Solutions

- We carry out many reactions in solutions
- Remember that in the liquid state molecules move much easier than in the solid, hence the mixing of reactants occurs faster
  - Solute is the substance which we dissolve
  - Solvent is the substance in which we dissolve the solute
  - In aqueous solutions, the solvent is water

Concentration of Solutions

- The concentration of a solution defines the amount of solute dissolved in the solvent
- We will express the concentration of a solution in one of the two most common ways:
  - percent by mass
  - molarity

Percent by mass of solute

$$\% \text{ by mass of solute} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 100\%$$

$$\text{mass of solution} = \text{mass of solute} + \text{mass of solvent}$$

- What does it tell us?
  - The mass of solute in 100 mass units of solution

$$w(\text{solute}) = \frac{m(\text{solute})}{m(\text{solution})} \times 100\%$$

  - usually expressed as "% w/w"

Example 1

- What is the concentration of the solution obtained by dissolving 25 g of NaOH in 300.0 mL of water?

Example 2

- What mass of NaOH is required to prepare 250.0 g of solution that is 8.00% w/w NaOH?

$$\%\text{ by mass (NaOH)} = \frac{m(\text{NaOH})}{m(\text{solution})} \times 100\%$$

$$8.00\% = \frac{m(\text{NaOH})}{250.0\text{ g}} \times 100\%$$

$$m(\text{NaOH}) = \frac{250.0\text{ g} \times 8.00\%}{100\%} = \boxed{20.0\text{ g}}$$

Example 3

- Calculate the mass of 8.00% w/w NaOH solution that contains 32.0 g of NaOH.

$$\% \text{ by mass (NaOH)} = \frac{m(\text{NaOH})}{m(\text{solution})} \times 100\%$$

$$8.00\% = \frac{32.0\ g}{m(\text{solution})} \times 100\%$$

$$m(\text{solution}) = \frac{32.0\ g \times 100\%}{8.00\%} = \boxed{400.\ g}$$

Example 4

- What volume of 12.0% KOH contains 40.0 g of KOH? The density of the solution is 1.11 g/mL.

Molarity, or Molar Concentration

$$\text{molarity} = \frac{\text{number of moles of solute}}{\text{number of liters of solution}}$$

$$M = \frac{n(\text{solvent})}{V(\text{solution})} \left[\frac{\text{mol}}{\text{L}} \text{ or } \frac{\text{mmol}}{\text{mL}} \right]$$

- Always divide the number of moles of the solute by the volume of the solution, not by the volume of the solvent

Example 5

- Calculate the molarity of a solution that contains 12.5 g of sulfuric acid in 1.75 L of solution.

Example 6

- Determine the mass of calcium nitrate required to prepare 3.50 L of 0.800 M $Ca(NO_3)_2$.
- We first find the number of moles of $Ca(NO_3)_2$ dissolved in the solution:

$$M = \frac{\#\ \text{moles (solute)}}{V\text{(solution)}}$$

$$0.800\ \text{mol/L} = \frac{\#\ \text{moles}\ (Ca(NO_3)_2)}{3.50\ \text{L}}$$

$$\#\ \text{moles}\ (Ca(NO_3)_2) = 0.800\ \text{mol/L} \times 3.50\ \text{L} = 2.80\ \text{mol}$$

Example 6

- Now we calculate the molar mass of $Ca(NO_3)_2$ and find its mass in grams necessary for preparation of the solution:

$$M_r(Ca(NO_3)_2) = 164.09\ g/mol$$

$$m(Ca(NO_3)_2) = M_r(Ca(NO_3)_2) \times \#\ moles\ (Ca(NO_3)_2)$$

$$m(Ca(NO_3)_2) = 164.09\ g/mol \times 2.80\ mol = \boxed{459\ g}$$

Dilution of Solutions

$$M = \frac{n(\text{solute})}{V(\text{solution})} \Rightarrow n(\text{solute}) = M \times V(\text{solution})$$

- Solution 1: concentration = M_1
  volume = V_1

$$n = M_1 \times V_1$$

- We add more solvent (dilute the solution)

  concentration = M_2
  volume = V_2

$$n = M_2 \times V_2$$

- The amount of solute remains the same (we didn't add any solute to the solution)

Dilution of Solutions

$$M_1 \times V_1 = M_2 \times V_2$$

- If we know any 3 of these 4 quantities, we can calculate the other one
- The relationship is appropriate for dilutions but not for chemical reactions

Example 7

- If 10.0 mL of 12.0 M HCl is added to enough water to give 100. mL of solution, what is the concentration of the solution?

