

International Baccalaureate Chemistry Lab Report

Experiment Title

To determine the effect of Intermolecular
Forces on the Enthalpy of Solution for
various metal hydroxides

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Abstract:

In this experiment, energetics theories and principles were used to calculate the enthalpy of solution of several hydroxides. Calorimetry carried out in a polystyrene cup was used to measure the enthalpy of solution. A temperature probe was used for accurate data tabulation.

The purpose of this experiment is to determine the affect of intermolecular forces, and hence reactivity on the enthalpy of solution. The enthalpy solution values were tabulated, and then conclusions were drawn as to the difference in reactivity and intermolecular forces.

Through this experiment, it was concluded that the stronger the cation in the compound, makes it harder to disassociate, and hence is more endothermic that the enthalpy of solution of a cation that is weaker in its compound. Hence, the enthalpy of solution of sodium hydroxide was found to be more endothermic than that of potassium hydroxide, as sodium has a smaller ionic radius than potassium, and hence attracts its anion strongly.

Similarly, it was found that cations with a relative positive charge of 2, have a more endothermic enthalpy of solution than those with a positive charge of 1, since they attract their anion counterpath with greater intermolecular forces, hence takes more energy to break bonds. Since bond breaking is endothermic, the enthalpy is also more endothermic.

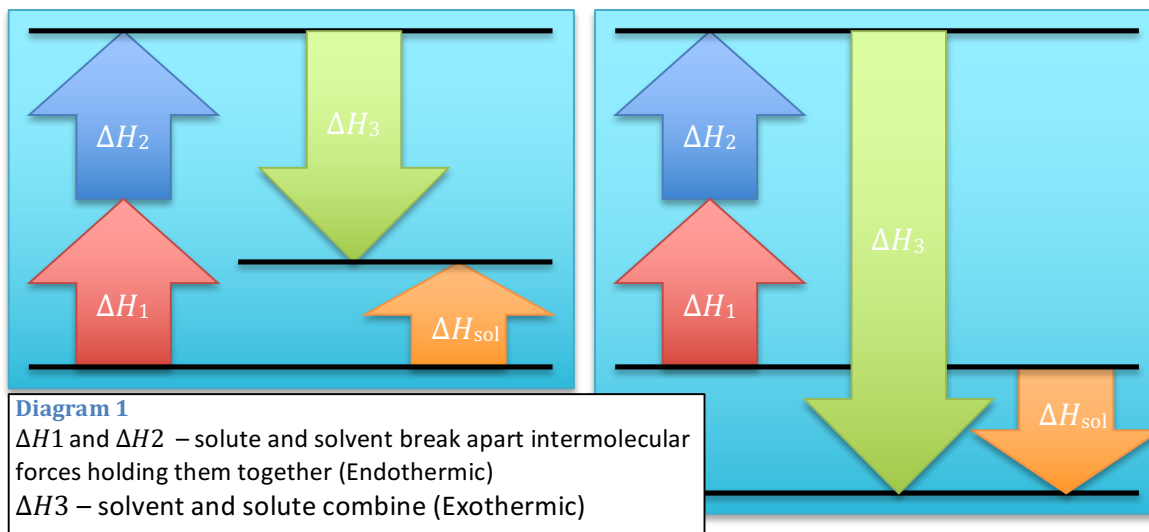
Overall the experiment was quite successful since it fulfilled the aim and its conclusions were useful. Even uncertainty was kept to a minimum. However, there was great uncertainty in the case of calcium hydroxide due to its limited solubility in water.

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INTRODUCTION

The enthalpy change of solution [$\Delta H_{\text{sol}}^{\circ}$] is the enthalpy change when one mole of solute dissolves in an infinite volume of water. In practice, a point of infinite dilution is not possible, so instead, it is common practice to reach a point where further dilution has no significant effect on the enthalpy of solution. Then results are extrapolated to obtain accurate and precise results.¹



The enthalpy of a solution is affected by three main factors (three other enthalpies) that depend on the solvent and the solute and their interaction with each other. If the energy required to break the intermolecular forces in either the solvent or solute decreases, the enthalpy of solution becomes more exothermic or less endothermic.

Therefore, a solute or solvent with greater intermolecular forces than another will have a more exothermic enthalpy or a less endothermic enthalpy.²

Intermolecular forces are the attractive forces that operate between atoms of a molecule. In ionic compounds (as this experiment will be concerned with) they are known as electrostatic forces of attraction. The greater or stronger these electrostatic forces are, the more energy is required to separate the ionic compound. Breaking bonds is endothermic; therefore, the overall reaction becomes less exothermic because more net intake of energy takes place.³

Two main factors affecting the intermolecular forces of an ionic compound are –

1. Charge of Ions involved in the ionic compound
2. Ionic Radii of the elements involved

¹ Talbot, Christopher, Richard Harwood, and Christopher Coates. *Chemistry for the IB Diploma*. London: Hodder Murray, 2009. Print.

² Javeed, Zafir. "Enthalpy of Solution - ChemWiki." *Enthalpy of Solution*. UC Davis ChemWiki by University of California, n.d. Web. 09 Mar. 2013.

<http://chemwiki.ucdavis.edu/Physical_Chemistry/Physical_Properties_of_Matter/Solutions/Page_Title>.

³ "Intermolecular Forces." *Intermolecular Forces*. Georgia Southern University, n.d. Web. 09 Mar. 2013. <<http://cosm.georgiasouthern.edu/chemistry/general/molecule/forces.htm>>.

DESIGN

ASPECT 1: *DEFINING THE PROBLEM*

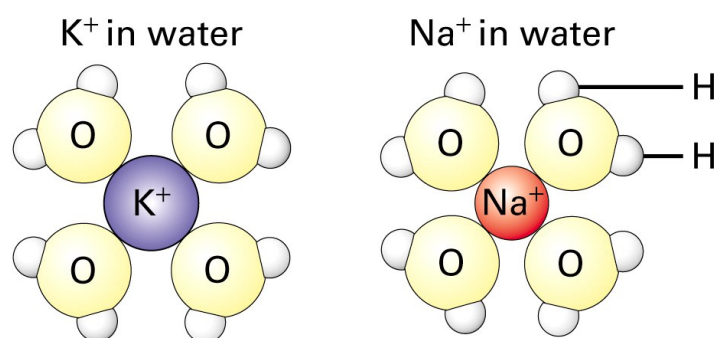
RESEARCH QUESTION

How does the strength of ionic bonds in various metal hydroxides of the first and second group elements, affect the enthalpy of solution when dissolved in water, while concentration, temperature and pressure are kept constant?

