Chapter 2
The Chemical Basis of Life

Student Learning Outcomes

After reading this chapter, students should be able to:

2.1A Define *matter, mass,* and *weight.*
2.1B Distinguish between elements and atoms, and state the four most abundant elements in the body.
2.1C Name the subatomic particles of an atom, and indicate their mass, charge, and location in an atom.
2.1D Define *atomic number, mass number, isotope, atomic mass,* and *mole.*
2.1E Compare and contrast ionic and covalent bonds.
2.1F Differentiate between a molecule and a compound.
2.1G Explain what creates a hydrogen bond and relate its importance.
2.1H Describe solubility and the process of dissociation, and predict if a compound or molecule is an electrolyte or nonelectrolyte.
2.2A Summarize the characteristics of synthesis, decomposition, and reversible and oxidation-reduction reactions.
2.2B Illustrate what occurs in dehydration and hydrolysis reactions.
2.2C Explain how reversible reactions produce chemical equilibrium.
2.2D Contrast potential and kinetic energy.
2.2E Distinguish between chemical reactions that release energy and those that take in energy.
2.2F Describe the factors that can affect the rate of chemical reactions.
2.3A Distinguish between inorganic and organic compounds.
2.3B Describe how the properties of water contribute to its physiological functions.
2.3C Describe the pH scale and its relationship to acidic, basic, and neutral solutions.
2.3D Explain the importance of buffers in organisms.
2.3E Compare the roles of oxygen and carbon dioxide in the body.
2.4A Describe the structural organization and major functions of carbohydrates, lipids, proteins, and nucleic acids.
2.4B Explain how enzymes work.
2.4C Describe the roles of nucleotides in the structures and functions of DNA, RNA, and ATP.

Chapter Outline

2.1 Basic Chemistry

Matter, Mass, and Weight

1. Matter is anything that occupies space and has mass.

2. Mass is the amount of matter in an object.
3. Weight results from the force exerted by earth's gravity on matter.

Elements and Atoms

1. An element is the simplest type of matter having unique chemical and physical properties.
2. An atom is the smallest particle of an element that has the chemical characteristics of that element. An element is composed of only one kind of atom.
3. Atoms consist of protons, neutrons, and electrons.
   - Protons are positively charged, electrons are negatively charged, and neutrons have no charge.
   - Protons and neutrons are in the nucleus; electrons are located around the nucleus, and can be represented by an electron cloud.
4. The atomic number is the unique number of protons in an atom. The mass number is the sum of the protons and the neutrons.
5. Isotopes are atoms that have the same atomic number but different mass numbers.
6. The atomic mass of an element is the average mass of its naturally occurring isotopes weighted according to their abundance.
7. A mole of a substance contains Avogadro's number (6.022×10^{23}) of atoms, ions, or molecules. The molar mass of a substance is the mass of 1 mole of the substance expressed in grams.

Electrons and Chemical Bonding

1. The chemical behavior of atoms is determined mainly by their outermost electrons. A chemical bond occurs when atoms share or transfer electrons.
2. Ions are atoms that have gained or lost electrons.
   - An atom that loses 1 or more electrons becomes positively charged and is called a cation. An anion is an atom that becomes negatively charged after accepting 1 or more electrons.
   - An ionic bond results from the attraction of the oppositely charged cation and anion to each other.
3. A covalent bond forms when electron pairs are shared between atoms. A polar covalent bond results when the sharing of electrons is unequal and can produce a polar molecule that is electrically asymmetric.

Molecules and Compounds

1. A molecule is two or more atoms chemically combined to form a structure that behaves as an independent unit. A compound is two or more *different* types of atoms chemically combined.
2. The kinds and numbers of atoms (or ions) in a molecule or compound can be represented by a formula consisting of the symbols of the atoms (or ions) plus subscripts denoting the number of each type of atom (or ion).
3. The molecular mass of a molecule or compound can be determined by adding up the atomic masses of its atoms (or ions).

Intermolecular Forces

1. A hydrogen bond is the weak attraction between the oppositely charged regions of polar molecules. Hydrogen bonds are important in determining the three-dimensional structure of large molecules.

2. Solubility is the ability of one substance to dissolve in another. Ionic substances that dissolve in water by dissociation are electrolytes. Molecules that do not dissociate are nonelectrolytes.

2.2 Chemical Reactions and Energy

Synthesis Reactions

1. A synthesis reaction is the chemical combination of two or more substances to form a new or larger substance.
2. A dehydration reaction is a synthesis reaction in which water is produced.
3. The sum of all the synthesis reactions in the body is called anabolism.

