Experiment 13
Mol-to-Mol Ratio

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Name:

Date:

Key Objectives

1. Understand importance and use of mol-to-mol ratio.
2. Making good graphs.

Discussion

A balanced chemical equation gives the ratio of the reactants and products for a chemical reaction. If the formula for all of the reactants and products are known, it is easy to balance the reaction based on conservation of mass. However, when the formula of the products is unknown, and/or there are multiple products that could potentially form, one must experimentally determine the mol-to-mol ratio.

This experiment uses the method of **continuous variations** to determine the mol-to-mol ratio of the reactants in a chemical equation. In this method, equal molar solutions of each reactant are mixed in varying ratios, and a property that is dependent on the amount of product formed is measured. Let us examine each of the three requirements individually.

Equal molar solutions are required because one must know the number of moles or molarity of each reactant so that the ratio of the volumes (or mass) reacted are in the same ratio as the coefficients in the balanced chemical equation.

The property measured in the experiment will vary depending on the reaction studied. The property may be the color intensity due to a product (similar to the Beer's Law Lab), the mass of a precipitate formed (similar to the Gravimetric Analysis Lab), the volume of gas evolved (Similar to the Determination of Gas Constant R Lab), or the temperature change in a reaction (similar to the Heat of Neutralization Lab). The property must depend on the amount of product formed so that it is maximized when the ratio of the reactants is the same as the stoichiometric ratio in the balanced chemical equation.

The volume (or mass) of the reactants is varied while keeping the total amount of the reactants the same. The property measured is maximized at the proper stoichiometric ratio because the reaction should consume the greatest amount of reactants, form the greatest amount of products, or generate the most heat. Any other ratio should not create the maximum change because one of the reactants will be the limiting reactant, and thus there will remain unreacted or excess reactant left over.

Example 1

Relating chemistry to baking, you maximize the number of cookies you bake when you have the exact right ratio of sugar and flour (we will ignore the other yummy ingredients like chocolate chips and nuts and peanut butter, dang now I am hungry).

Expt. #	Flour	Sugar	Cookies!
1	0	5	0
2	1	4	12
3	2	3	24
4	3	2	16
5	4	1	8
6	5	0	0

(a)

(b)

Figure 13.1: (a) Data obtained in lab (kitchen) baking cookies. (b) Picture of cookies!. credit: (a) author (b) `https://www.flickr.com/photos/kimberlykv/4643536339`

$$\underline{\text{ X }}\,\text{cups flour} + \underline{\text{ Y }}\,\text{cups sugar} \longrightarrow \underline{\text{ Z }}\,\text{cookies(yum)} \tag{21}$$

If we perform a series of reactions (err, baking experiments) where we vary the ratio of flour and sugar we can determine the correct ratio. The exact ratio of flour to sugar will yield the largest number of cookies.

