Chapter 4

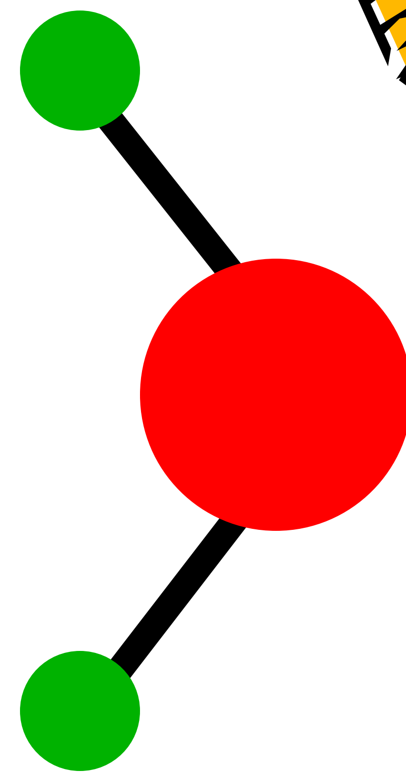
Aqueous Reactions and Solution Stoichiometry

Lesson 1: Section 4.1 General Properties of Aqueous Solutions

- Solution- homogeneous mixture.
- Solute- what gets dissolved.
- Solvent- what does the dissolving.
- Soluble- Can be dissolved.
- Miscible- liquids dissolve in each other.

Aqueous solutions

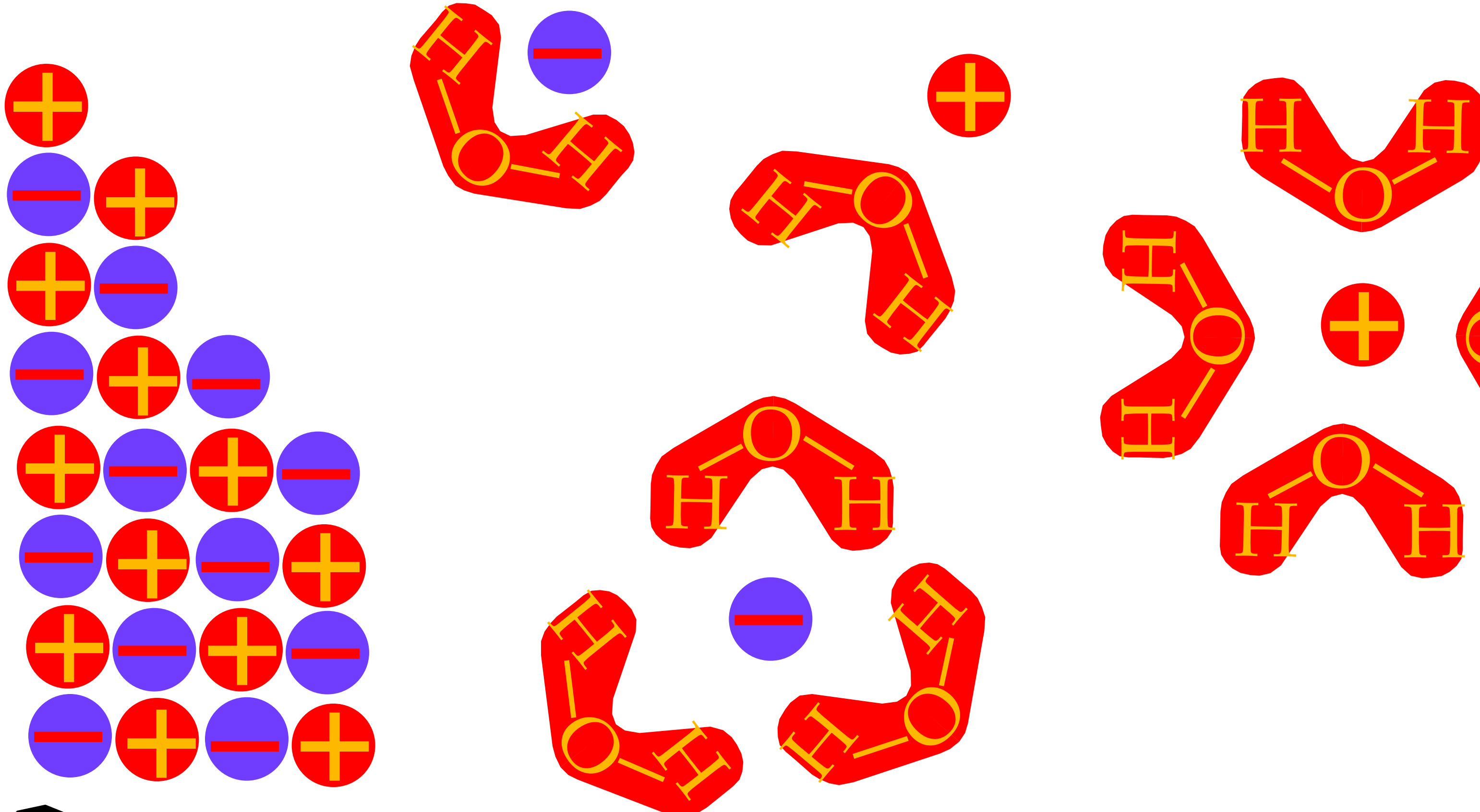
- Dissolved in water.
- Water is a good solvent because the molecules are polar.
- The oxygen atoms have a partial negative charge.
- The hydrogen atoms have a partial positive charge.
- The angle is 105°.



