CHAPTER 2: THE CHEMISTRY OF LIFE

Chapter Overview

Introduction

Chapter 2 introduces chemistry needed to understand the wide-ranging and diverse functions of the body. This chapter first embarks upon an explanation of atomic structure including reviews of ionization and electrolytes. The author continues to the next level in the organizational hierarchy of the body by elucidating the formation of the molecules through chemical bonds. These molecules are then used as the basic building blocks of much larger functional units. Saladin next explores various types of mixtures, pH, energy and its relationship to metabolism. The smaller organic molecules are put together through dehydration syntheses to make much larger and more complex polymers: some of which are made of thousands of units of monomers. An understanding of the structure and function of the macromolecules of polymers is essential so that the student will be able to make sense of the actions of the cell's organelles.

Key Concepts

Here are some concepts that students should come away with 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 properties of water;
- mixtures: solutions, colloids, and suspensions;
- concentration measurement;
- acids, bases, and buffers;
- the measurement and importance of pH;
- matter and energy;
- reaction rates and metabolism;
- oxidation and reduction;
- the nature of molecules and the different types of chemical bonds;
- types of chemical reactions and the value of enzymes;
- work and energy and metabolism;
- an introductory understanding of the roles of other inorganic substances in the body;
- dehydration syntheses, monomers, polymers;
- the make-up 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 including substrate specificity, induced fit, effects of disruptions in homeostasis, coenzymes, and metabolic pathways;
- and the production and function of ATP and related compounds.

Topics for Discussion

1. How is an understanding of pH necessary in diagnostic tests? The student might look at standard urinalysis and blood test report forms.
2. Make a list of the acids in a soft drink such as those in colas; determine the chemical structures of those acids.
3. List some common acids, bases, and salts. Get the students to start to think in terms of clinical applications. For example: Why would stomach or urinary pH matter in health and disease?
4. Itemize the uses of radioisotopes in medicine.

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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 we spend much time working on ions. Why should that be? Hint: Think in terms of homeostasis.
7. Enzymes help us in the great race for life. Ask students to reflect on the competition they face around them: the bacteria and other organisms on their skins and inside their intestinal systems. Were it not for our efficient enzymes, those other things 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 you 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 of 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. How is it important that a person has protein or glucose in their urine?
12. Identify the total percentages of proteins, lipids, and proteins in the food eaten for a day.
13. See the sides of the packages and in a diet book for the percentages of nutrients in common foods.
14. Ask the students how inorganic ions, pH, and heat may cause conformational changes of non-enzyme proteins.

Related Readings

McGraw-Hill. *Dictionary of Chemistry*, 2nd ed. Dubuque, IA: McGraw-Hill, 2003.

Daintith, J. *Oxford Dictionary of Chemistry* 7th ed. New York: Oxford Press, 2016.

Denniston, K.J. et al. *General, Organic, and Biochemistry*, 10th ed. Dubuque, IA: McGraw-Hill, 2020.

Hirschhorn, N. and W.B. Greenough, III. “Progress in Oral Rehydration Therapy,” *Sci. Am*. 264 (1991): 50-56.

Macklis, R.M. “The Great Radium Scandal,” *Sci. Am*. 269 (1993): 94-99.

Nelson, D. and M. Cox. *Lehninger Principles of Biochemistry*, 7th ed. San Francisco: W.H. Freeman and Company, 2017.

Silberberg, M. Chemistry: The Molecular Nature of Matter and Change, 8th ed. Dubuque, IA: McGraw-Hill, 2018.

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*, 6th ed. Dubuque, IA: McGraw-Hill, 2020.

Tran, N. and L. Baraj. “Contribution of Specific Dietary Factors to CHD in US Females,” *Public Health Nutr.* 13 (2010): 154-162. Discussion of *trans* fats and other aspects of the U.S. diet.

Walker, S and D. McMahon. *Biochemistry Demystified.* Dubuque, IA: McGraw-Hill, 2008.

Learning Strategies and Techniques

1. For students without access to the Internet, download and print out the practice quizzes for Saladin’s book and other McGraw-Hill anatomy and physiology text such as Seeley et al. Check through the questions to make sure they all relate to your learning objectives.
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.
4. Have the students role play the parts of the atom. 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 are useful for students who are not in the habit initially of thinking abstractly. Most students seem to change learning styles as the semester continues so that kinesthetic learning will probably diminish in its role.

