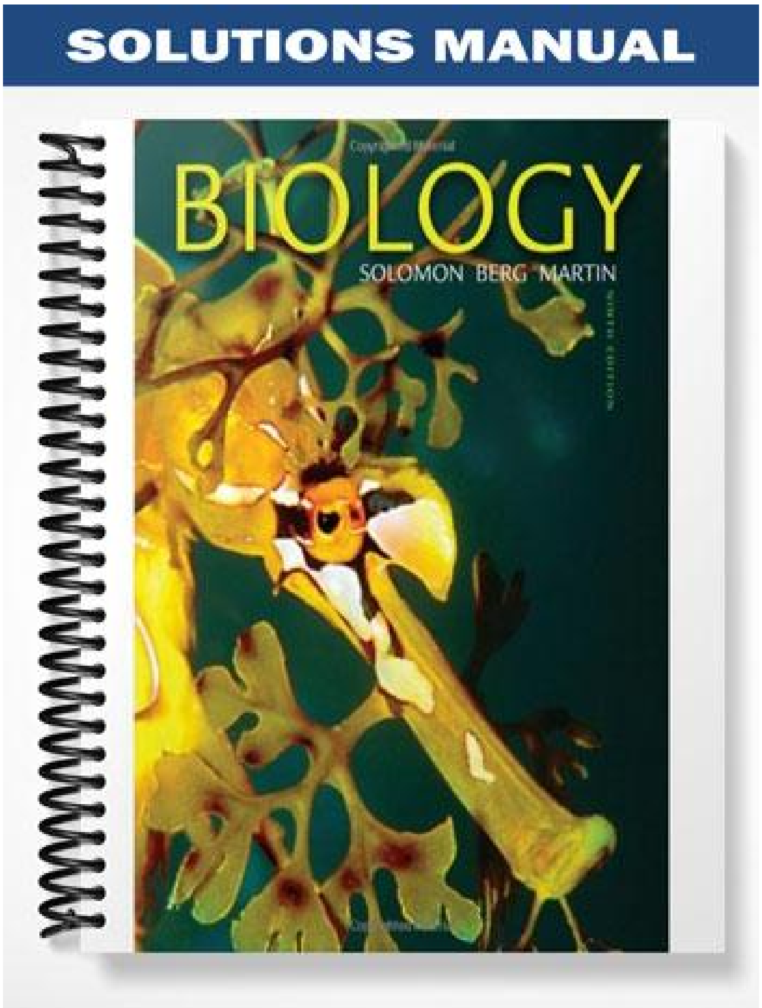
SOLUTIONS MANUAL
BIOLOGY
SOLOMON BERG MARTIN

2 Atoms and Molecules: The Chemical Basis of Life

Lecture Outline

I. Elements are not changed in normal chemical reactions.
  A. Each element has a unique chemical symbol.
  B. 92 naturally occurring elements range from hydrogen to uranium.
  C. 4 elements (C, H, O, N) make up 96% of most living organisms.
  D. Trace elements are necessary, but present in small quantities.

II. Atoms are the fundamental particles of elements.
  A. Atoms are the smallest component of an element that retains the chemical properties of that element.
    1. Atoms contain protons, neutrons, and electrons.
  B. An atom is uniquely identified by its number of protons.
    1. A proton is a subatomic particle with one unit of positive charge.
    2. The periodic table depicts the elements in order of their atomic number—the number of protons in the nucleus.
    3. Atomic numbers are written in subscript to the left of the chemical symbol.
  C. Protons plus neutrons determine atomic mass.
    1. The atomic mass indicates the number of protons and neutrons in an atom.
    2. Atomic mass units (amus) are also known as daltons.
    3. One amu equals the approximate mass of a proton or neutron.
  D. Isotopes differ in number of neutrons.
    1. Some isotopes are unstable (radioisotopes).
    2. Many radioisotopes are used in scientific research, such as for dating fossils.
    3. Other radioisotopes are used in medicine.
  E. Electrons occupy orbitals corresponding to energy level.
    1. Electrons occupy a space called an orbital.
    2. The outer electron(s) is(are) known as the valence electron(s), and contains the most energy.
    3. These outer electrons occupy the valence shell.
    4. All elements have naturally occurring isotopes.

III. Atoms undergo chemical reactions.
  A. Atoms form molecules and compounds.
    1. Two or more atoms combined chemically form a molecule.
    2. Molecules may be composed of different or similar atoms.
  B. A substance can be described by a chemical formula.
    1. Chemical formulas indicate ratios of atoms in a molecule.
    2. Structural formulas show the arrangement of atoms in a molecule.

