CHAPTER 3 THE CHEMISTRY OF ORGANIC MOLECULES

Chapter Outline

3.1 Organic Molecules

A. Definitions

1. **Organic molecules** have carbon bonded to other atoms and determine structure and function of living things.
2. **Inorganic molecules** do not contain carbon and hydrogen together; inorganic molecules such as salt ions can play important roles in living things.

B. The Carbon Atom

1. Most common elements in living things are carbon, hydrogen, nitrogen, and oxygen.
2. These four elements constitute about 95% of your body weight.
3. Chemistry of carbon allows the formation of an enormous variety of organic molecules.
4. Carbon has four electrons in outer shell; bonds with up to four other atoms (usually H, O, N, or another C).

C. The Carbon Skeleton and Functional Groups

1. Ability of carbon to bond to itself makes possible carbon chains and rings; these structures serve as the backbones of organic molecules.
2. **Functional groups** are clusters of atoms with characteristic structure and functions.
   a. Addition of an –OH (hydroxyl group) turns a carbon skeleton into an alcohol.
   b. The ethanol alcohol is hydrophilic, it dissolves in water, because the –OH functional group is polar.
   c. Nonpolar molecules are repelled by water and do not dissolve in water; are **hydrophobic.**
   d. A hydrocarbon is hydrophobic except when it has an attached ionized functional group such as carboxyl (acid) (—COOH); then the molecule is hydrophilic.
   e. Carboxyl groups ionize in solution and release hydrogen ions, being both polar and acidic.
   f. Cells are 70–90% water; the degree organic molecules interact with water affects their function.
3. **Isomers** are molecules with identical molecular formulas but differ in arrangement of their atoms (e.g., glyceraldehyde and dihydroxyacetone).

D. The Macromolecules of Cells

1. Cells contain four classes of macromolecules (carbohydrates, lipids, proteins, and nucleic acids) and they provide great diversity.
2. The largest macromolecules are polymers constructed of small subunits (e.g., monosaccharides, glycerol and fatty acids, amino acids, and nucleotides) that serve as **monomers**, subunits of polymers.
3. **Polymers** are the large macromolecules composed of three to millions of monomer subunits.
4. Polymers build by different bonding of different monomers; mechanism of joining and breaking these bonds is dehydration synthesis and hydrolysis.
5. Cellular enzymes carry out condensation synthesis and hydrolysis of polymers.
6. During **dehydration synthesis**, a water is removed and a bond is made (synthesis).
   a. When two monomers join, a hydroxyl (—OH) group is removed from one monomer and a hydrogen (—H) is removed from the other.
   b. This produces water.
7. **Hydrolysis reactions** break down polymers in reverse of dehydration; a hydroxyl (—OH) group from water attaches to one monomer and hydrogen (—H) attaches to the other.

3.2 Carbohydrates

A. Monosaccharides: Ready Energy

1. **Monosaccharides** are simple sugars with a carbon backbone of three to seven carbon atoms.

    a. Best known sugars have six carbons (hexoses).
    b. Glucose and fructose isomers have same formula ($C_6H_{12}O_6$) but differ in structure.
    c. Glucose is commonly found in blood of animals; is immediate energy source to cells.
2. **Ribose** and **deoxyribose** are five-carbon sugars (pentoses); they contribute to the backbones of RNA and DNA, respectively.

B. Disaccharides: Varied Uses
1. **Disaccharides** contain two monosaccharides joined by dehydration synthesis.
2. **Lactose** is composed of galactose and glucose and is found in milk.
3. **Maltose** is two glucose molecules; forms in digestive tract of humans during starch digestion.
4. **Sucrose** is composed of glucose and fructose and is transported within plants.

C. Polysaccharides as Energy Storage Molecules
1. **Polysaccharides** are polymers of monosaccharides.
2. **Starch** is straight chain of glucose molecules with few side branches.
3. **Glycogen** is highly branched polymer of glucose with many side branches; called "animal starch," it is the storage carbohydrate of animals.

B. Polysaccharides as Structural Molecules
1. **Cellulose** is glucose bonded to form microfibrils; primary constituent of plant cell walls.
    a. Cotton is nearly pure cellulose.
    b. Cellulose is not easily digested due to the strong linkage between glucose molecules.
    c. Grazing animals can digest cellulose due to special stomachs and bacteria.
2. **Chitin** is a polymer of glucose with amino acid attached to each; it is primary constituent of crabs and related animals such as lobsters and insects.

