2

LIFE'S CHEMICAL BASIS

Chapter Outline

MERCURY RISING
START WITH ATOMS
ISOTOPES AND RADIOISOTOPES
WHY ELECTRONS MATTER
- About Vacancies
- Chemical Bonds: From Atoms to Molecules
- Ionic Bonds
- Covalent Bonds

HYDROGEN BONDS AND WATER
- Hydrogen Bonding
- Water's Special Properties
- Water Has Cohesion
- Water Stabilizes Temperature
- Water Is an Excellent Solvent

ACIDS and BASES
MERCURY RISING (REVISITED)
SUMMARY
DATA ANALYSIS EXERCISE
SELF-QUIZ
CRITICAL THINKING

Objectives

1. Understand how protons, electrons, and neutrons are arranged into atoms and ions.
2. Understand the properties of isotopes and how these properties can be useful to researchers.
3. Explain how the distribution of electrons in an atom or ion determines the number and kind of chemical bonds that can be formed.
4. Know the various types of chemical bonds, the circumstances under which each forms, and the relative strengths of each type.
5. Understand the essential chemistry of water and some common substances dissolved in it.
6. Discuss the unique properties of water that make it vital to living organisms.
7. Understand the pH scale and the relationships between acids, bases, and buffers.

Key Terms

atom	mass number	free radical	triple covalent bond
protons	periodic table	electronegativity	nonpolar covalent bond
neutrons	radioisotopes	chemical bond	polar covalent bond
electrons	radioactive decay	molecule	polarity
charge	tracer	compounds	hydrogen bond
nucleus	PET scan	mixture	solvent
atomic number	orbital	ionic bond	solutes
elements	shell model	covalent bond	hydrophilic
isotopes	ion	double covalent bond	hydrophobic

temperature	hydrogen ions (H^+)	acids, acidic	buffer system
evaporation	hydroxide ions (-OH)	bases, basic	
cohesion	pH	salt	

Lecture Outline

2.1 Mercury Rising

A. Mercury combines with carbon to form methylmercury.

1. Mercury in this form enters the tissues of fish and shellfish.
   a. Humans who consume organisms containing mercury may have adverse effects.
   b. The FDA recommends that ingested mercury levels not exceed 7 micrograms per day.

2.2 Start with Atoms

A. An atom is the smallest unit of matter that is unique to a particular element.

1. Atoms are composed of three subatomic particles.
   a. *Protons* (p^+) are part of the atomic nucleus and have a positive charge. Their quantity is called the atomic number (unique for each element).
   b. *Neutrons* are also a part of the nucleus; they are neutral. Protons plus neutrons = atomic mass.
   c. *Electrons* (e^-) have a negative charge. Their quantity is equal to that of the protons. They move around the nucleus.
2. Charge is an electrical property that attracts or repels other subatomic particles.
3. Elements consist only of atoms with the same number of protons in their nucleus.

B. The periodic table is an arrangement of elements based on their chemical properties.

1. The symbols for different elements are often derived from Greek or Latin words.
2. Elements are arranged based on their chemical properties.

C. Isotopes and Radioisotopes

1. Atoms with the same number of protons (for example, carbon with six), but a different number of neutrons (carbon can have six, seven, or eight), are called isotopes (^{12}C, ^{13}C, and ^{14}C).
2. Radioisotopes are unstable and break down while emitting radiation.
   a. Radioactive tracers can be used to monitor biological processes (e.g., using radioactive carbon to study photosynthesis in plants).
   b. Radioisotopes can be used to gather important medical information (e.g., PET scans).

2.3 Why Electrons Matter

A. Electrons and Energy Levels

1. Electron behavior influences atom bonding.
   a. Electrons are attracted to protons but are repelled by other electrons.
   b. Orbitals are like volumes of space around the atomic nucleus in which electrons are likely to be at any instant.
   c. Each orbital contains one or two electrons.

B. Orbitals can be thought of as occupying shells around the nucleus.

1. The shell closest to the nucleus has one orbital holding a maximum of two electrons.
2. The next shell can have four orbitals with two electrons each for a total of eight electrons.