HYPOTHESIS

I hypothesize that as the strength of ionic bonds in compounds increase, the enthalpy of solution will become less exothermic or more endothermic. In other words, the enthalpy of solution will numerically increase because now more energy is needed to separate the ionic compounds. As it absorbs more energy, the net endothermic part of the reaction increases (it needs to absorb more energy). This results in the sum of all endothermic and exothermic forces of the reaction to tend more towards endothermic (increases numerically as endothermic reactions are noted by a positive enthalpy of reaction).

Firstly, I hypothesize, that when it comes to changing the cation, the smaller ions like Sodium (Na^+) will have a more endothermic reaction than larger ions like Potassium (K^+). Since they both have the same charge, the main factor that will affect the enthalpy of solution would be the size of the atom.



As seen in [Diagram 2](#), the sodium ion is much smaller in size compared to the potassium ion. The electrostatic forces between sodium and its compounds is higher than that of potassium and its

Diagram 2

compounds because its nucleus is closer to the anion's electrons forming a stronger bond due to higher attractive forces. Though potassium is more reactive than sodium due to its larger ionic radius, in its compounds, potassium is easier to separate than sodium since in sodium, the distance between ion centers is lesser which leads to greater attraction between the cation (Na^+) and the anion (constant in this case).

This follows for Ca^{2+} and Mg^{2+} where Mg^{2+} will have a more endothermic reaction when compared to Ca^{2+} with water. Since Magnesium has a stronger lattice with a constant anion, the lattice enthalpy is much greater which in turn causes its reaction (mainly enthalpy of solution) to be more endothermic in comparison to Calcium.

Secondly, I hypothesize that when the charge of the cation is different (Na^+ and Mg^{2+}), then, the enthalpy of solution of Mg^{2+} will be higher. Since Mg^{2+} and Na^+ are in the same period and are consecutive, there is very less difference between their ionic radius. But, magnesium has a +2 charge in its compounds compared to sodium's +1. The higher charge leads to a stronger attractive force between ions that are harder to separate. More energy is required to separate them.

So, I hypothesize that Magnesium's enthalpy of solution will be more endothermic than Sodium's because Magnesium has a greater charge which leads to stronger lattices in its ionic compounds. It takes more energy to separate the compound. This higher intake of energy is endothermic which results in a more endothermic enthalpy of solution.

The above two hypothesis' assume that the anion is constant and only the cation changes. Evaluating the change when both cation and anion are changed would be impossible because having 2 independent variables changed at the same time makes it impossible to know what change of independent variable caused which change in dependent variable. Here the independent variable will be the change of cation. The dependent variable or the variable I will be measuring making all these changes will be the enthalpy of solution and other suitable reactions.

Changing the anion of the compound will have similar effects compared to changing the cation. The more electronegative the atom of the ion (the more attractive the negative ion), the more energy it will require for the compound to be separated in order to dissolve it in a solvent.

So, even when the negative ion is changed, the ions having higher attractive forces (F^-) will have a more endothermic enthalpy compared to less attractive ions (Cl^-).

I will keep the negative ion constant. I will also control other factors such as the size of particles, concentration of solutions used and thermodynamic conditions.

ASPECT 2: *CONTROLLING VARIABLES*

STATEMENT and CONTROL OF VARIABLES

Independent Variable –

1. The compound (4 different hydroxides) – The independent variable is the variable that I will change in the experiment. Since the purpose of my experiment is to determine the affects on enthalpy of solution due to strength of ionic bonds, I will attempt to change the strength of the ionic bonds in an ionic compound.

I will change the cation of the compound in the reactions planned. This will allow me to form a relationship between the cation. The elements I will be using as the cations will be Sodium, Potassium, Magnesium and Calcium when possible. Hence, I will use the hydroxides of these 4 metals and conduct the same reaction for all 4 of these hydroxides. By comparing the different enthalpies, a relationship will be formed based on the strength of bonds in those 4 compounds.

Dependent Variable –

1. Temperature (heat evolved or absorbed by the reaction) - The dependent variable is the variable I expect to change due to changing the independent variable. This is also the variable I will be measuring. For the experiments, I will be mainly measuring the enthalpy of solution. For some types of compounds, I will also be measuring the enthalpy of other suitable reactions. For example, for the hydroxides, I will be measuring the enthalpy of neutralization as a solution.

Subtracting the enthalpy of neutralization from this will also yield the enthalpy of solution. This will be used as an error checking technique to affirm the enthalpy of solution derived from other reactions. This is measured to 2 decimal places significance level with a temperature probe, every 5 seconds.

Controlled Variables –

1. Size of Solid Particles - The size of particle of the solid (powdered, chips or blocks) will not directly affect the enthalpy of any reactions but it does affect the rate. A change in particle size will make some reactions end faster and others slower. The slower the reaction is, the more heat is lost to the surrounding which leads to a lower reading of enthalpy and more uncertainty. If some reactions are

slower and others faster, then in some reactions, more heat will be lost and in others less. Since in this experiment, the comparison of enthalpies is more important than the absolute value, I will be aiming to keep the rate of the reaction constant. Therefore, I will use all solids as small chips. All solid particles are mashed up and passed through a sieve to confirm that sizes are congruent.

2. Concentration of Liquid Reagents - I will also be keeping the concentration of liquid reagents constant. An increase in concentration will affect the rate of the reaction. Additionally, a change in concentration could affect the enthalpy of a solution depending on which reagent is the limiting reagent. If the concentration of the limiting reagent is increased, there will be more enthalpy change. I will use reagents of 1mol dm^{-3} .

3. Temperature of Surroundings - The temperature and pressure of the surroundings will be kept constant because either can cause a change in the enthalpy. The higher the surrounding temperature, the more endothermic the reaction will tend to be. Even when the reaction is exothermic, less heat will be lost to the surroundings due to a harsher gradient of heat energy. The surrounding is already saturated with heat so it will be harder for it to absorb the energy released by the solution.

4. Pressure of Surroundings - A change in surrounding pressure will change the rate of the reaction that in turn will indirectly affect the enthalpy of the reactions.