3.3 Lipids

A. Lipids are varied in structure.
1. Lipids are insoluble in water because they lack polar groups.
2. **Fat** provides insulation and energy storage.
3. **Phospholipids** form plasma membranes and **steroids** are important cell messengers.
4. **Waxes** function to protect many organisms.

B. Triglycerides: Long-Term Energy Storage
1. Lipids contain two molecular units: glycerol and fatty acids.
2. **Glycerol** is a water-soluble compound with three hydroxyl groups.
3. **Triglycerides** are glycerol joined to three fatty acids by dehydration synthesis.
4. A **fatty acid** is a long hydrocarbon chain with a carboxyl (acid) group at one end.
    a. Most fatty acids in cells contain 16 to 18 carbon atoms per molecule.
    b. **Saturated fatty acids** have no double bonds between their carbon atoms.
    c. **Unsaturated fatty acids** have double bonds in the carbon chain where there are less than two hydrogens per carbon atom.
4. **Fats** are triglycerides containing saturated fatty acids (e.g., butter is solid at room temperature).
5. **Oils** are triglycerides with unsaturated fatty acids (e.g., corn oil is liquid at room temperature).
6. Animals use fat rather than glycogen for long-term energy storage; fat stores more energy.

C. Phospholipids
1. **Phospholipids** are like neutral fats except the third fatty acid is replaced by phosphate group or a group with both phosphate and nitrogen.
2. The phosphate group bonds to another organic group (*R*) and is the polar head; hydrocarbon chains become nonpolar tails.
3. Phospholipids arrange themselves in a double layer in water, so the polar heads face outward toward water molecules and nonpolar tails face toward each other away from water molecules.
4. This property enables them to form an interface or separation between two solutions (e.g., the interior and exterior of a cell); the plasma membrane is a phospholipid bilayer.

D. Steroids
1. **Steroids** differ from neutral fats; steroids have a backbone of four fused carbon rings and vary according to attached functional groups.
2. Steroid functions vary due to different attached functional groups.
3. **Cholesterol** is a part of an animal cell's membrane and a precursor of other steroids, including aldosterone and sex hormones.

4. **Testosterone** is the male sex hormone; **estrogen** is the female sex hormone.
5. A diet high in saturated fats and cholesterol can lead to circulatory disorders.

E. Waxes
1. **Waxes** are a long-chain fatty acid bonded to a long-chain alcohol.
2. Solid at room temperature, waxes have a high melting point and are waterproof and resist degradation.
3. Waxes form a protective covering in plants that retards water loss in leaves and fruits.
4. In animals, waxes maintain animal skin and fur, trap dust and dirt, and forms honeycomb.

3.4 Proteins

A. Protein Functions
1. **Support** proteins include **keratin,** which makes up hair and nails, and **collagen** fibers, which support many organs.
2. **Enzymes** are proteins that act as organic catalysts to speed chemical reactions within cells.
3. **Transport** functions include channel and carrier proteins in the plasma membrane and hemoglobin that carries oxygen in red blood cells.
4. **Defense** functions include antibodies that prevent infection.
5. **Hormones** include **insulin** that regulates glucose content of blood.
6. **Motion** is provided by **myosin** and **actin** proteins that make up the bulk of muscle.

B. Amino Acids: Subunits of Proteins
1. All amino acids contain an acidic group (— COOH) and an **amino** group ($—NH_2$).
2. Amino acids differ in nature of *R* group, ranging from single hydrogen to complicated ring compounds.
3. *R* group of amino acid cysteine ends with a sulfhydryl (— SH) that serves to connect one chain of amino acids to another by a disulfide bond (— S— S—).
4. There are 20 different amino acids commonly found in cells.

C. Peptides
1. **Peptide bond** is a covalent bond between amino acids in a peptide.
2. Atoms of a peptide bond share electrons unevenly (oxygen is more electronegative than nitrogen).
3. Polarity of the peptide bond permits hydrogen bonding between parts of a polypeptide.
4. A **peptide** is two or more amino acids bonded together.
5. **Polypeptides** are chains of many amino acids joined by peptide bonds.
6. Protein may contain more than one polypeptide chain; it can have large numbers of amino acids.
7. The three-dimensional shape of the protein is critical; an abnormal sequence will have the wrong shape and not function normally.
8. Frederick Sanger determined first protein sequence (with hormone insulin) in 1953.

