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AP/IB Chemistry SL

16 December 2012

Through most chemical experiments, the variable that is most associated with being controlled is temperature. This makes sense in many ways, as we assume that an increase or a decrease in temperature is able to severely skew the results, whether it be in the amount of reaction actually reacted or the physical properties of the substance after the experiment. However, what kind of correlation actually exists between the temperature of a solution and the amount of reaction that occurs?

Prior to this experiment, the experimenters had some general knowledge about heat or temperature. It is actually the measure for how quickly the particles within the substance were moving. If those particles were moving exceptionally quickly, the energy of that substance would be high, the temperature of that substance would be high, and the substance itself would likely to be a gas or liquid. On the other hand, if the particles were moving slowly, it is likely that the energy is low and the temperature is low, and if the particles were barely moving at all, and just vibrating, it is a possibility that the substance is a solid.

Given this prior knowledge, the experimenters formulated the idea that as temperature increases, the amount of substance produced in a reaction should directly increase, due to how increased temperature would correspond to the molecules of the reactants able to hit and react with each other more easily.

In order to carry out this experiment, the reaction between $CaCl_2$ and $NaOH$ was studied. This reaction provided a good base for studying the correlation, as the temperature of $CaCl_2$ could be raised and lowered without a serious adverse effect. Also, one of the products of this reaction, $Ca(OH)_2$ could be found through filtration, and then can be processed in order to evaluate the amount of reaction that occurred. Therefore, the temperature of $CaCl_2$ prior to the reaction was the independent variable, while the grams of $Ca(OH)_2$ was the dependent variable. All other variables, such as the temperature of the $NaOH$, the molarity of the solution, and the amount of solution was kept constant. The temperature of $NaOH$ was kept constant mostly for the reason that a heated solution of $NaOH$ was extremely dangerous, but also because if the temperature of one substance was controlled, the temperature of the reaction should be controlled in a similar fashion.

Other variable that were controlled included the molarity and volumes of the solutions. As both the molarity of the solution as well as the volume of the solution had a direct influence on the theoretical yield of the product, attempts were made to keep these constant throughout all trials and all different conditions. Also, the effect of a differing volume or a differing molarity, while assumed to be negligent, was unknown to the experimenters at the time of the experiment, so if there were changes to these values, there was the possibility of having more than one independent variable, which would make it extremely difficult in isolating the correlation between temperature and yield.

In order to test the hypothesis, trials of $CaCl_2$ and $NaOH$ were set up to react, and the amount of product produced was studied. Although the experiment had access to a variety of standard laboratory equipment, a limitation was the amount of chemicals the experiment had access to. Instead of having unlimited chemicals, 25 trials of data needed to be produced from a

mere 250 mL of $NaOH$ and 125 mL of $CaCl_2$. However, everything else was very much prepared, and the excellent laboratory was able to cater to all of the needs of the experiment.

In order to circumnavigate the problem of too little solution, the original chemicals of $CaCl_2$ and NaOH were diluted to 0.250 M, so that there would be more solution to work with every trial. Even though the mass of the $Ca(OH)_2$ should be about the same, the larger volumes would allow for more accurate monitoring of the temperature, perhaps revealing more clearly the effect of the temperature as well.

If all went according to plan, there should be a clear upwards linear trend in the data analysis of this lab. There would be a direct increase in the amount of $Ca(OH)_2$ produced, in grams, as the temperature of the $CaCl_2$ increased.

Materials:

The materials that we used included:

Chemicals

- 125 mL of $CaCl_2$of 0.500 M
- 250 mL of $NaOH$ of 0.500 M

Equipment

- 100 mL Erlenmeyer Flasks
- 100 mL Beaker (for reaction)
- Two 500 mL Beaker (for storing chemicals in bulk)
- Two more 500 mL Beakers (for dilution purposes)
- 100 mL Beaker (for heating $CaCl_2$)
- 50 mL Graduated Cylinders (for holding trials of chemicals)
- Pipet Bulb