Solvation

- This is known as HYDRATION when the solvent is water.
- The process of breaking the ions of salts apart.
- Ions have charges and attract the opposite charges on the water molecules.

Hydration

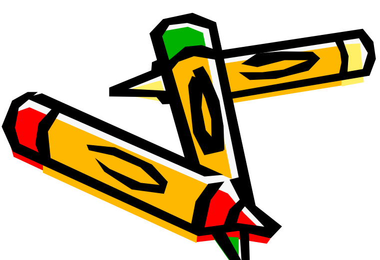


Solubility

- How much of a substance will dissolve in a given amount of water.
- Usually g/100 mL
- Varies greatly, but if they do dissolve the ions are separated,
- and they can move around.
- The ionic solid dissociates into its component ions as it dissolves.
- Water can also dissolve non-ionic compounds if they have polar bonds.

Electrolytes

- Electricity is moving charges.
- The ions that are dissolved can move.
- Solutions of ionic compounds can conduct electricity.
- Electrolytes.
- Solutions are classified three ways.



Types of solutions

- Strong electrolytes- completely dissociate (fall apart into ions).
  - Many ions- Conduct well.
- Weak electrolytes- Partially fall apart into ions.
  - Few ions -Conduct electricity slightly.
- Non-electrolytes- Don't fall apart.
  - No ions- Don't conduct.

Molecular Compounds

- Molecular Compounds in water usually consist of intact molecules dispersed throughout the solution. Consequently, most molecular compounds are **NONELECTROLYTES**
  - There are, however, a few molecular substances whose aqueous solutions contain ions. The most important of these are ACIDS.

Acidic Solutions

- Acids- form H^+ ions when dissolved.
- Strong acids fall apart completely.
  - many ions (Memorize)
- H_2SO_4 HNO_3 HCl HBr HI $HClO_{4,}$ $HCLO_3$
- Weak acids- don' dissociate completely.
- Write the dissociation equation for
  - Hydrochloric acid
  - Acetic Acid

Give it some thought…

- Sample questions in notepacks…

Lesson 2: Section 4.2
Precipitation Reactions

- When aqueous solutions of ionic compounds are poured together a solid forms.
- A solid that forms from mixed solutions is a precipitate
- "If you're not a part of the solution, your part of the precipitate."