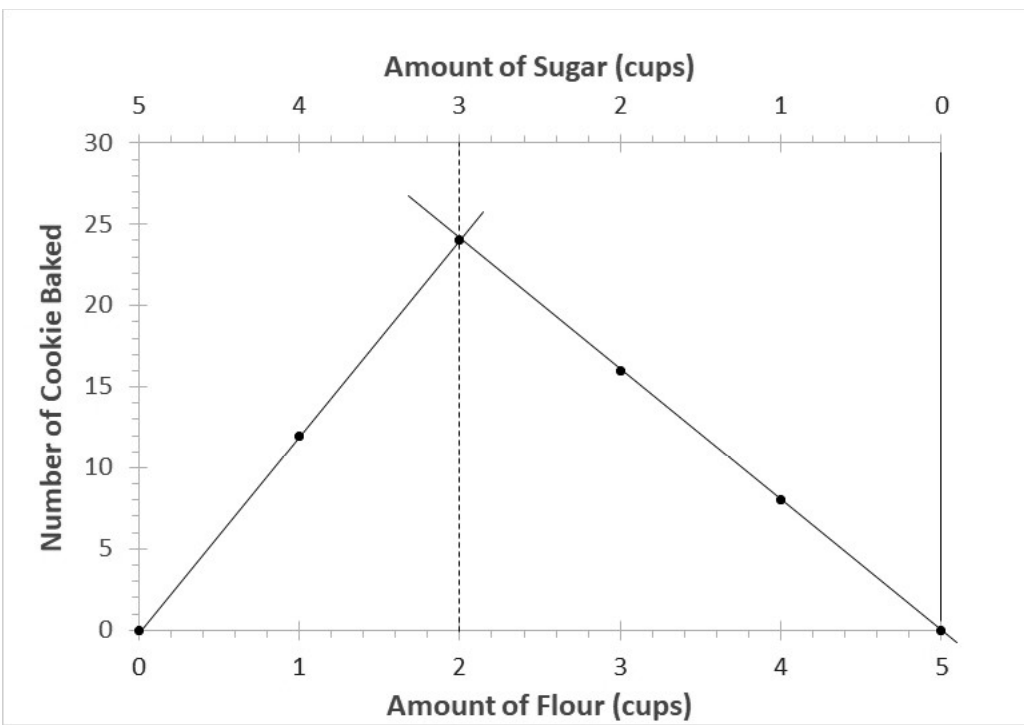


Figure 13.2: A graph of data obtained in lab (kitchen). Note the axis labels. The maximum number of cookies made is the correct mol to mol ratio for the reaction (recipe). credit: author

We can see from our data and the graph that the maximum number of are made when we have 2 cups of flour and 3 cups of sugar producing 24 cookies. We can thus write:

2 cups flour + 3 cups sugar $\longrightarrow$ 3 cookies (yum!) (22)

Example 2

A second example using a known chemical reaction will hopefully illuminate the process. Let us examine the following reaction:

$$\mathrm{PbCO_3(aq) + 2HCl(aq) \longrightarrow PbCl_2(s) + H_2O(l) + CO_2(g) + heat} \tag{23}$$

We can measure the mass of precipitate formed (Hein Ch. 9 or OER Ch. 7), the volume of CO_2 gas produced, using $PV = nRT$ (Hein Ch. 12 or OER Ch. 8), or the heat produced (OER Ch. 9) and thus the temperature change assuming a constant volume of reactants using $q = ms\Delta t$ (Hein Ch. 4 or OER Ch. 9). All three properties will depend on the number of moles of product formed. For simplicity we will only calculate the mass of $PbCl_2$ produced. We will assume that we are using 1.5 M solutions of both $PbCO_3$ and HCl and using the proper mol-to-mol ratio calculate the amount of $PbCl_2$ produced. Table **??** contains the data for many ratios of the reactants. A graph of the data is shown in Figure 13.4.

Exp. #	**mL of** $PbCO_3$	**mL of** HCl	**grams of** $PbCl_2$ produced
1	0	50	0.00
2	5	45	2.09
3	10	40	4.17
4	15	35	6.26
5	16.6	33.4	6.92
6	20	30	6.26
7	25	25	5.21
8	30	20	4.17
9	35	15	3.13
10	40	10	2.09
11	45	5	1.04
12	50	0	0.00

(a)

(b)

Figure 13.3: (a) Data collected for the reaction between $Pb(CO_3)_2$ and HCl to produce a precipitate of $PbCl_2$. (b) Picture of the precipitate formed. credit: (a) author (b) Recognizing Chemical Reactions. (2021, March 11). Retrieved June 22, 2021, from `https://chem.libretexts.org/@go/page/52547` CC BY-NC.

Note that while the graph has two x-axis labeled, one for each reactant, the top axis is reversed. This is possible because the total volume of the combined reactant solutions is a constant (50.0 mL in this example). Thus, only one set of the data needs to be graphed (the second set would simply overlap the first.