C. About Vacancies

1. If an atom’s outmost shell is filled, it is chemically stable and will not tend to interact with other atoms.

2. Atoms with "unfilled" orbitals in their outermost shell tend to be reactive with other atoms.
    a. Atoms with unfilled outer shells are called free radicals.
    b. Free radicals may be a health risk.
3. The number or distribution of its electrons changes when an atom gives up, gains, or shares electrons.
    a. Any atom with an unequal number of protons and electrons is called an ion.
    b. All ions carry a positive or negative charge.

2.4 Chemical Bonds: From Atoms to Molecules

A. A chemical bond is a union between the electron structures of atoms.
B. A molecule is a bonded unit of two or more (same or different) atoms.
C. A compound is a substance in which the relative percentages of two or more elements never vary.
D. Ionic Bonds
  1. When an atom loses or gains one or more electrons, it becomes positively or negatively charged—an ion.
  2. In an *ionic bond,* (+) and (–) ions are linked by mutual attraction of opposite charges—for example, NaCl.
      a. The term *polarity* refers to the separation of charge into positive and negative regions.
      b. Electronegativity refers to the atom's ability to obtain electrons from another atom.
E Covalent Bonding
  1. A *covalent bond* holds together two atoms that share one or more pairs of electrons.
      a. Two atoms sharing one pair of electrons is a *single bond*.
      b. Two atoms sharing two pairs of electrons is a *double bond*.
      c. Two atoms sharing three pairs of electrons is a *triple bond*.
  2. In a *nonpolar covalent bond*, atoms share electrons equally.
  3. In a *polar covalent bond*, because atoms share the electron unequally, there is a slight difference in charge between the two poles of the bond; water is an example.
      a. Most covalent bonds are polar.

2.5 Hydrogen Bonds and Water

A. Hydrogen Bonding
  1. In a *hydrogen bond,* an atom of a molecule interacts weakly with a hydrogen atom already taking part in a polar covalent bond.
  2. These bonds impart structure to liquid water and stabilize nucleic acids and other large molecules.
B. Water's Special Properties
  1. Water Has Cohesion
      a. Hydrogen-bonding of water molecules provides *cohesion* (capacity to resist rupturing), which imparts surface tension.
      b. Cohesion is especially important in pulling water through plants.
  2. Water Stabilizes Temperature
      a. Water tends to stabilize temperature because it can absorb considerable heat before its temperature changes.
      b. In evaporative processes, the input of heat energy increases the molecular motion so much that hydrogen bonds are broken and water molecules escape into the air, thus cooling the surface.
      c. In freezing, the hydrogen bonds resist breaking and lock the water molecules in the bonding pattern of ice.
  3. Water is an excellent solvent.

a. The *solvent properties* of water are greatest with respect to the polar molecules with which they interact.
b. Solvents are usually liquids and can dissolve other substances.
c. Solutes are the substances that are dissolved.
d. Solvents cluster around the solute (dissolved) molecules, keeping them separate.
e. Polar substances are hydrophilic (water loving); nonpolar ones are hydrophobic (water dreading) and are repelled by water.

2.6 Acids and Bases

A. The pH Scale
1. pH is a measure of the H^+ concentration in a solution; the greater the H^+ the lower the pH value.
2. The scale extends from 0 (acidic) to 7 (neutral) to 14 (basic).

B. How Do Acids and Bases Differ?
1. A substance that releases hydrogen ions (H^+) in solution is an *acid*—for example, HCl.
   a. Products of combustion bring about a change in the pH of water in the atmosphere known as acid rain.
2. Substances that release ions (such as OH^-) that can combine with hydrogen ions are called *bases*—for example, NaOH.
3. The closer to 7 (neutral), the weaker the acid or base; the farther from 7 (neutral), the stronger the acid or base.

C. Buffers Against Shifts in pH
1. Buffer molecules combine with, or release, H^+ to prevent drastic changes in pH.
2. Bicarbonate is one of the body's major buffers.

2.7 Mercury Rising (Revisited)

A. It is estimated that the amount of mercury in the Pacific Ocean will double within the next 40 years.
1. Mercury can be found in humans, largely due to the ingestion of fish from the Pacific Ocean.