C. One mole of any substance contains the same number of units.
   1. The molecular mass of a compound is the sum of the atomic masses of the atoms composing the molecule.
   2. The molecular weight is dimensionless.
   3. The number of units in a mole is Avogadro's number.
      a) One mole is 6.02×10^{23} atoms or molecules.

D. Chemical equations describe chemical reactions.
   1. Reactants are written on the left side of the equation.
   2. Products are written on the right side of the equation.
   3. Reversible reactions are indicated by double arrows between reactants and products.

IV. Atoms are joined by chemical bonds.

A. In covalent bonds electrons are shared.
   1. The electrons in the outer shell are the valence electrons.
      a) Atoms tend to be reactive if the valence shell is not full.
      b) The Lewis structure of the atoms represents the valence electrons.
      c) The function of a molecule is related to its shape.
   2. Covalent bonds result in filled valence shells.
      a) A single electron pair shared between two atoms is a single covalent bond.
      b) Double and triple covalent bonds are formed by two or three shared electron pairs, respectively.
      c) Hydrogen forms one covalent bond.
      d) Carbon forms a maximum of four covalent bonds.
      e) Covalent bonds between atoms with different electronegativities result in polar covalent bones, hence forming a polar molecule.

B. In ionic bonds electrons are donated.
   1. An atom becomes an ion when it gains or loses one or more electrons.
   2. Cations are positively charged ions.
   3. Anions are ions with a negative charge and are named with the suffix -ide.
   4. An ionic bond forms between cations and anions.
      a) Sodium and chloride ions form sodium chloride.
   5. Ionic compounds tend to dissociate in water (ionize).

C. Hydrogen bonds are weak attractions involving partially charged atoms.
   1. In the water molecule, hydrogen is partially positively charged and oxygen is partially negatively charged.
   2. Hydrogen bonds form between the hydrogen atom in a water molecule and a partially negatively charged atom.
   3. Hydrogen bonds, individually, are weak, but collectively very strong.
   4. Partially negatively charged atoms other than oxygen (e.g., nitrogen) can also form hydrogen bonds with hydrogen.

V. Electrons and their energy are transferred in redox reactions.
   A. Oxidation and reduction reactions occur simultaneously, hence they are called redox reactions; these reactions are always coupled.
   B. Reduction is a process in which an atom, ion, or molecule gains electrons.
      1. Reduction is so named because the gain of electrons reduces the positive charge.
   C. Redox reactions are important in both cellular respiration and photosynthesis.

VI. Water is essential to life.
   A. All organisms are composed of water and many live in water.
   B. Water molecules are polar.
      1. Hydrogen atoms in the water molecule have a partial positive charge, and oxygen molecules have a partial negative charge.
      2. Each water molecule can form up to four hydrogen bonds.
   C. Water is the principal solvent in living things.
      1. Water readily dissolves polar and ionic compounds.
      2. Water does not readily dissolve hydrophobic substances.
   D. Hydrogen bonding makes water cohesive and adhesive.
      1. Water molecules tend to hydrogen-bond to each other, making water both cohesive and adhesive.
      2. Capillary action is a result of adhesion and cohesion.
      3. Cohesion results in water moving upward in plants.
      4. Hydrogen bonding also results in surface tension.
   E. Water helps maintain a stable temperature.
      1. Water has a high specific heat due to hydrogen bonding; it takes a lot of energy to raise the temperature of water.
      2. Temperature stability is important to all organisms.
      3. The high heat of vaporization of water results in cooling during sweating or other evaporative processes.

VII. Acids are proton donors; bases are proton acceptors.
   A. Water tends to slightly dissociate into hydrogen and hydroxide ions.
   B. The concentration of hydrogen ions in pure water is 10^{-7} moles per liter, equaling the hydroxide ion concentration.
   C. Acids are substances that dissociate in a solution to yield hydrogen ions.
      1. Acids are proton donors.
      2. Acidic solutions have a higher hydrogen ion concentration than hydroxide ion concentration.
   D. Bases dissociate in solution to yield hydroxide ions.
      1. Bases are proton acceptors.
      2. Basic solutions have a lower hydrogen ion concentration than hydroxide ion concentration.

