CHEMISTRY LECTURE – JUNE 27, 2016

I. What is chemistry? Chemistry is the science that tries to understand how matter behaves by studying how atoms and molecules behave.
   A. The central science: needed in the study of biology, physics, geology, engineering, medicine, and environmental sciences.
   B. Needed definitions:
      1. Matter is anything that occupies space and weighs something ("stuff")
      2. Properties = the characteristics that give a specific type of matter its unique identity
         a. For example: Water freezes at 32°F and boils at 212°F (at sea level).
         b. For example: Water reacts with iron and oxygen to form rust.
      3. Substance = a form of matter that has a definite composition and distinct properties.
         a. Composition: The types and amounts of simpler substances in a sample.
         b. For example: Water is always 1/9 hydrogen by mass and 8/9 oxygen by mass.

II. Atoms, molecules, elements and compounds
   A. Aluminum is a substance that is composed of only one kind of atom.
      1. A substance that is composed of only one kind of atom is called an <u>element</u>.
      2. An aluminum atom is the smallest possible piece of aluminum that can exist.
      3. The smallest possible particle of <u>any</u> pure metal, such as copper or iron, that has all of the properties of that metal is an <u>atom</u> of that metal.
   B. Air is composed primarily of two substances: oxygen and nitrogen
      1. Oxygen gas has properties that are distinctly different from those of nitrogen gas (for example: oxygen gas supports life, nitrogen gas does not).
      2. A sample of pure oxygen gas can be subdivided until the smallest possible sample that remains that has the properties of pure oxygen gas. In this case, this is a particle called a <u>molecule</u> of oxygen.
      3. A molecule of oxygen gas can be split in half. Two identical particles with properties that differ from those of oxygen gas are formed. These are <u>atoms</u> of oxygen.
      4. Therefore, the formula for oxygen gas is O_2, and is an example of a <u>diatomic molecule</u>. Hydrogen gas is also diatomic, and so has the formula H_2.
      5. An ozone molecule is composed of <u>three</u> oxygen atoms, and so has the formula O_3. Ozone has different properties from those of diatomic oxygen. Both diatomic oxygen and ozone are forms of the element oxygen.
   C. Atoms cannot be split into smaller particles by ordinary chemical means. Any element is composed of only one kind of atom.
      1. There are currently 116 known element, of which 88 occur naturally.
      2. Oxygen, nitrogen and hydrogen, along with aluminum, are all examples of elements.
      3. Water (H_2O) is an example of a <u>compound</u>, a substance composed of two or more elements (two or more kinds of atoms) in fixed definite proportions.
   D. If one molecule of O_2 reacts with two molecules of H_2, two molecules of H_2O form immediately while producing large amounts of heat.
      1. H_2O (water) has properties that are very different from those of O_2 and H_2.
      2. A <u>chemical reaction</u> (= chemical change) has occurred between O_2 and H_2.
      3. This can be represented by a <u>chemical equation</u>: $2\ H_2 + O_2 \longrightarrow 2\ H_2O$

III. John Dalton's atomic theory (1808)
   A. All matter is composed of small, indestructible particles called atoms.
   B. All atoms of a given element are identical in size, mass and chemical properties.

C. Atoms of one element differ from atoms of all other elements in these properties.
D. Chemical reactions involve the separation, combination or rearrangement of atoms, not their creation or destruction or conversion into atoms of other elements.
E. Atoms of different elements combine only in whole number ratios to form chemical compounds. There are many millions of known compounds.

IV. The Structure of Atoms
  A. Electrical charge
    1. Electrical charges are responsible for static electricity and electrical current. There are two kinds of electrical charges: positive and negative.
    2. Like charges repel, unlike charges attract. This means that two negatively charged objects will repel each other, as will two positively charged objects.
    3. However, a positively charged object and a negatively charged object will be attracted to each other.
  B. Atoms are composed of protons, neutrons and electrons.
    1. Electrons are negatively charged (discovered by J. J. Thomson in 1897).
    2. Protons are positively charged.
    3. Electrons are as negatively charged as protons are positively charged.
    4. Neutrons have no electrical charge (discovered by James Chadwick in 1936).
  C. The protons and neutrons are both found only in a very small region in the center of the atom called the <u>nucleus</u> (discovered by Ernest Rutherford in 1910).
    1. Protons and neutrons weigh about the same and are almost 2000 times heavier than electrons.
    2. The nucleus has a diameter that is only about 1/10,000 that of the atom, although the nucleus contains nearly all the mass of the atom.
    3. A cloud of electrons surrounds the nucleus and occupies most of the volume of the atom
  D. Analogy; a swarm of bees (electrons) surrounds a hive (the nucleus).