Suggestions for Presenting the Material

- There is no escaping the fact that Chapter 2 is chemistry. And chemistry can be intimidating — especially to non-science majors. The material in the book is elementary and written in a lucid manner, but the quality of presentation is up to the individual instructor.
- Perhaps a quick survey of class members who have and have not had high school chemistry will aid in adjusting your level of presentation. Students who took physical science in high school have also been exposed to basic chemical principles.
- One approach that might help your students in organizing this material is to write it in outline form on an overhead transparency or PowerPoint presentation. This may work especially well for this chapter because a large portion of the material consists of definitions.
- Stress the importance of learning biology from the smallest building blocks up. Living beings are more than the sum of their parts, so it is important to see how those "parts" arrange to form the basis for life. Use the example of a picture collage that takes thousands of small pictures of an object (like the space shuttle) to make a big picture of that same object.
- The use of ball-and-stick models (see the Enrichment section below) is very helpful. If the lecture room is large, you may have to "tour" the room with the models for better viewing or use a document camera to facilitate viewing for all students. Try using magnets to illustrate ionic bonding.

- Remind students frequently that atoms work to complete their outer electron shells. They accomplish this by bonding or by forming ions.
- If students become discouraged, assure them that several of these topics will be reinforced in future chapters (hopefully before the next exam). They need to understand the basic chemistry that drives cellular processes, and this information will help them. Tie future discussions in later chapters back to the basic principles of this chapter as much as possible.
- The text gives careful attention to useful examples of isotopes, electron excitation, bonding, buffers, and water.
- Use Figure 2.12 as your visual reference to help explain acid, base, and pH scale. Note particularly the pH values of common household products. Emphasize that acids and bases are not necessarily terms that describe *corrosive* substances! Point out the pH of the soda some students may be drinking (hopefully not in class!). Ask the students if they ever performed the childhood experiment where a tooth is left in soda for a few days or weeks to study the effects of the acids on tooth enamel.
- The properties of water are vital to life on Earth. After describing the polarity of water molecules, elaborate on the influence that water molecules have on cells and cellular environments. Tie the concepts to events that the students have likely experienced themselves. Use local examples (beach water temperature variance in the summer or fish survival through winter in a frozen-over pond) in discussing the properties of water.

Classroom and Laboratory Enrichment

- Students often approach even basic chemistry with considerable trepidation, especially if they lack sufficient high school background in this area or have been out of school for several years. Emphasize that studying biology includes studying chemistry, physics, math, etc. Explain how the lines between the scientific disciplines are now blurred. An elemental knowledge of chemistry is essential to understanding the structure and function of living things. Give students frequent opportunities to use new terms. Using overheads, diagrams, or PowerPoint presentations, pause often and interject questions to gauge their level of understanding.
- If you are teaching in a room with a "periodic table of the elements" hanging on the wall, point out the major elements, or use a diagram to show the same items. Refer back to the importance of filling the outer electron shells when forming molecules.
- Students frequently have trouble visualizing atoms and molecules as real entities. To help them get a clearer mental picture of some of the basic atoms and molecules, use ball-and-stick models that are very large and easy to see from the back of the room. These models will help students understand the size relationships among molecules. Overhead transparencies of ball-and-stick diagrams will also help. Such models and diagrams will be especially useful when covering the larger carbon compounds. You can also use foam-and-stick models of orbitals if you wish to emphasize electron orbitals.
- Marshmallows and inexpensive plastic straws or coffee stirrers may be used to have students make their own "molecules."
- Present sketches of polar covalent molecules and nonpolar covalent molecules. Ask students to identify which molecules are polar and which are nonpolar, and to explain their choices.
- Ball-and-stick models or a well-drawn diagram or slide, like the ones from the textbook in Figure 2.11, are also useful for demonstrating the hydrogen bonding that occurs between water molecules and the latticework structure of ice.

