

Chapter Summary

Chapter 2 provides an overview of basic biological chemistry. Although this is often a topic students dread, it is important to convey to them that the physical chemistry and molecular interactions covered in the chapter will serve as a foundation of knowledge for the mechanisms of physiological processes discussed throughout the rest of the course. For example, this chapter is important for gaining a better understanding of how membrane depolarization works in the nervous and muscular systems for communication (Chapters 6 and 7), as well as for the biochemical metabolic pathways discussed in the digestive system (Chapter 12).

This chapter begins with the fundamental concepts related to matter and energy, then proceeds to show the breakdown of matter into its components. A discussion of the periodic table reveals the way in which elements are arranged by properties, which enable determination of element characteristics, based on their position on the periodic table. The four most abundant elements in all living organisms (i.e., carbon, oxygen, hydrogen, and nitrogen) are emphasized.

Atomic structure is presented next, and the planetary and orbital models provide a framework upon which students begin to build their understanding of atoms. Atomic number, atomic mass (number), and atomic weight are discussed, followed by comments on the characteristics of isotopes and their role in healthcare assessment and management. The concepts presented about atomic structure lead naturally into a discussion of molecules and compounds. Chemical bonds and reactions are presented as a means by which molecules and bonds are continuously formed and destroyed. The differences between ionic, covalent, and hydrogen bonds are all discussed, as are synthesis and decomposition reactions.

The final section of this chapter provides an overview of biochemistry. The differences between organic and inorganic compounds are presented, along with applied examples of each. Water is noted to be the most abundant compound in the body, which helps students understand its role as the universal “solvent” of life. The reactions of acids and bases then leads into the discussion of biochemical reactions in the body. The types of organic compounds (i.e., carbohydrates, lipids, proteins, and nucleic acids) further these concepts, as students begin to see the importance of the proper utilization of these compounds in all body processes.

Suggested Lecture Outline

I. Concepts of Matter and Energy (pp. 25–27)

A. Matter (pp. 25–26)

B. Energy (pp. 26–27)

1. Forms of Energy
 - a. Chemical Energy
 - b. Electrical Energy
 - c. Mechanical Energy
 - d. Radiant Energy
2. Energy Form Conversions

II. Composition of Matter (pp. 27–31)

- A. Elements and Atoms (p. 27)
- B. Atomic Structure (pp. 27, 29–30)
 1. The Basic Atomic Subparticles
 2. Planetary and Orbital Models of an Atom
- C. Identifying Elements (pp. 30–31)
 1. Atomic Number
 2. Atomic Mass
 3. Atomic Weight and Isotopes

III. Molecules and Compounds (pp. 31–33)

IV. Chemical Bonds and Chemical Reactions (pp. 33–39)

- A. Bond Formation (pp. 33–38)
 1. Role of Electrons
 2. Types of Chemical Bonds
 - a. Ionic Bonds
 - b. Covalent Bonds
 - c. Hydrogen Bonds
- B. Patterns of Chemical Reactions (pp. 38–39)
 1. Synthesis Reactions
 2. Decomposition Reactions
 3. Exchange Reactions
 4. Factors Influencing the Rate of Chemical Reactions

V. Biochemistry: The Chemical Composition of Living Matter (pp. 39–57)

- A. Inorganic Compounds (pp. 40–43)
 1. Water
 2. Salts
 3. Acids and Bases
 - a. Characteristics of Acids
 - b. Characteristics of Bases
 - c. pH: Acid-Base Concentrations
- B. Organic Compounds (pp. 43–54, 56–57)
 1. Carbohydrates
 - a. Monosaccharides

TEACHING TIP

Demonstrate acidic or basic nature of household products in class to introduce pH. This can be done with the use of red cabbage juice (water that turns color after boiling a red cabbage for 30 minutes). Discuss how the red cabbage juice can function as an indicator. Use lemon juice, coffee, milk, water, baking soda solution, and bleach to show the spectrum of acid-base pH color change. Vary the exercise by asking students their hypotheses as to which solutions are acidic or basic and why. Also initiate a discussion on how Alka-Seltzer or Pepto-Bismol works, and demonstrate by adding to lemon juice and then using the red cabbage juice indicator. This will drive home the concept of pH and acid-base to the students in an understandable and engaging manner.

MEDIA TIP

Basic Chemistry for Biology Students (HRM: 21 min., 1993). Excellent video for clarifying basic chemistry concepts.

