Lab 3: Stoichiometry I

Stoichiometry of Chemical Reactions

Introduction

Part I. Reaction of Hydrogen Peroxide and Bleach

When hydrogen peroxide (H_2O_2, sold to the public as a 3% (w/w) solution in water as a disinfectant for cuts) is mixed with bleach (active ingredient is sodium hypochlorite, NaOCl, sold to the public as a 6.0% (w/w) solution in water), oxygen gas (O_2) is formed. In this experiment, you will measure the volume of oxygen gas produced when known amounts (moles) of hydrogen peroxide solution are mixed with known amounts (moles) of bleach. Based on the moles of **reactants** used (bleach and hydrogen peroxide) and the volume of oxygen gas (**product**) you will determine the **stoichiometry** (mole ratio of the reactants) of the chemical reaction.

If you mix 4 mL of bleach with varying amounts of hydrogen peroxide, a point is reached when an increase in the volume of the hydrogen peroxide does not increase the amount of gas produced. (Note: the volume of O_2 gas produced is **directly proportional** to the moles of O_2 gas produced.) Before this point, hydrogen peroxide is the limiting reagent and beyond this point, bleach is the limiting reagent. The point at which the reactants completely react with each other is the equivalence point. When the volume of the oxygen gas is plotted against the mass of hydrogen peroxide, two linear regions can be identified as indicated in Figure 1.

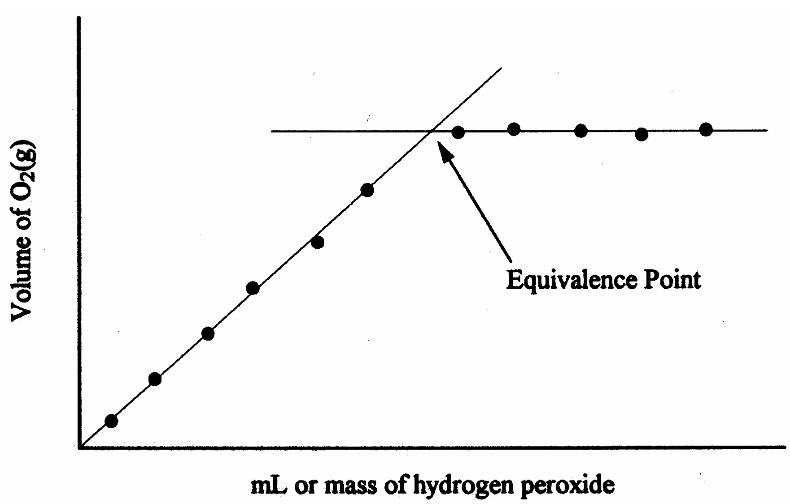


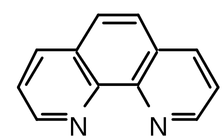
Figure 1. Volume of O_2 (g) produced when a fixed mass (or volume) of bleach is mixed with varying masses (or volumes) of hydrogen peroxide.

The **equivalence point** is the intersection of the two straight lines. It is not necessary to convert the volume of O_2 produced into moles of O_2 produced in order to determine the equivalence point. The moles of bleach and the moles of hydrogen peroxide corresponding to the equivalence point can be calculated, and from these the reaction ratio (stoichiometry) can be calculated.

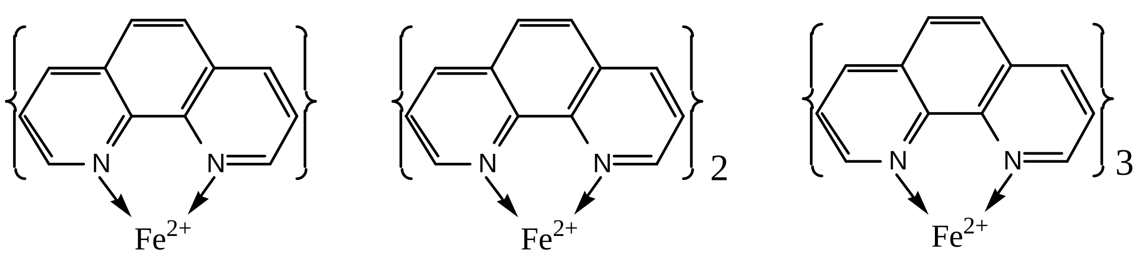
Part II. Reaction Between Iron (II) and 1,10-Phenanthroline