- Fill a large jar with water then add salad oil. Shake the bottle then allow it to sit on the front desk. Ask students to explain what has happened. Add a few drops of methylene blue (a polar dye) and sudan III fat stain (a nonpolar dye) to the jar and shake. Students will note that the water layer is blue and the oil layer is red; ask them why this is so.
- To help students connect the more inanimate "chemistry" from this chapter with living organisms, bring to class (season permitting) a pond water-filled jar with a live water strider or other surface-tension dwelling aquatic insect, so students can see cohesion in biology in action. You can also show slides of these organisms as you discuss this property of water.
- Draw a pH scale on the board (or use an overhead transparency or slide of Figure 2.13), and discuss pH values of familiar substances.
- Cover a raw chicken egg with vinegar in a small cup or plastic container. After three or four days the weak acid (vinegar) will eat away the shell, leaving the cell membrane and egg contents intact. With care, one can handle the shell-less egg and illustrate how even weak acids must be buffered by living organisms.
- If your class is small, demonstrate the use of a pH meter. For larger groups, pH paper can be used to give each student a chance to quickly determine the pH of some sample solutions.
- Have students list common acids they consume on a regular basis. Salsa, lemonade, soda, etc. are common examples. Ask why and how antacids work to neutralize these substances.
- Lead a class discussion on why our digestive systems can withstand such wide variation in pH, whereas internal tissues cannot. List areas of the body that are commonly more acidic or basic and why: stomach, arterial blood, etc. Also emphasize the advantages of having an acidic environment in the stomach.
- Initiate a class discussion on acid rain. What is it? Is acid rain a problem where you live? Ask students to come up with a chemical formula for acid rain. What are some of the effects of this kind of precipitation?
- Prepare a glass of iced tea (instant mix) with added sugar and lemon. Ask students to identify which ingredients are compounds. What are the components of this mixture?
- Bring a package of "buffered" and "regular" aspirin to class. Ask students to discover the difference(s) in ingredients.
- Using the names of the active ingredients on an antacid package, explain how they act as *buffers* to stomach acid.
- You may wish to show *Atoms* (PBS, 1987, Video, 1 hour, *Ring of Truth Series)*. Philip Morrison leads a tour through the atom, elaborating on its properties and the quest for proof of its existence. New techniques in electron microscopy can visualize atoms, and Quantum Theory outlines behaviors within the atom. Put a full jar of colored water on paper towels in front of the class. Ask several students to predict how many pennies can be added to the water before it overflows onto the paper towel. Most likely the students' guesses will be too low, since they may underestimate the cohesive properties of water. Show how the water bulges over the top of the jar before it spills.
- Illustrate how students can make their own pH indicator at home. Add several finely diced purple cabbage leaves to very hot water. Let the cabbage remain in the water for approximately one hour. Once you filter out the cabbage leaves, you are left with a purple liquid that acts as a simple pH indicator. Add various household substances (such as vinegar, tea, ammonia, oven cleaner, etc.) to small quantities of the liquid. The color changes (acids–pink, bases–green) are impressive. Have the students add buffered substances to a small sample of the liquid to see its effect.
- Design a Jeopardy-style quiz to test the students' knowledge of the chemistry terms in this chapter. A template for this format can be found at: http://jeopardylabs.com/.

Classroom Discussion Ideas

- Which food molecules are comprised of the main elements C, H, O, and N?
- What does the word "trace" mean when speaking of trace elements?
- The difference between a trace element being toxic and actually beneficial to the body is often a matter of __________.
- If humans are made of the same elements as are found in the earth and non-living things, what is it that makes us "alive"?
- Why is it important to understand the building blocks of molecules that form living things?
- Is it necessary for living things to have ALL these elements? Why is the combination so important?
- How is the handling of mercury different than it was in a past? How has the structure of thermometers changed? What substance has replaced mercury in dental fillings?

Additional Ideas for Classroom Discussion

- Distinguish between a compound and a mixture, an atom and a molecule.
- What chemicals are in the human body? Ask students to name as many as they can; help them complete their list.
- What is the difference between polar and nonpolar covalent bonds?
- Why do soft drinks have such a low pH? What ingredient is responsible for this low pH?
- Why is the insulating effect of frozen water so important to living organisms? What would happen to aquatic organisms living in temperate climates if water sank when it froze instead of floated?
- Lots of people go to the beach in the summer. Why is the water still very cool in early summer but still warm well into fall?
- What is the difference between the composition of a *molecule* of a substance and an *atom* of that substance?
- If atoms are beyond the reach of visualization even by "super" electron microscopes, how then do we know so much about their structure?
- Why is it important to understand both physics and chemistry when studying living things?
- How does the regular usage of the term "buffering the blow" relate to the function of buffers? Do both attempt to reduce drastic changes?
- Water is the "universal solvent" on Earth. Do you know of any other compound that would serve as well or better? If life existed on a remote waterless planet, could another substance replace it as an effective solvent?
- Some pain relievers are advertised as "tribuffered." Is this a real advantage or just a sales gimmick?
- Television commercials portray the "acid stomach" as needing immediate R-O-L-A-I-D-S®. Is the stomach *normally* acidic? How do you know when there is too much acid down there?
- There are different kinds of antacids—some work quickly and others work more slowly. Under what circumstances would you use each type of antacid?
- Why do alcohols dissolve in water?
- Why are some medications packaged in gel caps of mineral oil?
- What is the difference between methyl alcohol and ethyl alcohol? How is each of these alcohols processed by the human body?