E. pH is a convenient measure of acidity.
   1. The pH of a solution is the negative log of the hydrogen ion concentration expressed in moles per liter.
   2. A pH below 7 is acidic; above 7 is basic.
   3. The pH of most living cells is slightly above 7.0.

F. Buffers allow for gradual pH change.
   1. Weak acids and weak bases act as buffers.

G. An acid and a base react to form a salt.
   1. When an acid and base are mixed, water is formed from the hydrogen ions of the acid and the hydroxide ions of the base.
   2. The cation of the base and the anion of the acid form the salt.
   3. Electrolytes are salts, acids, or bases that can conduct an electrical current when dissolved in water.
   4. Nonelectrolytes are molecules that do not dissociate in water and therefore do not conduct an electrical current.

Research and Discussion Topics

- Investigate the roles of some of the trace elements in living things. Some are well known, like iron and iodine, but what is the importance of copper, selenium, vanadium, silicon, or chromium? Include in the discussion the possible deleterious effects of too much of a certain trace element.

- Investigate the medical uses of radioisotopes. What radioisotopes are used to date recent fossils? Very old fossils? Why would different isotopes be used?

- Research the disposal of radioisotopes. How does their disposal impact the environment?

- Compare and contrast the halogens and the noble gases. Elements in which group are likely to be involved in chemical reactions? Why?

- Chemical formulas can be written as empirical formulas, molecular formulas, or structural formulas. Explain why these different forms of molecular expression are necessary.

- What are the pros and cons of the utilization of hydrogen gas as a source of energy? What are the obstacles that have prevented its widespread use?

Teaching Suggestions

- A good demonstration of surface tension may be accomplished if you have an overhead projector. Bring in a Petri dish filled nearly to the brim with water. Put it on the overhead projector. If your hands are steady, you will be able to put a razor blade on the surface and it will float there. Try using a pair of tweezers to place it on the water. On the screen, the students will be able to see the blade floating on the water. You can exhibit capillary action in the same way. Bring a capillary tube. Put the end in the water in the Petri dish. On the screen, the students can see the water rise in the tube.

- The central concept of hydrogen bonding and how this bonding makes water such a unique substance can't be emphasized enough. There are many common examples, in this and other texts, familiar to students that illustrate these concepts. You might also discuss these concepts in relation to aquatic organisms. What would happen to a turtle in a lake if water froze from the bottom to the top?

- Remind students that the pH scale is logarithmic. Log scales are often difficult for students to conceptualize. The Richter scale for earthquakes is a familiar example and is similar to the pH scale. Just as an earthquake measuring 4 is actually 10 times greater in magnitude than an earthquake measuring 3 on the Richter scale, a solution of pH 5 is 10 times more acidic than a solution of pH 6. A solution of pH 2 is 100 times more acidic than a solution of pH 4. On the Richter scale, earthquakes measuring 1 point higher have a more than 20-times increase in energy.

- It is difficult to lecture on things that can't be seen or touched, particularly for visual and tactile learners. Use models when discussing atoms, elements, and bonding. Balloons work well for demonstrating atomic structure. Springs, tennis balls, and bar magnets work well for demonstrating covalent, ionic, and hydrogen bonding, respectably.

Lecture Enrichment

- <u>Relative sizes</u>

Students need to get a feel for the size of atoms. Some may think that atoms or molecules are large enough to be seen easily. The fact that a million atoms would be as big as the period at the end of this sentence puts perspective to actual size. The fact that an atom is mostly empty space can be envisioned by the comparison of a golf ball representing a nucleus, and the electrons orbiting 1 km (over a half mile) away.

- Characteristics of water

The importance of hydrogen bonding can be made more interesting, and perhaps more enigmatic, by telling students that the bond lasts 1/100,000,000,000th of a second, yet it is one of the most important bonds on Earth!

One additional example of hydrogen bonding results in surface tension of water. This is one familiar to many children (and adults)—skipping rocks on water.

Students are often under the mistaken impression that all hydrophilic substances dissolve in water. Hydrophilic means having an affinity for water; not all hydrophilic substances dissolve, because their molecules are too large. Cellulose is a familiar example. Later in this course, they will see the movement of water into plant roots partially because of the affinity for water of the cell walls composed of cellulose. One might point out that towels are made of cotton (100% cellulose) rather than nylon. The hydrophilic nature of cotton allows the towel to dry us off by absorbing the water, but the towel doesn't dissolve in water.

