Solution Manual for Biology The Essentials 2nd Edition by Marielle Hoefnagels ISBN 0078024250 9780078024252

CHAPTER 2 – The Chemistry of Life

CHAPTER OUTLINE

Atoms Make Up All Matter
- A. Elements Are Fundamental Types of Matter
- B. Atoms Are Particles of Elements
- C. Isotopes Have Different Numbers of Neutrons

Chemical Bonds Link Atoms
- A. Electrons Determine Bonding
- B. In an Ionic Bond, One Atom Transfers Electrons to Another Atom
- C. In a Covalent Bond, Atoms Share Electrons
- D. Partial Charges on Polar Molecules Create Hydrogen Bonds

Water Is Essential to Life
- A. Water Is Cohesive and Adhesive
- B. Many Substances Dissolve in Water
- C. Water Regulates Temperature
- D. Water Expands as It Freezes
- E. Water Participates in Life's Chemical Reactions

Cells Have an Optimum pH

Cells Contain Four Major Types of Organic Molecules
- A. Large Organic Molecules Are Composed of Smaller Subunits
- B. Carbohydrates Include Simple Sugars and Polysaccharides
- C. Proteins Are Complex and Highly Versatile
- D. Nucleic Acids Store and Transmit Genetic Information
- E. Lipids Are Hydrophobic and Energy-Rich

LEARNING OUTCOMES

02.00.01 Explain the relationship between chemistry and biology.
Identify the most important elements in living organisms.
Describe the structure of atoms.
Compare and contrast the different types of bonds.
Differentiate between atoms and molecules.
02.03.01 Explain how the structure of water affects its chemical properties.
02.04.01 Explain how acids and bases affect pH.
Explain the relationship between monomers and polymers.
Compare and contrast the structures and functions of the four classes of biological molecules.

WHERE DOES IT ALL FIT IN?

Chapter 2 provides an overview of the basic principles of chemistry making up the first hierarchal level of living systems discussed in Chapter 1. The chemistry concepts and terminology can be intimidating to many students because of the diversity of concepts needed to build an understanding of biological molecules. Reinforce to students that the elemental chemistry being covered in this chapter is essential for understanding cell structure and organismic function, and principles of homeostasis being taught during the semester. The scope of information about organic matter covered in Chapter 2 sets down the foundation of understanding cell metabolism, cell replication, cell structure, genetics, and membrane transport. Regularly refer to Chapter 2 when discussing the topics that rely on information about elements, organic molecules, and the properties of water.

SYNOPSIS

This chapter presents students with the basic chemistry background essential for understanding the underlying principles of biology. Living organisms can be viewed as chemical machinery composed of molecules that build their structure and that take part in chemical reactions that run a variety of metabolic reactions. The chapter demonstrates the roles of elements and molecules to the function and structure of organisms and their interaction with the environment. Basic concepts about atoms and elements are discussed in a way that is pertinent to biological systems. Emphasis is placed on the biological roles of ions and bonding. The important features of isotopes pertinent to living systems are also discussed.

The properties of water are also discussed in this chapter. The features of water that permit cell function and the overall survival of organisms on the Earth are highlighted. Examples of water’s characteristics are illustrated using examples of how organisms adapted to the Earth’s watery environment. It is stressed that water is the main unifying molecule that maintains the chemical and physical environmental conditions needed for cells and organisms to function. Coverage is also given to pH and its role in organisms and the environment. Buffers are introduced, as well as information about how organisms regulate their internal environments.

Organic molecules are later introduced in the chapter once the foundations of elements and bonds are established. The chapter introduces the fundamental properties of biological molecules and their existence as monomers and polymers. Each group of molecules is then introduced. The basic chemistry and biological roles of carbohydrates, proteins, nucleic acids, and lipids are discussed.
Examples of common monomers and polymers are discussed. Enough background about each group of molecules is provided to promote class discussions about environmental health, medical treatments, and nutrition.

COMMON STUDENT MISCONCEPTIONS

There is ample evidence in the educational literature that student misconceptions of information will inhibit the learning of concepts related to the misinformation. The following concepts covered in Chapter 2 are commonly the subject of student misconceptions. This information on "bioliteracy" was collected from faculty and the science education literature.