From everyday observation we know that the more food coloring we add to a glass of water, the darker the color of the solution becomes. This suggests that there is a relationship between the color intensity and concentration of the food coloring in solution. We will use this relationship between color intensity and concentration to determine the stoichiometry of the reaction between Fe^{2+} and 1,10-phenanthroline, $C_{12}H_8N_2$, (abbreviated phen):

This is 1,10-phenanthroline (also called 4,5-diazaphenanthrene)



In this reaction the two nitrogen atoms use their lone pairs of electrons to form bonds with the Fe^{2+} ion to form a substance called a **complex ion**. Because many different complex ions can be formed from the same reactants, the question ***"What is the value of n in the formula*** $Fe(phen)_n^{2+}$ ***?"*** is a true experimental question. The three possible complex $Fe(phen)_n^{2+}$ ions are shown below:



Arrows indicate lone pair electron donation (chemical bond) from nitrogen to iron (II). (Note: the structures above are not meant to display the 3-dimensional structure of these ions.) In abbreviated forms, these can be written as $Fe(phen)_1^{2+}$, $Fe(phen)_2^{2+}$, and $Fe(phen)_3^{2+}$, respectively. $Fe(phen)_n^{2+}$ is red, so we can measure the intensity of this red color. The unit for measuring color intensity is absorbance, abbreviated (A), and is reported as a numerical value with no units listed. An instrument called a spectrophotometer will be used to measure the absorbance (intensity) of the red color.

You will monitor the absorbance of a phen solution with a colorimeter while slowly adding the Fe^{2+} solution. Since **absorbance is proportional to concentration** (moles of Fe^{2+} per liter of

solution), you will get some change in absorbance due to dilution as you add the Fe^{2+} solution. However, this problem can be avoided by using a large volume of the phen solution (~50 ml) and adding a small volume of concentrated Fe^{2+} solution (1 mL total volume, in 100 µL increments, of a Fe^{2+}solution that is more than 100 times more concentrated than the phen soluiton). Thus the error due to dilution is less than 1% and will not affect your ability to determine n.

In Figure 2 a hypothetical plot is presented. Note the similarity between Fig. 1 and Fig. 2. Again, the point at which you have added enough Fe^{2+}solution to react with all of the phenanthroline, without either reagent being limiting or in excess, is the equivalence point.