5. Number of Reactions (Hess' Law) *(read below for further explanation)* - For most compounds, the enthalpy of solution can be found directly. For others, I will have to use Hess' Law following a number of reactions to find out the enthalpy of the reaction that I want. However, I will have to keep the number of reactions constant. The more the number of reactions following the Hess' Law the more uncertainty and lower the enthalpy will be compared to the actual value. Each step involves heat loss. Therefore, the more the number of steps, the more heat loss occurs. Though the absolute value doesn't matter, the more the number of reactions, the more error there will be and less reliability when comparing data. Therefore the number of steps to the final reaction has to be kept constant.

6. Physical State of Reactants and Products - Lastly, the physical state of the reactants and products makes a huge and monumental difference to the calculated enthalpy. If in one reaction the reactant is a solid and in other a gas, then the reaction with the gaseous reactant will yield a more exothermic enthalpy. In the reaction with the solid reactant, energy is absorbed to convert

the reactant into its gaseous state. This endothermic change is absent from the reaction with the already gaseous reactant.

Similarly, when the reaction yields a gaseous product, some energy has been used to convert the otherwise solid product to a gaseous product. Both of the cases above could lead to erroneous data readings. Therefore, all reactants will be in solid and liquid state (one liquid and one solid) and all products will be kept constant in solution state.

7. Insulation - The insulation directly affects the enthalpy change during experiments. It determines the amount of energy conserved or lost. Keeping this constant will make my experiment more precise but won't affect accuracy. I will try to insulate the polystyrene cup as well as possible and then keep the insulation constant.

8. Anion of Compound - I will also be keeping the anion constant. I will use hydroxides (hydroxide ion) for this experiment. Changing anion of the compound leads to a change in behavior and properties of the compound. It might also behave as a covalent compound instead. This would change the enthalpy values. Therefore, I will keep it constant.

Additional Information

I will conduct all the experiments in the same surrounding on the same day. I will use all the same apparatus (cleaned between trials and experiments) in order to keep uncertainty and other factors constant.

The mass of the reactant is not variable. Enthalpy change of a solution is measured based on the energy evolved or absorbed per mole of the reactant (independent variable). Therefore, the mass only has to be noted, but the end value will be irrespective of mass, as it will convert all masses to mole and all values to kJ/mol. I will still try to keep the mass about constant for linearity of data.

ASPECT 3: *DEVELOPING A METHOD FOR COLLECTION OF DATA*

APPARATUS

1. Beaker (1000 ml)
2. Polystyrene Cup as container for reaction
3. Cotton for Insulation
4. Data Logger with Temperature Probe $\pm 0.01^{\circ}\text{C}$
5. Graduated Measuring Cylinder (100 ml) to measure liquid reagents $\pm 0.5\text{ml}$
6. Liquid Reagents
 - a. $\text{HCl} - 1 \text{ mol dm}^{-3}$
 - b. Distilled Water
7. Solid Reagents
 - a. Hydroxides
8. Beakers for Liquid Reagent
9. Crucible for Solid Reactants
10. Electronic Mass Balance $\pm 0.001\text{g}$

DIAGRAM OF SETUP

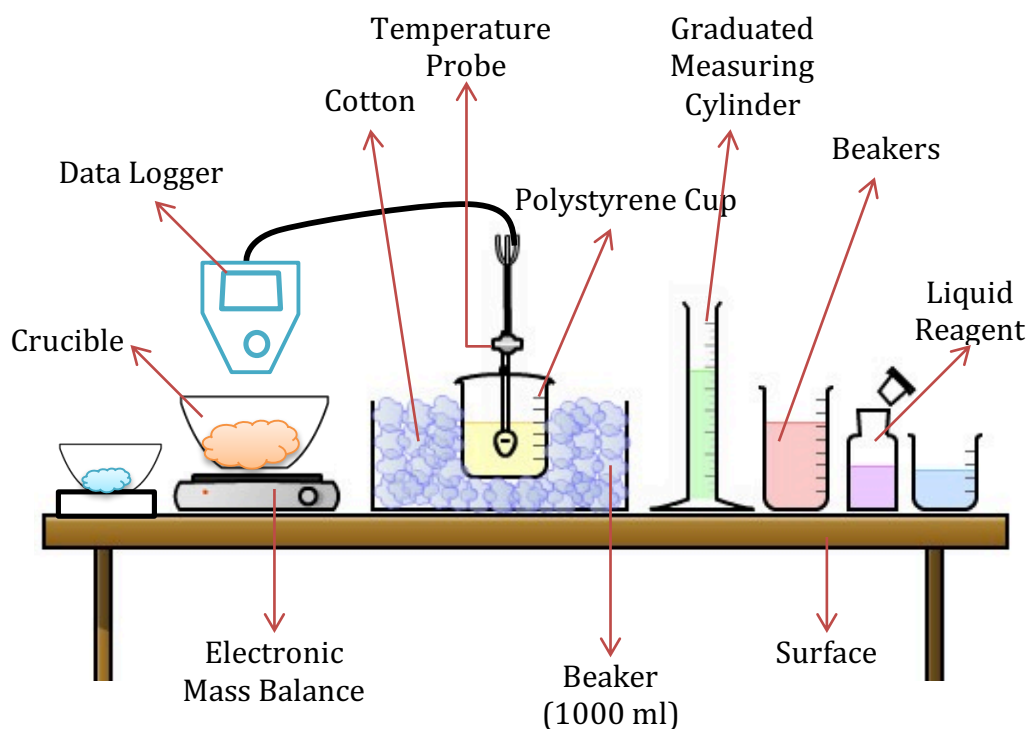


Diagram 3

PROCEDURE

1. First, I setup the Beaker (1000 ml), polystyrene cup and the insulation. This part of the set up will remain same throughout. I put the polystyrene cup inside the beaker and coated all sides with as much cotton as possible. Between trials and reactions, I would simply take the polystyrene cup out, clean it and reuse it again.
2. Then I added the cap with the temperature probe. I set the data logger to take temperature readings every 5 seconds. The temperature probe allowed the collection of sufficient data, as it could collect temperature data every 5 seconds to a certain accuracy. Taking readings every 5 seconds is very important since the exact progression of reaction is important when drawing and extrapolating graphs.
3. Then, I setup the distilled water. I used a constant of 60 cm³. Hence, for every trial and experiment, I first measured out 60ml of distilled water using the measuring cylinder (the greatest source of uncertainty). This distilled water is then poured into the polystyrene cup.
4. Then, I set the temperature probe into the distilled water and started the probe. I measured about some amount of hydroxide, first starting with sodium hydroxide. I tried to take a constant of 5g of mass, even though it was not required, in order to directly compare results.
5. At exactly 60 seconds of the temperature probe taking data, I added the solid to the polystyrene cup. Then I allowed the temperature probe to continue taking data for a total of 300 seconds. Later, graphs will be extrapolated from the cooling graph to 60 seconds, to compensate for part of the heat loss to surrounding.
6. When I put the mass into the distilled water, I closed the cap of the cup as fast as possible and tried to limit the heat loss to surrounding by further covering the cup with cotton insulation.
7. Then I cleaned the polystyrene cup and did more trials. By repeating the steps described above. I further repeated the experiment for four hydroxides. Measurements of mass of solid were conducted using the crucible and an electronic mass balance, to great precision.

