Chapter 3

3.1 Organic Molecules

Organic molecules contain carbon and hydrogen atoms bonded to other atoms.

1. Four types of organic molecules (**biomolecules**) exist in organisms**:** **carbohydrates, lipids, proteins, and nucleic acids.**
2. Organic molecules are a diverse group; even a simple bacterial cell contains some 5,000 organic molecules.

A. The Carbon Atom

1. The chemistry of the carbon atom allows it to form covalent bonds with as many as four other elements (generally with the CHNOPS elements).
2. **Hydrocarbons** are chains of carbon atoms bonded exclusively to hydrogen atoms; hydrocarbons can be branched and they can form ringed (cyclic) compounds.
3. Carbon atoms can form double or triple bonds with certain atoms (carbon, nitrogen).

B. The Carbon Skeleton and Functional Groups

1. The carbon chain of an organic molecule is called its **skeleton** or **backbone**.
2. **Functional groups** are clusters of specific atoms bonded to the carbon skeleton with characteristic structure and functions.
   a. As an example, the addition of an –OH (hydroxyl group) to a carbon skeleton turns the molecule into an *alcohol.*
   b. Ethyl alcohol (ethanol) is hydrophilic (dissolves in water) because the hydroxyl group is polar.
   c. Nonpolar organic molecules are **hydrophobic** (cannot dissolve in water) unless they contain a polar functional group (ex. ethane), while **hydrophilic** compounds (such as ethanol) can dissolve in water because the –OH functional group is polar.
   d. Depending on its functional groups, an organic molecule may be both acidic and hydrophilic. An example is a hydrocarbon that contains a carboxyl group; carboxyl groups ionize in solution by releasing hydrogen ions, becoming both polar and acidic.
   e. Because cells are 70–90% water, the degree to which an organic molecule interacts with water affects its function.
3. **Isomers** are molecules with identical molecular formulas but different arrangements of their atoms (e.g., glyceraldehyde and dihydroxyacetone).

C. The Biomolecules of Cells

1. Carbohydrates, lipids, proteins, and nucleic acids are called **biomolecules** because certain foods are known to be rich in them.
2. Cellular enzymes carry out **dehydration reactions** to synthesize biomolecules. In a dehydration reaction, a water molecule is removed and a covalent bond is made between two atoms of the monomers.

3. **Hydrolysis** ("water breaking") **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.

4. **Enzymes** are molecules that speed up chemical reactions by bringing reactants together; an enzyme may even participate in the reaction but is not changed by the reaction.
5. The largest biomolecules are called **polymers,** constructed by linking many of the same type of small subunits, called **monomers.** Examples: **amino acids** (monomers) are linked to form a **protein** (polymer); many **nucleotides** (monomers) are linked to form a **nucleic acid** (polymer).
   a. In a dehydration reaction, a hydroxyl (—OH) group is removed from one monomer and a hydrogen (—H) is removed from the other.
   b. This produces water, and, because the water is leaving the monomers, it is a dehydration reaction.

3.2 Carbohydrates

A. Monosaccharides: Ready Energy
   1. **Monosaccharides** are simple sugars with a backbone of 3 to 7 carbon atoms.
      a. Most monosaccharides of organisms have 6 carbons (hexose).
      b. Glucose and fructose are hexoses, but are isomers of one another; each has the formula ($C_6H_{12}O_6$) but they differ in arrangement of the atoms.
      c. Glucose is found in the blood of animals; it is the source of biochemical energy (ATP) in nearly all organisms.
   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 a dehydration reaction.
   2. **Maltose** is composed of two glucose molecules; it forms in the digestive tract of humans during starch digestion.
   3. **Sucrose** (table sugar) is composed of glucose and fructose; it is used to sweeten food for human consumption.
   4. **Lactose** is composed of galactose and glucose and is found in milk.

C. Polysaccharides: Energy Storage Molecules
   1. **Polysaccharides** are polymers of monosaccharides. They are not soluble in water and do not pass through the plasma membrane of the cell.
   2. **Starch,** found in many plants, is a straight chain of glucose molecules with relatively few side branches. *Amylose* and *amylopectin* are the two forms of starch found in plants.
   3. **Glycogen** is a highly branched polymer of glucose with many side branches. It is the storage form of glucose in animals.

D. Polysaccharides: Structural Molecules
   1. **Cellulose** is a polymer of glucose which forms microfibrils, the primary constituent of plant cell walls.
      a. Cotton is nearly pure cellulose.

b. Cellulose is indigestible by humans due to the unique bond between glucose molecules.
c. Grazing animals can digest cellulose due to special stomachs and bacteria.
d. Cellulose is the most abundant organic molecule on Earth.

2. **Chitin** is a polymer of glucose with an amino group attached to each glucose.
   a. Chitin is the primary constituent of the exoskeleton of crabs and related animals (lobsters, insects, etc.).
   b. Chitin is not digestible by humans.
3. **Peptidoglycan** is a polymer of glucose derivatives and is found in bacteria.

3.3 Lipids

Lipids are varied in structure.

1. **Lipids** are hydrocarbons that are insoluble in water because they lack polar groups.
2. **Fat** provides insulation and energy storage in animals.
3. **Phospholipids** form plasma membranes and **steroids** are important cell messengers.
4. **Waxes** have protective functions in many organisms.

A. Triglycerides: Long-Term Energy Storage

1. **Fats** and **oils** contain two molecular units: glycerol and fatty acids.
2. 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.
3. **Glycerol** is a water-soluble compound with three hydroxyl groups.
4. **Triglycerides** are glycerol joined to three fatty acids by dehydration reactions.
5. **Fats** contain saturated fatty acids and are solid at room temperature (e.g. butter).
6. **Oils** contain unsaturated fatty acids and are liquid at room temperature.
7. Animals use fat rather than glycogen for long-term energy storage; fat stores more energy.