Follow this Demonstration

Precipitation reaction

- Called METATHESIS – Greek word for "to transpose."
- We can predict the products
- Can only be certain by experimenting
- The anion and cation switch partners
- $AgNO_3(aq) + KCl(aq) \rightarrow$
- $Zn(NO_3)_2(aq) + BaCr_2O_7(aq) \rightarrow$
- $CdCl_2(aq) + Na_2S(aq) \rightarrow$

Precipitations Reactions

- Only happen if one of the products is insoluble
- Otherwise all the ions stay in solution- nothing has happened.
- Need to memorize the rules for solubility (pg 127)

Solubility Rules

1 All nitrates are soluble

2. All acetates are soluble.

3. Alkali metals ions and NH_4^+ ions are soluble

4. Halides are soluble except Ag^+, Pb^{+2}, and Hg_2^{+2}

5. Most sulfates are soluble, except Pb^{+2}, Ba^{+2}, Hg^{+2},and Ca^{+2}

Solubility Rules

6. Sulfides are insoluble except NH_4^+, the alkali metal cations, and Ca^{2+}, Sr^{2+} and Ba^{2+}.
7. Carbonates are insoluble except for NH_4^+, and the alkali metal cations.
8. Phosphates are insoluble except for ammonium and the alkali metal cations.
9. Hydroxides are insoluble except the alkali metal cations, and NH_4^+, Ca^{2+}, Sr^{2+} and Ba^{2+}.

CHOPS NAAAA

- Generally Insoluble
  - CHOPS
    - C = Carbonates
    - H = Hydroxides
    - O = Oxides
    - P = Phosphates
    - S = Sulfides

CHOPS NAAAAA

- Always Soluble
  - NAAAAA
    - N = Nitrates
    - A = Acetates
    - A = Alkali Metals (Group 1A)
    - A = Common Acids
    - A = Ammonium ion
    - A = Always!

CHOPS NAAAAA

- Generally Soluble
  - Halides except = Ag^{+}, Pb^{+2}, and Hg_2^{+2}
  - Sulfate except = Pb^{+2}, Ba^{+2}, Hg^{+2},and Ca^{+2}

Three Types of Equations

- Molecular Equation- written as whole formulas, not the ions.
- $K_2CrO_4(aq) + Ba(NO_3)_2(aq) \rightarrow$
- Complete Ionic equation show dissolved electrolytes as the ions.
- $2K^+ + CrO_4^{-2} + Ba^{+2} + 2\ NO_3^- \rightarrow BaCrO_4(s) + 2K^+ + 2\ NO_3^-$
  - Spectator ions are those that don't react.

Three Type of Equations

- Net Ionic equations show only those ions that react, not the spectator ions
- $Ba^{+2} + CrO_4^{-2} \rightarrow BaCrO_4(s)$
- Write the three types of equations for the reactions when these solutions are mixed.
- iron (III) sulfate and potassium sulfide Lead (II) nitrate and sulfuric acid

Lesson 3: Section 4.3
Acid – Base Reactions

- For our purposes an acid is a proton donor.
- a base is a proton acceptor usually OH^-
- What is the net ionic equation for the reaction of HCl(aq) and KOH(aq)?
- Acid + Base $\rightarrow$ salt + water

$H^+ + OH^- \rightarrow H_2O$

Representing the Hydrogen Ion in water

- Just as cations are surrounded and bound by water molecules, the proton is also solvated by water molecules.
- You will see this represented 2 ways:
  - H^+ (aq)
  - H_3O^+ (aq) called the hydronium ion
    - This is the correct way, but both are acceptable

Mono, Di, TriProtic Acids

- Molecules of different acids can ionize and form different numbers of H^+ ions in water.
- Both HCl and HNO_3 are monoprotic acids, which yield one H^+ per molecule of acid.
- Sulfuric acid, H_2SO_4, is a diprotic acid, one that yields two H^+ per molecule of acid.
- Phosphoric acid is a triprotic acid, H_3PO_4

Step-wise Ionization

- The ionization of sulfuric acid occurs in two steps:
  - $H_2SO_4\ _{(aq)} \rightarrow H^+\ _{(aq)} + HSO_4^-\ _{(aq)}$
    - 100% Ionization because sulfuric acid is a STRONG acid.
  - $HSO_4^-\ (aq) \leftrightarrow H^+\ _{(aq)} + SO_4^{-2}\ _{(aq)}$

Weak acid, so equilibrium is shown.

Bases

- Bases are substances that accept hydrogen ions.
- Bases produce hydroxide ions when they dissolve in water.
- Ionic hydroxide compounds such as NaOH, KOH, and $Ca(OH)_2$ are among the most common bases.