- Students do not discern mass and weight and think they are equal at all times.
- Students think density of an object depends only on its volume.
- Students are unaware that atoms cannot be seen with a standard microscope.
- Students confuse the terms atoms and elements as synonymous in meaning.
- Students believe the atomic nucleus is large and in close proximity to the orbitals.
- Students think the electron shell is there to protect the nucleus.
- Students misconceive that elements of solids are hard, whereas elements of gases are soft.
- Students are unaware that atomic mass values are unaffected by electron number.
- Students think all bonds store and release energy.
- Students believe ionic compounds form neutral molecules such as Na^+Cl^- in water.
- Students think electrons in covalent bonds belong to the particular atom they came from.
- Students are unaware that electron pairs are not always equally shared in covalent bonds.
- Students think the strength of acids and bases is the same thing as its concentration.
- Students think substances containing H are acidic; substances containing OH are basic.
- Students are unaware the pH scale is not a linear change in measurement.
- Students misconceive that buffers make a solution neutral.
- Students think all acids and bases are harmful and poisonous.
- Students are unaware that salts have a pH value.
- Students believe pH is a measure of acidity.
- Students believe the chemistry in biological systems does not follow all the same rules of chemistry.
- Students are unsure about the hierarchical order of atoms, molecules, and cells.
- Students are unaware that carbohydrates serve other purposes beyond a source of fuel for the body.
- Students think all polysaccharides are starches.
- Students think all carbohydrate polymers are for food storage.
- Students are unaware that proteins are energy sources for the body.
- Students are unfamiliar with more than the common 20 types of amino acids in nature.
- Students are unaware that amino acids and proteins are related molecules.
- Students think fats produce more energy than carbohydrates.
- Students think fats only serve as a stored source of energy.
- Students often confuse amino acids and nucleic acids.
- Students believe all proteins have tertiary structure.
- Students believe proteins are a 100% representation of the DNA information.
- Students think nucleic acids solely serve the purpose of genetic material.
- Students believe saturated fats are bad, while unsaturated fats are good.
- Students are unaware that cholesterol is required by the body.

- Students think fats travel as clumps of insoluble material in the blood.
- Students think organic molecules are only produced by organisms.

The following articles provide strategies for increasing bioliteracy in the college classroom:

Baldwin JD, Ebert-May D, Burns, D. 1999. The development of a college biology self-efficacy instrument for non-majors. Science Education 83(4): 397-408.

Ebert-May D. 2001. Research-based change: how one college professor approached the challenge of changing teaching. In: Implementing the Science Standards in Higher Education, eds. W. J. McIntosh and E. Siebert, pp. 36-39. Arlington, VA: National Science Teachers Association.

Khodor J, Halme DG, Walker GC. 2004. A Hierarchical Biology Concept Framework: A Tool for Course Design. Cell Biology Education, 3(2): 111-121.

Klymkowsky MW, Garvin-Doxas K, Zeilik M. 2003. Bioliteracy and teaching efficacy: what biologists can learn from physicists. Cell Biol Educ, 2(3):155-61.

INSTRUCTIONAL STRATEGY PRESENTATION ASSISTANCE

Molecular models are quite helpful when reinforcing the concept of molecular structure. Many aspects of chemistry such as the differences between isomers just don't work on a two- dimensional surface. Three-dimensional isomer models can be built and shown to the class.
Large plastic or polystyrene molecular model kits usually used to teach organic chemistry are appropriate for large lecture sections. The importance of molecular shape in living organisms can be demonstrated using hands and different size gloves. The hands can represent a substrate and the gloves represent an enzyme that must bind with the substrate.

Researchers have been known to use common objects to represent the structure of molecules they were studying. Provide students with tangible examples of 3-D molecular structure by constructing molecules from polystyrene balls and straws. Pop-it beads are valuable for describing polymerization of nearly all of the molecules of life, especially amino acids forming polypeptide chains. A coiled telephone cord effectively resembles an alpha helix while a zigzag strip of crimped paper can demonstrate pleated sheets.

The characteristics of water become intuitive to students when related to everyday observations such as the tempering effects on weather, sweating, surface tension, and so forth. Use as many common examples as possible. Students can measure the relative pH of various household solutions using tea – the normal unadulterated drinking variety. Tea becomes more yellow in color when lemon juice is added because the juice is acidic, not because the tea is diluted by a yellow liquid. Red cabbage is also an acid-base indicator; red when acid, blue when basic.

Construct protein amino acid sequence demonstrations by using a chain of pop beads composed of 20 differently labeled beads to represent the 20 different amino acids commonly making up proteins (the beads can be labeled with an indelible marker). The beads can be put together to show the variation in primary structure. Pipe cleaners, or wire, can be used to help demonstrate secondary, tertiary, and quaternary structure.

It is encouraged to use some lecture or recitation time to discuss the "What's the Point?," "Why We Care," "Burning Questions" boxes, and the end-of-chapter reading titled "Investigating Life:
E. T. and the Origin of Life." The information in these resources encourages students to use the chapter information in critical thinking situations.

When assigning the chapter as a reading, encourage the students to stop and complete the "Mastering Concepts" features as a way of assessing their knowledge of what they read. In addition, the "Pull It Together" provides students with a visual summary of the important concepts in the chapter.

HIGHER LEVEL ASSESSMENT

Higher level assessment measures a student's ability to use terms and concepts learned from the lecture and the textbook. A complete understanding of biology content provides students with the tools to synthesize new hypotheses and knowledge using the facts they have learned. The following table provides examples of assessing a student's ability to apply, analyze, synthesize, and evaluate information from Chapter 2.

