# CHAPTER 2: LIFE, MATTER, AND ENERGY

## Chapter Overview

### *Introduction*

Chapter 2 introduces the chemistry needed to understand the wide-ranging and diverse functions of the body. Section 2.1 begins with the most basic level of body organization explaining atomic structure, ionization, electrolytes, and isotopes. Moving their way up the organizational hierarchy, the authors discuss the formation of molecules through chemical bonds, providing the reader with the tools to understand cell theory in the next chapter. Section 2.2 explores the profound biological effect of the structure of water, various types of mixtures, and pH. The authors also promote the understanding of energy and its relationship to metabolism. Organic compounds such as lipids, proteins, carbohydrates, and nucleic acids are of paramount importance when discussing metabolism and cellular function. In Section 2.3, these compounds and their relationships to metabolism are explained in conjunction with ATP, the energy currency of the body. Finally, Section 2.4 discusses different chemical reactions and how they relate to metabolism. Understanding the chemistry of life is an essential tool in the study of human anatomy and physiology. All structures can be reduced to the atoms and molecules that comprise them, and all physiological functions can be traced back to the chemical reactions that make them happen.

### *Key Concepts*

Here are some concepts that students should understand after reading this chapter:

- atomic structure and weight, isotopes, radiation, and elements
- the process of ionization, the significance of electrolytes, and the formation and importance of free radicals
- the nature of molecules and chemical bonds
- the properties of water
- mixtures: solutions, colloids, and suspensions
- concentration measurement
- acids, bases, and buffers
- the measurement and importance of pH
- dehydration syntheses, monomers, polymers
- the makeup of the most significant types of biochemicals in living things and their roles in health and disease
- carbohydrates, including subtypes and examples of each
- lipids, including subcategories and examples of each
- amino acids and proteins, including the four levels of structure
- the central role and functions of enzymes
- nucleic acids
- the production and function of ATP and related compounds
- forms of energy
- classes of chemical reactions
- metabolism, oxidation, and reduction

## Topics for Discussion

1. Why is an understanding of pH necessary in diagnostic testing? The student might look at standard urinalysis and blood test reports.
2. Make a list of the acids in a popular soft drink; determine the chemical structures of those acids.

3. List some common acids, bases, and salts. Get the students to start thinking in terms of clinical application. For example: Why would stomach or urinary pH matter in health and disease? Why is it necessary to have a low pH in the stomach, but harmful to have a low pH in the esophagus?
4. Itemize the uses of radioisotopes in medicine.
5. Blood is a complex mixture. Which blood components are in solution, colloidal, or in suspension?
6. Ionic molecules are less abundant in the body than covalently bonded chemicals but more time is spent studying ions. Why should that be? *Hint: Think in terms of homeostasis and/or the electrical properties of ions.*
7. Enzymes help humans in the great race for life. Ask students to reflect on the competition they face around them: bacteria and other organisms on the skin and inside the intestinal system. Were it not for these efficient enzymes, the bacteria would literally steal our lunches.
8. What is a good source of polyunsaturated or monounsaturated fatty acids? What difference to human health does it make whether a fatty acid is in the *trans* or the *cis* form? Why should one care about the different types of lipids? How is a phospholipid different from a steroid?
9. What is it about carbon that makes it such a good element in the compounds found in living things? What alternatives might there be?
10. Here is something easy for the class to see: point out that urine and blood pH levels are critical and are important in diagnosis. Often if you can find a clinical application for the information, students see the importance of the lessons.
11. It is important to be able to distinguish the different types of biochemicals in urinalysis and blood testing. Why is it important to know if one has protein or glucose in their urine?
12. Identify the total percentages of proteins, lipids, and carbohydrates in the food eaten for a day.
13. Use the label of a food package to apply the importance of percentages of nutrients in common foods.
14. Ask the students how inorganic ions, pH, and heat may cause conformational changes of non-enzyme proteins.