Decomposition Reactions

1. A decomposition reaction is the chemical breakdown of a larger substance to two or more different and smaller substances.
2. A hydrolysis reaction is a decomposition reaction in which water is depleted.
3. The sum of all the decomposition reactions in the body is called catabolism.

Reversible Reactions

Reversible reactions produce an equilibrium condition in which the amount of reactants relative to the amount of products remains constant.

Oxidation-Reduction Reactions

Oxidation-reduction reactions involve the complete or partial transfer of electrons between atoms.

Energy

1. Energy is the ability to do work. Potential energy is stored energy, and kinetic energy is energy resulting from the movement of an object.
2. Chemical energy
   - Chemical bonds are a form of potential energy.
   - Chemical reactions in which the products contain more potential energy than the reactants require the input of energy.
   - Chemical reactions in which the products have less potential energy than the reactants release energy.
3. Heat energy
   - Heat energy is energy that flows between objects that are at different temperatures.
   - Heat energy is released in chemical reactions and is responsible for body temperature.

Speed of Chemical Reactions

1. Activation energy is the minimum energy that the reactants must have to start a chemical reaction.
2. Enzymes are specialized protein catalysts that lower the activation energy for chemical reactions. Enzymes speed up chemical reactions but are not consumed or altered in the process.
3. Increased temperature and concentration of reactants can increase the rate of chemical reactions.

2.3 Inorganic Chemistry

Inorganic chemistry is mostly concerned with non-carbon-containing substances but does include some carbon-containing substances, such as carbon dioxide and carbon monoxide that lack carbon-hydrogen bonds. Some inorganic chemicals play important roles in the body.

Water

1. Water is a polar molecule composed of one atom of oxygen and two atoms of hydrogen.
2. Because water molecules form hydrogen bonds with each other, water is good at stabilizing body temperature, protecting against friction and trauma, making chemical reactions possible, directly participating in chemical reactions (e.g., dehydration and hydrolysis reactions), and serving as a mixing medium (e.g., solutions, suspensions, and colloids).
3. A mixture is a combination of two or more substances physically blended together, but not chemically combined.
4. A solution is any liquid, gas, or solid in which the substances are uniformly distributed with no clear boundary between the substances.
5. A solute dissolves in the solvent.
6. A suspension is a mixture containing materials that separate from each other unless they are continually, physically blended together.
7. A colloid is a mixture in which a dispersed (solutelike) substance is distributed throughout a dispersing (solventlike) substance. Particles do not settle out of a colloid.

Solution Concentrations

1. One measurement of solution concentration is the osmole, which contains Avogadro's number (6.022×10^{23}) of particles (i.e., atoms, ions, or molecules) in 1 kilogram of water.
2. A milliosmole is 1/1000 of an osmole.

Acids and Bases

1. Acids are proton (H^+) donors, and bases (OH^-) are proton acceptors.
2. A strong acid or base almost completely dissociates in water. A weak acid or base partially dissociates.
3. The pH scale shows the H^+ concentrations of various solutions.
   - A neutral solution has an equal number of H^+ and OH^- and is assigned a pH of 7.
   - Acidic solutions, in which the number of H^+ is greater than the number of OH^- , have pH values less than 7.
   - Basic, or alkaline, solutions have more OH^- than H^+ and a pH greater than 7.
4. A salt is a molecule consisting of a cation other than H^+ and an anion other than OH^-. Salts form when acids react with bases.
5. A buffer is a solution of a conjugate acid-base pair that resists changes in pH when acids or bases are added to the solution.

Oxygen and Carbon Dioxide

Oxygen is necessary for the reactions that extract energy from food molecules in living organisms. When the organic molecules are broken down during metabolism, carbon dioxide and energy are released.

2.4 Organic Chemistry

Organic molecules contain carbon and hydrogen atoms bound together by covalent bonds.

Carbohydrates

1. Monosaccharides are the basic building blocks of other carbohydrates. Examples are ribose, deoxyribose, glucose, fructose, and galactose. Glucose is an especially important source of energy.
2. Disaccharide molecules are formed by dehydration reactions between two monosaccharides. They are broken apart into monosaccharides by hydrolysis reactions. Examples of disaccharides are sucrose, lactose, and maltose.
3. A polysaccharide is composed of many monosaccharides bound together to form a long chain. Examples include cellulose, starch, and glycogen.

