UNIT 1: CELL BIOLOGY
CHAPTER 2: THE MOLECULES OF CELLS

LEARNING OUTCOMES

2.1 Introduction to Chemistry

1. Describe how protons, neutrons, and electrons relate to atomic structure.
2. Understand how to interpret the periodic table of elements.
3. Describe how variations in an atomic nucleus account for its physical properties.
4. Identify the beneficial and harmful uses of radiation.

2.2 Molecules and Compounds

1. Describe how elements are combined into molecules and compounds.
2. List the different types of bonds that occur between elements.
3. Compare the relative strengths of ionic, covalent, and hydrogen bonds.

2.3 Chemistry of Water

1. Evaluate which properties of water are important for biological life.
2. Identify common acidic and basic substances.
3. Describe how buffers are important to living organisms.

2.4 Organic Molecules

1. Compare inorganic molecules to organic molecules.
2. Identify the role of a functional group.
3. Recognize how monomers are joined to form polymers.

2.5 Carbohydrates

1. Identify the structural components of a carbohydrate.
2. List several examples of important monosaccharides and polysaccharides.

2.6 Lipids

1. Compare the structures of fats, phospholipids, and steroids.
2. Identify the functions lipids play in our bodies.

2.7 Proteins

1. Describe the functions of proteins in cells.
2. Explain how a polypeptide is constructed from amino acids.
3. Compare the four levels of protein structure.

2.8 Nucleic Acids

1. Compare the structure and function of DNA and RNA.
2. Explain the role of ATP in the cell.

LECTURE OUTLINE

2.1 Introduction to Chemistry

Matter refers to anything that takes up space and has mass. All matter, both nonliving and living, is composed of certain basic substances called **elements**.

Atomic Structure

Elements consist of tiny particles called **atoms**, which are the smallest part of an element that displays the properties of that element. Atoms are made up of positively charged **protons**, uncharged **neutrons**, and negatively charged **electrons**. All atoms of an element have the same number of protons. This number is called the **atomic number**. The **mass number** is the sum of an atom's protons and neutrons.

The Periodic Table

The periodic table was constructed as a way to group the elements according to certain similar chemical and physical characteristics.

Radioactive Isotopes

Isotopes are atoms of the same element that differ in their number of neutrons; therefore, isotopes have the same number of protons, but their mass numbers are different.

Low Levels of Radiation

The chemical behavior of a radioactive isotope is essentially the same as that of the stable isotopes of an element, so you can use small amounts of radioactive isotopes as tracers to detect molecular changes.

High Levels of Radiation

Radioactive substances in the environment can harm cells, damage DNA, and cause cancer. Radiation is also used to sterilize items, treat cancer, and provide images (X-rays) of things we otherwise couldn't see directly.

Electrons

In an electrically neutral atom, the positive charges of the protons in the nucleus are balanced by the negative charges of electrons moving outside the nucleus in orbitals. The number of electrons in the outer orbital determines whether an atom reacts with other atoms. A common model of the atom, devised by Niels Bohr, shows electrons in concentric rings around the nucleus.

2.2 Molecules and Compounds

A **molecule** is formed when two or more atoms bond together. When the atoms of two or more different elements bond together, the product is called a **compound**.

Ionic Bonding

Ions form when electrons are transferred from one atom to another. Ionic compounds are held together by an attraction between negatively and positively charged **ions** called an **ionic bond**. An example is NaCl.

Covalent Bonding

A **covalent bond** results when two atoms share electrons in such a way that each atom has a complete outer orbital.

The Shape of Molecules

Molecules have a three-dimensional shape that often determines their biological function. The shapes of molecules are necessary to the structural and functional role they play in living things.

Nonpolar and Polar Covalent Bonds

When the sharing of electrons between two atoms is fairly equal, the covalent bond is said to be nonpolar. The unequal sharing of electrons in a covalent bond results in a slightly negative charge and a slightly positive charge, and the covalent bond is polar.

Hydrogen Bonding

Polarity within a water molecule causes the hydrogen atoms in one molecule to be attracted to the oxygen atoms in other water molecules, forming a **hydrogen bond**.

2.3 Chemistry of Water

The unique properties of water make it essential to the existence of life.