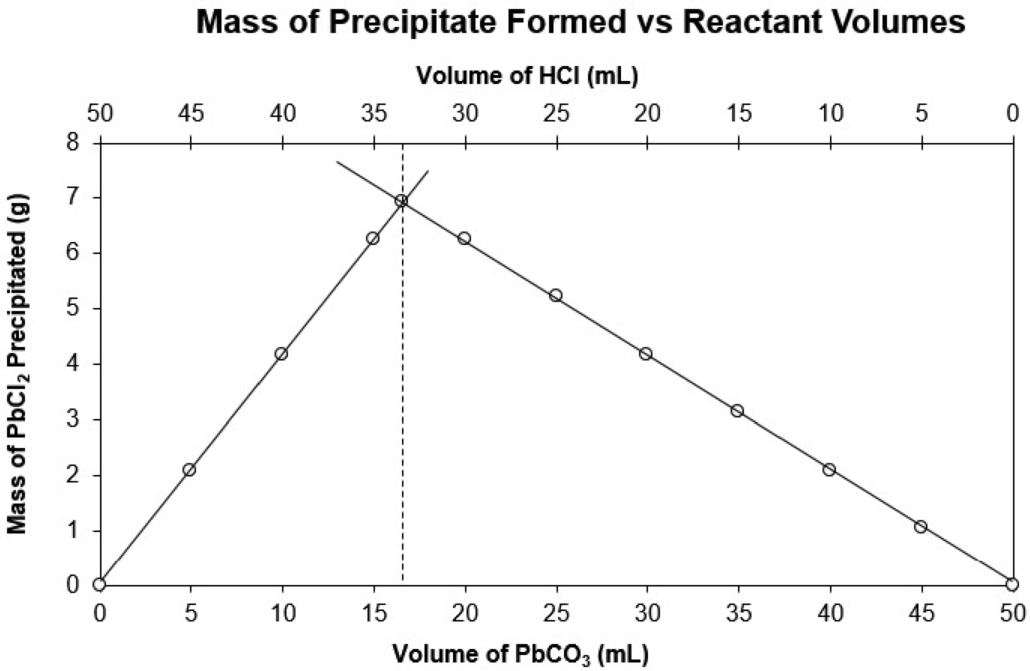


Figure 13.4: Data for example reaction showing the correct ratio of reactants to maximize the mass of product formed. credit: author.

Once the data is plotted two straight lines are drawn through the data to extrapolate the peak value. We can then extrapolate the volume of each reactant that represents the correct mol-to-mol ratio. From the data we see that the maximum amount of product is formed when the ratio of $PbCO_3$ to HCl is 16.6:33.4 (dotted line) which simplifies to a 1:2 ratio as expected from the balanced equation.

In this experiment we will use the method of continuous variations to determine the mol-to-mol ratio of two reactants. The reactions are exothermic, and the change in temperature will be measured and used to determine the ration of reactants that gives the largest change in temperature. The total volume of the solutions is kept constant so that the change in temperature is directly proportional to the amount of products made, thus the maximum change in temperature corresponds to the maximum amount of product formed, and the correct mol-to-mol ratio. Note, generally the maximum is not a data point, but the intersection of the two lines. The data shown in the table includes the maximum to show that there is indeed a single ratio of reactants that produces the maximum amount of product. Experimental data will rarely contain the maximum as a data point and instead it must be extrapolated.

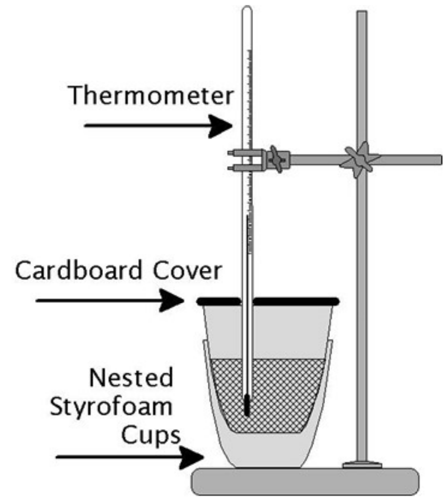
The reactions considered will be that of an unknown compound A or B, and a variety of unknown compounds (C, D, and E).

Procedure

1. Obtain approximately 175 mL of the each reactant solution in a clean 250 mL Erlenmeyer flask. Record the identity of your unknown(s).