Lipids

1. Triglycerides are composed of glycerol and fatty acids. One, two, or three fatty acids can attach to the glycerol molecule.
    - Fatty acids are straight chains of carbon molecules with a carboxyl group. Fatty acids can be saturated (having only single covalent bonds between carbon atoms) or unsaturated (having one or more double covalent bonds between carbon atoms).
    - Energy is stored in fats.
2. Phospholipids are lipids in which a fatty acid is replaced by a phosphate-containing molecule. Phospholipids are a major structural component of plasma membranes.
3. Steroids are lipids composed of four interconnected ring molecules. Examples are cholesterol, bile salts, and sex hormones.
4. Other lipids include fat-soluble vitamins, prostaglandins, thromboxanes, and leukotrienes.

Proteins

1. The building blocks of a protein are amino acids, which are joined by peptide bonds.
2. The number, kind, and arrangement of amino acids determine the primary structure of a protein. Hydrogen bonds between amino acids determine secondary structure, and hydrogen bonds between amino acids and water determine tertiary structure. Interactions between different protein subunits determine quaternary structure.
3. Enzymes are protein catalysts that speed up chemical reactions by lowering their activation energy.
4. The active sites of enzymes bind only to specific reactants.
5. Cofactors are ions or organic molecules, such as vitamins, that are required for some enzymes to function.

Nucleic Acids: DNA and RNA

1. The basic unit of nucleic acids is the nucleotide, which is a monosaccharide with an attached phosphate and an organic base.
2. DNA nucleotides contain the monosaccharide deoxyribose and the organic base adenine, thymine, guanine, or cytosine. DNA occurs as a double strand of joined nucleotides. Each strand is complementary and antiparallel to the other strand.
3. A gene is a sequence of DNA nucleotides that determines the structure of a protein or RNA.
4. RNA nucleotides are composed of the monosaccharide ribose. The organic bases are the same as for DNA, except that thymine is replaced with uracil.

Adenosine Triphosphate

Adenosine triphosphate (ATP) stores energy derived from catabolism. The energy released from ATP is used in anabolism and other cell processes.

Topics Related to Levels of Organization and the Chemical Basis of Life

Many people enter their first course in anatomy and physiology envisioning the body as a solid and singular entity that has teleological control of its internal functions. To increase student understanding, develop a short, written assignment that asks them to integrate the various levels of organization that are introduced here and in Chapter 1. Here's an example: Choose any body part or organ, such as the hand or heart. Name all structural levels of the choice, including molecules, organelles, cells, tissues, organs, etc.

Introduce the production and uses of radioactive isotopes during the discussion of atomic structure. Use the Clinical Impact 2.1: Clinical Uses of Atomic Particles as a reading assignment and ask students to think about how clinical tests have a chemical basis. For homework, have students research diagnostic tests and procedures and determine the chemical foundation of each.

Engineering and biological problems are associated with the bioengineering of synthetic substances that replace body chemicals or tissues. Have the class discuss the chemical and biological considerations of such new technologies such as: Teflon hip replacements, synthetic hormones, artificial heart valves, and synthetic blood.

Themes in Chapter 2
Structure and Function
Enzyme Specificity and Protein Functions Although there are many examples of structural and functional relationships with a chemical basis, perhaps the example that students can most readily grasp is the lock and key model of enzyme/substrate interactions. This metaphor easily expands to the next levels of organization, which are other functions of protein in the cell membrane, cell, tissues, and the body. Proteins have a complex structure and a variety of functions that depend on specific structural parameters. Ask students, "How does the structure of a protein affect its function?" (Examples: collagen, insulin, hemoglobin.) Changing the structure of a protein will alter its functional capabilities. This theme recurs in the study of anatomy and physiology. **Functions of Organic Molecules** The following tables are excellent resources about the function of the different organic molecules in the body: Table 2.6, Roles of Carbohydrates in the Body, Table 2.7, Roles of Lipids in the Body, and Table 2.8, Roles of Proteins in the Body.

Homeostasis
Chemical Equilibrium The concept of chemical equilibrium is, in essence, a simpler form of the dynamic equilibrium established and maintained by the body. Help students explore the similarities and differences between chemical equilibrium and biological homeostasis.

Learning Outcomes Correlation with Predict Question Types

Question Type	Question #	Bloom's level	Learning Outcome
Learn to Predict		Application	2.2a,f
Predict	1	Comprehension	2.1a
Predict	2	Comprehension	2.1d
Predict	3	Comprehension	2.2a,c
Predict	4	Comprehension	2.2a
Predict	5	Comprehension	2.2e
Predict	6	Application	2.3d