Chapter 2

chemistry of life

# LEARNING OUTCOMES

## 2.1 From Atoms to Molecules

1. Distinguish between atoms and elements.
2. Describe the structure of an atom.
3. Define an isotope and summarize its application in both medicine and biology.
4. Distinguish between ionic and covalent bonds.

## 2.2 Water and Life

1. Describe the properties of water.
2. Explain the role of hydrogen bonds in the properties of water.
3. Summarize the structure of the pH scale and the importance of buffers to biological systems.

## 2.3 Molecules of Life

1. List the four classes of organic molecules found in cells.
2. Describe the processes by which the organic molecules are assembled and disassembled.

## 2.4 Carbohydrates

1. Summarize the basic chemical properties of a carbohydrate.
2. State the roles of carbohydrates in human physiology.
3. Compare the structures of simple and complex carbohydrates.
4. Explain the importance of fiber in the diet.

## 2.5 Lipids

1. Compare the structures of fats, phospholipids, and steroids.
2. State the function of each class of lipids.

## 2.6 Proteins

1. Describe the structure of an amino acid.
2. Explain how amino acids are combined to form proteins.
3. Summarize the four levels of protein structure.

## 2.7 Nucleic Acids

1. Explain the difference between RNA and DNA.
2. Summarize the role of ATP in cellular reactions.

# EXTENDED LECTURE OUTLINE

## 2.1 From Atoms to Molecules

Matter refers to anything that takes up space and has mass. It can exist in a number of forms such as solid, gas, liquid, or plasma.

Elements

An element is one of the basic building blocks of matter and cannot be broken down by chemical means. There are only 92 naturally occurring elements. The human body is composed of carbon, nitrogen, oxygen, and hydrogen. Every element has a name and symbol.

The Periodic Table (Figure 2.1)

In the periodic table of elements, the number on the top of each square is the atomic number. The letter symbols represent each element. Below the symbol is the value for atomic mass. A complete periodic table is located in Appendix A.

 Atoms

An atom is the smallest unit of an element. Atoms are made of subatomic particles called positively charged protons, uncharged neutrons, and negatively charged electrons. Positively charged protons and neutral neutrons occupy the nucleus of the atom, with negatively charged electrons in orbit about the nucleus.

**The Periodic Table**

Atoms have an atomic symbol, atomic number, and mass number. The atomic number is equal to the number of protons. Each atom has its own mass number, which is the sum of protons and neutrons in the nucleus.

Isotopes

Isotopes are atoms with the same atomic number but a different atomic mass due to a different number of neutrons.

Low Levels of Radiation

A radioactive isotope behaves the same as a stable isotope of an element. This means that small amounts of radioisotopes can be used as tracers to detect molecular changes. Specific tracers are used in imaging equipment to detect and diagnose the presence of tumors.

High Levels of Radiation

High levels of radiation can harm cells, damage DNA, and cause cancer. Conversely, the effects of radiation can also be put to good use by killing bacteria and viruses, sterilizing medical and dental equipment, and by increasing food safety. Another form of high energy radiation is the X-ray.

Molecules and Compounds

Atoms bond with each other to form molecules. If the atoms come from different elements, the molecule is a compound.

Ionic Bonding

During an ionic reaction, certain atoms give up and others receive electrons to achieve a stable outer shell.

**Ions**

Ions are particles that carry either a positive or a negative charge. The attraction between opposite charged ions forms an ionic bond.

Covalent Bonding

Atoms share pairs of electrons within a covalent bond in order to achieve a stable outer shell.

Double and Triple Bonds

In addition to single bonds, double and triple bonds are also possible in some molecules. In double bonds, atoms share two pairs of electrons. In a triple bond, atoms share three pairs of electrons.

Structural and Molecular Formulas

Covalent bonds can be represented in a number of ways, including structural and molecular formulas. Structural formulas use straight lines to show covalent bonds between the atoms. Molecular formulas represent only the number of each type of atom making up a molecule.

## 2.2 Water and Life

Water makes life possible due to its physical and chemical properties. Water makes up 60–70% of total body weight, making water the most abundant molecule in living organisms. Water molecules are polar, in that the oxygen end has a slight negative charge and the hydrogen end has a slight positive charge.

Hydrogen Bonds

Hydrogen bonds occur when a covalently bonded, slightly positively charged hydrogen atom is attracted to a negatively charged atom in the vicinity.

Properties of Water

Due to its polarity and/or hydrogen bonding, water is liquid at room temperature, loses and gains heat slowly, has a high heat of vaporization, is less dense when frozen, fills vessels, and is the universal solvent. These properties are necessary to life.

Water Has a High Heat Capacity

Water holds onto its heat. Its temperature falls and rises more slowly than that of other liquids. This aids in human maintenance of the normal internal temperature and protection from rapid temperature changes.