- 10 mL Pipet
- 100 mL Volumetric Flasks (for dilution)
- Thermometer
- Heat Plate
- Heat Resistant Gloves
- Stir Rods
- Goggles
- 5 filter papers (small)
- 10 filter papers (large)
- Cone
- Labeling Tape
- Sharpie
- Storage Cabinet
- Scale (precision $\pm 0.0001g$)
- 100 mL Graduated Cylinders (for dilution)

Diagram

Data Tables:

Temperature of $CaCl_2$ (Degrees Celsius)	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
	Mass of Filter Paper	Mass of Filter Paper + Residual Substance	Same as previous	Same						
20										
40										
50										
60										
65										

Procedure:

Dilution:

1. Obtain 125 mL of $CaCl_2$ from teacher, and store in 500 mL beaker
2. Obtain 250 mL of NaOH from teacher, and store in 500 mL beaker
3. Fill up three 100 mL Volumetric Flasks with regular water
4. Fill one 100 mL Graduated Cylinder with 25 mL of water, and one 100 mL Graduated cylinder with 50 mL of water.
5. Pour 125 mL of $CaCl_2$ as well as 125 mL of water, using the measured water from the volumetric flasks and the graduated cylinders, into another 500 mL beaker. With tape and sharpie, label this beaker "250 mL $CaCl_2$, 0.250M"
6. Pour 250 mL of $CaCl_2$ as well as 250 mL of water, using the measured water from the volumetric flasks and the graduated cylinders, into another 500 mL beaker. With tape and sharpie, label this beaker "500 mL NaOH, 0.250M"
7. Wash and replace all other beakers, including all volumetric flasks, graduated cylinders, and used beakers.

Experiment:

8. Using scissors, cut the large filter papers in half.
9. Label a filter paper with the trial number and the experiment number. IE, if it is the 3^{rd} trial of the 4^{th} experimental condition, label as "3.4". [note 1]

10. Mass that filter paper, and record mass in data table under “Mass of Filter Paper”.
11. Place filter paper in cone, and place cone on a 100 mL Erlenmeyer flask.
12. Using a 15 mL pipet, draw out 20 mL of NaOH and transfer to a 50 mL graduated cylinder labeled “NaOH” by drawing out two 10 mL volumes of NaOH at a time.
13. Pour out about 30 mL of $CaCl_2$ into a 50 mL beaker, and heat to 20 degrees Celsius (if not already at that temperature)
14. Using a different 15 mL pipet, draw out 10 mL of $CaCl_2$ and place into a 50 mL graduated cylinder, labeled “$CaCl_2$”.
15. Confirm that the temperature of the $CaCl_2$ is currently at the desired temperature. If not, reheat or let cool until the desired temperature is reached.
16. After the $CaCl_2$ is at desired temperature, pour it into the 150 mL mixing beaker, followed by the 20mL of NaOH.
17. Using the stir rod, mix the solution for 15 seconds, and then pour the solution into the filter paper on top of Erlenmeyer flask that was previously set up.
18. Using a wash bottle, add a little bit of water (~2-3 squirts) into the mixing beaker to get all remaining solute, and pour that into the filter.
19. Using the wash bottle, squirt water onto the sides of the filter.
20. Wash out mixing beaker with water.
21. Allow the filtration set up to sit overnight in the storage cabinet. [note 2]
22. Mass the dried filter paper, and record new data in the data table, under “Mass of Filter Paper + Residual Substance”.
23. Repeat steps 9-21 four more times to get a total of 5 trials.
24. Repeat steps 9-22 four times with different temperatures, of 40, 50, 60, and 65 degrees Celsius.
25. If there are leftover materials in the large beakers of chemicals, use saranphil wrap to ensure minimal evaporation overnight.
26. If the lab goes for multiple days, store all materials in storage cabinet overnight, with clear labels for every piece of glassware.

Note 1: Through this experiment, we tended to use the small filter paper for trial 1 of each experimental condition, and the larger papers for the other trials. However, this should not have influenced our data in any which way.

Note 2: For time reasons, it is very much reasonable to allow for the mixture to sit and begin the next procedure while the previous solution is filtering.

