CHAPTER 2
FUNDAMENTALS OF CHEMISTRY

☞*Chapter Overview*

Chemistry has never been a very popular subject among beginning students of microbiology. It is often initially difficult for students to understand that knowledge of basic, organic and biological chemistry is fundamental to a functional understanding of the many structures that bacteria possess. It is important for students to understand that that everything is made up of chemicals and that life relies on chemical reactions. After all, cells are really just big bags of chemicals and the processes that occur in cells involve chemical reactions. Without knowledge of chemistry, the basis for the Gram stain, the role of the bacterial cell membrane, the action of antibiotics, the mechanisms of fermentation, and countless other processes could not be understood.

This chapter begins with an attempt to instill in the student a need and desire to seek out this basic chemical knowledge. A foundation is provided by presenting the structure of the atom and discussing the important features of chemical bonding and reactions. Because water is one of the fundamental molecules in living systems, a thorough analysis of this marvelous substance is provided along with important terms and concepts that will help the student relate to mechanisms such as active transport and osmosis that will be covered later in the textbook.

The last part of the chapter is devoted to a presentation of the complex molecules of organisms: carbohydrates, lipids, proteins, and nucleotides. Numerous examples are provided to help the student see how these molecules relate to living systems, especially to bacteria.

Considering that some students may have had prior experience with the concepts of chemistry, this chapter may be omitted. However, it can be used as an excellent reference chapter for students with previous preparation.

☞*Chapter Objectives*

- Explain why knowledge of basic chemistry is necessary to understand microbiology.
- Define the terms *atom, element, molecule, and compound*; list the most common elements (and their symbols) found in living organisms.
- Describe the structure of an atom, noting especially the characteristics of protons, neutrons, and electrons; explain the formation and structure of ions and isotopes.
- Provide several distinguishing characteristics for ionic, covalent, and hydrogen bonds, and show how they are involved in holding atoms together.
- List and describe the characteristics of chemical reactions.
- List and describe at least four properties of water that are important to its function in living systems.
- Describe the properties of solutions and colloidal dispersions that are important to their function in living systems.
- Define the terms *acid, base, and pH*; explain how these terms are used in relationship to living systems.
- Define organic chemistry and identify the four major functional groups of organic molecules.

- Describe the general structure and chemical properties of carbohydrates, and explain the role of carbohydrates in living systems.
- List and describe the characteristics of the three main types of carbohydrates, and provide two examples of each.
- Describe the general structure and chemical properties of simple lipids, compound lipids, and steroids, and explain the role of each in living systems.
- Describe the general structure and chemical properties of amino acids, and note how amino acids form into proteins.
- Describe the four levels of structure found in proteins; contrast structural proteins and enzymes.
- Describe the general structure and chemical properties of nucleotides, and explain the role of nucleotides in living systems.
- Contrast the characteristics, chemistry, and roles of the two nucleic acids, DNA and RNA.

☞ ***Teaching Tips***

- Ball-and-stick models of various molecules such as carbon dioxide and water can be used to illustrate spatial relationships.
- Make solutions in water to demonstrate exergonic (10M sodium hydroxide, for example) and endergonic (10% ammonium persulfate, for example) reactions.
- Obtain a conductivity-of-solutions apparatus to test the electrical properties of liquids. Immerse the electrodes in various solutions to illustrate electrolytes and current flow.
- To illustrate the various organic molecules and their properties, bring examples of food that consist primarily of specific sugars, proteins, lipids, and so forth.
- Video: *Functional Chemistry in Living Cells* (60 min, C, VHS). Overall review of fundamental concepts of cell biochemistry. (LO77 1139VH, PLP)
- Use a heavy piece of rope to illustrate the various levels of protein organization. By twisting and coiling the rope, all three levels of protein structure can be demonstrated

☞ ***In-Class Activity***

Activity – Protein structure

Time: Approximately 10-20 minutes

Materials: Bring in various lengths of a heavy piece of rope.