Water Has a High Heat of Evaporation

Because of water’s capacity for high heat vaporization, it makes it easier for our bodies to release excess body heat in a hot environment.

Water Is a Solvent

Due to its polarity, water facilitates chemical reactions, both outside and within living systems. Water dissolves substances, which makes a solution, which contains solutes.

Water Molecules Are Cohesive and Adhesive

Cohesion refers to the ability of water molecules to cling to one another, which is made possible by hydrogen bonds between water molecules. Adhesion refers to the ability of water molecules to cling to other polar surfaces.

Frozen Water Is Less Dense Than Liquid Water

As liquid water cools, the molecules come closer together. Below 4°C, hydrogen bonding becomes more open, meaning that water expands and is why ice floats on liquid water. This property of water plays an important role in many aquatic ecosystems.

Acids and Bases

Water dissociates into an equal number of hydrogen and hydroxide ions.

Acidic Solutions (High H+ Concentrations)

Acids are substances that dissociate in water to release hydrogen ions. The acidity of a substance depends on how fully it dissociates in water. Compared to water, acidic solutions have more hydrogen ions than hydroxide ions.

Basic Solutions (Low H+ Concentrations)

Bases are substances that take up hydrogen ions or release hydroxide ions. Compared to water, basic solutions have more hydroxide ions than hydrogen ions.

pH Scale

The pH scale is used to indicate the acidity or basicity (alkalinity) of a solution. The pH scale ranges from 0 to 14 with 7 being neutral. Acids have a pH lower than 7, and bases have a pH higher than 7.

Buffers

Buffers are mechanisms that help keep pH within normal limits by taking up excess hydrogen ions or hydroxide ions. Maintaining pH within a narrow range is important to health.

## 2.3 Molecules of Life

There are four categories of organic molecules that are unique to cells. These are carbohydrates, lipids, proteins, and nucleic acids. Organic refers to a molecule that contains carbon and hydrogen and are typically associated with living organisms. Each type of organic molecule in cells is composed of subunits. Macromolecule is a molecule that has many subunits. When a cell builds a macromolecule, it uses a dehydration reaction. To do the reverse, the cell uses what is called hydrolysis reaction.

## 2.4 Carbohydrates

Carbohydrates are used as an energy source for living organisms. Carbohydrate molecules contain carbon, hydrogen, and oxygen atoms grouped H–C–OH, in which the ratio of hydrogen atoms to oxygen atoms is approximately 2:1.

Simple Carbohydrates: Monosaccharides

Monosaccharides, also called simple sugars, have a low number of carbon atoms that range from three to seven. The most common monosaccharides is hexose glucose, which provides a ready source of energy for cells. Other types of hexoses are fructose and galactose. Monosaccharides are the monomers used to build longer carbohydrate chains.

Disaccharides

Disaccharides are made by the joining of two monosaccharides in a dehydration reaction. Types of disaccharides are maltose, sucrose, and lactose.

Complex Carbohydrates: Polysaccharides

Polysaccharides are long polymers that contain long chains of glucose subunits. Because of their lengths, polysaccharides are also called complex carbohydrates. These long polymers are starch, glycogen, and cellulose. Starch is composed of glucose molecules joined in a linear fashion and may have a branched or unbranched and found in plants. Glycogen is also joined in a linear fashion but have numerous branches and serves vertebrates. Cellulose, a polysaccharide found in plant cell walls, is commonly called fiber. The linkages joining glucose units cannot be digested, and, therefore, cellulose adds bulk that passes through our digestive system as fiber.

**2.5 Lipids**

Lipids are hydrophobic and do not dissolve in water. They function well in the storage of energy.

Triglycerides: Fats and Oils

Triglycerides are a type of fat composed of glycerol and three fatty acids, also known as fats and oils. Fats are of animal origin and are solid at room temperature; whereas, oils are of plant origin and are liquid at room temperature.

Triglycerides serve many functions for an organism, such as long-term energy storage, insulation against heat loss, and as a protective cushion around major organs. Triglycerides are hydrophobic but can be reversed with emulsifiers which cause fat droplets to disperse in water.

Saturated, Unsaturated, and Trans Fatty Acids

Fatty acids are molecules that contain a hydrocarbon chain and ends with an acid group. Saturated fatty acids lack double bonds between the atoms and its carbon chain. Unsaturated fatty acids are fatty acids that have one or more double bonds between the atoms and its carbon chain. Saturated fats are associated with cardiovascular disease. Trans fats are created artificially from vegetable oils and are even more harmful than naturally occurring saturated fats. Trans fats may be partially hydrogenated to make them semisolid. Current dietary guidelines from the American Heart Association advise replacing trans fats with unsaturated oils such as olive oil, corn oil, canola oil, and safflower oil.

Dietary Fat

The diet should contain some fat. The total recommended amount of fat in a 2,000-calorie diet is 65 g. In recent research, it is indicated that what was important was not the total amount of fat in the diet but the type of fat in the diet.