Group	Reaction
1	___A(aq) + ___C(aq) ⟶ AC(aq) + heat
2	___A(aq) + ___D(aq) ⟶ AD(aq) + heat
3	___A(aq) + ___E(aq) ⟶ AE(aq) + heat
4	___B(aq) + ___C(aq) ⟶ BC(aq) + heat
5	___B(aq) + ___D(aq) ⟶ BD(aq) + heat
6	___B(aq) + ___E(aq) ⟶ BE(aq) + heat

(a)



(b)

Figure 13.5: (a) Groups and reactions to be studied. (b) Example setup for a calorimeter. credit: (b) https://chemdemos.uoregon.edu/demos/Comparing-Specific-Heats-of-Metals

2. Measure the temperature of each solution, and record it in the data table.

3. Using clean pipits, carefully measure out the appropriate values of each reactant into two separate beakers.

4. Mix the reactants together in the calorimeter and record the maximum temperature reached.

5. Dispose of the solution in the sink. Rinse the calorimeter and dry it.

6. Repeat steps 3-5 for each of the different ratio's of the reactants, always keeping the total volume at 50.0 mL.

7. Once your measurements are complete, immediately plot your data, to determine if additional measurements are required.

8. Plot your data as shown in Figure 13.2. Be sure to include the points for the 0 mL, 50 mL and 50 ml, 0 mL ratios. Draw two straight lines through your data and determine where they intersect. If any of your points do not fall close to the lines drawn, repeat those measurements. The point of intersection is the ratio of reactants that produced the maximum amount of products and thus heat in the reaction. Find the stoichiometric mol-to-mol ratio of the reactants from the point of intersection.

9. Take any additional measurements required, and place them at the end of the data table.

10. Bonus points for making a nice Excel Version of the graph!

Making a Pretty Graph

Making the graphs shown in lab requires a few more steps than the graphs we have made in class before. Consult Lab 2 for a thorough review of making a good graph. Below is a short check-list (in no particular order) to use when making a graph.

1. Use the x-axis for the independent variable (that which is experimentally varied; also known as the manipulated variable) and the y-axis for the dependent variable (that which is a function of the independent variable; also known as the responding variable).
2. Label both the x and y-axis. Be sure to include units.
3. Include major and minor ticks on each axis, chose reasonable spaced units for them.
4. Show the proper number of Significant Figures for the data on each axis.
5. Include a title.
6. Symbols should be properly sized.
7. Make sure the graph is black and white.
8. If more than one set of data is plotted include a Legend.
9. Do not put grid lines on your graph.
10. For the greatest accuracy, select scales so that the graph fills the page.
11. The data points should fill up the entire graph; they are not all bunched together in one corner.
12. Some examples of good graphs can be found in Lab 2, Lab 10, and this lab.

To add a second line and a second axis on a graph in Excel requires the following steps:

1. Make a data table with your data as shown in Figure 13.6
   (a) Column A - x-axis data for variable one.
   (b) Column B - y-axis data for variable one (what was measured in lab).
   (c) Column C - leave blank
   (d) Column D - x-axis data for variable two.
   (e) Column E - y-axis data for variable two (should be the same as the data for variable one in this lab).
2. Highlight the first two columns and make a graph like normal.

3. On the graph right click on the data points and choose "Select Data", then "Add". For the Series name select the name of the y-axis data, then for x-values and y-values highlight the selected data, then select "Ok" and "Ok". The resulting graph should show two sets of data offset (because excel is not very bright and doesn't scale the two x-axis correctly).

4. Under the Design Tab choose Change Chart Type and select Combo graph, and the 4th option over (Custom). Make both chart types "Scatter", then check the box for the second set of data for the secondary axis. This should create a graph with a second y-axis on the right hand side.

5. Under Add Chart Element add a secondary horizontal axis and secondary axis label.

6. To reverse the numbering on the second (top) axis select the axis, and under axis options, put a check in the "Values in Reverse Order" box. Also change the axis maximum to 50. Choose the bottom axis and also adjust its axis maximum to 50. Your data should now overlap (its the same data in reverse).