## Learning Strategies and Techniques

1. For students without access to the Internet, download and print out the practice quizzes from the Saladin: *Essentials* Companion website's Student Resources for this text, or create practice quizzes from the Connect questions provided for this chapter.
2. Use modeling clay to make models of molecules. Use different colors and sizes of clay to make balls representing the atoms. Some students use colored Styrofoam™ in much the same way. Toothpicks can represent the bonds. Commercial models also work well but are more expensive.
3. There are many commercial sources for molecular models—sometimes these help students to visualize molecular bonds. These models are usually available in the school bookstore.
4. Have each student play the role of a different subatomic particle. Prepare signs to be worn with "proton," "electron," and "neutron" and get them to figure out where to stand and what they should do (e.g., the electron should orbit). Similar kinesthetic learning demonstrations can be done with ions as well as with many other activities. These types of role-playing activities are useful for students who are not in the habit of thinking abstractly. Most students seem to change learning styles as the semester continues so that kinesthetic learning will probably diminish in its role.
5. One way to demonstrate acids and bases is to combine acetic acid (vinegar) and sodium bicarbonate (baking soda) in a flask at the beginning of the class. Make sure the opening of the flask is pointing away from the students and do the demonstration over a sink—it can be a bit messy. The lecturer should then go through the reaction, explaining what the reactants did and what the products were.
6. In the laboratory, get the students to work with a variety of solutions such as lemon juice, dissolved aspirin, tomato juice, milk, vinegar, dissolved sodium bicarbonate, etc. to determine pH. Either pH papers (such as pHydron™) or pH meters can be used. The effect of buffers also might be demonstrated using commercial phosphate buffer solutions. Watch to make sure that students do not add bases and acids together.
7. Half-fill a thermos with bean seeds intended for sprouts. Add enough water to equal about a quarter of the volume of the thermos. Plug with a single-hole stopper equipped with an immersion thermometer. The plug should not be fitted tightly but just seated lightly. The bulb of the thermometer should be inside the wet mass of seeds but the shaft of the thermometer should be high enough so that one can

read the 30° to 40°C range without having to remove the stopper. Have the students explain why there is such a buildup of heat.

8. Put a bag of regular tea in a beaker of hot water and watch the tannic acid diffuse from the bag. Ask the students to suggest ways to determine whether the tannin (the brownish material seeping out) is in solution or suspension.
9. In the laboratory, the students can perform chemical tests (e.g., starch-iodine) to differentiate the various biochemical groups that have been discussed in the chapter.
10. Use the animation utilities provided in the presentation software as well as in Connect to demonstrate dehydration synthesis. It may also be useful to have a student do this as a project.
11. To present protein structure as part of the organizational hierarchy, try the following. The amino acids are like different types of bricks and the protein is like the wall. Many different types of walls can be made from the same types of bricks. To form the house (*viz.* organelles or cell) properly, the wall must be shaped in just the right way, with the correct type of brick in just the right place, or the house will collapse.
12. The vital importance of getting the DNA code just right is illustrated with sickle-cell hemoglobin. There is only a single base-pair substitution, which will cause the body to form hemoglobin with only a single change in the amino acid sequence. This alteration results in sickle-cell hemoglobin, which will, under special circumstances, allow the hemoglobin to stick together. The red blood cells containing this variant hemoglobin will assume unusual forms. The oddly-shaped red blood cells (rarely in the eponymous sickle shape) will then cause capillary blockages. The capillary blockages lead to edema, ischemia, and infarction in various parts of the body that may lead to death. This sequence of disasters points out the significance of form to function.
13. The double helices of DNA and of (in certain viruses) RNA resemble a spiral staircase. The railings are the sugar-phosphate backbone and the steps are the nitrogenous bases.
14. Try to get students to adopt the use of flow charts for outlining processes. It makes it easy to see sequences and the required participants in the process. It is also a good analysis tool for understanding just how disease works, by interrupting some part of the flow.