- b. Disaccharides
 - c. Polysaccharides
- 2. Lipids
 - a. Triglycerides
 - b. Phospholipids
 - c. Steroids
- 3. Proteins
 - a. Structural Levels of Proteins
 - b. Fibrous and Globular Proteins
 - c. Enzymes and Enzyme Activity
- 4. Nucleic Acids
- 5. Adenosine Triphosphate (ATP)

Key Terms

-ase	electrical energy	nucleic acids
acids (proton donors)	electrolytes	nucleotides
adenosine diphosphate (ADP)	electron shells (energy levels)	orbital model
adenosine triphosphate (ATP)	electrons (e^-)	organic compounds
amino acids	elements	periodic table
anion	energy	pH
atomic mass	energy levels	phospholipids
(atomic mass number)	enzyme (catalyst)	planetary model
atomic number	exchange reactions	polysaccharides
atomic symbol	fatty acids (monounsaturated, polyunsaturated)	potential energy
atomic weight	fibrous (structural) proteins	proteins
atoms	globular (functional) proteins	protons (p^+)
bases (proton acceptors)	glucose	radiant energy
buffers	glycerol	radioactivity
carbohydrates	hydrogen bonds	radioisotopes
cation	hydrolysis	reactant
chemical energy	inorganic compounds	ribonucleic acid (RNA)
chemical reactions	ionic bonds	salt
cholesterol	ions	saturated
colloid	isotopes	solute
compound	kinetic energy	solution
covalent bonds	lipids	solvent
decomposition	matter	steroids
reactions	mechanical energy	structural proteins
dehydration synthesis	molecules	suspension
deoxyribonucleic acid (DNA)	monosaccharides	synthesis reactions
disaccharides	neutral fats	trans fats
	neutralization reaction	triglycerides
	neutrons (n^0)	unsaturated
		valence shell

Resources for Teaching Online

Discussion Board Topic: Radioisotopes

In the textbook on p. 31, radioisotopes are defined as heavier, less stable variants of an element that tends to decompose to become more stable. Stability is accomplished by ejecting particles or electromagnetic energy from the nucleus. Engage your students by using the following discussion questions in lecture or by posting them to the discussion board on your course management system.

Discussion Questions

1. What are some diagnostic or therapeutic uses of radioisotopes?
2. What are the potential dangers of radioisotope use?
3. What is radiation hormesis? What do current scientific studies suggest?

Investigate Online

Take learning a step further by searching for relevant research articles on the web. Visit science websites, such as those listed below, and begin by searching for key terms such as *radioisotope therapy*, *radioisotope imaging*, *radioisotope treatment*, *radiation safety*, and *radiation hormesis* and see how what you're learning in the course applies to science and medicine today.

<http://www.sciencedaily.com/>

<http://www.scientificamerican.com/>

<http://www.the-scientist.com/>

<http://www.pubmed.org/>

Potential student responses to discussion questions:

1. Cancer treatment, hyperthyroidism, diagnostic imaging such as PET scans
2. Cancer, teratogenic effects, developmental effects in children are some examples
3. Radiation hormesis is the idea that small doses/levels of radiation can actually be beneficial. Scientists are still debating whether or not this is or is not the case; scientific studies have shown both positive and negative results, so this may spark some debate with the students

Lecture Hints

1. Introduce the topic of chemistry with an eye-catching experiment. For example, creating a “volcano eruption” by combining baking soda and vinegar.

Go through the dissociation of ions in water:

baking soda: $\text{NaHCO}_3 \rightarrow \text{Na}^+(\text{aq}) + \text{HCO}_3^-(\text{aq})$

vinegar: $\text{CH}_3\text{COOH} \leftrightarrow \text{H}^+(\text{aq}) + \text{CH}_3\text{COO}^-(\text{aq})$

Then the synthesis reaction of carbonic acid: $\text{H}^+ + \text{HCO}_3^- \rightarrow \text{H}_2\text{CO}_3$

Followed by the decomposition reaction where carbon dioxide is released: $\text{H}_2\text{CO}_3 \rightarrow \text{H}_2\text{O} + \text{CO}_2$

CO₂ is what causes the volcano eruption.

Key point: Show the fun side of chemistry. Many of the students are familiar with this experiment and may have done it themselves, or with siblings or kids. This experiment will show how chemical reactions occur using common household products. Tie in decomposition and synthesis reactions to physiological processes in the body to relate chemical reactions to body function,

2. Remind students of the levels of structural organization, starting with the atom. Explain the relevance of chemistry to this hierarchy and reiterate that higher levels of complexity are dependent upon the smooth workings of preceding, less complex, levels.