7. Delete the second y-axis as it is redundant.

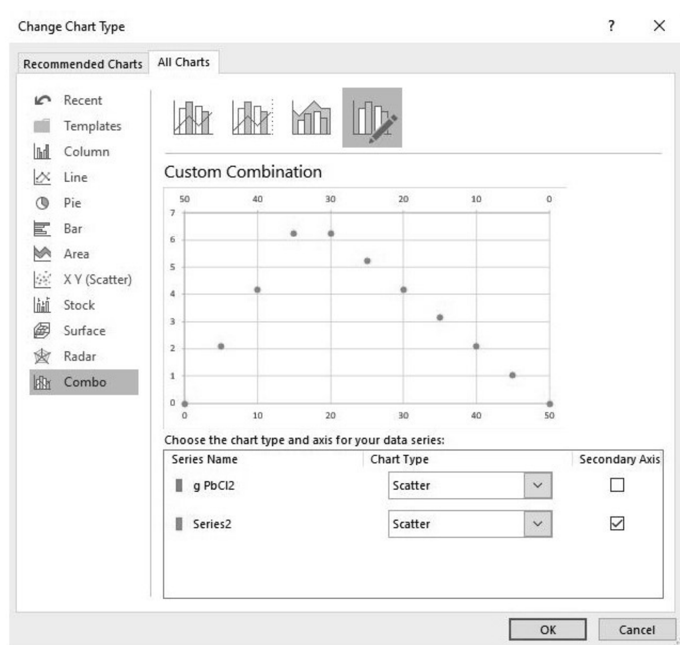
8. Add a legend and delete the second data set symbol.

9. If you want to add the lines on the graph choose Insert, Shapes, and add a line.

10. Proceed to make a good looking graph. It doesn't have to look identical to the graph in Figure 13.4 but it should look similar.

	A	B	C	D	E
1	mL PbCO3	g PbCl2		mL HCl	g PbCl2
2	0	0		50	0
3	5	2.085825		45	2.085825
4	10	4.17165		40	4.17165
5	15	6.257475		35	6.257475
6	20	6.257475		30	6.257475
7	25	5.214563		25	5.214563
8	30	4.17165		20	4.17165
9	35	3.128738		15	3.128738
10	40	2.085825		10	2.085825
11	45	1.042913		5	1.042913
12	50	0		0	0

(a)



(b)

Figure 13.6: (a) Data used to make graph. (b) Custom Combination Chart menu. credit: author

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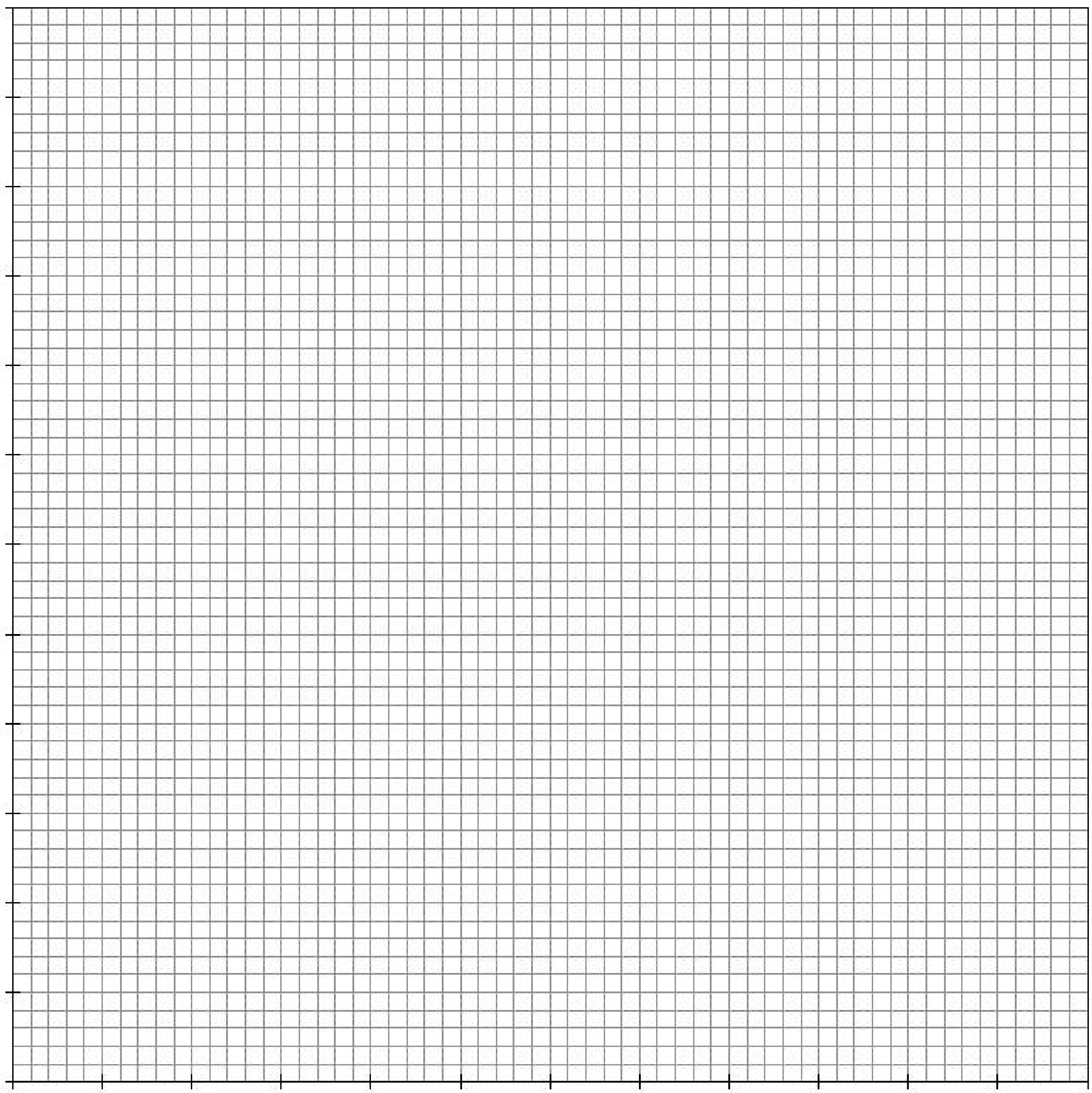
Results