- Chemical elements necessary for human life

We have known for centuries that carbon, copper, iron, and sulfur are necessary components of the human body. However, the discovery that some of the micronutrients such as boron, potassium, selenium, and silicon, and even the macronutrients sodium and calcium, are required for life was not made until the 1800s.

- Some of the most commonly used radiometric dating methods

Parent Isotope	**Half-Life (years)**	**Parent Isotope Abundant In**
Potassium-40	1.3 billion	Potassium-rich minerals including feldspar, mica
Rubidium-87	48.8 billion	Potassium-rich minerals
Uranium-238	4.5 billion	Uranium ores: zircon and other minor minerals
Carbon-14*	5730	Organic matter, atmospheric carbon dioxide, dissolved carbonate

* Because of the relatively short half-life of carbon, it is used primarily in archaeological, not fossil, dating.

- Iron

Iron is well known as the important central atom to the hemoglobin molecule, as well as other biologically important molecules. But iron pills are a leading cause of childhood poisoning deaths in the U.S. In the early 1990s, over 10,000 children accidentally swallowed these pills annually. Just as many as five high-potency over-the-counter tablets could be fatal for a small child. The FDA now requires warnings to be placed on these pill bottles, and the pills are often in packaging that is difficult—even for an adult—to open.

Answers to Review Questions

Elements and Atoms: Objectives 1, 2, 3

- Atomic number is based on the number of protons; therefore all atoms of a particular element have the same atomic number. Isotopes vary in the number of neutrons, and so have a different atomic mass.

- Radioisotopes are variations of an atom in which there are a different number of neutrons, hence different atomic masses. Radioisotopes tend to decay to a more stable form, and in doing so, emit radiation. They are commonly used in autoradiography, medical diagnoses and treatments, and dating of fossils.

- Electrons in different orbitals of the same electron shell have nearly the same amount of energy, but electrons in outer shells have more energy than those in inner shells.

Chemical Reactions: Objectives 4, 5, 6

- Radioisotopes react similarly in chemical reactions, as they have the same number of valence electrons as other isotopes.

- Structural formulas show the most information: the types and number of atoms in a molecule as well as the arrangement of the atoms.

- One gram of hydrogen atoms would contain a mole of hydrogen atoms. One gram of hydrogen molecules (diatomic hydrogen) would contain 0.5 moles of atoms.

Chemical Bonds: Objective 7

- A compound is defined as a combination of atoms of two or more different elements. However, the term *molecule* is not exactly appropriate when referring to ionic compounds such as sodium chloride, as no discrete molecules exist between the two atoms.

- An anion is formed when an atom with five, six, or seven valence electrons gains electrons and becomes negatively charged. A cation is formed when an atom with one, two, or three valence electrons loses one or more and becomes positively charged.

- Ionic bonds involve the gain or loss of electron(s) by two or more atoms; covalent bonds involve the sharing of electron(s) between two or more atoms.

- They are required in order for macromolecules to maintain their 3-D structure.

Redox Reactions: Objective 8

- By definition, oxidation is a loss of electrons and reduction is a gain of electrons, so both processes must occur simultaneously with respect to a chemical reaction.

- Redox reactions are important, as they also involve transfer of the energy of the transferred electron.

Water: Objective 9

- Water forms hydrogen bonds, as the water molecule is polar. The electronegative oxygen atom of the molecule is attracted to the electropositive hydrogen atom of an adjacent molecule.

- Because of hydrogen bonding, water exhibits both adhesion and cohesion (capillary action), important in making water available in soil for plant roots to absorb, and also playing a part in movement of water in a plant. The high specific heat of water is also due to hydrogen bonding and is important in modulating the body temperature of living things, as they are composed primarily of water. Hydrogen bonding also results in the characteristic of ice to float, surface tension to exist at the surface of bodies of water, the wetting characteristic of water, the structure of ice, and evaporative cooling.

- Hydrogen bonds are by themselves weak, but they are constantly being formed and broken, so their collective strength is significant.

Acids, Bases, and Salts: Objectives 10, 11, 12

- A solution with a hydrogen ion concentration of 0.01 mol/L has a concentration of 10-2 mol/L, hence a pH of 2. This is a strong acid. Its hydroxide ion concentration would be 10-12 mol/L. The difference in hydrogen ion concentration between a solution of 1 and 2 is 10-fold.

- Adding or removing a reactant or product changes the concentration of that component, producing a stress on the system. To reduce the stress, the reaction “shifts to the right or left” until the concentrations are evened out and the system is again at equilibrium.