Phospholipids

Phospholipids are lipid molecule that forms the bilayer of the cell’s membrane. Phospholipids have a polar, hydrophilic head bonded to two nonpolar, hydrophobic tails.

Steroids

A steroid is a type of lipid molecule having a complex of four carbon rings that differ according to the functional groups attached to the rings. Examples of steroids are cholesterol, progesterone, and testosterone.

## 2.6 Proteins

Proteins are of primary importance in the structure and function of cells. Some of their functions include: support (structural), enzymes (reactants), transport (channel and carrier), defense (antibodies), hormones (regulatory), and motion (movement). The structures and functions of vertebrate cells and tissue differ according to the type of proteins they contain.

Amino Acids: Subunits of Proteins

An amino acid contains an amino group, an acid group, and an *R* (remainder) group, which covalently bonds to produce peptide molecules. Amino acids differ according to their particular *R* group.

Peptides

The covalent bond between two amino acids is called a peptide bond. Three or four amino acids linked together are called a polypeptide.

Shape of Proteins

The function of proteins is directly associated with structure. Any changes in its structure or shape may impact the effectiveness of a protein to perform its function. When proteins are exposed to extremes in heat and pH, they undergo an irreversible change in shape called denaturation, which destroys the proteins’ ability to function.

Levels of Protein Organization

The structure of a protein has at least three levels of organization. The first level is called the primary structure and is the linear sequence of the amino acids joined by peptide bonds. The secondary structure is an alpha helix or a pleated sheet. The tertiary structure of a protein is its final, three-dimensional shape where many proteins establish their function. In this level of organization, enzymes determine the types of molecules they will interact with. The shape is maintained by various types of bonding between the *R* groups. Environmental factors may disrupt the tertiary structure, causing the protein to denature. A quaternary structure occurs if there is more than one polypeptide.

## 2.7 Nucleic Acids

Nucleic acids are polymers of nucleotides that store information. The two types of nucleic acids are DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). Each DNA molecule contains many genes, and genes specify the sequence of the amino acids in proteins. RNA is the intermediary that conveys DNA’s instructions regarding the amino acid sequence in a protein. Some nucleotides are directly involved in metabolic functions in cells. Coenzymes are nonprotein organic molecules that help regulate enzymatic reactions. ATP (adenosine triphosphate) stores large amounts of energy needed for synthetic reactions and processing.

How the Structures of DNA and RNA Differ

Both DNA and RNA are polymers of nucleotides but have small differences in the types of subunits each contains and in their final structure. DNA contains the sugar deoxyribose; RNA contains the sugar ribose. Adenine (A), thymine (T), guanine (G), and cytosine (C) are the different types of bases in DNA. Base uracil (U) replaces the base thymine in RNA. The presence of bases raises the pH of a solution. DNA is a double helix—if unwound, its structure resembles a stepladder. Phosphate and the pentose sugar make up the sides of the ladder, and the hydrogen-bonded bases are the rungs. RNA is a single-stranded molecule and is complementary to one DNA strand. RNA is important in protein synthesis.

ATP: An Energy Carrier

ATP is a nucleotide that has been modified by the addition of three phosphate groups. It functions as an energy carrier in cells.

Structure of ATP Suits Its Function

ATP is a high-energy molecule because the last two phosphate bonds are unstable and easily broken. ATP provides energy to cells for various functions. After ATP breaks down, it can be recycled by adding ADP (adenosine diphosphate) to reform ATP.

# STUDENT ACTIVITIES

pH Measurements

1. 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.

2. 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.

What Are You Eating?

3. Ask students to bring in one food label from a processed food they normally consume. Does it have added sugar? Where is sugar in the list of ingredients? (Ingredients are listed in order from the most abundant to the least abundant.) What other terms (such as corn syrup) could be used on the nutrition label instead of sugar?

4. Ask students to keep a food log of everything they eat for 24 hours. Using a calorie/fat counter or the nutritional label on the food, determine how many grams of fat and how many calories they consumed in one day. Convert the grams of fat into calories by multiplying by nine. What percentage of their total dietary calories was made up of fat? What is the recommended amount?

Jobs for Chemists

5. Have a chemistry professor, graduate student, technician, or chemist from your town water treatment facility talk to your students about the job opportunities available to those with a background in chemistry.

# CLASSROOM DISCUSSION TOPICS

1. Ask someone who is a diabetic to come to class and describe their disease and its management. Discuss the dietary changes that are necessary to control diabetes.

2. Describe how the primary structure helps determine the secondary structure. Discuss how certain diseases, such as sickle-cell anemia or cystic fibrosis, result from a change in the primary sequence of a protein. Why does one amino acid change result in so many symptoms?

3. 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?

4. Ask the students to explain the difference between a period and a group using the periodic table (Figure 2.1 or Appendix A).