B. Phospholipids: Membrane Components

1. **Phospholipids** are constructed like neutral fats except that the third fatty acid is replaced by a polar (hydrophilic) phosphate group; the phosphate group usually bonds to another organic group (designated by *R*).
2. The hydrocarbon chains of the fatty acids become the nonpolar (hydrophobic) tails.
3. Phospholipids arrange themselves in a double layer in water, so the polar heads face toward water molecules and nonpolar tails face toward one other, away from water molecules.
4. This property enables phospholipids 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.

C. Steroids: Four Fused Rings

1. **Steroids** have skeletons of four fused carbon rings and vary according to attached functional groups; these functional groups determine the biological functions of the various steroid molecules.
2. **Cholesterol** is a component of an animal cell's plasma membrane, and is the precursor of the steroid hormone (aldosterone, testosterone, estrogen, calcitriol, etc.).
3. A diet high in saturated fats and cholesterol can lead to circulatory disorders.

D. Waxes

1. **Waxes** are long-chain fatty acids bonded to long-chain alcohols.
2. Waxes have a high melting point, 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 form the honeycomb.

3.4 Proteins

Protein Functions

1. **Metabolic enzymes** are proteins that act as organic catalysts to accelerate chemical reactions within cells.
2. **Support** proteins include **keratin,** which makes up hair and nails, and **collagen** fibers, which support many of the body's structures (e.g., ligaments, tendons, skin).
3. **Transport** functions include channel and carrier proteins in the plasma membrane, and hemoglobin that transports oxygen in red blood cells.
4. **Defense** functions include antibodies that prevent infection.
5. **Hormones** are **regulatory** proteins that influence the metabolism of cells. For example, **insulin** regulates glucose content of blood and within cells.
6. **Motion** within cells and by muscle contraction is provided by the proteins **myosin** and **actin.**

A. Peptides

1. A p**eptide bond** is a covalent bond between two amino acids.
2. Atoms of a peptide bond share electrons unevenly (oxygen is more electronegative than nitrogen).
3. The polarity of the peptide bond permits hydrogen bonding between different amino acids in 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. A **protein** may contain more than one polypeptide chain; it can thus have a very large number of amino acids.
   a. The three-dimensional shape of a protein is critical; an abnormal sequence will have the wrong shape and will not function normally.
   b. Frederick Sanger determined the first protein sequence (of the hormone insulin) in 1953.

B. Amino Acids: Proteins Monomers

1. Amino acids contain an **acidic** group (— COOH) and an **amino** group (— NH_2).

2. Amino acids differ according to their particular *R* group, ranging from single hydrogen to complicated ring compounds.
3. The *R* group of amino acid cystine 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. Shape of Proteins
1. Protein shape determines the function of the protein in the organism; proteins can have up to four levels of structure (but not all proteins have four levels).
2. The **primary structure** is the protein's own particular sequence of amino acids.
   a. Just as the English alphabet contains 26 letters, 20 amino acids can join to form a huge variety of "words."
3. The **secondary structure** results when a polypeptide coils or folds in a particular way.
   a. The **α (alpha) helix** was the first pattern discovered.
      1) In a peptide bond, oxygen is partially negative, hydrogen is partially positive.
      2) This allows for 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 the spiral shape of an α helix.
   b. The **β (beta) 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** (e.g. keratin) are structural proteins with helices and/or pleated sheets that hydrogen bond to one another.
4. **Tertiary structure** results when proteins are folded, giving rise to the final three-dimensional shape of the protein. This is due to interactions among the *R* groups of the 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; each polypeptide has a primary, secondary, and tertiary structure.

D. Protein Folding Diseases
1. As proteins are synthesized, **chaperone proteins** help them fold into their correct shapes; chaperone proteins may also correct misfolding of a new protein and prevent them from making incorrect shapes.
2. Certain diseases (e.g., the transmissible spongiform encephalopathies, or TSEs) are likely due to misfolded proteins, called **prions**.

3.5 Nucleic Acids
1. Nucleic acids are polymers of nucleotides with very specific functions in cells.

2. **DNA** (**deoxyribonucleic acid**) stores the genetic code for its own replication and for the amino acid sequences in proteins.
3. **RNA** (**ribonucleic acid**) allows for translation of the genetic code of DNA into the amino acid sequence of proteins; other functions for RNA in the cell exist.
4. Some 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 for synthetic reactions and other energy-requiring metabolic activities in the cell.

A. 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. Both RNA and DNA contain adenine, guanine, and cytosine.
    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.
        3) In DNA, thymine is always paired with adenine; cytosine is always paired with guanine. Thus, in DNA: $A + G = C + T$.
    d. Two strands of DNA twist to form a **double helix**; RNA does not form helices.

B. ATP (Adenosine Triphosphate)
1. **ATP** (**adenosine triphosphate**) is a nucleotide in which **adenosine** is composed of ribose and adenine.
2. **Triphosphate** derives its name from three phosphate groups attached together and to the ribose.
3. ATP is a high-energy molecule because the last two phosphate bonds release energy when broken.
4. In cells, the terminal phosphate bond is hydrolyzed, leaving ADP (adenosine diphosphate); energy is released when this occurs.
5. The energy released from ATP breakdown is used in the energy-requiring processes of the cell, such as synthetic reactions, muscle contraction, and the transmission of nerve impulses.