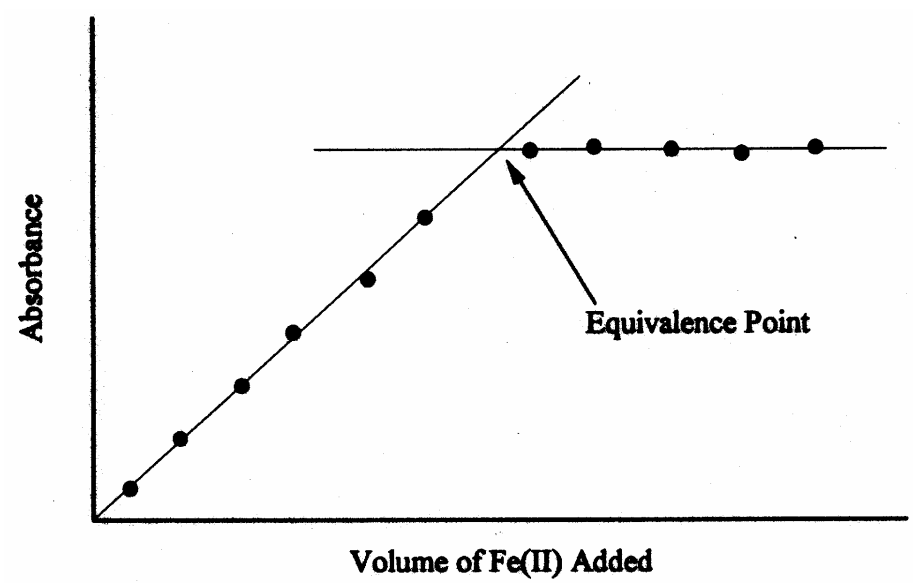


Figure 2. Spectrophotometric Measurement of phen with Fe (II).

Once the equivalence point is identified by the intersection of the two straight lines, the moles of each reagent can be calculated by M x L (where M is the molarity (moles/L) and L is the volume in liters). The ratio n is calculated from the formula:

$$\frac{\text{moles (phen)}}{\text{moles (Fe(II))}} = n,$$

fitting the general equation:

$$Fe^{2+}(aq) + n\,(phen) \longrightarrow Fe(phen)_n^{2+}.$$

The prelab assignment on WebAssign addresses the following, using the example of hydrochloric acid reacting with solid magnesium:

- Plotting data in Excel and using the plot to determine the equivalence point of the reaction.
- Calculating moles of HCl from the volume of HCl at the equivalence point (given the %mass/volume and density of HCl).
- Calculating moles of Mg from the mass of Mg used in each trial.
- Calculating the mole ratio of HCl/Mg for the reaction.
- Based on the mole ratio, determining the coefficients of the reaction.

Helpful information

- Consult the Excel tutorial (Part II) on the front page of the Chem 142 labs website if you need help plotting the data. You will either need to use the “drawing tool” to draw two lines on your plot or print out the plot and use a ruler to draw the lines. You will not be able to use the “Trendline” in Excel to draw two separate lines on the same plot.
- Using the plot of the volume of O_2 versus the mass of H_2O_2 added, you will find the lowest mass of H_2O_2 that gives a limiting volume of O_2. After this point, even if you add larger and larger amounts of H_2O_2 to a 4 mL volume of bleach, you will not be able to produce a larger volume of O_2. This equivalence point is the one where the two lines drawn on the data intersect. Using a ruler, draw a vertical line from the intersection down to the x-axis. The mass at which the line crosses the x-axis will determine the mass of H_2O_2 at the equivalence point.
- Use dimensional analysis (discussed in Zumdahl Appendix Two) to calculate the moles of the reactants from the volume or mass of each. For example, to calculate the moles of hydrogen peroxide, you need the mass of solution at the equivalence point, the %mass/mass (grams of H_2O_2 molecules per grams of H_2O_2 solution), and the molecular mass for H_2O_2. For calculating the moles of bleach, there is an additional step because you are starting with volume and have to convert to mass of solution (through the density) before calculating the mass of NaOCl molecules and then the moles of NaOCl molecules.

- % mass/mass and % mass/volume are calculated according to the following equations:

$$\%\ Mass/mass = \frac{mass\ of\ solute}{mass\ of\ solution}\ X\ 100\%$$

$$\%\ Mass/volume = \frac{mass\ of\ solute}{volume\ of\ solution}\ X\ 100\%$$

  where “solute” is the molecule of interest dissolved in a solvent and the “solution” is the solute plus the solvent.

- In part II, you will be dealing with concentration units called molarity (M), which is moles of solute per liter of solution (M = mol/L). See Zumdahl Chapter 4, section 3 for more help with molarity and calculating concentrations when dilutions are involved.

Safety Considerations

The products of the reaction in part I need to be placed in the waste container in the hood and the products of the reaction in part II are non-toxic and can be disposed of down the drain.

Be careful when swirling the Erlenmeyer flask in part I to prevent breaking the vial.