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. Four elements (CHON) 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 the 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 (amu's) 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 important in scientific research
         a. Other radioisotopes are used in medicine
   E. Electrons occupy orbitals corresponding to energy levels
      1. Electrons occupy a space called an orbital
      2. The outer electron(s) are known as the valence electron(s) and
         contain the most energy
      3. These outer electron(s) occupy the valence shell

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 $6.02 \times 10^{23}$ 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
      2. Atoms tend to be reactive if the valence shell is not full
      3. Covalent bonds result in filled valence shells
      4. The Lewis structure of the atoms represents the valence electrons
      5. A single electron pair shared between two atoms is a single covalent bond
      6. Double and triple covalent bonds are formed by sharing two or three electron pairs, respectively
      7. Hydrogen forms 1 covalent bond
      8. Carbon forms a maximum of 4 covalent bonds
      9. The function of a molecule is related to its shape
         a. Molecules composed of two atoms are linear
         b. Molecules composed of more than two atoms form complicated shapes
      10. Covalent bonds can be nonpolar or polar
          a. Electrons preferentially orbit the most electronegative of the atoms in a molecule
          b. Covalent bonds in which atoms are of varying electronegativity are polar
          c. A polar molecule has a portion of the molecule that is partially positive and another portion that is partially negative in charge
   B. Ionic bonds form between cations and anions
      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 hydrogen atoms
      1. In the water molecule, hydrogen is partially positively 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

V. Electrons and their energy are transferred in redox reactions
   A. Oxidation and reduction reactions occur simultaneously, hence they are called redox reactions
   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. Water is important because most organisms are composed of water and may live in water
B. Water molecules are polar
   1. Hydrogen atoms in the water molecule have a partial positive charge
   2. Each water molecule can form up to 4 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 cohesive
   2. Water molecules tend to hydrogen bond to other molecules, making water adhesive
   3. Capillary action is a result of adhesion and cohesion
   4. Cohesion results in water moving upwards in plants
   5. 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 much energy to raise the temperature of water
   2. Temperature stability is important to aquatic 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, equals 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 minimize 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 which can conduct an electrical current when dissolved in water.
4. Nonelectrolytes are molecules which do not dissociate in water and therefore do not conduct an electrical current.