How Would You Vote? Classroom Discussion Ideas

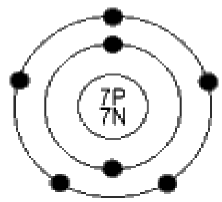
- Monitor the voting for the online question. Canvas the class to determine their opinions on the issue. Have some students in the class prepare a "warning statement" that could appear on tuna cans. Should the warning be aimed at just women of childbearing age or all populations? Research the literature to see if the effects of increased levels of mercury have been studied on varying ages of participants.
- If the class agrees that warning labels should be placed on tuna cans, are there other foods that should carry warning labels? Alcohol? Soda?
- What human activities could be curtailed to reduce mercury emissions? Should certain industries be targeted?

Term Paper Topics, Library Activities, and Special Projects

- How are hydrophobic substances such as fats broken down in the human digestive tract? What chemicals are released by the body to assist with fat breakdown?
- Why are the cells lining the stomach able to withstand pH ranges between one and two? What is an ulcer and why does it produce a burning feeling after eating?
- How does the body measure blood pH? What are the homeostatic mechanisms that help the human body regulate blood pH? Research causes, symptoms, and treatments for acidosis and alkalosis.
- Discuss strategies currently being considered by the United States and other nations to remedy acid precipitation. What suggestions would you make to help solve this problem?
- Describe some of the roles played by ions in the human body. Note: These ions may be referred to as electrolytes in a clinical setting.
- Why are buffers critical to maintaining homeostasis in living things? What happens when the capacity of a buffer is exceeded?
- How does conservation of temperature in large bodies of water on Earth affect weather? Does this same principle apply on a smaller scale in living things?
- How are different pH levels maintained in different places in the human body? Why are these pHs advantageous in certain areas of the body?
- Many elements have radioactive isotopes that are useful as tracers in biological systems. Show how $^{14}CO_2$ can be used to follow the fate of carbon as it is incorporated into carbohydrate. In addition, make the connection between thyroid studies and the use of radioactive iodine.
- The structure of atoms can be deduced using nuclear magnetic resonance (NMR) and mass spectrometer machines. Report on the principles underlying the performance of each of these instruments.
- Using a pH meter, test the degree of acidity/alkalinity of common household products. If the substance is not a liquid, mix it with water according to package directions before testing.
- Most of the content of human blood is water. However, synthetic blood has been made and tested. What is the base in this fluid? Is it a feasible substitute? Report on its advantages and disadvantages.
- Describe the effects of alcohol on the human body.

Possible Responses to *Critical Thinking* Questions

1. Lead and gold have different numbers of protons. To change the element, one must change the number of protons in each and every atom of the substance. It is impossible to change the number of protons by chemical means. Today physicists have the ability to add or remove protons by extraordinary means, but this was not possible in ancient time. Also, lead is a very stable substance. Enticing lead to give up three protons would require a huge amount of energy, and the cost involved in doing this would far outweigh the profit realized from changing the lead into gold.

2. 

3. Polonium has a half-life of 138 days and decays to form ^{206}Pb (a stable form of lead) after emitting an alpha particle.
4. When an acid is mixed with water, it dissociates and becomes more reactive. Therefore, it is prudent to remove the majority of the acid before washing the area with water.

Possible Responses to *Data Analysis Exercise* Questions

Mercury emissions are a dangerous source of air pollution and are produced by various industries worldwide.

1. Approximately 2200 tons of mercury were released worldwide in 2006.
2. The source that released the most mercury was the combustion of fossil fuels, and the next greatest emissions resulted from artisanal and small-scale gold production.
3. Asia produced the most mercury from cement production.
4. Approximately 150 tons of mercury were released from South America in 2006 due to gold production.