V. Numbers of protons vs. neutrons vs. electrons and the periodic table
  A. The number of protons in an atom <u>always</u> determines the identity of the element.
    1. All atoms of a given element have the same number of protons.
    2. Therefore, <u>all</u> oxygen atoms have 8 protons in their nuclei, and an atom containing 8 protons in its nucleus is, <u>by definition</u>, an atom of oxygen.
    3. An atom that contains only 7 protons is not an oxygen atom but is, by definition, a nitrogen atom.
    4. To be electrically <u>neutral</u>, any atom must possess <u>exactly</u> as many electrons as there are protons in its nucleus.
  B. The number of neutrons in the nucleus of an atom of a given element can vary from one atom to the next. Certain ratios of the number of protons to the number of neutrons make that atom radioactive, which means that atom spontaneously emits radiation and may be quite harmful to living things.
  C. The number of electrons possessed by an atom of a given element can also vary from one atom to the next. For example: an atom of iron, which has 26 protons by definition, can also have 26 electrons (as found in an iron nail) or 24 electrons (as found in foods and in the blood) or only 23 electrons (as found in iron rust).
  D. The number of protons (and electrons in a neutral atom) can be obtained from the <u>periodic table</u>, which was first devised by the Russian chemist Dmitri Mendeleev (1870).

1. When the elements are arranged in order of increasing numbers of protons, the properties of the elements tend to repeat in a periodic fashion. [Give some examples.]
2. The number of protons possessed by an atom of a particular element will always be a whole number on the periodic table. The number of electrons in a neutral atom of that element will be the same as the number of protons.
3. The number of protons plus the average number of neutrons in an atom of a given element is shown on a periodic table as a decimal.

E. Ions are atoms or groups of atoms in which the total number of protons does not equal the total number of electrons. For example:
1. The ion H_3O^+ has a total of 11 protons but only 10 electrons.
2. The ion OH^- has a total of 9 protons but has 10 electrons.
3. These two ions will play a central role in our discussion of acids and bases.

ACIDS AND BASES

VI. Water and the Ions H_3O^+ and OH^-

A. Even in pure water, two water molecules will very occasionally react with each other to form one ion each of H_3O^+ and OH^- as follows: $H_2O + H_2O \rightleftharpoons H_3O^+ + OH^-$
1. The equilibrium sign ($\rightleftharpoons$) is used to indicate that as soon as these ions form, they react with each other to reform two water molecules.
2. Chemists express the concentration of these ions in a solution in moles per liter.
   a. The mass of an atom, ion or molecule in grams is numerically equal to the total number of protons plus the average number of neutrons and can be obtained from the periodic table. This is the mass of one mole of this substance.
   b. The mass of the electrons present is so small it can be neglected.
   c. Therefore, one mole of H_3O^+ ions weighs 19 grams, and one mole of OH^- ions weighs 17 grams. [3 quarters weighs about 17 grams.]
3. In pure water at room temperature, the concentration of the H_3O^+ ions equals that of the OH^- ions and is 0.00000010 moles per liter. This very small number can be written in scientific notation as 1.0×10^{-7} moles per liter.
4. A solution in which the concentration of each of these ions is 1.0×10^{-7} moles per liter is called a neutral solution.
5. Adding any acidic substance to pure water will increase the concentration of H_3O^+ ions and will decrease the concentration of OH^- ions.
6. Adding any basic (or alkaline) substance to pure water will have the opposite effect.