Properties of Water

High Heat Capacity

The many hydrogen bonds that link water molecules help water absorb heat without a great change in temperature. Water has a high heat capacity because the main hydrogen bonds that link water molecules together help water absorb heat without a great change in temperature.

High Heat of Vaporization

Water has a high heat of vaporization because hydrogen bonds must be broken before water boils and changes to a vaporized state.

Solvent

Water is a solvent, and due to its polarity, it facilitates chemical reactions inside and outside living organisms.

Cohesive and Adhesive

Water molecules are cohesive and adhesive. Water flows freely, but its molecules do not separate, and it is able to adhere to polar surfaces. The strong hydrogen bonds between water molecules result in high surface tension.

Frozen Water Less Dense Than Liquid Water

Ice is less dense than liquid water because the water molecules form a regular crystal lattice with more open space, and, therefore, ice floats.

Acids and Bases

When water ionizes, it releases an equal number of hydrogen ions and hydroxide ions.

Acid Solutions (High H^+ Concentrations)

Acids are substances that release hydrogen ions (H^+) when they dissociate in water.

Basic Solutions (Low H^+ Concentration)

Bases are substances that either take up hydrogen ions (H^+) or release hydroxide ions (OH^-).

pH Scale

The **pH scale** is used to indicate the acidity or basicity (alkalinity) of solutions. The pH scale ranges from 0 to 14.

Buffers and pH

A **buffer** is a substance that keeps pH within normal limits. In animals, the pH of body fluids is maintained within a narrow range or else health suffers.

2.4 Organic Molecules

Organic molecules always contain carbon (C) and hydrogen (H). To achieve eight electrons in its outer shell, a carbon atom shares electrons covalently with as many as four other atoms, including other carbon atoms.

Functional Groups

A **functional group** is a specific combination of bonded atoms that always react in the same way.

From Monomers to Polymers

A **monomer** is a simple organic molecule that exists individually or can link with other monomers to form a **polymer**. **Dehydration** and **hydrolysis reactions** join monomers and degrade polymers, respectively.

2.5 Carbohydrates

Carbohydrates function as quick fuel and short-term energy storage in all organisms and play a structural role in woody plants, bacteria, and insects. Carbohydrate molecules are characterized by the presence of the atomic grouping H–C–OH.

Monosaccharides—Simple Sugars

Monosaccharides consist of a single sugar molecule and are called simple sugars. They have a carbon backbone of three to six carbons. **Glucose** is a six-carbon monosaccharide found in our blood.

Disaccharides

A **disaccharide** contains two monosaccharides that have joined during a dehydration reaction.

Polysaccharides—Complex Carbohydrates

Long polymers such as starch, glycogen, and cellulose are **polysaccharides** that contain many glucose subunits.

Energy Storage Polysaccharides

Plants store large amounts of glucose as **starch**; animals store it as **glycogen**.

Structural Polysaccharides

The polysaccharide **cellulose** is found in plant cell walls and makes them strong. **Chitin**, another structural polysaccharide, is found in the exoskeleton of crabs and related animals.

2.6 Lipids

Lipids function as energy storage molecules. Their structures vary, but all are hydrophobic molecules that are insoluble in water. Phospholipids form a membrane that separates the cell from its environment, and the steroids are a large class of lipids that includes, among others, the sex hormones.

Triglycerides: Fats and Oils

Fats are usually of animal origin and solid at room temperature while **oils** are of plant origin and liquid. In the body, fat is used for long-term energy storage, to insulate against heat loss, and to form a protective cushion around major organs. Fats and oils form when one glycerol molecule reacts with three fatty acid molecules. A fat molecule is sometimes called a **triglyceride**.

Saturated, Unsaturated, and Trans-Fatty Acids

A **fatty acid** is a hydrocarbon chain that ends with the acidic group –COOH.

Saturated fatty acids have no double covalent bonds between carbon atoms.

Unsaturated fatty acids have double bonds between carbon atoms.

Trans fats are often produced by hydrogenation or the chemical addition of hydrogen to vegetable oils.

Phospholipids

Phospholipids contain a phosphate group and have a hydrophobic end and a hydrophilic end. They are the primary components of cellular membranes.

