CHAPTER

2 The Chemical Level of Organization

Introduction to the Chapter

Chemistry often draws out a certain level of anxiety among students, but if they are planning on a career in a health field, students must come to understand certain chemical concepts. The incredibly small scale of atoms and molecules makes them difficult for many students to visualize. This is understandable since atomic and molecular events are—in a literal sense—invisible in daily life. Yet physiologists and clinicians see all of the body's activities as the end result of interactions between chemicals. All thoughts, movements, and memories rely on ions interacting with protein molecules suspended in a boundless sea of fluid phospholipids. The enzymatic breakdown of sugars and fats yields the energy that powers our bodies and enables the addition of new molecules to the body during growth, development, and repair. Pharmaceutical researchers scrutinize the chemical properties of their drugs to ensure they are properly transported, processed, and recognized by our bodies once injected or ingested. Numerous biotechnologies and genetic tests hold great potential to diagnose or treat disorders passed down through changes in nucleotides in our DNA. Thinking like a doctor or a physiologist requires such familiarity with the chemical basis of life that it is almost deceiving to separate out chemistry into its own distinct chapter. Students will find that chemistry reappears in some way in every chapter to follow. Because of that fact, many instructors take this as a chance to only very briefly introduce some common terms and concepts, with much more detailed examinations of specific molecules put off until those molecules are applied to physiological processes in the following chapters. Real-world applications, diagramming exercises, and the use of larger-scale models or role-playing activities will help students gain familiarity with this tiniest level of organization, which is central to the work of all health scientists.

Chapter Learning Outcomes

2-1 Describe an atom and how atomic structure affects interactions between atoms. p. 74

2-2 Compare the ways in which atoms combine to form molecules and compounds. p. 78

2-3 Distinguish among the major types of chemical reactions that are important for studying physiology. p. 83

2-4 Describe the crucial role of enzymes in metabolism. p. 85

2-5 Distinguish between inorganic compounds and organic compounds. p. 86

2-6 Explain how the chemical properties of water make life possible. p. 86

2-7 Explain what pH is and discuss its importance. p. 89

2-8 Describe the physiological roles of acids, bases, and salts and the role of buffers in body fluids. p. 90

2-9 Describe monomers and polymers, and the importance of functional groups in organic compounds. p. 91

2-10 Discuss the structures and functions of carbohydrates. p. 91

2-11 Discuss the structures and functions of lipids. p. 93

2-12 Discuss the structures and functions of proteins. p. 97

2-13 Discuss the structures and functions of nucleic acids. p. 103

2-14 Discuss the structures and functions of high-energy compounds. p. 105

Teaching Strategies

1. Encouraging Student Talk

a. Show students a picture of someone doing a belly flop in a calm swimming pool (numerous such open-access pictures can be found online). Ask students to think about why this is not an ideal method for getting into a pool full of water. Instruct students to work in pairs to create a labeled diagram of the water molecules on the surface of the pool just before the belly flop. Tell students to label the names of any chemical bonds or charges in their drawing. Select a few random pairs to share/describe their diagrams, resisting the chance to immediately correct any inaccuracies in the diagrams. Numerous misconceptions (see Misconceptions Section) might be present in the diagrams. You can address these misconceptions as the topics arise during lectures on chemical annotation and molecular bonds. Have students return to this exercise after instruction, looking to see whether water molecules are appropriately drawn, covalent and hydrogen bonds are labeled, and partial charges on oxygen and hydrogen atoms are indicated.

b. See what your students know before delving into a standard lecture on basic biochemistry. Ask the students to name the four macromolecules found in the body. If they are stumped, start to give them clues. Try using the term "building blocks" instead of "macromolecules." Encourage them to think about the types of foods they eat, too. Most students will know what a "carb" is, but may have trouble connecting that to humans being composed of carbohydrates, lipids, proteins, and nucleic acids. Write the macromolecules on the board; then ask if they know what smaller pieces each macromolecule is composed of. You will likely get a mix of proper chemical names like sucrose and amino acids along with trans fats and sugars. This is a good place to emphasize that they might know a good bit but need to learn the language of biology so that you can all communicate effectively. Take the exercise one step further and talk about the atoms making up each macromolecule. This will help break things down for the students and allow them to realize just how important basic chemistry will be when thinking about larger physiological processes.