Key point: Since chemistry seems abstract to students, they often fail to understand its importance until that connection is made for them. Providing clear examples of some of the chemical reactions we use to sustain life (e.g., IV therapy, medication administration) helps them to put chemistry into its proper applied perspective.

3. Emphasize the fact that energy is not created or destroyed, but can be converted from one form to another. Use food as an example, starting with electromagnetic radiation from the sun and ending with the chemical bonds of an ATP molecule in a human muscle cell.

Key point: It is important for students to understand that energy is never lost, it is just found in different forms, some of which we can capture and others of which, at this point, we cannot.

4. Use the periodic table as a tool to discuss atoms and elements, and continue to use it while presenting the mechanics of bond formation. Work through a few examples (e.g., sodium reacting with chlorine) then have the students work through several combinations of elements contained within the same columns.

Key point: Once the students see how the elements react based on their valence electrons, they begin to form a clearer picture of the chemical properties of the elements.

5. Use as many visual aids as you can to demonstrate bonding patterns between atoms. Ball-and-stick models or Zometool models are optimal.

Key point: The more experience students have with forming molecules and compounds in model form, the better their understanding of the various bond formations.

6. Explain the tendency of elements with less than four electrons in their valence shell to want to *lose* those electrons, while elements with more than four electrons in their valence shell will want to *gain* electrons, all in the name of achieving “stability.” Further explain that it is when there are four electrons in the valence shell that the element doesn’t want to gain or lose electrons, but is willing at that point to *share* electrons. Note that only a few elements (the noble gases) come equipped with a stable valence shell and that prolonged excess of highly reactive unstable molecules within the body upsets homeostasis and may cause chronic diseases.

Key point: The entire field of organic chemistry is dependent upon these principles. Carbon has the capacity to form not only single bonds, but also double and triple bonds, making it a very versatile element. Without the property of carbon to share electrons, life on Earth would be entirely different or not existent at all. It is important to emphasize that humans are carbon-based organisms, as are all living things on our planet.

7. Ionic bonds form when electrons are transferred from one atom to another. In covalent bonds, electrons are shared among the atoms of the molecule and are 18 times stronger than ionic bonds.

Key point: The fact that a covalent bond is 18 times stronger is the “take home” concept when comparing the two bonds.

8. Make sure students understand that hydrogen bonds can be formed between molecules or can be formed within a molecule. Use water as an example of intermolecular hydrogen bonding and proteins for intramolecular bonding.

Key point: Hydrogen bonds, although weak, are important for holding DNA and large proteins together, as well as for holding water molecules together. The fact that only weak hydrogen bonds join these base pairs together within the middle of the DNA molecule and very strong covalent bonds join the sugar-phosphate backbones is very important because the DNA molecule is enabled to split apart and replicate.

9. Discuss surface tension to explain the outcome of hydrogen bonds. Students have usually seen insects “walk on water” and appreciate gaining an understanding of why this is possible.

Key point: Until they can visualize the effects of millions of hydrogen bonds holding water together, it is difficult for students to understand their importance.

10. Emphasize the fact that the larger the pH number, the smaller the concentration of hydrogen ions and thus the larger the relative concentration of hydroxyl ions, and the more alkaline the solution. The smaller the pH number, the larger the concentration of hydrogen ions, and thus the more acidic the solution. This concept can be further demonstrated with pH meter measurements of lemon juice versus bleach. Each of these can be serially diluted tenfold, and the pH meter can illustrate the change in 1 pH unit.

Key point: Students frequently confuse this point. It is important to point out that each change of 1 pH unit represents a tenfold change in hydrogen-ion concentration. Relating the pH reading to substances students know as acidic or basic, and further demonstrating what happens to the pH with tenfold dilutions, would aid in the students’ understanding of the concept.

11. Discuss the importance of maintaining pH in different regions of the body. Use pH values of blood and gastric juice to illustrate two different environments in the body, and explain how enzymes in one area may not work in another area.

Key point: Explain how chemical reactions and therefore cell functions do not occur if the environmental conditions where the reactions are to take place are outside the optimal normal pH range for the particular chemicals to interact. This concept will be important later when discussing the respiratory buffer system in Chapters 13 and 15.