Steroids

Steroids have a backbone of four fused carbon rings. Cholesterol is an important steroid because it is a component of a cell's plasma membrane and the precursor to other steroids.

2.7 Proteins

Proteins are polymers composed of amino acid monomers. An amino acid has a central carbon atom bonded to a hydrogen atom, an amino group ($–NH_2$), an acidic group (–COOH), and an *R* group. **Amino acids** differ by their *R* groups. Proteins perform many functions. Some are **enzymes** that speed chemical reactions.

Peptides

A **polypeptide** is a chain of amino acids that are joined to one another by a **peptide bond**.

Levels of Protein Organization

Proteins have a *primary* (linear sequence of amino acids), *secondary* (alpha helices or beta pleated sheet), and *tertiary structure* (globular shape). Some proteins exhibit a *quaternary structure* (more than one polypeptide chain). The final shape of a protein is very important to its function.

2.8 Nucleic Acids

The two types of nucleic acids are **DNA** (**deoxyribonucleic acid**) and **RNA** (**ribonucleic acid**). DNA stores genetic information in the cell and in the organism.

Structure of DNA and RNA

Both DNA and RNA are polymers of nucleotides. Every **nucleotide** is composed of a phosphate, a pentose sugar, and a nitrogen-containing base. The nucleotides form a linear molecule. DNA is a **double helix**, while RNA is single stranded.

ATP (Adenosine Triphosphate)

ATP (**adenosine triphosphate**) is the energy carrier in cells, storing the energy in glucose and providing that energy to reactions in the cell.

LECTURE ENRICHMENT IDEAS

1. The various organic molecules and types of bonds are easily visualized with models and remembered better than when presented on flat pictures in the textbook, videos, or computer screen.
2. Students should research the topic of acid rain on the Internet before coming to class. They should also collect and bring in water samples from their dorm faucets, drinking fountains, rainwater, snow, or a nearby pond or stream. Have pH paper or a pH meter available in class to determine the pH of these samples. Discuss the known or potential effects of acid rain in your particular geographic location, which

might include effects on forests (including interruption of the symbiotic association between trees and their mycorrhizae), depletion of fisheries in lakes, or deterioration of car finishes and statues.

3. Bring in various types of colas and coffee. Have pH paper or a pH meter available in class to determine the pH of these beverages. How acidic are these? Discuss why you can drink such acidic beverages and not damage your stomach.

4. Have students read the Science in Your Life—Health "Japan's Nuclear Crisis" before coming to class. Discuss the answers to the discussion questions at the end of the reading.

5. Have students read the Science in Your Life—Health "A Balanced Diet" before coming to class. Discuss the answers to the discussion questions at the end of the reading.

6. Of the four organic molecules discussed in this section (carbohydrates, lipids, proteins, and nucleic acids), why are nucleic acids the best suited to store and transmit information? What properties of DNA allow these particular functions?

ESSAY QUESTIONS WITH ANSWERS

1. Name five characteristics of water and relate them to the structure of water.

Answer: Because electrons orbit around oxygen more than hydrogen, a slight positive charge is present on the hydrogen atoms and a slight negative charge on the oxygen atom, creating a polarity. Hydrogen bonds form between the water molecules, which leads to various characteristics of water: boils at 100°C and freezes at 0°C; absorbs large amounts of heat before it becomes warm and evaporates, which helps to maintain constant body temperature; excellent transport medium; ice floats in liquid water (less dense); and dissolves various chemical substances.

2. All proteins have three basic structural levels. Describe those. Why does hemoglobin have a quaternary structure?

Answer: The primary structure of a protein consists of the linear sequence of amino acids joined by peptide bonds. The secondary structure comes about when the polypeptide chain takes a particular orientation in space (alpha helix or beta pleated sheet). The tertiary structure represents the final three-dimensional shape of the protein. When more than one polypeptide chain is present, a quaternary structure is formed, which is found in hemoglobin.

3. Explain how soaps, when added to oils, will cause the oil to mix with water.

Answer: Soaps have a polar and a nonpolar end. The nonpolar ends of the soap project into the nonpolar fat droplet while the polar ends of the soap project outward into the water, which is polar.