For the most part, we divided up into two parts: One person focusing on performing the measurements and setting up the filter paper while the other heated the $CaCl_2$ and performed the mixing. This setup was able to save us the most time, enabling us to get done as quickly as possible. It also allowed for the constant of the same person doing the same tasks every single round, ensuring that any problems one person may have had were listed as a systematic error.

The ratio at which the two solutions was combined was 1 part $CaCl_2$ to 2 parts NaOH, because the chemical formula for their reaction is:

$$CaCl_{2\,(aq)} + 2\,NaOH_{aq} \rightarrow 2NaCl_{aq} + Ca(OH)_{2(s)}$$

This formula is subsequently used throughout this paper in order to evaluate yields.

Data Collection:

Raw Data:

Temperature in CaCl2	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
	Mass of filter paper (g)	Mass final (g)	Mass of filter paper (g)	Mass final (g)	Mass of filter paper (g)	Mass final (g)	Mass of filter paper(g)	Mass final (g)	Mass of filter paper(g)	Mass final (g)
20	0.9044	1.0486	1.15621	1.2495	1.15632	1.2307	1.1582	1.3006	1.1582	1.3001
40	0.9044	1.0269	1.0778	1.3335	1.1799	1.3297	1.2008	1.3675	1.0433	1.4369
50	0.9107	1.075	1.0697	1.3213	1.2473	1.279	1.3164	1.4494	1.172	1.2947
60	0.8957	1.0954	1.299	1.5572	1.2615	1.5151	1.2535	1.5087	1.2289	1.4439
65	0.8911	1.0545	1.2365	1.4174	1.2184	1.4242	1.3242	1.5301	1.309	1.5339

Tracking of uncertainty:

Dilutions

125 mL of .500 M $CaCl_2$ ($\pm$ 1 mL) + 125 mL of H_2O ($\pm$ 1 mL) -> 250 mL of .250 M $CaCl_2$ ($\pm$ 1 mL)

250 mL of .500 M NaOH (± 1 mL) + 250 mL of H_2O (± 1 mL) -> 500 mL of .250 M NaOH (± 1 mL)

Initial Mass measurements: ± 0.0001 grams $Ca(OH)_2$

Final Mass measurements: ± 0.0001 grams $Ca(OH)_2$

Measurement of temperature: ± 1 Degree Celsius

Measurement of solution to use for reaction: ± 0.1 mL of $CaCl_2$ / NaOH

Final uncertainties: ± 1 mL of solutions, ± 1 Degree temperature, ± 0.0001 grams $Ca(OH)_2$

Data Analysis:

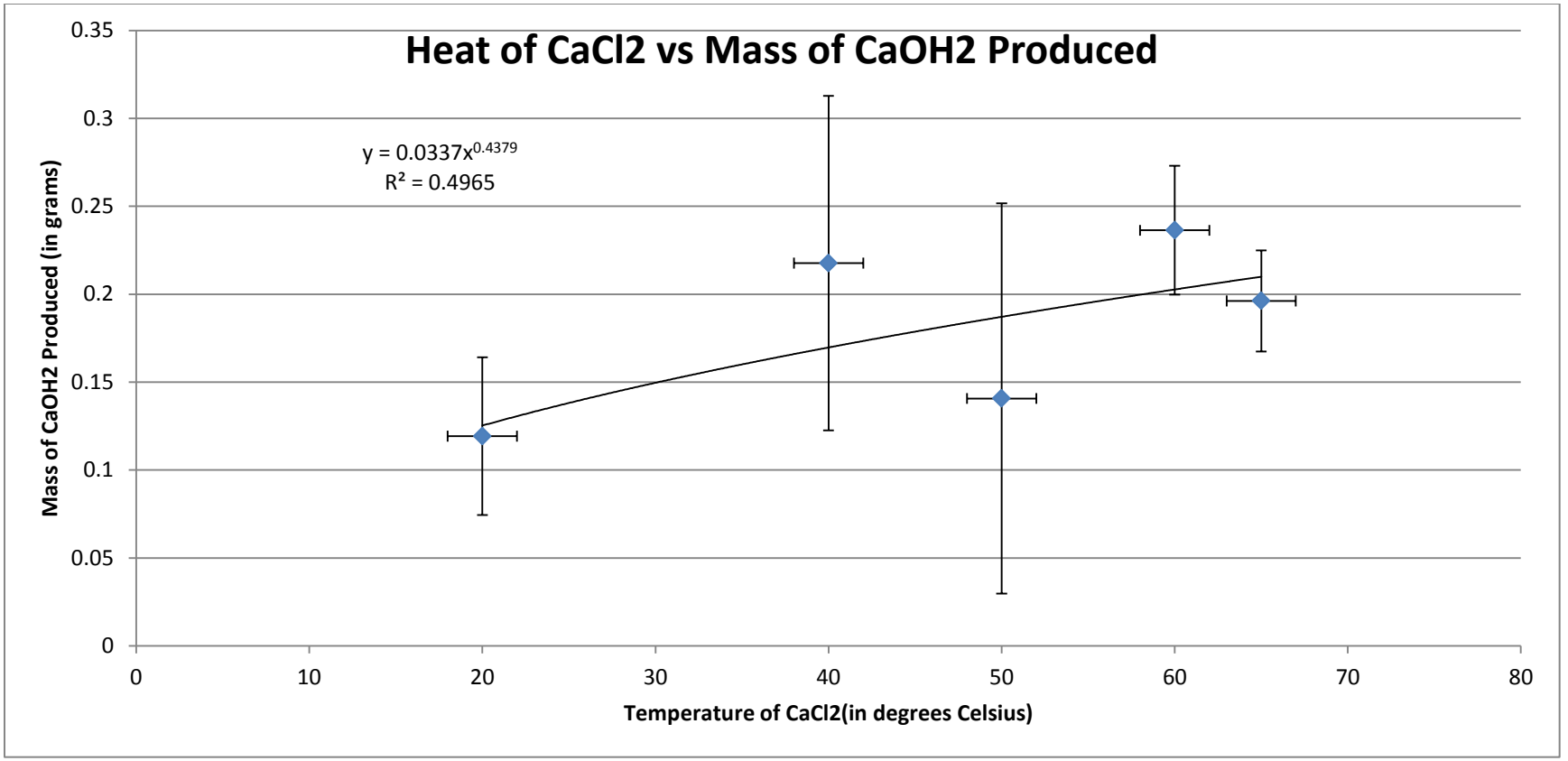
Processed Data:

Temperature of CaCl2 (degrees Celsius)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Uncertainty
	Mass of CaCl2 Produced(g)						
20	0.1442	0.09329	0.07438	0.1424	0.1419	0.119234	0.044854
40	0.1225	0.2557	0.1498	0.1667	0.3936	0.21766	0.09516
50	0.1643	0.2516	0.0317	0.133	0.1227	0.14066	0.11094
60	0.1997	0.2582	0.2536	0.2552	0.215	0.23634	0.03664
65	0.1634	0.1809	0.2058	0.2059	0.2249	0.19618	0.02872

Calculations

In order to arrive at the average, we naturally added up each trial and divided by five, as seen in: $Avg = \frac{T_1+T_2+T_3+T_4+T_5}{5}$, and to get the uncertainty associated with this average, the most deviant number was found and the absolute difference between the most deviating and the average was found, as shown in: $Uncertainty = |T_{deviating} - Avg|$.

Processed Data graph:



The theoretical value for the amount of substance produced can be found, as the volume and the molarity of the substances combined are both known. This allows for the evaluation of the percent error, which is stated as $\frac{Actual\ Yield}{Theoretical\ Yield} \cdot 100\%$. The theoretical yield can be found by:

$$TY = \frac{(10\ mL\ CaCl_2)}{1} \cdot \frac{0.001\ L}{1\ mL} \cdot \frac{0.125\ mol\ CaCl_2}{1L} \cdot \frac{1\ mol\ Ca(OH)_2}{1\ mol\ CaCl_2} \cdot \frac{74.0968\ g}{1\ mol\ Ca(OH)_2}$$

This evaluates to a theoretical yield of 0.09262 grams of $Ca(OH)_2$ produced each trial.