2. Lecture Ideas and Key Points to Emphasize

a. In support of the crucial role that careful observation plays, you can point out that Mendeleev, the author of the best-accepted periodic table in the 1860s, lacked a comprehensive structural model of the atom, which is commonplace today, but he still saw and ordered the periodicities.

b. The most frequently discussed chemical bonds in physiology are ionic bonds, covalent bonds, and hydrogen (H) bonds. Even though a single hydrogen bond possesses only about 1/100 of the bonding energy of a covalent bond, the total energy of all the hydrogen bonds within a single molecule or between molecules can be quite significant. H bonds maintain the 3-D shape of large molecules and supramolecular ensembles such as proteins and nucleic acids. It is the H bonds that are disrupted when pH drops or temperature rises during denaturation reactions.

c. It is important to illustrate that H bonds occur between separate molecules (or distant regions of a large molecule) whose atoms are joined by covalent bonds. A board drawing of several water molecules, with both the polar covalent bonds and the H bonds clearly labeled, will emphasize this point.

d. The information on chemical notation in Spotlight Figure 2–4 is not necessarily obvious or intuitive for students. However, chemical annotation will become an important part of the communication skills that students apply throughout A&P courses. Further, students will need to understand chemical annotation for applied purposes in health science fields. This figure nicely translates chemical notation information into visual representations, making it relatively simple to look at the written annotations and directly compare them to the appearance of the chemicals themselves.

e. Enzymes are an excellent example of structure relating function at the subcellular level. This is one of the first places you can start to hammer home the concept that a protein's shape will dictate its function. The lock-and-key fit between enzyme and substrate molecule is what confers *specificity* on the catalyzed reaction. While a reaction results in chemically rearranged end products, the enzyme itself still retains its original shape and can carry out the same reaction over and over. Make sure students understand that each protein has a specific shape to allow it to participate in that lock-and-key type fit. This will also get them thinking about just how many different protein shapes there must be to run all of the chemical reactions in the body. This should start to give them an appreciation for just how important protein chemistry is and how many proteins there are. Don't be afraid to spend some time on this idea. It will come up again and again when discussing hormone receptors, channels, carriers, pumps, second messengers, cell adhesion molecules, and neurotransmission.

f. Students struggle with the pH scale. It becomes a real issue later in the semester when talking about acid-base balance in the blood, CSF, and renal and respiratory systems. Since more disease states, like diabetes and obstructive lung disorders, result in acidosis rather than alkalosis, students tend to think in terms of acids and often mistakenly associate a more acidic condition to a larger number on the pH scale. Make sure you use a visual of the pH scale when introducing this topic and shatter that misconception as early as possible.

g. When presenting the different classes of reactions, have students anticipate their roles in metabolism (catabolism vs. anabolism). Also, link each with an important physiological example, such as dissociation/association to the chemistry of carbonic acid dissociation/association. This connects to buffering reactions as well.

3. Making Learning Active

a. Perform a "jigsaw" activity on organic molecules to use in peer teaching. Prior to class, assign students roles as either carbohydrates, lipids, proteins, or nucleic acids. Instruct students to perform some research on the monomers, polymers, physiological functions, and common examples/variations for their organic molecule. To extend the content, ask students to identify and describe a disease directly related to their molecule. On the class day, students would check in briefly with other homogenous molecules and then divide into heterogeneous groups to share their knowledge. Even in large classrooms, these logistics are relatively easy to arrange. Tape sheets of paper to the walls to direct students into groups. In the heterogeneous "jigsaw" groups, students share the information they researched and take notes on the molecules presented by their peers. The instructor can then administer some brief discussion/quiz questions to enforce student accountability for learning the material and address any misconceptions that arose.

b. With student actors, demonstrate the polar property of water and hydrogen bonding between water molecules. Call a few students up to the front and ask them to hold their arms outstretched in front of them while making fists. Each student is now a water molecule. Their heads are the oxygen atom and their fists are the hydrogen atoms. You may have to adjust their arms to approximate the 104.5˚ angle observed in water molecules. Have them move around until they find a configuration that will result in hydrogen bonding. If they have trouble arranging themselves, remind them that water is polar and two oxygen "heads" can never be directly next to one another.