Bases

- Compounds that do not contain OH- can also be bases.
- For example, ammonia (NH_3) is a common base.
- $NH_{3(aq)} + H_2O_{(l)} \rightarrow$
  $\leftarrow NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$

  Because only a small fraction of the ammonia forms ammonium ion, ammonia is a weak electrolyte.

Strong and Weak Acids and Bases

- Acids and bases that are strong electrolytes, completely ionize in water, are called strong acids and strong bases.
- Those that are weak electrolytes, partly ionize in water, are called weak acids and weak bases.

Strong Acids and Strong Bases

- Strong acids are more reactive than weak acids when the reactivity depends only on the concentration of H+ ion.
- The reactivity of an acid, however, can depend on the anion as well as on the H+ ion.
  - HF is a weak acid, but it is very reactive and vigorously attacks many substances, including glass.

Common Strong Acids

- Strong Acids - MEMORIZE
  - HCl
  - HBr
  - HI
  - $HClO_3$
  - $HClO_4$
  - HNO_3
  - H_2SO_4

Common Strong Bases

- Strong Bases – MEMORIZE
  - Group 1A metal hydroxides
    - Lithium, sodium, potassium, rubidium, cesium hydroxides
  - Heavy Group 2A metal hydroxides,
    - Calcium, Strontium, and Barium hydroxides

Summary

	Strong Electrolyte	Weak Electrolyte	Non-electrolyte
Ionic	All soluble salts	None	None
Molecular	Strong Acids	Weak acids H… Weak Bases, NH_3	All other compounds

You Try It…

- Classify each of the following dissolved substances as a strong electrolyte, weak electrolyte or nonelectrolyte.
  - Calcium chloride
  - Nitric Acid
  - Ethanol (C_2H_5OH)
  - Formic Acid ($HCHO_2$)
  - Potassium Hydroxide

Answer

- Classify each of the following dissolved substances as a strong electrolyte, weak electrolyte or nonelectrolyte.
  - Calcium chloride - Strong
  - Nitric Acid - Strong
  - Ethanol (C_2H_5OH) - Non
  - Formic Acid ($HCHO_2$) - Weak
  - Potassium Hydroxide - Strong

Your Try It…

- Consider solutions in which 0.1 mole of each of the following compounds is dissolved in 1 L of water: Calcium nitrate, glucose, sodium acetate, and acetic acid. Rank the solutions in order of increasing electrical conductivity, based on the fact that the greater the number of ions in solution, the greater the conductivity.

Answer:

- Glucose < Acetic Acid < Sodium Acetate < Calcium Nitrate.
  - Glucose yields no ions in solution
  - Acetic acid is weak so it yields only a few ions in solution
  - Sodium Acetate is a strong electrolyte, but yields only 2 ions per formula unit.
  - Calcium Nitrate is a strong electrolyte, and yields 3 ions per formula unit.

Neutralization Reactions and Salts

- Acids and Bases have different properties.
  - Acids taste sour, bases taste bitter.
  - Acids change the colors of certain dyes in a specific way different from that of bases. (indicators)
  - More coming in later chapters!

Neutralization

- Acid + Base → Salt + Water
  - HCl(aq) + NaOH(aq) → NaCl (aq) + H_2O(l).
  - Water acts as the driving force.
- Water acts as the driving force:
  - H^+ (aq) + OH^- (aq) → H_2O (l)

Demonstration

- Write the molecular, complete ionic, and net ionic equation for the following demonstration:
  - Milk of Magnesia (Magnesium Hydroxide) reaction with Gastric Juice (Hydrochloric Acid)

Answer

- Molecular Equation:
  - $Mg(OH)_2\ (s) + 2HCl\ (aq) \rightarrow$
    $MgCl_2\ (aq) + 2\ H_2O(l)$
- Net Ionic Equation:
  - $Mg(OH)_2\ (s) + 2\ H^{+}(aq) \rightarrow$
    $Mg^{2+}(aq) + 2H_2O(l)$

You Try It…

- Write the Molecular Equation and Net Ionic Equation for the following neutralization reaction:
  - Acetic Acid + Barium Hydroxide