Example 8

- What volume of 18.0 M sulfuric acid is required to make 2.50 L of a 2.40 M sulfuric acid solution?
  - V_1 = ?
  - M_1 = 18.0 M
  - V_2 = 2.50 L
  - M_2 = 2.40 M

$$V_1 \times 18.0 \text{ M} = 2.50 \text{ L} \times 2.40 \text{ M}$$

$$\boxed{V_1 = 0.333 \text{ L}}$$

Using Solutions in Chemical Reactions

- Combine the concepts of molarity and stoichiometry to determine the amounts of reactants and products involved in reactions in solution.

Example 9

- What volume of 0.500 M $BaCl_2$ is required to completely react with 4.32 g of Na_2SO_4?

Example 10

- What volume of 0.200 M NaOH will react with 50.0 mL of 0.200 M aluminum nitrate, $Al(NO_3)_3$? What mass of $Al(OH)_3$ will precipitate?

$$3NaOH + Al(NO_3)_3 \rightarrow 3NaNO_3 + Al(OH)_3$$

- First we calculate the number of moles of $Al(NO_3)_3$ (remember to convert mL to L):

$$M(Al(NO_3)_3) = \frac{\#\,moles(Al(NO_3)_3)}{0.0500\ L} = 0.200\ mol/L$$

$$\#\,moles(Al(NO_3)_3) = 0.0100\ mol$$

Example 10 (continued)

- From the equation we see that each mole of $Al(NO_3)_3$ reacts with 3 moles of NaOH. Therefore, we multiply the number of moles of $Al(NO_3)_3$ by 3 to find the number of moles of NaOH required for the reaction:

  # moles (NaOH) = 0.0300 mol

- Now we again use the formula for the molarity to find the volume of the NaOH solution reacting:

$$0.200\ \text{mol/L} = \frac{0.0300\ \text{mol}}{V(\text{solution})}$$

V(solution) = 0.150 L = **150 mL**

Example 10 (continued)

- Each mole of $Al(NO_3)_3$ produces 1 mole of $Al(OH)_3$. Since the reacting solution contains 0.0100 mole of $Al(NO_3)_3$, 0.0100 mole of $Al(OH)_3$ will be formed:

$$m(Al(OH)_3) = \#moles(Al(OH)_3) \times M_r(Al(OH)_3)$$

$$m(Al(OH)_3) = 0.0100 \text{ mol} \times 78.00 \text{ g/mol} = \boxed{0.780 \text{ g}}$$

$$0.200 \text{ mol/L} = \frac{0.0300 \text{ mol}}{V(\text{solution})}$$

$$V(\text{solution}) = 0.150 \text{ L} = \boxed{150 \text{ mL}}$$

Example 11

- What is the molarity of a KOH solution if 38.7 mL of the KOH solution is required to react with 43.2 mL of 0.223 M HCl?

$$KOH + HCl \rightarrow KCl + H_2O$$

- First we calculate the number of moles of HCl in the solution (remember to convert mL to L):

$$M(\text{HCl}) = \frac{\#\,\text{moles(HCl)}}{0.0432\,\text{L}} = 0.223\,\text{mol/L}$$

$$\#\,\text{moles(HCl)} = 9.63 \cdot 10^{-3}\ \text{mol}$$

Example 11 (continued)

$$KOH + HCl \rightarrow KCl + H_2O$$

- From the equation we see that each mole of HCl reacts with 1 mole of KOH. Therefore, $9.63 \cdot 10^{-3}$ mole of HCl will react with $9.63 \cdot 10^{-3}$ mole of KOH.
- Now we can use the formula for the molarity:

$$M(\text{KOH}) = \frac{\#\,\text{moles(KOH)}}{\text{V(solution)}}$$

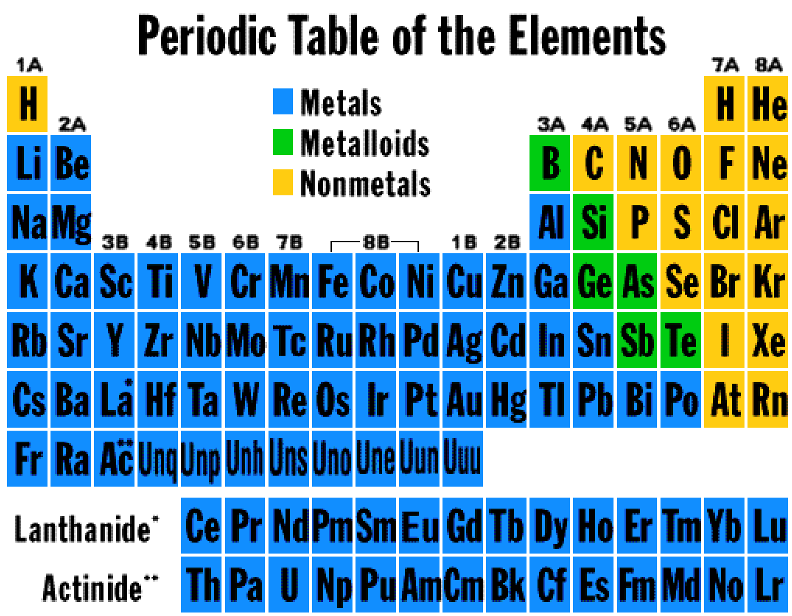
$$M(\text{KOH}) = \frac{9.63 \cdot 10^{-3}\ \text{mol}}{0.0387\ \text{L}} = 0.249\ \text{mol/L} = 0.249\ \text{M}$$

Example 12

- What is the molarity of a barium hydroxide solution if 44.1 mL of 0.103 M HCl is required to react with 38.3 mL of the $Ba(OH)_2$ solution?

Metals and Nonmetals

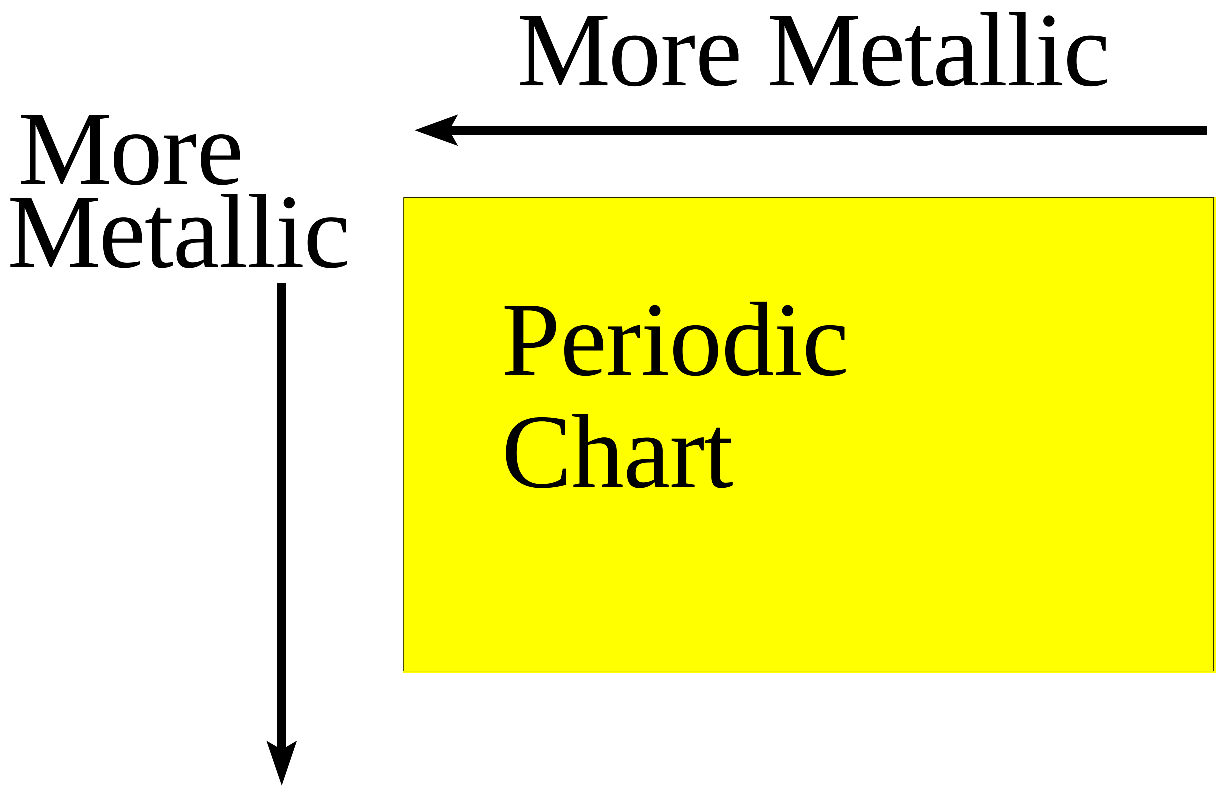
- Stair step function on periodic table separates metals from nonmetals.