Safety and Precautions Taken -

1. Since heat was evolved in this reaction, I wore eye goggles to protect from the heat and the unknown amount of heat that might be evolved by dissolving the mass in the distilled water.
2. Enthalpy of solutions were first calculated theoretically by using data of other reactions and by using Hess Law, to make sure that reactions were safe and would not lead to temperatures above 60°C that could be potentially dangerous.
3. Hence, only 2.5g of potassium hydroxide as opposed to 5g of other reactants were used, as potassium hydroxide reacts more exothermically according to calculations and 5g could have lead to large spikes in temperature.

Formula's Used and Data Presented -

1. The temperature data as opposed to time collected by the temperature probe will first be graphed and the garphs will be extrapolated, to find the change in temperature, with minimum heat loss.
2. Once this change in temperature is calculated, the heat energy evolved due to this change in temperature will be calculated in joules through the equation -

$$\Delta H = m \cdot c \cdot \Delta T$$

3. After the heat energy change was calculated for each trial and all hydroxides, this heat energy had to be further changed to standard heat change or enthalpy for the solution, so that data could be compared and analyzed. This is done through the equation -

$$\text{Standard Enthalpy} = \frac{\text{Heat Evolved}}{\text{No. of Moles } (n)}$$

Where number of moles refers to the moles of solid, of either hydroxides, were dissolved in the distilled water. The number of moles can be calculated using stoichiometric equations -

$$n(\text{moles}) = \frac{\text{mass}}{\text{molar mass}}$$

where mass was also measured in some step of the procedure.

4. It is this standard enthalpy of solution which is finally presented.

DATA COLLECTION PROCESSING

ASPECT 1: *RECORDING RAW DATA*

DATA ON HYDROXIDES

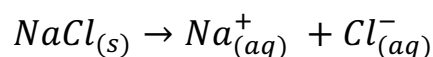
Hydroxides Used –

1. $NaOH$
2. KOH
3. $Ca(OH)_2$
4. $Ba(OH)_2$

REACTION

This reaction involves reacting metal hydroxides with water. When metal hydroxides are mixed with water, they disassociate into metal and hydroxide ions. This dissociation leads to a change in enthalpy. This enthalpy change could be positive or negative. In other words, the absolute temperature could either increase or decrease.

This change in enthalpy will be calculated in order to conclusively decide on the strength/reactivity of the cation in the compound.



The enthalpy change of solution is the change that occurs when one mole of solute dissolves in large excess. In this experiment, one mole will not be dissolved, but the final enthalpy will be scaled up to be calculated.

Table 1: Mass and Volume readings for all reactions concerning hydroxides

| | | REACTION 1 (With Water) | | | |
|--|---------|----------------------------|---------|-------------|--------------|
| | | Before* | After** | Mass *** | Vol. **** |
| $NaOH$ | Trial 1 | 57.832 | 62.632 | 4.800 | 60 |
| | Trial 2 | 65.134 | 69.684 | 4.550 | 60 |
| | Trial 3 | 57.826 | 62.15 | 4.324 | 60 |
| KOH | Trial 1 | 65.147 | 67.527 | 2.380 | 60 |
| | Trial 2 | 57.828 | 60.190 | 2.362 | 60 |
| | Trial 3 | 65.126 | 67.699 | 2.573 | 60 |
| $Ca(OH)_2$ | Trial 1 | 57.838 | 62.618 | 4.780 | 60 |
| | Trial 2 | 57.826 | 62.719 | 4.893 | 60 |
| | Trial 3 | 65.127 | 69.912 | 4.785 | 60 |
| $Ba(OH)_2$ | Trial 1 | 57.832 | 62.666 | 4.834 | 60 |
| | Trial 2 | 57.831 | 62.649 | 4.818 | 60 |
| | Trial 3 | 65.128 | 69.923 | 4.795 | 60 |
| * The mass of the crucible (empty) – (± 0.001) grams | | | | | |
| ** The mass of the crucible (with the solid) – (± 0.001) grams | | | | | |
| *** The mass of the solid – (± 0.002) grams | | | | | |
| **** Volume of Liquid Used – (± 0.5) cm^3 | | | | | |

| |
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| |
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Qualitative Data for measuring mass

1. Though it's not necessary to take the same mass of solid, I approximately tried to take it as a constant.
2. I used two crucibles to make measuring the solids easier. However, the masses of the two crucibles were different. That however doesn't affect my results because my experiment is only concerned with the change in mass.
3. The volume had the highest uncertainty. However, the best apparatus possible to measure 60cm³ of the liquid was the graduated measuring cylinder. I could have used the 10ml and 25ml pipette to make up 60 ml but that would take too long. So, I settled with the measuring cylinder.
4. The electronic mass scale was quite accurate but was almost too precise. Passing wind and minute atmospheric changes would change the reading. This proved problematic since in this experiment, precise measurements of mass are imperative.

