Chemistry of life

I. Introduction

- living things are composed of the same chemical elements as the nonliving world and obey the same physical and chemical laws
- living things have unique characteristics, properties -- life
- structural hierarchy to biological systems: atomic level to biosphere
- to understand life:
  - understand properties of molecules that make up living systems and reactions in which they participate
  - understand basic concepts regarding building blocks of such molecules -- atoms

II. Atoms

A. General characteristics

1. All matter is composed of atoms
   - consist of a positively charged nucleus containing one or more protons
   - may contain one or more neutrons
   - negatively charged electrons move around nucleus
2. Atoms and constituents have mass
   - proton and neutron have mass of about 1 dalton (1.7×10^{-24} grams)
     - mass of proton serves as standard unit of molecular mass measurement (atomic mass unit)
   - mass of electron is very small -- not factored into calculation of mass of an atom
3. Atomic constituents are charged and neutral
   - proton has charge of +1
   - neutron is neutral
   - electron has charge of -1

- charge of atom depends on number of protons and electrons

4. Atoms are mostly empty space
   - if you expand atom proportionately to the size of the largest dome in the world:
     - the nucleus would be the size of a grain of salt, electrons would be too small to see
     - remainder of this enormous atom would be empty space

B. Elements

1. Elements are pure substances that contain only one type of atom -- for example, hydrogen consists solely of hydrogen atoms
- more than 100 different elements are found in the universe
    - elements arranged in a periodic table
    - periodic table groups the elements according to their physical and chemical properties
        - arranges elements left to right based on number of protons
        - arranges elements in columns based on similarities in their properties

2. Characteristics of an element
    - atomic number -- number of protons in each of its atoms
    - atomic weight (mass) -- total number of protons and neutrons in nucleus of each of its atoms, mass of atom in daltons

3. About 98% of the mass of living organisms is made of carbon, hydrogen, nitrogen, oxygen, and sulfur.

III. Chemical reactions between elements

A. Electron behavior

1. Chemical reactions are changes in atomic composition of substances
    - depend on the number and arrangement of electrons in elements
    - involve changes in relationship of electrons with one another
2. Electrons arranged in electron shells (energy levels) around nucleus
    - first electron shell can hold two electrons
    - second electron shell can hold eight electrons
    - third electron shell can hold eight electrons
    - usually outermost shells hold only eight electrons
4. The outermost electron shell determines how an atom combines with other atoms
    - outermost shell with eight electrons -- no unpaired electrons -- atom is stable
    - atoms of chemically reactive elements have unpaired electrons in outer shell
    - seek to attain stability by:
        - sharing electrons with other atoms
        - gaining or losing electrons from outer shell

B. Chemical bonds

- a chemical bond is an attractive force that links two atom to form a molecule

- types of chemical bonds:
  - covalent bonds
  - hydrogen bonds
  - ionic interactions

1. Covalent bonds consist of shared pairs of electrons
   - hydrogen molecule
   - behavior of carbon -- methane molecule example
   - covalent bonding capabilities of biologically important elements
   - multiple covalent bonds
   - covalent bonds are very strong
2. Polar vs. nonpolar covalent bonds -- equal vs. unequal sharing of electrons

- sometimes when atoms share electrons, nucleus of one atom exerts a great attraction on the electron pair than the other nucleus -- pair tends to be closer to that atom

- electronegativity -- attractive force that atom exerts on electrons; ability of an atom to attract electrons

   - nonpolar covalent bonds form when electronegativities between two atoms about equal -- ethane
   - polar covalent bonds form when atoms with strong electronegativity (oxygen) bond to atoms of weak electronegativity (hydrogen)
     - no net charge, but charge distributed unevenly between

- example of water (H_2O)
   - $\delta-$
   - $\delta+$

3. Hydrogen bonds

- form between an electronegative atom and a hydrogen bonded to an electronegative atom

   - example of hydrogen bonds between molecules: water
   - example of hydrogen bonds within a molecule -- stabilization of protein and DNA structure

- hydrogen bonds only 1/10 the strength of covalent bond -- however, when many H-bonds form they have considerable strength

4. Ionic bonds

- ionic bonds are formed by electrical interactions between ions bearing opposite charges
- ions form when an atom gains or loses one or more electrons
- when one interacting atom is much more electronegative than the other a complete transfer of one or more electrons occurs
- example of NaCl
- ions can interact with other ions or with polar molecules -- basis of solubility of ions in aqueous systems

5. Hydrophilic and hydrophobic molecules

- hydrophilic molecules are polar molecules that interact with water
- hydrophobic molecules - nonpolar molecules that interact with one another -- can't form hydrogen bonds, nonpolar molecules aggregate

V. Acids, bases and the pH scale

- acids are substances that dissolve in water and release hydrogen ions (H^+)
- bases are substances that dissolve in water and accept hydrogen ions (H^+)
- acids donate H^+; bases accept H^+

1. Strong acids completely dissociate in solution:
   - $HCl \rightarrow H^+ + Cl^-$
   - $H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$
2. Weak acids partly dissociate in solution
   - $H_2CO_3 \leftrightarrow H^+ + HCO_3^-$
3. Strong bases completely dissociate in water, tie up H^+

$NaOH \rightarrow Na^+ + OH^-$

4. Weak bases do not completely dissociate in solution and as such are slower to accept H^+
   - $H_2CO_3 \leftrightarrow H^+ + HCO_3^-$
   - $NH_2 + H^+ \leftrightarrow NH_3^+$
5. The pH scale

- the pH scale indicates the strength of a solution of an acid or base
  - the scale is arrayed as a set of values 1 through 14
  - these values may be measured by electronic instruments

- the pH value is defined as the negative logarithm of the hydrogen ion concentration in moles per liter (molar concentration):

- $pH = - \log_{10} [H^+]$