- Metals are to the left of the stair step
- Nonmetals are to the right of the stair step

Metals and Nonmetals

- Periodic trends in metallic character



Metals and Nonmetals

- Metals tend to form cations
  - Li^{1+}, Ca^{2+}, Ni^{2+}, Al^{3+}
- Nonmetals tend to form anions or oxoanions
  - Cl^{1-}, O^{2-}, P^{3-}
  - ClO_4^{1-}, NO_3^{1-}, CO_3^{2-}, SO_4^{2-}, PO_4^{3-}
- Important exceptions:
  - H^{1+}, NH_4^{1+}

Aqueous Solutions

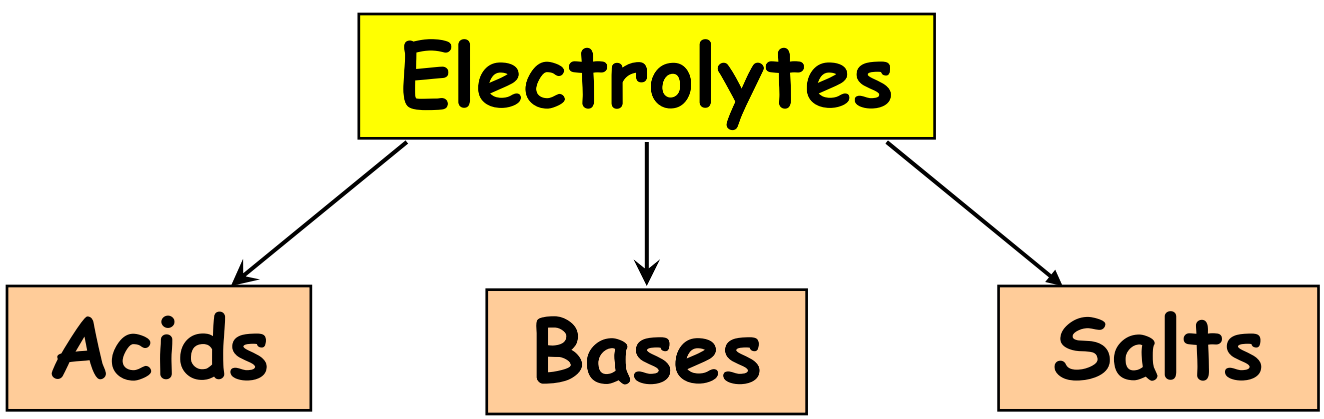
- Classification of solutes:
  - Electrolytes – solutes whose aqueous solutions conduct electricity
  - Nonelectrolytes – solutes whose aqueous solutions do not conduct electricity

Nonelectrolytes

- Exist in solution in form of electroneutral molecules
- No species present which could conduct electricity
- Some examples:
  - H_2O, C_2H_5OH, CH_3COOH

Electrolytes

- Exist in solution as charged ions (both positive and negative)
- Ions move in the electric field and the solution conducts electricity



Electrolytes

- Acids
  - Form H^+ cations in aqueous solution
  - HCl, H_2SO_4, H_3PO_4
- Bases
  - Form OH^- anions in aqueous solution
  - $NaOH$, $Ca(OH)_2$
- Salts:
  - Form ions other than H^+ or OH^- in aqueous solution
  - $NaCl$, $MgBr_2$, $Zn(NO_3)_2$