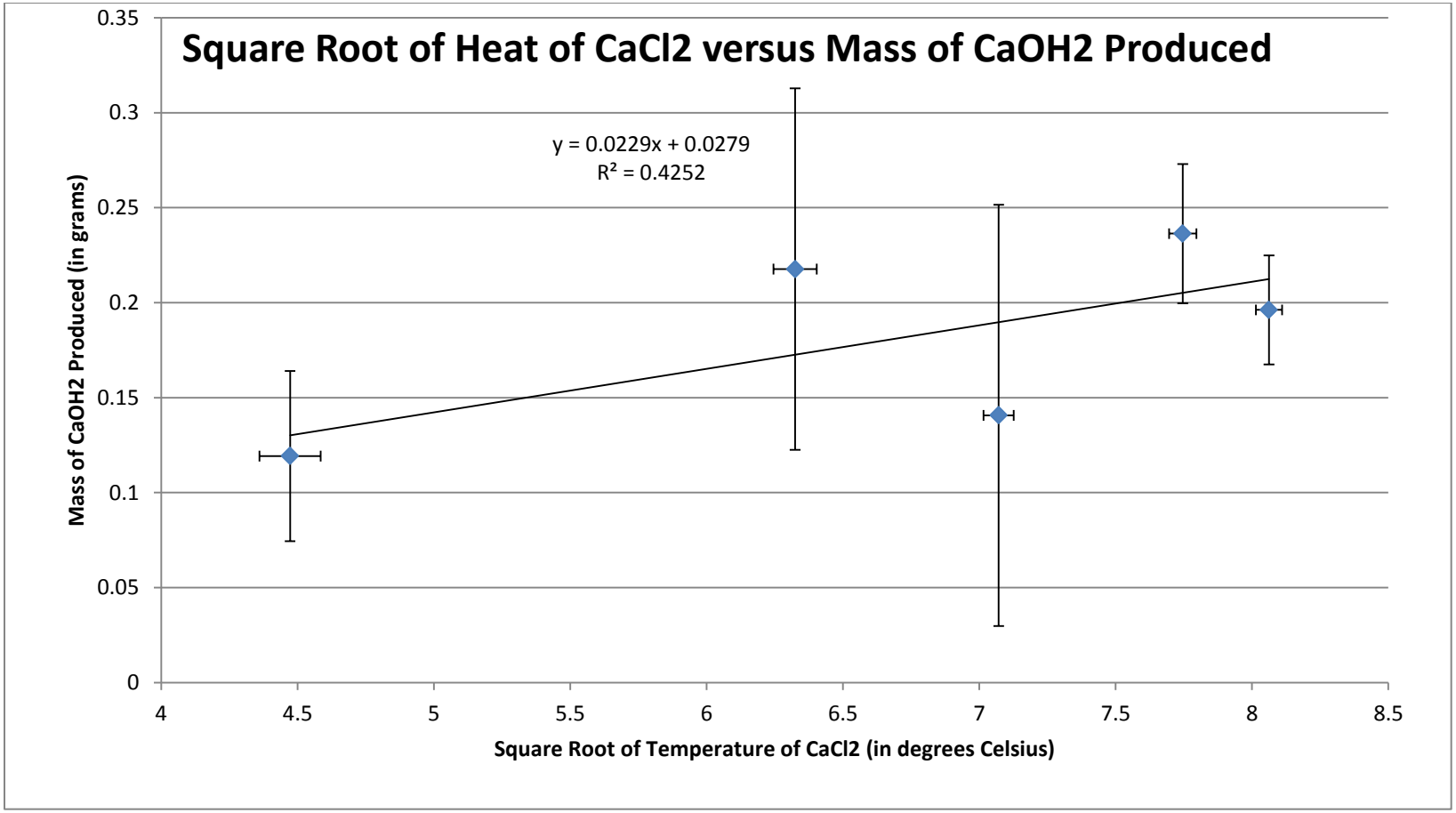
The percent yield of each trial is shown in the following data table:

Temperature of CaCl2 (degrees Celsius)	AY/TY	Percent Yield (%)
20	1.2873	128.73
40	2.3500	235.00
50	1.5187	151.87
60	2.5517	255.17
65	2.1181	211.81

As seen in the graph of the processed data, there does not seem to be a linear model to suit the data. Instead, when the power regression was applied, it seems that a square root model would better suit the data. In order to accommodate for such a type of graph, each x-value, which was the temperature, was reduced to its square root, providing with the following graph:

Also, the uncertainty of the x-axis needed to be adjusted, in the form of:

$$Uncertainty = \frac{1}{Temperature} \cdot Temperature_{Square\ Root} \cdot \frac{1}{2}$$



Even though there is an extremely low R Squared value, because the best fit line passes through every error region, this best fit line is suitable for modeling our data as is.

The slope of our graph represents how much more $Ca(OH)_2$ would be produced per unit increase in the square root of the temperature. The y-intercept can be interpreted as how much $Ca(OH)_2$ would be produced at 0 degrees Celsius. The reason that this number is not 0 is because through the experiment, the temperature was taken with the Celsius scale. If, instead, the Kelvin scale was used, it is likely that at 0 Kelvin, or absolute 0, there would be no reaction. In fact, at the point where the $CaCl_2$ became solid, there should be no more reaction.

Because the Celsius scale was used instead of the Kelvin scale, the best fit line of the graphs do not make perfect sense, especially when the negative values of $CaCl_2$ are considered. However, the general trend of the data, in the form of the square root increase, should maintain the same way regardless of the scale of temperature, because one degree Centigrade is equivalent to one Kelvin.

Conclusion and Evaluation

Through this experiment, a general trend of the amount of material produced increasing per the increase of the square root of the temperature was found, contrary to our initial beliefs that the increase in temperature would directly correlate to an increase in the material produced. Through the graphs of the processed data, this trend has been shown to be very clear. Although this was not in accordance to the original hypothesis, the results do make sense. They imply that eventually, an increase in temperature of high ranges can only slightly increase the amount of substance produced, while an increase of temperature in low ranges can greatly impact the amount of substance produced. One consideration that should have been accounted for was that all temperature should have been reported in Kelvin rather than Centigrade, as that would provide the baseline of absolute zero.

As is obvious with the graph and the glaringly large error bars, there was a considerable amount of random error, as well as a remarkable amount of systematic error. From the error bars, it can be seen that every single trial had error greater than 15 % of the average. However, due to the complexity of the lab, there were multiple areas where the area could have arose.

For one, the temperature of the $CaCl_2$ was not perfectly controlled. Even though the temperature was retaken and confirmed while it was in the graduated cylinder, through most high temperature trials there was a rapid cooling of the solution. This could have translated to an uncertain temperature of when the Calcium Chloride was actually mixed. Also, not every single bit of $CaCl_2$ was utilized. In earlier trials, the mixing bottle was not often washed out to conserve every bit of solid, and there is always the possibility that solute was left in that beaker. Finally, through every trial, the drainage in the Erlenmeyer flasks always showed some solid floating in the supposedly clear solution of H2O and NaCl. This implies that our filter was not functioning at 100%, and that some solid did escape through. Alternatively, there is the possibility of human error in the part that the filter was not fully processed to eliminate any extra NaCl, resulting in an increase in the percent yield.

The majority of these errors can be solved with a more steady hand and more time spent per trial of data. This would allow for reprocessing the solution if an excess amount of solute passed through the filter, more proper washing down of the filter every single trial to ensure a minimum amount of NaCl was caught, and some sort of digital way of measuring temperature. These would help eliminate error throughout our experiment.

This experiment has revealed that there is a considerable impact of the temperature on the amount of solute produced, and therefore, the percent yield of the reaction. However, this

experiment has also evaluated that that difference is quite minimal in the 283 to 313 range, as it seems that the percent yield only differs for an increase in the square root of the temperature, as well as how it seems to increase very minimally for temperatures of high Kelvin.