12. Construct a flowchart to help students identify molecular formulas for carbohydrates, lipids, and proteins. For example, if H:O = 2:1, the molecule is a carbohydrate. If there is mostly carbon and hydrogen and relatively little oxygen, it is probably a lipid. If there is nitrogen, along with carbon, hydrogen, and oxygen, most likely it is a protein or protein derivative. Then, put cutout pictures of various examples of carbohydrates, lipids, or amino acids on the board and ask students to classify them using the chart.

Key point: It is important to help students visualize organic compounds and their component parts. This will be particularly relevant later when students begin analyzing anabolism and catabolism.

13. Create ball and stick models or Zometool models to create monosaccharides, amino acids, and ionic compounds such as NaCl. Demonstrate synthesis, decomposition, and exchange reactions between the molecules.

Key point: Visual demonstration of the major reactions between molecules makes the interactions and processes tangible to students.

14. Discuss why proteins are important in the body; both as structural components, as well as their functional roles in physiological processes.

Key point: Since proteins account for over 50 percent of organic matter in the body, it is valuable for students to understand the wide variety of functions that proteins play, from formation of enzymes to construction of body substances.

15. Discuss the role of enzymes in catalyzing reactions. Explain that enzymes work in a lock-and-key method. The particular three-dimensional shape (active site) of the enzyme determines what substrate they “fit” with chemically. Note that the “key” is not used up on a single reaction, but can, in fact, be used over and over.

Key point: Visualizing the three-dimensional shape of enzymes helps students understand what happens when proteins (enzymes) are denatured such as when body temperature is excessively elevated. Without intact binding sites, enzymes cannot perform their designated function.

16. Adipose tissue cells shrink or swell like sponges depending on how much fat (triglyceride) is deposited within them. Fat represents stored “potential energy” and is mobilized out into the bloodstream where it travels to skeletal muscles and is utilized for energy during exercise. Future chapters will build on this information.

Key point: Fat tissue is not metabolically active tissue whereas skeletal muscle is. Thus, the stored energy within the fat must first be mobilized into the bloodstream in order to travel to other cells such as skeletal muscle to be used for energy.

Classroom Demonstrations and Student Activities

Classroom Demonstrations

1. Demonstrate the classic static electricity experiments to allow students to visualize positive and negative charges and electron movement. Take a balloon and rub against your or a student’s hair. Then show how the balloon sticks to the wall. Explain how electrons are transferred from hair to the balloon, and the hairs rubbed have a positive charge after electron loss and repel each other. The negatively charged balloon can then attract positive charges on the wall and therefore stick.
2. Demonstrate to the students how the amount of energy increases in atoms that have more electrons (and more electron orbitals). Under a fume hood, add small particles of lithium, sodium, and potassium to water in a glass beaker or Petri dish. Students can observe the length of time before the substance reacts, how long it reacts, and how bright the flame will be depending on the number of electrons each element has in its orbitals.
3. Use the periodic table of elements to show the ionic bonding of sodium and chlorine to form salt. Have the students then diagram the ionic bonding of potassium chloride, potassium bromide, and similar salts, using the periodic table as a guide. Then use the periodic table of elements to show the covalent bonding of carbon and methane. Have the students then diagram other organic compounds using the periodic table as a guide.
4. Go through the periodic table emphasizing the difference between the atomic number (# of protons, and also indirectly, number of electrons) versus the atomic mass number

- (the sum of protons and neutrons). Point to various elements and ask how many protons, neutrons, and electrons make up the element in question.
5. Demonstrate hydrogen bonding with a surface tension demonstration; carefully place a paper clip on the surface of the water in a container and have it float, but then touch the water and the paper clip will sink down, showing the fragile nature of the hydrogen bonding in the water.
 6. Create ball-and-stick models or Zometool models of monosaccharides, amino acids, and ionic compounds such as NaCl. Demonstrate synthesis, decomposition, and exchange reactions. Then have students in small groups also go through synthesis, decomposition, and exchange reactions with preconstructed molecules. The concept of reactants and products can also be discussed in this exercise.
 7. Create models of primary structure proteins. Combine to make secondary structure proteins. Use those same models to demonstrate formation of tertiary and quaternary proteins.
 8. Use a Slinky to demonstrate denaturation of an enzyme. Tie colored yarn on the Slinky at two sites that are widely separated, and then coil and twist the Slinky upon itself to bring the two pieces of yarn next to each other. Identify the active site where the yarn pieces are located. Then remind students that when the hydrogen bonds holding the enzyme (or functional protein) in its specific 3-D structure are broken, the spherical structure (and the active site) is destroyed, by allowing the Slinky to resume its helical shape. (Best done when protein and enzyme structure has been discussed.)
 9. Use or create a 3-D model of a portion of DNA and RNA. Demonstrate DNA's units and overall structure. Have students search out similarities and differences with RNA while looking at both models, and have them fill in a chart or write the characteristics on the board.
 10. Discuss the important role of cholesterol in the body, and then describe the consequences of high circulating levels in the bloodstream. Explain the difference between LDL (low density lipoprotein—"bad" cholesterol) and HDL (high density lipoprotein—"good" cholesterol). Examine the role of each type with respect to cardiovascular disease.

