Mader: Essentials of Biology, 5e

Instructor's Manual

Chapter 2 The Chemical Basis of Life

Learning Outcomes

2.1 Atoms and Atomic Bonds

1. Distinguish among the types, locations, and charges of subatomic particles.

2. Relate how the arrangement of electrons determines an element's reactivity.

3. Explain how isotopes are useful in the study of biology.

4. Contrast ionic and covalent bonds.

5. Identify the reactants and products in a chemical equation.

2.2 Water's Importance to Life

1. Describe the general structure of a water molecule.

2. List the properties of water that are important to life.

3. Understand the importance of hydrogen bonds to the properties of water.

2.3 Acids and Bases

1. Distinguish between an acid and a base.

2. Interpret the pH scale.

3. Explain the purpose of a buffer.

Extended Lecture Outline

2.1 Atoms and Atomic Bonds

Matter is anything that takes up space and has mass. All matter is composed of elements.

Atomic Structure

Atoms are made up of protons, neutrons, and electrons in an organized fashion. The atomic mass of an element depends on the number of protons and neutrons in the nucleus; the atomic number indicates the number of protons of an element.

The Periodic Table

Chemists have organized all known elements in the periodic table, grouping them by shared characteristics.

Isotopes

Isotopes are atoms of the same element with extra neutrons in their nucleus. Sometimes a nucleus with extra neutrons is unstable, may decay, and emit radiation. Radioactive isotopes are used in many medical and research procedures.

Arrangement of Electrons in an Atom

Electrons are arranged by their energy levels, illustrated by electron shells in models of atoms. The octet rule states that an atom is most stable if it has 8 electrons in its valence shell.

Types of Chemical Bonds

When two or more atoms bond together, they form a molecule. If the molecule contains atoms of more than one element, it can be called a compound. Two primary types of chemical bonds are ionic bonds and covalent bonds.

Chemical Formulas and Reactions

Chemical reactions can be represented by equations showing reactants (shown on the left of the arrow) and products (shown on the right of the arrow).

2.2 Water's Importance to Life

The Structure of Water

Because of the electronegativity of hydrogen and oxygen, these atoms form polar covalent bonds, giving water a consistent shape and important properties.

Properties of Water

Because of the polar covalent bonds and the ability to form hydrogen bonds, water has the following properties important to life: it is a solvent; it is cohesive and adhesive; it has a high surface tension; it has a high heat capacity; as a solid, it is less dense than as a liquid.

2.3 Acids and Bases

Acidic Solutions (High H^+ Concentration)

Acidic solutions have a high hydrogen ion (H^+) concentration. An example of a strong acid is hydrochloric acid (HCl), which dissociates in this manner:

$HCl \rightarrow H^+ + Cl^-$

Basic Solutions (Low H^+ Concentration)

Basic solutions have a low hydrogen ion (H^+) concentration. An example of a strong base is sodium hydroxide, which dissociates in this manner:

$NaOH \rightarrow Na^+ + OH^-$

pH and the pH Scale

The pH scale was created to indicate the hydrogen ion concentration of a solution. The lower the pH, the more acidic the solution, and the higher the pH, the more basic the solution. The pH scale ranges from 0 to14. A pH of 7 represents a neutral state.

Buffers and pH

Buffers are important substances found in living organisms that help maintain a certain range of pH.

Lecture Enrichment Topics

2.1 Atoms and Atomic Bonds

1. Present Dmitry Mendeleyev's story. Mendeleyev was a professor of chemistry in the mid-1800s and author of *The Principles of Chemistry*. Throughout the 1800s, scientists were discovering the elements and their properties and trying to find patterns of similarity. Mendeleyev worked on the puzzle of how to organize the elements for nearly 20 years. He wrote each element and its properties on a card and would arrange and rearrange these cards, looking for patterns. Finally, he realized a logical pattern in a dream. "I saw in a dream a table where all the elements fell into place as required. Awakening, I immediately wrote it down on a piece of paper." Mendeleyev published the periodic table in 1869 in a paper titled, "A Suggested System for the Elements."
2. Book recommendation for instructor and student: Oliver Sacks, *Uncle Tungsten: Memories of a Chemical Boyhood*. Vintage Books, 2001.
3. In order to reinforce their understanding of the organization in the periodic table, quiz the students by asking for the element that, for example, has four electrons in its valence shell and has two shells [carbon]. Repeat with other elements; create a contest between groups.
4. More information on radioactivity: ionizing radiation, the radiation given off by isotopes, has enough energy to remove electrons from atoms. There are three types of ionizing radiation: alpha particles, beta particles, and gamma rays. Some of the sources of ionizing radiation are the rocks and soil, which may contain radioactive isotopes of uranium or radon; cosmic radiation; and human-produced radiation from weapons, energy reactors, and medical technology. Household products such as smoke detectors use radioactive isotopes enclosed in a protective housing.