4. Analogies

a. Compare the primary structure of a protein to a toy train made up of many types of cars (amino acids). When hooking the cars together, there is a definite front and back, just like the C- and N-termini of a polypeptide chain. The chain of cars may be made as long as you wish and of very different form and function by assembling boxcars, passenger cars, club cars, baggage cars, tank cars, and so on. The hydrolytic digestive enzymes can be analogized to railroad workers that separate the cars at their couplings, thus making the cars available to form new trains.

b. Enzymes will work at their optimum rate as long as there is plenty of substrate and other conditions are favorable. Think of a roofer fixing a roof. He pounds in nails to hold down shingles (combining two substrates to produce a product) and can use the same hammer again and again (enzymes are catalysts not consumed in the reaction). This process can continue as long as there are nails and shingles, and as long as the environmental conditions on the roof don't become so harsh as to harm the roofer (denaturing).

c. Compare one strand of DNA to a spiral staircase: The alternating sugar and phosphate groups make up the helical supports, while the bases are analogous to the steps. Of course, DNA is made of two antiparallel helices, which would be a very confusing stairway!

d. Enzymes can be thought to work like helpers getting a car from down in one valley, over the hill, and down into a lower valley. The enzyme "lowers the hill," making it easier to get from one side to the other with much less kinetic (heat) energy. Enzymes don't change where you start or where you finish but just make it easier (and thus faster) to get over the hill. Refer to Figure 2–9 during this analogy.

5. Demonstrations

a. Compare the different levels of protein structure with ribbon used to wrap a package. A ribbon can be stretched out straight (primary), coiled in a spiral (secondary), or stripped with scissors so that it develops many overlapping curls (tertiary). You can even bunch several of the curly ribbons together to make a wreath (quaternary). You can also use an old-fashioned phone cord to represent the coiling of the protein molecule (secondary, tertiary, and quaternary structures).

6. Applications

a. Explain the role of cholesterol, both as a membrane component and as starting material for steroid hormones. Cholesterol gets a bad reputation since it is overly abundant in a western diet and can lead to cardiovascular disease states, but it is an important building block we must consume. Mention that there are at least two possible reasons for having high cholesterol. One is diet, and the other is genetic. With the diagnosis of high cholesterol, diet and exercise may be prescribed to reduce it. Those with the genetic condition of familial hypercholesterolemia may need an additional medical intervention such as a prescription for a statin. Some clinicians even argue that everyone on a western diet should take a statin to lower their cholesterol.

b. Explain the structural and functional roles of phospholipids and glycolipids. You can use Figure 2–19c to anticipate the phospholipid bilayer by asking the students to imagine what would result if a spherical micelle were flattened.

c. Most students have probably heard of "trans fats," and have read nutritional information about saturated vs. unsaturated fats in food products. This provides an excellent opportunity to discuss the chemical differences between those molecules, their sources, and their uses in the body.

d. Solutions are very important in biology and medicine. Be sure students are clear about how a solution forms, which is the solute, and which the solvent. The cell cytoplasm and the blood plasma are good examples of complex biological solutions.

e. Issues of polarity and water solubility are highly relevant to pharmaceutical drug makers. As will become clearer when cell membranes are studied in the next chapter, large polar molecules often require special techniques to get in and out of cells. Hence, drugs made mostly of large polar molecules may have difficulty getting to their sites of action. On the other hand, drugs composed of hydrophobic molecules tend to easily gain access to even those places heavily protected by membrane layers, like the nervous systems, and can also sometimes lead to dependency. Take time to ensure that students understand the nature and implications of polarity, so they can begin to apply those concepts when studying cell membrane physiology.