Student Activities

1. Have the students draw Bohr models of the elements most important to organic chemistry to clarify their understanding of the arrangement of electrons in shells.
2. Have the students draw electron dot models (Lewis structures) of various molecules to help further their understanding of ionic and covalent bonds.
3. Put a chair at the front of the room and have students come up and demonstrate the fixed pathway an electron would take in the planetary model versus the area of probability of where the electron would be in the orbital model to emphasize the difference between the two models.
4. Have students go through chemical equations of such molecules as NaCl. Have them write out synthesis of NaCl from Na^+ and Cl^- , and ask them to explain what the + and - signs mean. Ask which side designates the reactant and product in the equation, and how the direction of the arrow is significant. Then have the students go through the decomposition reaction of NaCl. Finally have students work through an exchange reaction with NaCl and KOH.

5. Ask students to name all the foods containing saturated fats and all those containing unsaturated fats that they have eaten in the last 24 hours.
6. Bring in materials or objects that are composed of common elements (e.g., a gold chain, a piece of coal, a piece of copper pipe, a cast iron skillet). Also provide examples of common compounds, such as water, table salt, vinegar, and sodium bicarbonate. Ask students to define atom, element, and compound, and explain how an atom and a molecule of a compound differ.
7. Have students make cheese using citric acid, milk, and the enzyme rennet. Kits are available from education supply companies. Discuss how enzymes work.
8. Have students extract DNA from fruit, such as bananas or strawberries, so they can visualize the genetic material.
9. Bring students to an imaging lab where they can see examples of radioisotope use in medicine, and talk to a technologist and/or doctor about nuclear medicine.
10. Have your students answer the following questions to demonstrate their understanding of how to select appropriate equipment and technology:

Mrs. Newkirk has some wonderful news to share with her family. She had a test at her doctor's office, and it was determined that in a few months, twins will be joining the family! Which test, which uses medical technology, provided this information?

- A. Cholesterol screening
- B. Ultrasound*
- C. EEG
- D. Arthroscopy

Nick is running hard, trying to score the winning run. He slides into home base just in time, but feels a popping in his wrist. Amid the cheers he is holding his aching wrist with his other hand, and the coach puts ice on it and sends him to the emergency room. The doctor orders a test to find out if there is a fracture. What is the name of this test that uses medical technology?

- A. Phlebotomy
- B. X ray*
- C. Stress test
- D. EKG

MultiMedia

See page 156 for a listing of media distributors.

1. *The Atom Revealed* (FHS: 50 min., 1993, VHS, DVD). Journeys into the atomic structure of substances that make up our world.
2. *Chemical Bonding* (FHS: 18 min., 2000, VHS, DVD, 3-year streaming webcast). From *Chemistry: The Standard Deviants Core Curriculum*, this video presents Lewis structures and the Octet Rule and its exceptions.

3. *Double Helix* (FHS: 108 min., 1987, VHS, DVD, 3-year streaming webcast). Exceptional Hollywood-style film (starring well-known actor Jeff Goldblum) that captures all the drama of the discovery of DNA.
4. *Jurassic Park* (127 min., 1993, VHS, DVD). A fictional story of how a wealthy entrepreneur creates a theme park featuring living dinosaurs from prehistoric DNA. Scientifically sound arguments lead to interesting class discussions on the possibility of dinosaur cloning today, and the resulting ethical and ecological ramifications of bringing back extinct species.
5. *Unlocking the Secrets of Life* (FHS: 50 min., 1993, DVD). Presents the atomic structure of living things, showing how DNA governs the manufacture of proteins.