B. Since most of us are not comfortable thinking in terms of very small numbers, the pH scale was invented. The pH of a given solution is defined as negative logarithm of the H_3O^+ concentration. pH values range from about 0 to about 14.

C. On this scale, a neutral solution will have a pH of 7, an acidic solution will have a pH less than 7, and a basic solution will have a pH greater than 7.

D. A decrease of 1 pH unit corresponds to a 10-fold increase in H_3O^+ concentration.

E. Example: If the H_3O^+ concentration is 1.0×10^{-4} moles per liter, what is the pH?

VII. Properties and examples of acids

A. Properties: Have a sour taste and react with many metals to give H_2 gas.

B. Acids are a source of H^+ ions, which react with water to form hydronium ions, H_3O^+.

C. Formulas for acids usually begin with H.

D. Some common examples of acids: hydrochloric acid, HCl (stomach acid), acetic acid, $HC_2H_3O_2$ (present in vinegar), sulfuric acid, H_2SO_4 (battery acid)

VIII. Properties and examples of bases

A. Properties: Have a bitter taste and feel slippery to the touch.

B. Bases are a source of OH^- ions in water-based solutions.

C. Bases react with acids to form ionic compounds and water.

D. Two common bases: sodium hydroxide, NaOH (present in drain cleaner) and magnesium hydroxide, $Mg(OH)_2$ (milk of magnesia).

IX. Strong and Weak Acids and Bases

A. Strong acids <u>dissociate</u> completely when dissolved in water, and so produce only ions when dissolved in water. See the diagram in the laboratory experiment.

1. Example: $HCl + H_2O \longrightarrow H_3O^+ + Cl^-$
2. Therefore, HCl is a <u>strong electrolyte</u> because it forms ONLY ions when dissolved in water. No <u>molecules</u> of HCl are present when dissolved in water.

B. Weak acids are weak electrolytes = compounds that exist <u>mostly as molecules</u> in water-based solutions but that also exist to some extent as ions.

1. Acetic acid and hydrofluoric acid are weak acids: they exist 95% to 99% of the time as molecules when dissolved in water and only 1% to 5% of the time as ions, depending on concentration.
2. This is illustrated by the equation: $HF + H_2O \rightleftarrows H_3O^+ + F^-$.

C. Strong Bases: Dissociate completely in solution to give hydroxide ions.

1. Common strong bases: NaOH, $Mg(OH)_2$.
2. These exist ONLY as ions in aqueous solution, NOT as molecules.
3. Example when dissolved in water: $Mg(OH)_2 \longrightarrow Mg^{2+} + 2\,OH^-$

D. Weak Bases exist mostly as molecules in water-based solution but react with water to a small extent to form hydroxide ions. Therefore, they are weak electrolytes.

1. An example of a weak base is ammonia, NH_3 (present in Windex).
2. Ammonia, NH_3 (present in Windex) is a weak base: it exists 98% to 99% of the time as NH_3 molecules when dissolved in water and only 1% to 2% of the time as NH_4^+ and OH^- ions, depending on concentration.
3. This is illustrated by the equation: $NH_3 + H_2O \rightleftarrows NH_4^+ + OH^-$.
4. Ionic compounds of CO_3^{2-} and HCO_3^-, such as sodium carbonate and sodium bicarbonate, are weak bases due to the following equilibria:
   a. $CO_3^{2-} + H_2O \rightleftarrows HCO_3^- + OH^-$
   b. $HCO_3^- + H_2O \rightleftarrows H_2CO_3 + OH^-$

X. Buffer solutions are solutions that resist changes in pH as long as not too much acid or base is added.

A. Buffer solutions contain a weak acid and a weak base in the same solution.

B. BOTH must be present in comparable amounts in order to have a buffer solution.

C. The pH of human blood must be in the range of 7.0 to 7.8, or the patient will die. It is kept in this range by a series of buffer solutions.

D. However, adding too much acid or base: will overwhelm a buffer – a <u>large</u> pH change will result if the buffer solution is overwhelmed.

E. The "phosphate buffer" you will use in lab today is a solution of a mixture of K_2HPO_4, which is weakly basic, and KH_2PO_4, which is weakly acidic.