7. Common Student Misconceptions and Problems

a. Even if students have had an introductory chemistry course in the past, it is not unusual for them to struggle with chemical notation. Surprisingly, many students will draw a water (H_2O) molecule with two oxygen atoms and one hydrogen atom, with the idea that the "2" refers to "two O's." You may need to provide students with some practice by showing a number of sample molecule names/symbols and asking them how many of each type of atom are present.

b. Students frequently consider any covalent bond involving a hydrogen atom to be a "hydrogen bond." Create opportunities to confront students directly with this misconception. Point to covalent bonds involving hydrogen atoms and ask students if you're pointing to a hydrogen bond. If not, why? If possible, have individual students create drawings to practice their annotation of covalent vs. hydrogen bonds (see Encouraging Student Talk Section, a). Remind students how scientists use solid lines for electron-sharing covalent bonds, and dashed or dotted lines for the weaker attractions of hydrogen bonds.

c. The subject of acids vs. bases vs. salts is often difficult for students. Try to provide plenty of applied examples of each, so that students see the similarities and differences between those substances when dissolved in water. Students generally know that acidity relates to pH, but they frequently guess that more acidic solutions have a higher pH. Contrary to what students might guess, the lower the pH value, the higher the concentration of hydrogen ions. Other students may confuse pH with an actual substance found in water (e.g., "This solution has more pH."). Demonstrate that each integer change in pH value represents a tenfold change in the concentration of hydrogen ions. If the blood pH is 7.3, although an alkaline pH, it is in fact more acidic than the normal pH of blood (7.35–7.45). Hydrogen ions affect the pH only if they are in solution. A buffer acts like an ion sponge, binding or releasing hydrogen ions, and so limits changes in pH if hydrogen ions are added or removed from solution.

d. Anticipate the possible confusion between the *alpha helix* in the secondary structure of proteins and the *double helix* of the two complementary antiparallel strands in DNA.

8. Terminology Aids

a. For mnemonics for cation vs. anion (that is, positive ion vs. negative ion), let the "**t**" in cation remind you of a "+": ca+ion. Also, let **AN**ion remind you of **A N**egative ion.

b. To distinguish hydro**philic** from hydro**phobic**, remember that "phobia" is a fear, in this case, molecules that fear (or hate) water. Also, hydrophi**lic** ends with "lic," which resembles "like," that is, water-liking molecules.

c. Regarding charged atoms and molecules, remind students that "opposites attract" (i.e., positively charged ions will be attracted to negatively charged ions). However, this rule does not apply when comparing hydrophobic and hydrophilic substances. Hydrophobic and hydrophilic substances, which could seem like another pair of "opposites," do not mix well together. That situation can be compared to "oil and water," which students know do not mix.

d. Describe to students that carbohydrates are literally "hydrated water" or "carbo-" + "-hydrate"; that is, their chemical formula is an integral number of "$C–H_2O$." Thus glucose, galactose, and fructose are all $C_6H_{12}O_6$, that is, $6 \times C•H_2O$. Disaccharides, of any class, are all $C_{12}H_{22}O_{11}$.

e. When discussing redox reactions and the transfer of electrons, use the mnemonic OIL RIG. **O**xidation **i**s **L**oss, **R**eduction **i**s **G**ain for redox reactions.

f. Clue students in on root words and suffixes that can help them identify new terms. For example, "enzymes" end in the suffix "-ase."

9. Incorporating Diversity & the Human Side of A&P

a. Marie Maynard Daly was a biochemist who performed research on the roles of nucleic acids, proteins, and cholesterol in the human body. She was also the first African American woman in the United States to earn a PhD in chemistry, which she received in 1947. Her father loved science and aspired to be a chemist, but was forced to drop out of college for financial reasons. This inspired Marie Daly to persist in the sciences and fulfill her father's dream. Marie Daly's work and personal story could help to introduce the chapter or frame the content in Sections 2-11 through 2-13.

References/Additional Information:

http://www.chemheritage.org/discover/online-resources/chemistry-in-history/themes/biomolecules/proteins-and-sugars/daly.aspx