Answer

- Molecular Equation:
  - $2HC_2H_3O_2(aq) + Ba(OH)_2 \rightarrow$

    $H_2O(l) + Ba(C_2H_3O_2)_2\ (aq)$
- Net Ionic Equation:
  - $HC_2H_3O_2(aq) + OH^-(aq) \rightarrow$

    $H_2O(l) + C_2H_3O_2^-(aq)$

Acid-Base with Gas Formation

- There are many bases besides OH- (hydroxide) that react with acids to form molecular compounds.
- Two of these that you must know are the sulfide ion, S^{-2}, and the carbonate ion, CO_3^{-2}.
  - Hydrogen sulfide gas smells like rotten eggs
  - Carbonates and bicarbonates give off carbon dioxide gas.

You Try It…

- Write the molecular and net ionic equations for:
  - Hydrochloric acid + Sodium sulfide
  - Hydrochloric acid + Sodium Bicarbonate

Answers

- Molecular Equation:
  - $2HCl(aq) + Na_2S(aq) \rightarrow H_2S\ (g) + 2NaCl(aq)$
- Net Ionic Equation:
  - $2H^{+}(aq) + S^{-2}(aq) \rightarrow H_2S\ (g)$

Answers

- Molecular Equation:
  - $HCl(aq) + NaHCO_3(aq) \rightarrow$
    $NaCl(aq) + CO_2\ (g) + H_2O(l)$
- Net Ionic Equation:
  - $H^+(aq) + HCO^{3-}(aq) \rightarrow$
    $H_2O(l) + CO_2(g)$

One more try…

- By analogy to examples already given in the lecture, predict what gas forms when sodium sulfite is treated with hydrochloric acid.

Answer

- Molecular Equation:
  - $Na_2SO_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2SO_3(g)$
- Net Ionic Equation:
  - $SO_3^{-2}(aq) + 2H^{+} \rightarrow H_2SO_3(g)$ (hydrogen sulfite gas)
- Why aren't hydrogen sulfide and hydrogen sulfite named as acids in these examples?

Lesson 4: Section 4.4, 20.1 & 20.2 Oxidation and Reduction Reactions

Commonly called Redox

- Ionic compounds are formed through the transfer of electrons.
- An Oxidation-Reduction reaction involves the transfer of electrons.
- We need a way of keeping track.

Oxidation States

- A way of keeping track of the electrons.
- Not necessarily true of what is in nature, but it works.
- need the rules for assigning (memorize).

1. The oxidation state of elements in their elemental form (standard state) is zero.
2. Oxidation state for monoatomic ions are the same as their charge

Oxidation states

3 Oxygen is assigned an oxidation state of -2 in its covalent compounds except as a peroxide, then it is a -1. Na_2O_2, H_2O_2.

4 Hydrogen is +1 when bonded to nonmetals and -1 when bonded to metals.

5 In its compounds fluorine is always –1.

6 The sum of the oxidation numbers of all atoms in a neutral compound is zero. The sum of the oxidation numbers in a polyatomic ion equals the charge of the ion.

You Try It…

- Assign the oxidation states to each element in the following.
- CO_2
- NO_3^-
- H_2SO_4
- Fe_2O_3
- Fe_3O_4

You Try It…

- What noble gas element has the same number of electrons as the fluoride ion?
- What is the oxidation number of that species?

You Try It…

- Determine the oxidation number of sulfur in each of the following:
  - Hydrogen sulfide
  - Elemental sulfur, S_8
  - Sulfur dichloride
  - Sodium sulfite
  - Sulfate ion

Oxidation-Reduction Reactions

- Transfer electrons, so the oxidation states change.
- $Na + 2Cl_2 \rightarrow 2NaCl$
- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
- Oxidation is the loss of electrons.
- Reduction is the gain of electrons.
- OIL RIG
- LEO GER

Oxidation-Reduction

- **<u>Oxidation</u>** means an increase in oxidation state - lose electrons.
- **<u>Reduction</u>** means a decrease in oxidation state - gain electrons.
- The substance that is oxidized is called the **<u>reducing agent</u>**.
- The substance that is reduced is called the **<u>oxidizing agent</u>**.

Agents

- **Oxidizing agent** gets reduced.
  - Gains electrons.
  - More negative oxidation state.
- **Reducing agent** gets oxidized.
  - Loses electrons.
  - More positive oxidation state.