NaOH

**Table 2: Temperature Reading for
Reaction 1 of NaOH**

| TIME | TRIAL 1 * | TRIAL 2 * | TRIAL 3 * |
|------|-----------|-----------|-----------|
| 0 | 296.4 | 297.4 | 297.7 |
| 5 | 296.4 | 297.4 | 297.6 |
| 10 | 296.4 | 297.4 | 297.6 |
| 15 | 296.4 | 297.5 | 297.6 |
| 20 | 296.4 | 297.4 | 297.7 |
| 25 | 296.4 | 297.3 | 297.6 |
| 30 | 296.4 | 297.5 | 297.6 |
| 35 | 296.4 | 297.4 | 297.7 |
| 40 | 296.4 | 297.4 | 297.6 |
| 45 | 296.4 | 297.4 | 297.6 |
| 50 | 296.4 | 297.5 | 297.6 |
| 55 | 296.4 | 297.4 | 297.6 |
| 60 | 296.4 | 297.5 | 297.7 |
| 65 | 296.4 | 297.4 | 297.9 |
| 70 | 296.7 | 297.6 | 298.1 |
| 75 | 297.3 | 298.1 | 298.6 |
| 80 | 297.9 | 298.8 | 299.9 |
| 85 | 298.7 | 300.2 | 301.6 |
| 90 | 299.5 | 301.4 | 303.4 |
| 95 | 300.3 | 302.6 | 305.6 |
| 100 | 301.1 | 303.8 | 306.3 |
| 105 | 301.9 | 305.0 | 308.1 |
| 110 | 302.6 | 306.1 | 309.4 |
| 115 | 303.4 | 307.3 | 310.2 |
| 120 | 304.3 | 308.4 | 310.9 |
| 125 | 305.4 | 309.3 | 312.6 |
| 130 | 306.4 | 309.9 | 313.8 |
| 135 | 307.3 | 310.7 | 313.9 |
| 140 | 308.1 | 311.2 | 314.0 |
| 145 | 309.0 | 311.9 | 314.0 |
| 150 | 309.7 | 312.3 | 314.1 |
| 155 | 310.4 | 312.9 | 314.0 |
| 160 | 311.2 | 313.1 | 314.0 |
| 165 | 311.8 | 313.3 | 314.0 |
| 170 | 312.2 | 313.6 | 314.1 |
| 175 | 312.6 | 313.6 | 314.1 |
| 180 | 312.8 | 313.7 | 314.0 |
| 185 | 313.1 | 313.7 | 313.9 |
| 190 | 313.3 | 313.7 | 314.0 |
| 195 | 313.2 | 313.7 | 314.0 |
| 200 | 313.2 | 313.7 | 313.8 |
| 205 | 313.2 | 313.6 | 313.9 |
| 210 | 313.3 | 313.6 | 313.9 |
| 215 | 313.2 | 313.5 | 313.8 |
| 220 | 313.1 | 313.6 | 313.7 |
| 225 | 313.1 | 313.5 | 313.6 |
| 230 | 313.0 | 313.5 | 313.7 |
| 235 | 313.0 | 313.4 | 313.6 |
| 240 | 313.0 | 313.5 | 313.7 |
| 245 | 312.9 | 313.3 | 313.6 |
| 250 | 312.9 | 313.4 | 313.5 |
| 255 | 312.9 | 313.3 | 313.5 |
| 260 | 312.9 | 313.3 | 313.6 |
| 265 | 312.8 | 313.3 | 313.5 |
| 270 | 312.8 | 313.3 | 313.5 |
| 275 | 312.6 | 313.3 | 313.4 |
| 280 | 312.6 | 313.2 | 313.5 |
| 285 | 312.6 | 313.1 | 313.4 |
| 290 | 312.5 | 313.2 | 313.4 |
| 295 | 312.5 | 313.0 | 313.4 |

| | | | |
|---|-------|-------|-------|
| 300 | 312.5 | 312.9 | 313.3 |
| 305 | 312.3 | 313.0 | 313.3 |
| 310 | 312.3 | 313.0 | 313.2 |
| 315 | 312.3 | 312.9 | 313.4 |
| 320 | 312.2 | 312.9 | 313.3 |
| 325 | 312.2 | 312.9 | 313.2 |
| 330 | 312.2 | 312.9 | 313.0 |
| 335 | 312.2 | 312.9 | 313.1 |
| 340 | 312.2 | 312.9 | 313.1 |
| 345 | 312.2 | 312.8 | 313.0 |
| 350 | 312.1 | 312.8 | 313.0 |
| 355 | 312.1 | 312.8 | 312.9 |
| 360 | 312.1 | 312.7 | 312.9 |
| 365 | 312.1 | 312.7 | 312.7 |
| 370 | 312.1 | 312.6 | 312.9 |
| 375 | 312.1 | 312.7 | 312.8 |
| 380 | 312.1 | 312.8 | 312.8 |
| 385 | 312.1 | 312.7 | 312.8 |
| 390 | 312.0 | 312.6 | 312.7 |
| 395 | 311.9 | 312.6 | 312.8 |
| 400 | 312.0 | 312.6 | 312.7 |
| 405 | 311.9 | 312.6 | 312.7 |
| 410 | 311.9 | 312.6 | 312.7 |
| 415 | 311.9 | 312.5 | 312.7 |
| 420 | 311.8 | 312.5 | 312.6 |
| 425 | 311.8 | 312.5 | 312.7 |
| 430 | 311.8 | 312.4 | 312.6 |
| 435 | 311.8 | 312.4 | 312.6 |
| 440 | 311.7 | 312.3 | 312.6 |
| 445 | 311.7 | 312.4 | 312.5 |
| 450 | 311.7 | 312.3 | 312.6 |
| 455 | 311.6 | 312.3 | 312.5 |
| 460 | 311.6 | 312.3 | 312.5 |
| 465 | 311.5 | 312.2 | 312.5 |
| 470 | 311.6 | 312.2 | 312.6 |
| 475 | 311.5 | 312.2 | 312.5 |
| 480 | 311.5 | 312.2 | 312.5 |
| 485 | 311.5 | 312.2 | 312.4 |
| 490 | 311.4 | 312.2 | 312.5 |
| 495 | 311.4 | 312.2 | 312.5 |
| 500 | 311.4 | 312.2 | 312.5 |
| 505 | 311.4 | 312.1 | 312.5 |
| 510 | 311.4 | 312.1 | 312.4 |
| 515 | 311.4 | 312.1 | 312.4 |
| 520 | 311.4 | 312.1 | 312.5 |
| 525 | 311.3 | 312.0 | 312.4 |
| 530 | 311.3 | 312.0 | 312.3 |
| 535 | 311.2 | 312.0 | 312.4 |
| 540 | 311.2 | 312.1 | 312.4 |
| 545 | 311.2 | 312.1 | 312.3 |
| 550 | 311.2 | 312.0 | 312.3 |
| 555 | 311.2 | 312.0 | 312.3 |
| 560 | 311.2 | 311.9 | 312.3 |
| 565 | 311.2 | 312.0 | 312.2 |
| 570 | 311.1 | 311.9 | 312.3 |
| 575 | 311.1 | 311.9 | 312.3 |
| 580 | 311.2 | 311.8 | 312.3 |
| 585 | 311.1 | 311.8 | 312.3 |
| 590 | 311.1 | 311.8 | 312.4 |
| 595 | 311.0 | 311.8 | 312.4 |
| 600 | 311.0 | 311.8 | 312.3 |
| * Temperature Reading from Data Logger – ($K \pm 0.1$) | | | |