D. Shape of Proteins
1. Protein shape determines the function of the protein in the organism; proteins can have up to four levels of structure.
2. **Primary structure** is sequence of amino acids joined by peptide bonds.
   a. Just as English alphabet contains 26 letters, 20 amino acids can join to form a huge variety of "words."
   b. Each protein has a unique sequence of amino acids.
3. **Secondary structure** results when a polypeptide coils or folds.
   a. The α **(alpha) helix** was the first pattern discovered by Linus Pauling and Robert Corey.
      1) In peptide bonds, oxygen is partially negative, hydrogen is partially positive.
      2) Allows hydrogen bonding between the C=O of one amino acid and the N—H of another.
      3) Hydrogen bonding between every fourth amino acid holds spiral shape of an α helix.
      4) α helices covalently bonded by disulfide (—S—S—) linkages between two cysteine amino acids.
   b. The **β sheet** was the second pattern discovered.
      1) Pleated β sheet polypeptides turn back upon themselves.
      2) Hydrogen bonding occurs between extended lengths.
   c. **Fibrous proteins** are structural proteins with helices and/or pleated sheets that hydrogen bond to each other.
4. **Tertiary structure** results when proteins of secondary structure are folded, due to various interactions between the *R* groups of their constituent amino acids.

a. Globular proteins tend to ball up into rounded shapes.
b. Strong disulfide linkages maintain the tertiary shape; hydrogen, ionic, and covalent bonds also contribute.

5. **Quaternary structure** results when two or more polypeptides combine.
   a. Hemoglobin is globular protein with a quaternary structure of four polypeptides.
   b. Most enzymes have a quaternary structure; changes in pH can change the polarity of *R* groups and disrupt the enzyme action or **denature** the protein.

E. Protein Folding Diseases
   1. As proteins are synthesized, chaperone molecules prevent them from making incorrect shapes.
   2. TSE brain diseases including mad-cow disease, are likely due to misfolded proteins.

3.5 Nucleic Acids

A. Nucleic Acid Functions
   1. Nucleic acids are polymers of nucleotides with very specific functions in cells.
   2. **DNA** (**deoxyribonucleic acid**) is the nucleic acid whose nucleotide sequence stores the genetic code for its own replication and for the sequence of amino acids in proteins.
   3. **RNA** (**ribonucleic acid**) is a single-stranded nucleic acid that translates the genetic code of DNA into the amino acid sequence of proteins.
   4. Nucleotides have independent metabolic functions in cells.
      a. **Coenzymes** are molecules which facilitate enzymatic reactions.
      b. **ATP (adenosine triphosphate)** is a nucleotide used to supply energy.

B. Structure of DNA and RNA
   1. Nucleotides are a molecular complex of three types of molecules: a phosphate (phosphoric acid), a pentose sugar, and a nitrogen-containing base.
   2. DNA and RNA differ in the following ways:
      a. Nucleotides of DNA contain **deoxyribose** sugar; nucleotides of RNA contain **ribose.**
      b. In RNA, the base uracil occurs instead of the base thymine, as in DNA.
      c. DNA is double-stranded with complementary base pairing; RNA is single-stranded.
         1) **Complementary base pairing** occurs where two strands of DNA are held together by hydrogen bonds between purine and pyrimidine bases.
         2) The number of purine bases always equals the number of pyrimidine bases.
      d. Two strands of DNA twist to form a double helix; RNA generally does not form helices.

C. ATP (Adenosine Triphosphate)
   1. **ATP** (**adenosine triphosphate**) is a nucleotide of adenosine composed of ribose and adenine.
   2. Triphosphate derives its name from three phosphates attached to the five-carbon portion of the molecule.
   3. ATP is a high-energy molecule because the last two unstable phosphate bonds are easily broken; however it is the entire molecule that releases the energy.
   4. Usually in cells, the terminal phosphate bond is hydrolyzed, leaving ADP (adenosine diphosphate).
   5. ATP is used in cells to supply energy for energy-requiring processes (e.g., synthetic reactions); whenever a cell carries out an activity or builds molecules, it “spends” ATP.