Identify the

- Oxidizing agent
- Reducing agent
- Substance oxidized
- Substance reduced
- in the following reactions
- $Fe\,(s) + O_2(g) \rightarrow Fe_2O_3(s)$
- $Fe_2O_3(s) + 3\,CO(g) \rightarrow 2\,Fe(l) + 3\,CO_2(g)$
- $SO_3^- + H^+ + MnO_4^- \rightarrow SO_4^- + H_2O + Mn^{+2}$

Oxidation of Metals by Acids

- Metals undergo single-displacement reactions with acids.
  - Magnesium metal reaction with hydrochloric acid
    - Label the substances that were oxidized and reduced.
    - Label the substances that are the oxidizing and reducing agents.
    - Write the net ionic equation.

Oxidation of Metals by Salts

- Metals can also be oxidized by aqueous solutions of various salts.
  - Iron metal reacts with a solution of Nickel (II) nitrate.
    - Label the substances that were oxidized and reduced.
    - Label the substances that are the oxidizing and reducing agents.
    - Write the net ionic equation.

The Activity Series

- A list of metals arranged in order of decreasing ease of oxidation.
- Any metal on the list can be oxidized by the ions of elements below it.
- You try it…
  - Will an aqueous solution of iron (II) chloride oxidize magnesium metal? If so, write the balanced molecular and net ionic equations for this reaction.

Answer

- Because Mg is above Fe in the table, the reaction will occur.
  - Molecular Equation:
    - $Mg(s) + FeCl_2(aq) \rightarrow MgCl_2(aq) + Fe\ (s)$
  - Net Ionic Equation
    - $Mg(s) + Fe^{+2}(aq) \rightarrow Fe(s) + Mg^{+2}(aq)$

You Try It…

- Which of the following metals will be oxidized by $Pb(NO_3)_2$?
  - Zn, Cu, Fe
- Answer:
  - Zn and Fe

Half-Reactions

- All redox reactions can be thought of as happening in two halves.
- One produces electrons - Oxidation half.
- The other requires electrons - Reduction half.
- Write the half reactions for the following.

- $Na + Cl_2 \rightarrow Na^+ + Cl^-$
- $SO_3^{-} + H^+ + MnO_4^- \rightarrow SO_4^- + H_2O + Mn^{+2}$

Balancing Redox Equations

- In aqueous solutions the key is the number of electrons produced must be the same as those required.
- For reactions in acidic solution an 8 step procedure.

1. Write separate half reactions
2. For each half reaction balance all reactants except H and O
3. Balance O using H_2O

Acidic Solution

4 Balance H using H^+

5 Balance charge using e^-

6 Multiply equations to make electrons equal

7 Add equations and cancel identical species

8 Check that charges and elements are balanced.

Practice

- The following reactions occur in aqueous solution. Balance them
- $Cr(OH)_3 + OCl^- + OH^- \rightarrow CrO_4^{-2} + Cl^- + H_2O$
- $MnO_4^- + Fe^{+2} \rightarrow Mn^{+2} + Fe^{+3}$
- $Cu + NO_3^- \rightarrow Cu^{+2} + NO(g)$
- $Pb + PbO_2 + SO_4^{-2} \rightarrow PbSO_4$
- $Mn^{+2} + NaBiO_3 \rightarrow Bi^{+3} + MnO_4^-$

Basic Solution

- Do everything you would with acid, but add one more step.
- Add enough OH^- to both sides to neutralize the H^+
- $CrI_3 + Cl_2 \rightarrow CrO_4^- + IO_4^- + Cl^-$
- $Fe(OH)_2 + H_2O_2 \rightarrow Fe(OH)^-$

Lesson 5: Section 4.5
Concentrations of Solutions

- **Concentration**- how much is dissolved.
- Review: Concentrated vs Dilute
- Review: Strong vs Weak
- Molarity = $\frac{\text{Moles of solute}}{\text{Liters of solution}}$
- abbreviated M
- 1 M = 1 mol solute / 1 liter solution
- Calculate the molarity of a solution with 34.6 g of NaCl dissolved in 125 mL of solution.

