Reactions in Solution

What happens on a molecular or atomic level

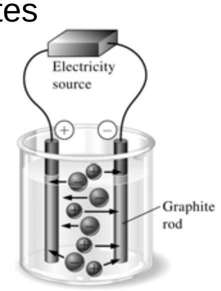
Ions in aqueous solution

- Some, but not all, ionic solid will dissolve in water creating free floating ions.
- The free floating ions can then carry an electric current.
- Ionic solids that do this are called ***electrolytes***.
- Covalent solids are ***non-electrolytes***.

Electrolytes

- Electrolytes can be strong or weak
- A Strong electrolyte will dissociate completely in solution
  - Examples: NaCl, HNO_3
- A weak electrolyte will only partially dissociate in solution.
  - Examples: NH_3, $HC_2H_3O_2$

Electrolytes



Chemical Equations Revisited

- We can represent a chemical equation that involves ionic substances in several different ways.
  - Molecular equation: We show everything as combined compounds.
  - Total ionic equation: we show all strong electrolytes as separated ions and weak and non-electrolytes as combined.
  - Net ionic equations: substances that appear the same on both sides of the ionic equation are eliminated.

How do we identify strong electrolytes

- Solubility Rules
  - Mostly Soluble:
    - Compounds containing Group IA ions, NH_4^+, NO_3^-, and $C_2H_3O_2^-$.
    - Compounds containing Cl^-, Br^-, and I^- except with Pb^{2+}, Ag^+, and Hg_2^{2+}.
    - Compounds containing SO_4^{2-} except with Ca^{2+} (slightly soluble), Ba^{2+}, Sr^{2+}, Pb^{2+}, Ag^+, and Hg_2^{2+}

How do we identify strong electrolytes

- Solubility Rules
  - Mostly Insoluble:
    - Compounds containing OH^- except with Group IA, Ca^{2+}, Ba^{2+}, and Sr^{2+}.
    - Compounds containing S^{2-} except Groups IA and IIA and NH_4^+.
    - Compounds containing PO_4^{3-} and CO_3^{2-} except with Group IA and NH_4^+.

Ionic equations

- Consider the equation:
  $Ca(OH)_2 + 2\ HNO_3 \quad Ca(NO_3)_2 + 2\ H_2O$
- What is soluble in this equation and what is not?
  - Everything is soluble except for water which is a liquid.
- We can rewrite this equation to reflect that.

Ionic Equations

- We get:
  $\cancel{Ca^{2+}} + 2\ OH^- + 2\ H^+ + \cancel{2\ NO_3^-}$
  $\cancel{Ca^{2+}} + \cancel{2\ NO_3^-} + 2\ H_2O$
- This is called the ***total ionic equation***.
- We can cancel the ions that are in the same form on both sides of the equation. These are called ***spectator ions***.

Net Ionic Equations

- When we do this we get:
  $2\ OH^- + 2\ H^+ \quad 2\ H_2O$
  or
  $OH^- + H^+ \quad H_2O$
- This is the ***net ionic equation***.

Precipitation Reactions

- All precipitation reactions are metathesis (double replacement) reactions
- A precipitation reaction results in an insoluble ionic substance (the precipitate) being formed.

Acid-Base Reactions

- Definitions
  - Acid: A substance the produces H^+ in solution
    - A substance that donates a proton to another substance
  - Base: A substance that produces OH^- in solution
    - A substance that accepts a proton from another substance

Acids and Bases

- Strong vs. Weak
  - Strong acids and bases dissociate completely in solution
    - Strong acids are: HI, HBr, HCl, HNO_3, $HClO_3$, $HClO_4$, H_2SO_4 (first proton only).
    - Strong bases are the group IA and IIA metal hydroxides.
  - Weak acids and bases do not dissociate completely.
  - Weak acids and bases are written as complete molecules in ionic equations.

Neutralization reactions

- When acids react with bases, they neutralize one another.
- The ionic compound produced in the reaction is a salt. Water is also sometimes produced.

$$2\ HNO_3 + Ca(OH)_2 \quad Ca(NO_3)_2 + 2\ H_2O$$

acid base salt

Solutions

- A ***solution*** is a homogeneous mixture of two or more substances.
- The two main components of a solution are the ***solute*** and the ***solvent***.
  - Solute is present in the smaller amount
  - The solvent is present in the larger amount.
- Any phase of matter can dissolve into any other phase.