2.2 Water's Importance to Life

1. Ask the students why water beads on a freshly washed or freshly waxed car. What characteristics of water and the car's finish or wax cause this? [Cohesion of water molecules along with the hydrophobic nature of the car's waxy finish repel water.]
2. Demonstrate water uptake in a plant. Leave two large, leafy celery stalks with some leaves remaining out at room temperature overnight. They should be limp

and bendable in the morning. Make a fresh cut and place one stalk in a container of water. After one to two hours, the stalk should be firmer, showing uptake of water through the stem. Compare it to the other stalk, which was not placed in water. Additionally, food coloring could be added to the water, which should show as the fluid is taken up into the celery stalk. This is the process florists use to color white daisies.

3. Animals other than insects can use the surface tension of water to walk across the surface. The green basilisk lizard, *Basiliscus plumifrons*, a type of iguana that is about two and a half feet from head to tip of tail and found in Central America, can run across the surface of the water to escape predators. (This lizard is sometimes referred to as the Jesus lizard.) Its feet are webbed, but it must run fast in order to stay on top of the water.

2.3 Acids and Bases

1. Give a preview of how blood pH impacts respiration and how increasing atmospheric CO_2 affects the pH of the oceans. Present the equation $CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$ and then ask students how it will be impacted when people hold their breath. Have students investigate ocean acidification online or steer them to the PMEL Carbon Program website.

Critical Thinking Questions

1. Define radioactivity, including a description of the structure of an atom that is radioactive. Explain why irradiating something does not make it radioactive.

Ans: Radioactivity involves the instability of an atom's nucleus, which has excess neutrons. High-energy radioactive particles are given off—this is called radiation. The property of radioactivity originates within the radioactive atom. Exposure to radiation may cause damage to living things or sterilize food, but it does not create radioactive atoms with excess neutrons.

2. Why is water critical for metabolic processes?

Ans: Cells are composed mostly of water. One property of water is that it is a solvent that dissolves many substances, including those that participate in metabolic reactions in cells. When dissolved in water, these substances can move about and interact.

3. The cohesive and adhesive abilities of water are critical in moving water up the conducting vessels of a plant. Since adhesion is important for this process, what must be true of the conducting vessels of a plant?

Ans: Molecules in the walls of plant-conducting vessels must also be polar (hydrophilic) so that water molecules can adhere to them.

Essay Questions

1. An oxygen atom has 8 protons, 8 neutrons, and 8 electrons. Its atomic mass is 16. Do electrons have mass?

Ans: Yes, electrons are composed of matter and do have mass; however, it is so slight that it is not included in an atomic mass number.

2. Why is it important for our blood to be buffered?

Ans: Digestion of different types of food can create H^+ and OH^- ions that are absorbed into the bloodstream. These ions, which cause acidic or basic conditions, can harm other molecules in our body if in excess, so the blood is buffered to maintain pH within a range that is not harmful.

3. Describe the two ways water maintains temperatures appropriate for living organisms.

Ans: Water is a polar molecule that links to other water molecules through hydrogen bonding. Because of these hydrogen bonds, water can absorb some heat (energy) without greatly changing temperature because the hydrogen bonds hold the water molecules together. This is called a high heat capacity. The resistance to temperature change protects living organisms.

Also, due to the nature of hydrogen bonding, a great deal of energy is needed to break these bonds, separating water molecules and creating gaseous water in evaporation. This is called high heat of vaporization, which provides a way for organisms to get rid of excess heat (energy).