KOH

**Table 3: Temperature Reading for
Reaction 1 of KOH**

| TIME | TRIAL 1 * | TRIAL 2 * | TRIAL 3 * |
|------|-----------|-----------|-----------|
| 0 | 298.3 | 297.7 | 298.6 |
| 5 | 298.4 | 297.7 | 298.7 |
| 10 | 298.5 | 297.7 | 298.6 |
| 15 | 298.4 | 297.7 | 298.6 |
| 20 | 298.3 | 297.6 | 298.6 |
| 25 | 298.4 | 297.7 | 298.6 |
| 30 | 298.5 | 297.7 | 298.7 |
| 35 | 298.6 | 297.7 | 298.7 |
| 40 | 298.4 | 297.6 | 298.7 |
| 45 | 298.4 | 297.6 | 298.6 |
| 50 | 298.5 | 297.6 | 298.7 |
| 55 | 298.6 | 297.6 | 298.7 |
| 60 | 298.4 | 297.7 | 298.8 |
| 65 | 298.6 | 298.4 | 300.3 |
| 70 | 299.2 | 301.6 | 301.9 |
| 75 | 301.0 | 305.4 | 302.7 |
| 80 | 303.1 | 307.3 | 304.3 |
| 85 | 304.8 | 306.2 | 304.6 |
| 90 | 305.8 | 306.1 | 306.1 |
| 95 | 306.2 | 306.2 | 306.4 |
| 100 | 306.5 | 306.2 | 306.9 |
| 105 | 306.6 | 306.2 | 306.7 |
| 110 | 306.5 | 306.3 | 306.9 |
| 115 | 306.5 | 306.2 | 306.8 |
| 120 | 306.6 | 306.2 | 306.9 |
| 125 | 306.6 | 306.3 | 306.9 |
| 130 | 306.6 | 306.3 | 306.8 |
| 135 | 306.5 | 306.3 | 306.7 |
| 140 | 306.5 | 306.3 | 306.6 |
| 145 | 306.5 | 306.2 | 306.7 |
| 150 | 306.6 | 306.2 | 306.6 |
| 155 | 306.5 | 306.2 | 306.7 |
| 160 | 306.5 | 306.1 | 306.7 |
| 165 | 306.5 | 306.2 | 306.6 |
| 170 | 306.5 | 306.2 | 306.6 |
| 175 | 306.4 | 306.2 | 306.7 |
| 180 | 306.5 | 306.2 | 306.6 |
| 185 | 306.5 | 306.1 | 306.6 |
| 190 | 306.5 | 306.1 | 306.5 |
| 195 | 306.5 | 306.1 | 306.5 |
| 200 | 306.5 | 306.2 | 306.6 |
| 205 | 306.5 | 306.1 | 306.5 |
| 210 | 306.5 | 306.1 | 306.5 |
| 215 | 306.4 | 306.1 | 306.5 |
| 220 | 306.4 | 306.1 | 306.5 |
| 225 | 306.3 | 306.2 | 306.5 |
| 230 | 306.3 | 306.1 | 306.5 |
| 235 | 306.3 | 306.1 | 306.4 |
| 240 | 306.3 | 306.0 | 306.3 |
| 245 | 306.4 | 306.1 | 306.5 |
| 250 | 306.4 | 306.0 | 306.4 |
| 255 | 306.3 | 306.1 | 306.4 |
| 260 | 306.4 | 306.0 | 306.3 |
| 265 | 306.4 | 306.1 | 306.2 |
| 270 | 306.2 | 306.1 | 306.1 |
| 275 | 306.4 | 306.1 | 306.2 |
| 280 | 306.3 | 306.1 | 306.2 |
| 285 | 306.2 | 306.0 | 306.1 |
| 290 | 306.2 | 306.0 | 306.2 |
| 295 | 306.2 | 306.1 | 306.1 |

| | | | |
|-----|-------|-------|-------|
| 300 | 306.2 | 306.0 | 306.1 |
| 305 | 306.2 | 306.1 | 306.0 |
| 310 | 306.2 | 306.0 | 306.1 |
| 315 | 306.3 | 306.0 | 306.0 |
| 320 | 306.2 | 306.1 | 305.9 |
| 325 | 306.2 | 306.0 | 306.1 |
| 330 | 306.1 | 306.0 | 306.0 |
| 335 | 306.2 | 306.0 | 305.9 |
| 340 | 306.1 | 306.0 | 305.9 |
| 345 | 306.2 | 306.0 | 305.9 |
| 350 | 306.1 | 306.0 | 305.9 |
| 355 | 306.2 | 306.0 | 305.9 |
| 360 | 306.1 | 306.0 | 305.9 |
| 365 | 306.2 | 306.0 | 305.9 |
| 370 | 306.1 | 306.0 | 305.9 |
| 375 | 306.1 | 305.9 | 305.8 |
| 380 | 306.2 | 306.0 | 305.9 |
| 385 | 306.2 | 306.1 | 305.9 |
| 390 | 306.0 | 306.0 | 305.8 |
| 395 | 306.0 | 305.9 | 305.9 |
| 400 | 306.1 | 306.0 | 305.8 |
| 405 | 306.1 | 305.7 | 305.7 |
| 410 | 306.0 | 305.9 | 305.6 |
| 415 | 306.1 | 305.9 | 305.8 |
| 420 | 306.1 | 305.9 | 305.8 |
| 425 | 306.0 | 305.9 | 305.7 |
| 430 | 305.9 | 305.8 | 305.6 |
| 435 | 306.1 | 305.9 | 305.7 |
| 440 | 305.9 | 305.8 | 305.7 |
| 445 | 306.0 | 305.8 | 305.6 |
| 450 | 306.1 | 305.7 | 305.7 |
| 455 | 305.9 | 305.8 | 305.7 |
| 460 | 305.9 | 305.9 | 305.6 |
| 465 | 306.0 | 305.8 | 305.6 |
| 470 | 306.0 | 305.8 | 305.7 |
| 475 | 306.0 | 305.9 | 305.6 |
| 480 | 306.0 | 305.8 | 305.6 |
| 485 | 305.9 | 305.8 | 305.6 |
| 490 | 305.8 | 305.8 | 305.6 |
| 495 | 306.0 | 305.8 | 305.6 |
| 500 | 305.8 | 305.9 | 305.5 |
| 505 | 305.8 | 305.8 | 305.5 |
| 510 | 306.0 | 305.7 | 305.5 |
| 515 | 305.9 | 305.8 | 305.5 |
| 520 | 305.9 | 305.7 | 305.5 |
| 525 | 306.0 | 305.8 | 305.4 |
| 530 | 305.9 | 305.7 | 305.5 |
| 535 | 305.9 | 305.7 | 305.4 |
| 540 | 305.7 | 305.7 | 305.4 |
| 545 | 305.9 | 305.8 | 305.5 |
| 550 | 305.9 | 305.7 | 305.4 |
| 555 | 305.7 | 305.9 | 305.4 |
| 560 | 305.9 | 305.7 | 305.3 |
| 565 | 305.7 | 305.7 | 305.5 |
| 570 | 305.8 | 305.7 | 305.3 |
| 575 | 305.7 | 305.6 | 305.3 |
| 580 | 305.8 | 305.7 | 305.3 |
| 585 | 305.7 | 305.6 | 305.3 |
| 590 | 305.8 | 305.5 | 305.3 |
| 595 | 305.7 | 305.7 | 305.2 |
| 600 | 305.7 | 305.5 | 305.3 |