Molarity

- How many grams of HCl would be required to make 50.0 mL of a 2.7 M solution?
- What would the concentration be if you used 27g of $CaCl_2$ to make 500. mL of solution?
- What is the concentration of each ion?

Molarity

- Calculate the concentration of a solution made by dissolving 45.6 g of $Fe_2(SO_4)_3$ to 475 mL.
- What is the concentration of each ion?

Making solutions

- Describe how to make 100.0 mL of a 1.0 M $K_2Cr_2O_4$ solution.
- Describe how to make 250. mL of an 2.0 M copper (II) sulfate dihydrate solution.

Dilution

- Adding more solvent to a known solution.
- The moles of solute stay the same.
- moles = M x L
- $M_1 V_1 = M_2 V_2$
- moles = moles
- Stock solution is a solution of known concentration used to make more dilute solutions

Dilution

- What volume of a 1.7 M solutions is needed to make 250 mL of a 0.50 M solution?
- 18.5 mL of 2.3 M HCl is added to 250 mL of water. What is the concentration of the solution?
- 18.5 mL of 2.3 M HCl is diluted to 250 mL with water. What is the concentration of the solution?

Dilution

- You have a 4.0 M stock solution. Describe how to make 1.0L of a .75 M solution.

Lesson 6: Section 4.6
Solution Stoichiometry

- When we are working with solutions of known molarity, we use molarity and volume to determine the number of moles.
- Example: How many grams of calcium hydroxide are needed to neutralize 25 mL of 0.1000 M nitric acid?
  - Answer: 0.0926 g Calcium Hydroxide

Solution Stoichiometry

- How many grams of sodium hydroxide are needed to neutralize 20 mL of 0.150 M Sulfuric acid solution?

  Answer: 0.240 g
- How many liters of 0.500 M hydrochloric acid are needed to react completely with 0.100 mole of lead(II) nitrate?
  - Answer 0.400 L

Titrations

- Used to determine the concentration of a particular solute in a solution.
- It involves combining a sample of the solution with a reagent solution of known concentration – called a <u>STANDARD</u> solution.
- Titrations can be conducted using acid-base, precipitation, or redox reactions.

Equivalence Point

- The point at which stoichiometrically equivalent quantities are brought together is known as the equivalence point of the titration.
- In acid-base reactions, dyes known as indicators are used to show the end point, they will change colors indicating that the equivalence point is near.
- End points are not always at the equivalence point, so care must be taken when selecting the indicator.

Practice Ppt. Titrations:

- The quantity of chloride ions in a municipal water supply is determined by titrating the sample with silver ion. The end point in this type of titration is marked by a change in color of a special type of indicator.
  - Write the net ionic equation.
  - How many grams of Cl^- are in a sample of water if 20.2 mL of 0.1 M Ag^+ is needed to react with all the chloride in the sample?
  - If the sample has a mass of 10.0 g, what percent Cl^- does it contain?

Practice Redox Titrations

- A sample of an iron ore is dissolved in acid, and the iron is converted from Fe^{+3} to Fe^{2+}. The sample is then titrated with 47.20 mL of 0.02240 M MnO_4^- solution.
  - Write the balanced redox reaction
  - How many moles of MnO_4- are added to the solution?
  - How many moles of Fe2+ were in the sample?
  - How many grams of iron were in the sample?
  - If the sample had a mass of 0.8890 g, what is the percentage of iron in the sample?

Practice Acid-Base Titrations

- One commercial method used to peel potatoes is to soak them in a solution of NaOH for a short time, remove them from the NaOH, and spray off the peel. The concentration of NaOH is normally in the range of 3 to 6 M. The NaOH is analyzed periodically In one such analysis, 45.7 mL of 0.500 M H_2SO_4 is required to neutralize a 20 mL sample of NaOH solution. What is the concentration of the NaOH solution?

Distributed Practice Problem

- A sample of 70.5 mg of potassium phosphate is added to 15.0 mL of 0.050 M silver nitrate, resulting in the formation of a precipitate.
  - Write the molecular equation for the reaction.
  - What is the limiting reactant in the reaction?
  - Calculate the theoretical yield, in grams, of the precipitate that forms.