## Related Multimedia

Abumrad, J. and R. Krulwich. *How Do You Solve a Problem Like Fritz Haber?* WNYC Radiolab, 2011. Podcast; 21 mins. http://www.radiolab.org/2012/jan/09/how-do-you-solve-problem-fritz-haber/
*All About Chemical Bonding*. Films for the Humanities and Sciences, 2010. DVD; 27 mins.
*Atom, The*. Hawkhill Associates, Inc., 2004. DVD; 48 mins.
*Atomic Structure: Mapping an Invisible World*. Insight Media, 1996. DVD; 20 mins.
*Basic Chemistry for Biology Students*. Insight Media, 1993. DVD; 21 mins.
*Biochemistry II: Carbohydrates, Proteins, Lipids, and Nucleic Acids*. Insight Media, 2005. DVD; 34 mins.
Fodor, J. *Biochemistry Basics*, The Science of Everything, 2011. Podcast; 44 mins.
http://www.podbean.com/home/podcast-directory-play.php?eid=4079794
*Greatest Discoveries in Chemistry, The*. The Science Channel, 2009. Streaming Video; 20 mins.
http://science.discovery.com/videos/greatest-discoveries-chemistry/
Khan, S. *Elements and Atoms.* The Khan Academy, 2011. Streaming Video; 13 mins.
http://www.khanacademy.org/science/chemistry/v/elements-and-atoms
*Marie Curie Finds Radium and Radioactivity*. Hawkhill Associates, Inc., 1994. VHS; 20 mins.
*Modern Chemistry: An Introduction*. Hawkhill Associates, Inc., 2003. DVD; 54 Mins.
*Radiation*. Hawkhill Associates, Inc., 2007. DVD; 38 mins.
*What Is an Atom?* Hawkhill Associates, Inc., 2003. VHS; 20 mins.

## Related Software

*Anatomy & Physiology Revealed 3.0.* McGraw-Hill, 2011. Module 2–Cells & Chemistry (See Chemistry Animations) http://anatomy.mcgraw-hill.com/v3/#
*ChemSite 3-D Molecular Modeling and Drawing.* ChemSW. http://www.chemsw.com/Software-and-Solutions/Laboratory-Software/Drawing-and-Modeling-Tools/ChemSite.aspx
Jensen, M. *Bio Molecule Classification.* WebAnatomy, University of Minnesota, 2005. Online Interactive http://msjensen.cehd.umn.edu/webanatomy/biochemistry/default.html
*LearnSmart, Chapter 2*. Connect Plus, McGraw-Hill, 2013. Adaptive Learning Tool.

*Molecular Biology*. Insight Media, 1997. CD-ROM
*Molecular Modeling Pro*; ChemSW http://www.chemsw.com/Software-and-Solutions/Laboratory-Software/Drawing-and-Modeling-Tools/Molecular-Modeling-Pro.aspx
*Physiology Interactive Laboratory Simulator 4.0 (Ph.I.L.S.), Laboratory #4–Cyanide and Electron Transport.* McGraw-Hill, 2012. http://phils4.mcgraw-hill.com/

## Related Readings


Anon. *Dictionary of Chemistry.* 2nd ed. Dubuque, IA: McGraw-Hill, 2003.
Daintith, J. *Oxford Dictionary of Chemistry*. 6th ed. New York: Oxford Press, 2008.
Denniston, K. J. et al. *General, Organic and Biochemistry*. 7th ed. Dubuque, IA: McGraw-Hill, 2011.
Hirschhorn, N. and W. B. Greenough III. “Progress in Oral Rehydration Therapy.” *Sci. Am*. 264, no.5 (1991): 50–56.
Macklis, R. M., “The Great Radium Scandal.” *Sci. Am*. 269, no. 2 (1993): 94–99.
Nelson, D. and M. Cox. *Lehninger: Principles of Biochemistry.* 5th ed. San Francisco: W.H. Freeman and Company, 2008.
Silberberg, M. *Chemistry: The Molecular Nature of Matter and Change.* 5th ed. Dubuque, IA: McGraw-Hill, 2009.
Singh, B. R. “A First-Day Exercise on Relevance of Chemistry to Nonscience Major Kindles Sustained Positive Student Response.” *J. Chem. Ed*. 76 (1999): 1219–1220.
Smith, J. G. *Organic Chemistry*. 3rd ed. Dubuque, IA: McGraw-Hill, 2011.
Tran, N. and L. Baraj, “Contribution of Specific Dietary Factors to CHD in US Females.” *Public Health Nutr.* 13 (2010): 154–162.
Walker, S. and D. McMahon. *Biochemistry Demystified.* Dubuque, IA: McGraw-Hill, 2009.


