Tryptophan (Trp or W)

Proline (Pro or P)

Hydrophobic: Therefore retreat from water!
Hydrophilic: Therefore Are Attracted to Water
Hydrophilic: But Electrically Charged!
Peptide Bonds

- 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, with a carboxyl end (C-terminus) and an amino end (N-terminus)
Peptide Bonds
Peptide Bonds
Protein Structure & Function

• At first—just amino acids with peptide bonds

• Amino acid chain then interacts with itself (folds, coils) and the (usually aqueous environment) until it is a 3D structure

• The sequence of amino acids determines a protein’s 3D structure

• A protein’s structure determines its function
Protein Structure: 4 Levels

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

- **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.
Secondary Structure

• The coils and folds of secondary structure result from hydrogen bonds between repeating parts of the polypeptide backbone.

• Typical secondary structures are a coil called an \( \alpha \) helix and a folded structure called a \( \beta \) pleated sheet.
Secondary Structure

- **α helix**
- **β pleated sheet**
  - β strand, shown as a flat arrow pointing toward the carboxyl end
  - Hydrogen bond
Tertiary Structure

- **Tertiary structure** is determined by interactions between R groups, rather than interactions between backbone parts.

- Interactions between R groups include actual *ionic bonds* and strong *covalent bonds* called *disulfide bridges* which may *reinforce* the protein’s structure.

- **Intermolecular forces** such as van der Waals, hydrogen bonds, and hydrophobic interactions may *affect* the protein’s structure.
Tertiary Structure
Quaternary Structure

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

- Collagen is a fibrous protein consisting of three polypeptides coiled like a rope.
Quaternary Structure

• Hemoglobin is a globular protein consisting of four polypeptides: two alpha and two beta chains
Four Levels of Protein Structure Revisited

(a) Primary structure

(b) Secondary structure

(c) Tertiary structure

(d) Quaternary structure

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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.
Denature: Break Bonds or Disrupt intermolecular forces
Nucleic Acids

- Nucleic acids store, transmit, and help express hereditary information.
- Make proteins inside cell!
- Genes are made of DNA, a nucleic acid made of monomers called nucleotides.
Two Types of Nucleic Acids

- Two types:
  - 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 on ribosomes
Figure 5.25-1

1 Synthesis of mRNA

DNA

mRNA

NUCLEUS

CYTOPLASM

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Figure 5.25-2

1. Synthesis of mRNA

2. Movement of mRNA into cytoplasm
**Figure 5.25-3**

1. Synthesis of mRNA
2. Movement of mRNA into cytoplasm
3. Synthesis of protein

**DNA**

**mRNA**

**NUCLEUS**

**CYTOPLASM**

**Amino acids**

**Polypeptide**

**Ribosome**
The Components of Nucleic Acids

- Each nucleic acid is made of monomers called **nucleotides**
- Each nucleotide consists of a *nitrogenous base*, *a pentose sugar*, *and one or more phosphate groups*
Figure 5.26ab

(a) Polynucleotide, or nucleic acid

(b) Nucleotide

Sugar-phosphate backbone

Nucleoside

Nitrogenous base

Phosphate group

Sugar (pentose)
Nitrogenous bases

Pyrimidines

Cytosine (C)

Thymine (T, in DNA)

Uracil (U, in RNA)

Purines

Adenine (A)

Guanine (G)

Sugars

Deoxyribose (in DNA)

Ribose (in RNA)

(c) Nucleoside components
double stranded DNA

Hydrogen bond

phosphodiester bonds

antiparallel

5'

3'

deoxyribose

3'

5'

purine

pyrimidine

T

A

G

C

C

G

A

T
- 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**
Sugar-Phosphate Backbone

- 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
RNA and DNA structure

- RNA molecules usually exist as single polypeptide chains
- DNA molecules have two polynucleotides spiraling around an imaginary axis, forming a double helix
- In the DNA double helix, the two backbones run in opposite 5′→ 3′ directions from each other, an arrangement referred to as antiparallel
- One DNA molecule includes many genes
Complimentary Base Pairing

• The nitrogenous bases in DNA pair up and form hydrogen bonds: adenine (A) always with thymine (T), and guanine (G) always with cytosine (C)
• Called complementary base pairing
• In RNA, thymine is replaced by uracil (U) so A and U pair
Sugar-phosphate backbones
Hydrogen bonds

Base pair joined by hydrogen bonding

(a) DNA

(b) Transfer RNA
Link to 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
Could Prove Useful

<table>
<thead>
<tr>
<th>Monomers or Components</th>
<th>Polymer or Larger Molecule</th>
<th>Type of Linkage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrates</td>
<td>Monosaccharides</td>
<td>Polysaccharides</td>
</tr>
<tr>
<td>Lipids</td>
<td>Fatty acids</td>
<td>Triacylglycerols</td>
</tr>
<tr>
<td>Proteins</td>
<td>Amino acids</td>
<td>Polypeptides</td>
</tr>
<tr>
<td>Nucleic acids</td>
<td>Nucleotides</td>
<td>Polynucleotides</td>
</tr>
</tbody>
</table>