Electrolytes

- Dissociation
  - The process in which a solid <u>ionic compound</u> separates into its ions in solution

$$NaCl(s) \xrightarrow{H_2O} Na^+(aq) + Cl^-(ag)$$

- Ionization
  - The process in which a <u>molecular compound</u> separates to form ions in solution

$$HCl(g) \xrightarrow{H_2O} H^+(aq) + Cl^-(ag)$$

Strong Electrolytes

- Strong electrolytes
  - Dissociate completely in aqueous solution
  - Good electric conductors in solution
- Examples:
  - Strong acids (Table 4-5)
    HCl, HNO_3, H_2SO_4
  - Strong bases (Table 4-7)
    KOH, $Ba(OH)_2$
  - Soluble ionic salts (Solubility Chart)
    KI, $Pb(NO_3)_2$, Na_3PO_4

Weak Electrolytes

- Weak electrolytes
  - Dissociate partially in aqueous solution
  - Poor electric conductors in solution
- Examples:
  - Weak acids (Table 4-6)

    HF, CH_3COOH, H_2CO_3, H_3PO_4
  - Weak bases

    NH_3, CH_3NH_2
- Dissociation of weak electrolytes is reversible

Reversible Reactions

- All weak acids and bases ionize reversibly in aqueous solution
  - This is why they ionize less than 100%
- CH_3COOH – acetic acid

$$CH_3COOH \xrightleftharpoons{H_2O} CH_3COO^-(aq) + H^+(aq)$$

- NH_3 – ammonia

$$NH_3 + H_2O \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

How to Write Ionic Equations

1) Write the formula unit equation:

$$Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2KNO_3$$

2) Show dissociation for every strong electrolyte (total ionic equation):

$$[Pb^{2+}(aq) + 2NO_3^-(aq)] + [2K^+(aq) + 2I^-(aq)] \rightarrow$$

$$\rightarrow PbI_2(s) + [2K^+(aq) + 2NO_3^-(aq)]$$

3) To obtain tne net ionic equation, get rid of spectator ions:

$$Pb^{2+}(aq) + 2I^-(aq) \rightarrow PbI_2(s)$$

Ionic Equations: Examples

- $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

- $NaOH + CH_3COOH \rightarrow CH_3COONa + H_2O$

Combination Reactions

- One or more substances react to form one new substance (compound)
  - Element + Element → Compound

    $2Na(s) + Br_2(l) \rightarrow 2NaBr(s)$

    $P_4(s) + 10Cl_2(g) \rightarrow 4PCl_5(s)$

  - Compound + Element → Compound

    $C_2H_4(g) + Cl_2(g) \rightarrow C_2H_4Cl_2(l)$

  - Compound + Compound → Compound

    $CaO(s) + CO_2(g) \rightarrow CaCO_3(s)$

Decomposition Reactions

- A compound decomposes to produce two or more substances
  - Compound → Element + Element

$$2HgO(s) \xrightarrow{heat} 2Hg(l) + O_2(g)$$

$$2H_2O(l) \xrightarrow{electrolysis} 2H_2(g) + O_2(g)$$

  - Compound → Compound + Element

$$2KClO_3(s) \xrightarrow{heat} 2KCl(s) + 3O_2(g)$$

  - Compound → Compound + Compound

$$Mg(OH)_2(s) \xrightarrow{heat} MgO(s) + H_2O(g)$$

Displacement Reactions

- One element displaces another from a compound
  - $Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$
  - $Zn(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2(g)$
  - $2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$

Metathesis Reactions

- Exchange of ions between two compounds
- General equation:
  - AX + BY → AY + BX
- Need a driving force in order to proceed
- Such driving force should act to remove ions from the solution

Metathesis Reactions

- Formation of a nonelectrolyte
  - Acid-Base neutralization – most typical

    $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

- Formation of an insoluble compound
  - Precipitation

    $Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$
  - Gas evolution

    $CaCO_3(aq) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

Reading Assignment

- Read Sections 4-1 through 4-3 and 4-8 through 4-11
- Get familiar with information presented in Sections 4-5 and 4-6
- Take a look at Lecture 6 notes (will be posted on the web 9/14)
- Read Sections 5-1 through 5-13

Homework #2

- Required:

  OWL Homework Problems
  based on Chapters 3 & 4
  due by 9/26/05, 9:00 p.m.

- Optional:

  OWL Tutors and Exercises

  Textbook problems
  (see course website)