Group Number: ______________

mL Unknown___	**mL Unknown___**	**Initial Temp. (℃)**	**Final Temp. (℃)**	**△ T (℃)**
5	45			
10	40			
20	30			
30	20			
40	10			
45	5			

Additional Data If Required

Table 13.1: Results



From the graph complete the reaction below (Explain):

___Unknown___(aq) + ___Unknown___(aq) $\longrightarrow$

Post Lab Questions

1. Write the reaction studied below with the correct mol-mol ratio for each reactant.

2. Explain (in your own words) how the method of continuous variations is used to determine the mole ratio of reactants in a chemical reaction.

3. What are 2 possible sources of error in the lab? Explain.

4. Which measurement, temperature or volume, limits the precision of the data obtained in the experiment. Explain.

5. Why was the total volume of the solutions kept constant in all trials?

6. Why when graphing the data can we always include the points 0 mL A, 0℃ and 50 ml A, 0℃ on our graphs, even though we don't measure those points?

7. Why is it good practice to have three data points on each side of the maximum value, in order to determine the most precise mol-to-mol ratio?

8. Which reactant is the limiting reagent along the upward slope of the graph? Explain.

9. Why is it more accurate to use the point of intersection of the two lines to find the mol-to-mol ratio rather than the ratio of reactants associated with the greatest temperature change?

10. What other physical properties than temperature change could have been used in the method of continuous variations for the two reactants tested in this experiment. Explain.

Name: ____________________________ Class: ______________ Date: ______________

Prelab Questions

1. The following values were obtained in a continuous variations experiment designed to find the mol-to-mol ratio for the reaction between 0.5 M $AgNO_3$ and 0.5 M K_2CrO_4. The mass of the resulting precipitate was measured.

Expt #	**mL $AgNO_3$**	**mL K_2CrO_4**	Grams Precipitate
1	5.0	45.0	1.8
2	15.0	35.0	5.0
3	25.0	25.0	8.3
4	30.0	20.0	10.0
5	35.0	15.0	9.9
6	40.0	10.0	6.6
7	45	5.0	3.3

Plot the data on graph paper (ok) or Excel (better) as shown in the example given in the discussion section and as outlined in the procedure portion of the lab. Use a ruler (or the line function in Excel) to draw the best-fitting straight lines though the data points and determine the coefficients for the reactants in the balanced chemical equation. Do not complete the reaction.

___$AgNO_3$(aq) + ___K_2CrO_4(aq) $\longrightarrow$ Products

Be sure to attach your graph to the pre-lab when you turn it in.