Procedures: Have the students twist and coil the rope, using it to demonstrate the different levels of protein structure. Alternatively, have students link paper clips together simulating the formation of peptide bonds between amino acids. Then have the students twist and coil the chain so that it takes on different forms in secondary and tertiary structure. Make sure that the students understand what types of bonds are being used to hold together the different structures.

Student instructions: Using the materials provided (either rope or paper clips), manipulate the materials in such a way as to demonstrate the different protein structures. Explain what kinds of bonds are important in the different levels of protein structure as you form them.

Specific suggestions: When talking about protein structure, be sure to focus on the bonds that are important in each structure (primary is due to peptide bonds, a form of covalent bond, secondary is due to hydrogen bonds between amino acids that are not directly connected to each other, tertiary is typically due to hydrophobic interactions – hydrophobic residues on the inside and hydrophilic residues on the outside with some disulphide covalent bonds holding it together, and quaternary due to hydrogen bonding and shape). After the structures have been formed, you can then emphasize that temperature is really a measure of the movement of molecules, and that when you increase temperature you increase movement, which can disrupt the weaker bonding (hydrogen bonds and hydrophobic interactions) thus causing denaturation. It would also be important to emphasize that shape defines function in proteins which will be examined later with examples of enzymes and substrates, virus proteins and receptors, and even antibodies and antigens.

Objectives: Giving the students a clear understanding of how important chemicals are to life and how shapes of molecules can define their function.

☞ ***Using Technology in Your Microbiology Classroom***

1. Animations – textbook website
    A. The formation of ions. This textbook animation is used to enhance Figure 2.2 in the text.
    B. Covalent bonds are formed by sharing electrons. This textbook animation is used to enhance Figure 2.3 in the text.
    C. Polar compounds and hydrogen bonding. This textbook animation is used to enhance Figure 2.4 in the text.
    D. Polarity and water molecules. This textbook animation is used to enhance Figure 2.5 in the text.
    E. The pH values of some common substances. This textbook animation is used to enhance Figure 2.7 in the text.

2. Animations – online
    A. Hydrogen bonds and water from Northland College website. http://programs.northlandcollege.edu/biology/Biology1111/animations/hydrogenbonds.html
    B. Chemical bond animations covering ionic, covalent and hydrogen bonds. http://www2.nl.edu/jste/bonds.htm
    C. Amino acid and peptide bond animation by John Kryk. http://www.johnkyrk.com/aminoacid.html
    D. Carbohydrates by Barbara Liang at the wisc-online site. http://www.wisc-online.com/objects/index_tj.asp?objID=AP13104
    E. Lipids by Barbara Liang at the wisc-online site. http://www.wisc-online.com/objects/index_tj.asp?objID=AP13204

F. John Kryk's website on amino acids and proteins
http://www.johnkyrk.com/aminoacid.html

☞ ***Web Destinations***

- http://www.biology.arizona.edu/biochemistry/tutorials/chemistry/main.html
  Chemistry tutorial
- http://biop.ox.ac.uk/www/mol_of_life/index_b.html
  Web site about proteins
- http://biop.ox.ac.uk/www/mol_of_life/index_a.html
  Web site about DNA
- http://www.chem1.com/acad/webtext/chembond/
  All about chemical bonding from Simon Fraser University

☞ ***Discussion Topics***

- How can electrons absorb energy and then give it off in chemical reactions?
- If both starch and cellulose contain the monosaccharide glucose, why can't most animals, including humans, digest cellulose?

☞ ***Track It Down***

- A number of vitamins are required to form the dinucleotides, NAD and FAD, which are then used as coenzymes in cellular metabolism. What vitamins are they? Are there any other vitamins that play a similar role, and how do they chemically form these dinucleotide molecules?
- How can DNA be used in fingerprinting criminals?