Concentration Units

- Molarity

$$M = \frac{\text{mol solute}}{\text{L solution}}$$

Solutions and Stoichiometry

- For solutions, it's easier to specify the volume and molarity of a solution instead of the mass of solute.
- These two numbers give us the number of moles of reactant(s).
- From moles of reactant we can continue the calculation as usual.

Example

- 22.51 mL of 0.5521 M Sodium Carbonate reacts with Calcium Nitrate solution. The products are solid Calcium Carbonate and aqueous Sodium Nitrate. How many grams of solid are produced?

Solve

- Write balanced chemical equation:
  - Na_2CO_3 (*aq*) + $Ca(NO_3)_2$ (*aq*) $CaCO_3$ (*s*) + 2 $NaNO_3$ (*aq*)
- Calculate:

$$? \text{ g CaCO}_3 = 22.51 \text{ mL Na}_2\text{CO}_3 \text{ sol'n} \times \frac{10^{-3} \text{ L Na}_2\text{CO}_3 \text{ sol'n}}{1 \text{ mL Na}_2\text{CO}_3 \text{ sol'n}}$$

$$\times \frac{0.5521 \text{ mol Na}_2\text{CO}_3}{1 \text{ L Na}_2\text{CO}_3 \text{ sol'n}} \times \frac{1 \text{ mol CaCO}_3}{1 \text{ mol Na}_2\text{CO}_3} \times \frac{100.09 \text{ g CaCO}_3}{1 \text{ mol CaCO}_3}$$

$$= 1.244 \text{ g CaCO}_3$$

Quantitative Analysis

- In quantitative analysis, one quantity is measured in order to determine another desired quantity.
- There are two types of quantitative analysis we will examine:
  - Volumetric analysis – measuring volumes to determine concentrations
  - Gravimetric analysis – measuring masses to determine concentrations

Volumetric Analysis

- The process used for volumetric analysis is called titration.
- In a titration, we add one solution to another until the end-point is reached.
- The end-point is the point where an chemical indicator shows that the two quantities are in a stoichiometric ratio.

Example

- A 25.00 mL sample of nitric acid is titrated with a 0.1568 M calcium hydroxide solution. It requires 15.69 mL of the calcium hydroxide solution to reach the end-point. What is the molar concentration of the nitric acid?

Solution

2 HNO_3 + $Ca(OH)_2$ $Ca(NO_3)_2$ + 2 H_2O

$$? \frac{\text{mol HNO}_3}{\text{L sol'n}} = \frac{15.69 \text{ mL Ca(OH)}_2 \text{ sol'n}}{25.00 \text{ mL HNO}_3 \text{ sol'n}}$$

$$\times \frac{0.1568 \text{ mol Ca(OH)}_2}{\text{L Ca(OH)}_2 \text{ sol'n}} \times \frac{2 \text{ mol HNO}_3}{1 \text{ mol Ca(OH)}_2} = 0.1968 \text{ M HNO}_3$$

Gravimetric Analysis

- Measuring mass gives the number of moles of product which tells us the number of moles of reactant.
- The moles of reactant and the volume of reactant solution tells us the concentration.

Example

- A 50.00 mL sample of tap water is analyzed for Lead(II) ion. The water is treated with sodium sulfate which causes all of the Lead(II) to precipitate out. The mass of the Lead(II) product is 113.6 mg. What is the concentration of Lead(II) in the tap water?

Solution

Pb^{2+} Ý + SO_4^{2-} Ý $PbSO_4$ß

$$?\frac{\text{mol Pb}^{2+}}{\text{L sol'n}} = \frac{113.6\text{ mg PbSO}_4}{50.00\text{ mL Pb}^{2+}\text{ sol'n}} \times \frac{1\text{ mol PbSO}_4}{303.25\text{ g PbSO}_4} \times$$

$$\frac{1\text{ mol Pb}^{2+}}{1\text{ mol PbSO}_4} = 7.492 \times 10^{-3}\text{ M Pb}^{2+}$$