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5. One way to demonstrate acids and bases is to combine acetic acid and sodium bicarbonate 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 lab, 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. Fill half of 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 with an immersion thermometer in it. 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 30-40° Celsius range without having to remove the stopper. Get the students to explain why there is such a buildup of heat.
8. Put a bag of regular tea in a beaker in 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. During lab, 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 of presentation software to demonstrate dehydration synthesis. Better yet, have a student do this as a project.
11. Here's a way to present protein structure as part of the organizational hierarchy. 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. Saladin uses flow charts in the text. Try to get students to adopt this method for outlining processes. It makes it easy to see sequences and required participants in the action. It is also a good analysis tool to understanding just how disease works by interrupting some part of the flow.

Related Films, DVDs, and Videocassettes

Atoms and Molecules; Hawkhill
The Atom; Hawkhill
Atomic Structure: Mapping an Invisible World; Insight Media
Basic Chemistry for Biology Students; Insight Media
Biochemistry various titles; Insight Media
Chemical Bonding; Films for the Humanities and Sciences
Double helix; Films for the Humanities and Sciences
DNA-The Master Molecule; EME-Science
Enzyme Investigations; EME-Science *How the Atom was Discovered*; Hawkhill
Francis Crick: Beyond the Double Jelix; Carolina
Marie Curie Finds Radium and Radioactivity; Hawkhill
Modern Chemistry: An Introduction; Hawkhill
Radiation; Hawkhill

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What is an Atom?; Hawkhill

Related Software

Chemistry Series; CyberEd
ChemSite 3D Molecular Modeling and Drawing; ChemSW
Enzyme Catalysis 2; Ward's
Enzyme Investigations; EME
Molecular Biology; Insight Media
Molecular Modeling Pro; ChemSW
Ph.I.L.S. 3; Available in *Connect* from McGraw-Hill
RNA Virtualab; game and other items from NOVA

Critical Thinking Questions

1. Otis used a pH test strip on his urine and found that it showed it to be pH 6. He wonders how much more concentrated the hydrogen ions are in his coffee (pH 5).
2. Why would researchers test vitamins D and E specifically to determine if large doses were exceptionally helpful in preventing heart attacks?
3. Mixing acid with milk will cause the milk proteins to become insoluble and the milk will curdle. What level of structure in the protein are you most likely changing?
4. If somebody is suffering from high acidity in their stomach and they take some sodium bicarbonate, they will be likely to burp. Why?
5. If an animal could not digest the double sugar trehalose, what enzyme would we probably say it lacks?
6. Would a truly fat-free diet be healthy? Why or why not?
7. When an inappropriate amino acid is substituted in place of another, as occurs in certain genetic disorders, the resulting protein is either poorly functional or non-functional. Since proteins contain hundreds if not thousands of amino acids, why should the change of a single amino acid be so critical?
8. Given only the information provided so far and if red blood cells contain hemoglobin, what dietary factors are important to avoid anemia (i.e., a low red blood cell count)?

Critical Thinking Answers

1. His coffee has ten times the hydrogen ion concentration of his urine (Fig 2.11).
2. These vitamins, along with carotenoids, are antioxidants and react with free radicals. Free radicals are an important cause of heart disease. Large studies have indeed shown that vitamin E and diets high in vitamin C do seem to reduce the incidence of heart attacks and other conditions.
3. Quaternary structure is readily disrupted by pH changes.
4. The reactions discussed in Section 2.3 go to the right and the person should produce a lot of carbon dioxide gas. The person releases the carbon dioxide as a burp.
5. The missing enzyme for the hydrolysis of this (real) disaccharide would be trehalase.
6. Human bodies cannot manufacture certain kinds of lipids, the essential fatty acids.
7. Students should be able to come up with at least one of the following answers: If the changed amino acid is cysteine, then a disulfide bridge may not be formed. Since these are sometimes important in stabilizing the tertiary structure of the protein, the protein may not perform its functions (Figs. 2.24, 2.25). Students may also note the importance of certain R groups in helping to make the protein hydrophilic or hydrophobic. Finally, it may not be too obvious to the class members but, if one realizes that there are certain key amino acids positioned to play a part in the active site, an incorrect amino acid at an active site can make an enzyme nonfunctional.
8. Iron and amino acids are the two needs mentioned in this chapter (Figs. 2.24, 2.25) but other factors are mentioned in later chapters. Some students may also realize that energy-containing compounds, such as glucose, are necessary also so that ATP may be produced. Figure 2.30 shows that ATP is needed for synthesis reactions.

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Clinical Application Question

Percy is in New Orleans during a very hot, humid August visiting some friends. He is from a cloud-shrouded island off the coast of Scotland where the temperature rarely rises above 16º C. One noontime he comes into your lab 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

Don't do it. Percy is sweating extensively in the high temperatures. Sweat contains electrolytes such as salts. The more the person sweated, the more electrolytes would be lost. If he continued in this manner, he would 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.

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