Application	☐ Have students apply the concept of water cohesion to the properties of glue. ☐ Ask students to explain why the digestive system of animals must be adapted to break down covalent bonds yet there is no particular mechanism for breaking down ionic bonds. ☐ Ask students to explain why foods high in saturated fats stay fresher than foods high in unsaturated fats.
Analysis	☐ Ask students to select and analyze three characteristics of water that would help an organism survive in the desert. ☐ Ask students to explain why keeping track of dietary amino acid intake is more important than just knowing what proteins are being taken in the diet. ☐ Ask students to explain what nutrient molecules would be deficient in food if crop plants were deprived of fertilizers containing nitrogen and phosphorus.
Synthesis	☐ Ask students to come up with potential agricultural uses of an instrument that measures the types of elements found within an intact living organism. ☐ Ask students to design a hypothetical low calorie food using isomers of carbohydrates and alternative forms of lipids. ☐ Ask students to describe how an organism would have to adapt to extremely hot environmental conditions in which the tertiary structure of normal proteins is disrupted.
Evaluation	☐ Ask students to discuss the probability of life on a planet that is not abundant in the elements that form covalent bonds. ☐ Ask students to evaluate the difference between nutrients obtained from nature versus those produced synthetically in a laboratory. ☐ Ask students to explain why the molecules in organisms found on another planet may not be of nutritional value to humans.

FUN FACTS

Trivial facts about biology are a fun way to spice up a lecture. They can be read in class or placed at appropriate points into a lecture using the board or a projected presentation. The trivia can be used as a jumping point for students to further investigate the fact.

- The only letter not appearing on the periodic table of elements is the letter J.
- Matter making up the Earth weighs approximately 7,000,000,000,000,000 tons.
- Types of matter called atoms were believed to exist by the Greeks about 2,400 years ago.
- At room temperature, the average air molecule travels at the speed of a rifle bullet.
- Air becomes liquid at about -190^{o} C.
- Cellophane food wrap is not made of plastic, rather it is made from cellulose that has been shredded and aged.
- In a 100-year period, a water molecule spends 98 years in the ocean, 20 months as ice, about two weeks in fresh water bodies, and less than a week in the atmosphere.
- An average adult human body contains around 250 g or ½ lb of salt.
- The amount of carbon in the human body is enough to fill about 9,000 lead pencils.
- It is estimated that a plastic container can resist decomposition when buried in a landfill for as long as 50,000 years.
- A bee sting is acidic and a wasp sting is alkali.

IN-CLASS CONCEPTUAL DEMONSTRATION

Exposing the Carbon Skeleton of Organisms

Organic chemistry is often the least enjoyable subject covered in general biology courses. This demonstration reinforces the fact that all organic molecules have a carbon skeleton. It shows the prevalence of carbon in organic molecules versus inorganic molecules. Plus, it demonstrates the amount of bond energy stored in organic molecules. It uses sulfuric acid to break down the covalent bonds of organic molecules releasing the oxygen and hydrogen. What remains in the container is a carbon mass puffed with gases (carbon dioxide and sulfur oxides) released by the molecular degradation.

Special Precautions

- Caution must be used with this demonstration. It produces a rapid burst of heat and noxious fumes. It should be done using personal protection equipment (gloves, goggles, and a laboratory apron) and in a well-vented area near a source of running water. Be careful to conduct the demonstration in a manner that students cannot be harmed if the glass container cracks. The waste remaining from the demonstration should be disposed in an acid waste container.

This procedure can be shown to a large class using a videocam attached to an LCD projector. Materials

- Large glass thermometer
- Three 400 ml Pyrex®, or equivalent glass, beakers
- Three large glass test tubes
- 300 ml of room temperature water
- Bottle of sucrose solution with dropper (20 g sucrose/100 ml water)
- Bottle of amino acid solution with dropper (20 g amino acids/100 ml water)
- Bottle of table salt solution with dropper (20 g table salt/100 ml water)
- Bottle of concentrated sulfuric acid solution with dropper
- Roll of aluminum foil
- Personal protection equipment

Procedure and Inquiry

1. Explain to the class that you will be demonstrating the carbon composition of organic molecules compared to inorganic molecules.
2. Lay down a sheet of aluminum foil on the table where the demonstration will take place.
3. Place one beaker in the middle of the foil.
4. Add 100 ml of water to the beaker.
5. Place one test tube into the beaker.
6. Add 5 ml of sucrose solution to the test tube while explaining your action to the class.
7. Place the thermometer in the beaker so that the bulb is touching the base of the test tube.
8. Announce to the class the starting temperature of the solution.
9. Slowly add approximately 2 ml of the concentrated sulfur acid (do not mix or stir).
10. Direct the class to observe what happens (the solution will darken followed by the rapid eruption of a black column of "puffy material").
11. Announce to the class the final temperature of the solution.
12. Repeat steps 4 through 11 for the amino acid and salt solutions.
13. Ask the class to explain the elemental composition of the "puffy material" (they should be directed to answer carbon with hydrogen gas and carbon dioxide).
14. Ask them why the table salt solution did not show carbon "puffy stuff."
15. Ask the class to explain the temperature elevation (they should explain it was due to the energy released by the breakage of covalent bonds).
16. Ask the students what they should expect to find if a similar demonstration was performed on the following materials:
    - ☐ A piece of chalk
    - ☐ Lump of bacon fat
    - ☐ A piece of paper