* Temperature Reading from Data
Logger – (Kelvin \pm 0.1)

Ca(OH)₂

**Table 4: Temperature Reading for
Reaction 1 of Ca(OH)₂**

| TIME | TRIAL 1 * | TRIAL 2 * | TRIAL 3 * |
|------|-----------|-----------|-----------|
| 0 | 298.3 | 297.9 | 298.1 |
| 5 | 298.4 | 297.9 | 298.1 |
| 10 | 298.3 | 297.9 | 298.1 |
| 15 | 298.3 | 297.9 | 298.1 |
| 20 | 298.3 | 297.9 | 298.1 |
| 25 | 298.3 | 297.9 | 298.2 |
| 30 | 298.4 | 297.9 | 298.1 |
| 35 | 298.3 | 297.9 | 298.1 |
| 40 | 298.3 | 297.9 | 298.2 |
| 45 | 298.2 | 297.9 | 298.2 |
| 50 | 298.3 | 297.9 | 298.1 |
| 55 | 298.4 | 297.9 | 298.1 |
| 60 | 298.4 | 297.9 | 298.1 |
| 65 | 298.3 | 297.9 | 298.2 |
| 70 | 298.8 | 298.8 | 298.5 |
| 75 | 298.8 | 298.9 | 298.6 |
| 80 | 298.2 | 298.8 | 298.6 |
| 85 | 298.6 | 298.9 | 298.6 |
| 90 | 298.6 | 298.9 | 298.6 |
| 95 | 298.6 | 298.8 | 298.6 |
| 100 | 298.6 | 298.8 | 298.6 |
| 105 | 298.6 | 298.8 | 298.6 |
| 110 | 298.6 | 298.8 | 298.6 |
| 115 | 298.6 | 298.8 | 298.6 |
| 120 | 298.8 | 298.8 | 298.6 |
| 125 | 298.6 | 298.8 | 298.6 |
| 130 | 298.6 | 298.7 | 298.6 |
| 135 | 298.6 | 298.6 | 298.6 |
| 140 | 298.6 | 298.8 | 298.6 |
| 145 | 298.5 | 298.8 | 298.6 |
| 150 | 298.6 | 298.7 | 298.6 |
| 155 | 298.7 | 298.7 | 298.5 |
| 160 | 298.7 | 298.7 | 298.6 |
| 165 | 298.6 | 298.7 | 298.6 |
| 170 | 298.6 | 298.7 | 298.6 |
| 175 | 298.7 | 298.7 | 298.6 |
| 180 | 298.6 | 298.6 | 298.5 |
| 185 | 298.6 | 298.7 | 298.6 |
| 190 | 298.7 | 298.7 | 298.6 |
| 195 | 298.7 | 298.6 | 298.6 |
| 200 | 298.6 | 298.7 | 298.6 |
| 205 | 298.6 | 298.6 | 298.6 |
| 210 | 298.7 | 298.7 | 298.6 |
| 215 | 298.8 | 298.6 | 298.5 |
| 220 | 298.6 | 298.7 | 298.5 |
| 225 | 298.6 | 298.6 | 298.6 |
| 230 | 298.7 | 298.6 | 298.5 |
| 235 | 298.6 | 298.6 | 298.5 |
| 240 | 298.6 | 298.6 | 298.6 |
| 245 | 298.8 | 298.7 | 298.5 |
| 250 | 298.6 | 298.6 | 298.5 |
| 255 | 298.6 | 298.6 | 298.6 |
| 260 | 298.5 | 298.6 | 298.5 |
| 265 | 298.7 | 298.6 | 298.5 |
| 270 | 298.5 | 298.5 | 298.5 |
| 275 | 298.6 | 298.5 | 298.6 |
| 280 | 298.5 | 298.5 | 298.5 |
| 285 | 298.6 | 298.4 | 298.5 |
| 290 | 298.6 | 298.5 | 298.5 |
| 295 | 298.5 | 298.5 | 298.5 |