## Testing Your Comprehension Questions

These questions can be found at the end of the Chapter 2 Student Study Guide.

1. How would the important life-sustaining properties of water change if it had nonpolar covalent bonds instead of polar covalent? Explain.
2. In one form of radioactive decay, a neutron breaks down into a proton and electron and emits a gamma ray. Is this an endergonic or exergonic reaction, or neither? Is it an anabolic or catabolic reaction, or neither? Explain both answers.
3. Some metabolic conditions such as diabetes mellitus cause disturbances in the acid–base balance of the body, which gives the body fluids an abnormally low pH. Explain how this could affect the ability of enzymes to control biochemical reactions in the body.

## Testing Your Comprehension Answers

1. Water would not be as versatile a solvent without its polarity. As is, it is the ideal medium for the chemical reactions that must occur in the body, and it is ideally suited for transporting substances from place to place, as in the bloodstream. Without its polarity, water would lose its adhesive quality and not serve as an essential lubricant in many of our extracellular fluids. Without its polarity, water would also be less cohesive and therefore lose its thermal stability, which makes it an effective coolant. Finally, the ionizing properties associated with water’s polar covalent bonds allow for the chemical reactions essential for life.
2. This reaction is exergonic because energy is released in the form of a gamma ray. Since anabolism and catabolism are both branches of metabolism, this reaction is neither.
3. Acids and bases can denature proteins, disrupting or destroying their secondary and tertiary structures. Since enzymes are proteins, a shift in the acid-base balance disturbs the normal pattern of metabolic activity catalyzed by these enzymes. Some cellular chemical reactions are accelerated; others are depressed.

## Apply What You Know Questions

1. Do you think ionic bonds are common in the human body? Why or not?

2. Liquid nitrogen, $N_2$, is commonly used for frozen storage of blood, sperm, bacterial and tissue cultures, and other biological specimens. It boils as –196ºC, in contrast to distilled water, which boils at +100ºC. Predict what type of covalent bond—polar or nonpolar—liquid nitrogen has. State the reason for your prediction and then explain how that relates to the boiling point of liquid nitrogen being almost 300º lower than that of water.

3. When sodium chloride is formed, an electron transfers from a sodium atom to a chlorine atom (see fig. 2.2). Therefore, which element—sodium or chlorine—is oxidized? Which one is reduced? Explain your answers.

## Apply What You Know Answers

1. Ionic bonds dissolve in water. Since the body is mostly water, ionic bonds are not very common.

2. Since the two atoms of the $N_2$ molecule are identical, the electrons are shared symmetrically. This means the bond is nonpolar. A water molecule ($H_2O$) is held together by polar covalent bonds and the separate molecules are held together by hydrogen bonds. These hydrogen bonds provide water with its cohesive property, meaning that the molecules stick together and it requires a lot of energy to get them apart and convert the liquid water to a gas. With the absence of polarity and hydrogen bonds, liquid nitrogen does not have the cohesion of water and therefore requires far less energy to convert it to a gas.

3. When a molecule gives up electrons and releases energy, the molecule is said to be oxidized. When a molecule gains electrons and energy, the molecule is said to be reduced. Since sodium atoms give up electrons in this reaction, sodium is oxidized. Since a $Cl_2$ molecule gains two electrons to form two ions of $Cl^-$, chlorine is reduced.

## Clinical Application Question

Percy is in New Orleans during a very hot, humid August as a student in an Anatomy & Physiology class. He is from a cloud-shrouded island off the coast of Scotland where the temperature rarely rises above 16ºC. One noontime he comes into your laboratory class very thirsty from his run and wants to drink the distilled water. He even wants to take some with him so he can drink it exclusively while he is visiting in Southern Louisiana. What should you tell Percy?

## Clinical Application Answer

Tell Percy not to drink the distilled water. Percy is sweating extensively in the high temperatures. Sweat contains electrolytes, such as salts. The more a person sweats, the more electrolytes lost. If he drinks distilled water, which is deionized, he will suffer electrolyte imbalance problems, such as muscle cramps and brittle bones. If no electrolyte replacement takes place, Percy may go into a coma and then cardiac arrest. Non-distilled water has ions, which will help Percy replace what is lost.