- Buffers are weak acids or bases. They do not completely ionize, and hence, most molecules are not dissociated, therefore resisting change in pH. This condition is the opposite in strong acids and strong bases.

- Electrolytes conduct an electric current because they dissociate when dissolved in water. This is characteristic of salts, acids, and bases.

Suggested Answers to Critical Thinking Questions

1. The type of chemical bond that forms is based on electronegativity differences between the atoms involved. With a greater difference in electronegativity between two atoms, an ionic bond (donating and receiving electrons) would occur. With a lesser difference between atoms, as in Groups 3, 4, and 5, (atoms such as carbon, oxygen, and sulfur), a covalent bond forms. However, the formation of a bond is ultimately driven by the involved atoms seeking to stabilize their outer energy level, i.e. have a full octet (in many cases). The "easiest" path is taken. For example, it is easier to give up one electron than to find seven more to add. Element A (such as calcium in Group II on the periodic table) would donate two electrons. That would be easier than finding six more electrons. Element B, with four valence electrons (like carbon), would share electrons in covalent bonds. For element C (such as chlorine), with seven valence electrons, it would be "easiest" to gain one electron from an element with one valence electron (such as sodium, Na).

2. If hydrogen bonds were stronger, the boiling point of water would be higher. It is the hydrogen bonds slowing the release of water molecules (as vapor) from the liquid water that causes the relatively high boiling point of water (hydrogen bonds cause a high heat of vaporization). Stronger bonds would further raise the boiling point. Water would also have a higher specific heat and would stay denser at a wider range of environmental temperatures due to the stronger hydrogen bonds. This would affect water's function as a solvent and evaporation rate as well.

3. HCl would be the reactant, while H^+ and Cl^- would be the products. The arrow pointing in one direction does **not** indicate that the reaction would be reversible. HCl could not be used as a buffer because HCl donates hydrogen ions, which would increase acidity rather than moderate pH changes. This reaction only proceeds in one direction, it is not reversible.

4. In this scenario, Log [H+] = -12. Thus, pH = 12, somewhere between ammonia and oven cleaner. It's probably not safe for bare skin.

5. Carbon dioxide and water vapor can be found on many celestial bodies. However, for evidence of existing life, oxygen gas—a possible indicator of photosynthesis—might be more useful.

Suggested Readings

Mohnen, V. A. "The Challenge of Acid Rain." *Scientific American.* August 1988. 30–38. Patterns of deposition in the United States, causes, atmospheric and watershed processes.

Schwartz, S. E. "Acid Deposition: Unraveling a Regional Phenomenon." *Science.* 10 February 1989: 753–762. Sources of sulfur and nitrogen oxides in eastern North America.

Curl, R. F. and R. E. Smalley. "Fullerenes." *Scientific American.* October 1991. 54–63. A description of fullerene (C_{60}) and its "relatives," buckybabies, bunnyballs, and fuzzyballs.

Welsch, R. L. "Stand-Up Chemist." *Natural History.* November 1994. 34–35. A humorous essay including some humorous chemical "formulas."

Lemly, B. "Lovin' Hydrogen." *Discover.* November 2001. 53–57, 86. The future of hydrogen as a "wonder" fuel.

Chemicals and Human Health. 11 May 2005. University of Arizona. 4 September 2006. http://www.biology.arizona.edu/chh/default.html. Includes problem sets relating to toxicology, such as "Are manmade chemicals more toxic than those found in nature?" Students read an engaging article and answer critical thinking questions.

Acids and Bases Problem Set. 3 November 2004. University of Arizona. 6 September 2006. http://www.biology.arizona.edu/biochemistry/problem_sets/ph/ph.html. Interactive pH tutorial from "The Biology Project."

Anthony, C. "Acids and Bases: An Introduction," 2003. Visionlearning CHE-2.2, 6 September 2006. http://www.visionlearning.com/library/module_viewer.php?mid=58. Provides a good summary of the history, basics, and examples of acids and bases.

Scott, C. B. and R. B. Kemp. "Direct and Indirect Calorimetry of Lactate Oxidation: Implications for Whole-Body Energy Expenditure." *Journal of Sports Sciences.* 23 January 2005: 15.5.

Expanded Academic *ASAP*. Thomson Gale. 4 September 2006. http://find.galegroup.com/itx/. Anaerobic respiration contribution to energy supply during exercise. This is a good way to interest students in redox reactions.