☞***Chapter Outline***

I. Why Study Chemistry?

II. Chemical Building Blocks and Chemical Bonds
- A. Chemical building blocks
  - 1. Atoms and elements
  - 2. Atomic formulas
  - 3. Molecules
  - 4. Compounds
- B. Structure of atoms
  - 1. Atomic particles
    - a. Protons
    - b. Neutrons

c. Electrons
2. Properties of atomic particles
3. Atomic number
4. Electron shells
5. Ions
a. Cation
b. Anion
6. Atomic weight
7. Isotopes
8. Gram molecular weight (mole)
9. Radioisotopes

C. Chemical bonds
1. Ionic bonds
2. Covalent bonds
3. Hydrogen bonds
a. Polar compounds
b. Molecular structure

D. Chemical reactions
1. Catabolism
2. Anabolism
3. Exergonic and endergonic reactions

III. Water and Solutions

A. Water
1. Importance to living systems
2. Properties
a. Solvent
b. Surface tension
c. Specific heat
d. Medium for reactions

B. Solutions and colloids
1. Mixtures
2. Solution
a. Solvent
b. Solute
3. Colloids

C. Acids, Bases, and pH
1. Acids
2. Bases
3. pH

IV. Complex Organic Molecules

A. Basic characteristics
1. Hydrocarbons
2. Functional groups
a. Hydroxyl groups

- b. Carbonyl groups
- c. Carboxyl groups
- d. Amino groups

3. Oxidation/reduction

B. Carbohydrates
1. Types of carbohydrates
2. Monosaccharides
   - a. Isomers
   - b. Glucose
   - c. Sugar reduction
3. Disaccharides
4. Polysaccharides
5. Glycosidic bonds

C. Lipids
1. Basic features
2. Fats
   - a. Fatty acids
   - b. Ester bonds
   - c. Saturated/unsaturated fatty acids
3. Phospholipids
4. Steroids

D. Proteins
1. Properties of proteins and amino acids
   - a. Amino acids
   - b. Carboxyl groups
   - c. Variable (R) groups
   - d. Peptide bonds
   - e. Polypeptide
2. Structure of proteins
   - a. Primary structure
   - b. Secondary structure
   - c. Tertiary structure
   - d. Quaternary structure
   - e. Denaturation
3. Classification of proteins
   - a. Structural proteins
   - b. Enzymes
4. Enzymes

E. Nucleotides and nucleic acids
1. Nucleotides
   - a. Basic parts
   - b. High-energy bonds
2. Nucleic acids
   - a. Basic features
   - b. Purines and pyrimidines
   - c. Ribonucleic acid (RNA)

d. Deoxyribonucleic acid (DNA)
e. Complementary base pairing
f. Nucleotide base sequencing

☞ ***Additional Resources***

- *Proteins* (34 min., C, VHS). The program provides insight into protein structure and function including their catalytic roles in metabolism. (FHC 6902, FFH)
- *Chemical Foundations of Life* (30 min., C, 1997, VHS). This program introduces chemical concepts necessary for understanding life processes. (BZ 834, IM)
- *Biochemistry: The Chemistry of living Things* (CD-ROM, 1996). This CD-ROM teaches the basics of biochemistry through molecular models, animations, photographs, and narratives. (BZ 800, IM)
- *Unseen Life on Earth: An Introduction to Microbiology Part 4 - Reading the Code of Life* (30 min., C, 1999, VHS). A 12- part series produced in part by the American Society for Microbiology which explains basic microbial principles and how microbes affect everything from medicine to environmental issues to global politics. (CA00125-ULSVE, CPB)
- *Basic Chemistry for Biology Students* (21 min., C, 1993, VHS). This video discusses atoms, molecules, types of bonds, oxidation-reduction reactions, and illustrates the basic organic molecules. (BAA 319, IM)
- *Biochemistry: The Chemistry of Life* (1997, CD-ROM). This program explores atoms, elements, molecules and all the chemical compounds of life using colorful models and special effects. (AAZ 31282, EDU)