| | | | |
|---|-------|-------|-------|
| 300 | 298.6 | 298.6 | 298.5 |
| 305 | 298.6 | 298.6 | 298.6 |
| 310 | 298.6 | 298.6 | 298.5 |
| 315 | 298.6 | 298.6 | 298.5 |
| 320 | 298.5 | 298.6 | 298.5 |
| 325 | 298.6 | 298.5 | 298.5 |
| 330 | 298.5 | 298.6 | 298.5 |
| 335 | 298.6 | 298.5 | 298.5 |
| 340 | 298.6 | 298.6 | 298.5 |
| 345 | 298.6 | 298.6 | 298.5 |
| 350 | 298.6 | 298.6 | 298.5 |
| 355 | 298.5 | 298.6 | 298.5 |
| 360 | 298.6 | 298.5 | 298.4 |
| 365 | 298.5 | 298.5 | 298.5 |
| 370 | 298.5 | 298.6 | 298.5 |
| 375 | 298.6 | 298.6 | 298.5 |
| 380 | 298.5 | 298.6 | 298.5 |
| 385 | 298.5 | 298.5 | 298.5 |
| 390 | 298.5 | 298.4 | 298.5 |
| 395 | 298.6 | 298.4 | 298.4 |
| 400 | 298.5 | 298.4 | 298.4 |
| 405 | 298.5 | 298.5 | 298.5 |
| 410 | 298.5 | 298.4 | 298.4 |
| 415 | 298.5 | 298.5 | 298.5 |
| 420 | 298.5 | 298.5 | 298.4 |
| 425 | 298.5 | 298.4 | 298.5 |
| 430 | 298.5 | 298.4 | 298.5 |
| 435 | 298.5 | 298.4 | 298.5 |
| 440 | 298.5 | 298.4 | 298.5 |
| 445 | 298.5 | 298.4 | 298.4 |
| 450 | 298.5 | 298.4 | 298.5 |
| 455 | 298.5 | 298.4 | 298.5 |
| 460 | 298.5 | 298.4 | 298.5 |
| 465 | 298.5 | 298.4 | 298.5 |
| 470 | 298.5 | 298.4 | 298.5 |
| 475 | 298.5 | 298.3 | 298.4 |
| 480 | 298.5 | 298.4 | 298.5 |
| 485 | 298.5 | 298.4 | 298.5 |
| 490 | 298.4 | 298.4 | 298.5 |
| 495 | 298.4 | 298.4 | 298.4 |
| 500 | 298.4 | 298.4 | 298.4 |
| 505 | 298.4 | 298.3 | 298.4 |
| 510 | 298.4 | 298.3 | 298.4 |
| 515 | 298.4 | 298.4 | 298.4 |
| 520 | 298.4 | 298.4 | 298.4 |
| 525 | 298.5 | 298.3 | 298.4 |
| 530 | 298.5 | 298.4 | 298.4 |
| 535 | 298.4 | 298.3 | 298.4 |
| 540 | 298.5 | 298.3 | 298.4 |
| 545 | 298.5 | 298.3 | 298.4 |
| 550 | 298.4 | 298.4 | 298.4 |
| 555 | 298.5 | 298.4 | 298.3 |
| 560 | 298.4 | 298.3 | 298.4 |
| 565 | 298.4 | 298.3 | 298.4 |
| 570 | 298.4 | 298.3 | 298.4 |
| 575 | 298.4 | 298.3 | 298.3 |
| 580 | 298.4 | 298.3 | 298.4 |
| 585 | 298.4 | 298.4 | 298.4 |
| 590 | 298.4 | 298.3 | 298.4 |
| 595 | 298.4 | 298.3 | 298.3 |
| 600 | 298.4 | 298.3 | 298.4 |
| * Temperature Reading from Data Logger – (K ± 0.1) | | | |

Ba(OH)₂

**Table 5: Temperature Reading for
Reaction 1 of Ba(OH)₂**

| TIME | TRIAL 1 * | TRIAL 2 * | TRIAL 3 * |
|------|-----------|-----------|-----------|
| 0 | 298 | 297.9 | 297.6 |
| 5 | 298.1 | 297.9 | 297.6 |
| 10 | 298.1 | 297.9 | 297.6 |
| 15 | 298.1 | 297.8 | 297.6 |
| 20 | 298.1 | 297.9 | 297.6 |
| 25 | 298.1 | 297.9 | 297.6 |
| 30 | 298.1 | 297.9 | 297.6 |
| 35 | 297.9 | 297.9 | 297.6 |
| 40 | 297.9 | 298.0 | 297.6 |
| 45 | 298 | 297.9 | 297.6 |
| 50 | 298.1 | 297.9 | 297.6 |
| 55 | 297.9 | 297.9 | 297.6 |
| 60 | 298 | 297.9 | 297.6 |
| 65 | 297.8 | 297.2 | 297.6 |
| 70 | 296.3 | 295.6 | 295.9 |
| 75 | 295.4 | 294.5 | 294.8 |
| 80 | 295.3 | 294.4 | 294.7 |
| 85 | 295.1 | 294.5 | 294.8 |
| 90 | 295.2 | 294.4 | 294.8 |
| 95 | 295.4 | 294.5 | 294.8 |
| 100 | 295.4 | 294.4 | 294.8 |
| 105 | 295.4 | 294.5 | 294.8 |
| 110 | 295.4 | 294.4 | 294.5 |
| 115 | 295.4 | 294.5 | 294.6 |
| 120 | 295.3 | 294.5 | 294.7 |
| 125 | 295.5 | 294.5 | 294.7 |
| 130 | 295.3 | 294.5 | 294.8 |
| 135 | 295.4 | 294.5 | 294.8 |
| 140 | 295.4 | 294.4 | 294.7 |
| 145 | 295.4 | 294.5 | 294.7 |
| 150 | 295.4 | 294.5 | 294.7 |
| 155 | 295.4 | 294.5 | 294.8 |
| 160 | 295.4 | 294.6 | 294.8 |
| 165 | 295.5 | 294.6 | 294.7 |
| 170 | 295.4 | 294.6 | 294.8 |
| 175 | 295.6 | 294.6 | 294.7 |
| 180 | 295.4 | 294.4 | 294.7 |
| 185 | 295.5 | 294.6 | 294.7 |
| 190 | 295.4 | 294.5 | 294.7 |
| 195 | 295.4 | 294.5 | 294.8 |
| 200 | 295.5 | 294.6 | 294.8 |
| 205 | 295.4 | 294.6 | 294.7 |
| 210 | 295.4 | 294.6 | 294.8 |
| 215 | 295.3 | 294.7 | 294.8 |
| 220 | 295.7 | 294.9 | 294.8 |
| 225 | 295.4 | 294.7 | 295.0 |
| 230 | 295.6 | 294.7 | 294.9 |
| 235 | 295.7 | 294.7 | 294.9 |
| 240 | 295.4 | 294.7 | 294.9 |
| 245 | 295.7 | 294.8 | 294.9 |
| 250 | 295.6 | 294.8 | 295.0 |
| 255 | 295.6 | 294.9 | 294.9 |
| 260 | 295.7 | 294.7 | 294.9 |
| 265 | 295.7 | 294.9 | 295.1 |
| 270 | 295.7 | 294.8 | 295.1 |
| 275 | 295.6 | 294.9 | 295.1 |
| 280 | 295.6 | 295.0 | 295.1 |
| 285 | 295.7 | 295.0 | 294.9 |
| 290 | 295.7 | 295.1 | 295.1 |
| 295 | 295.7 | 295.0 | 295.1 |

| | | | |
|---|-------|-------|-------|
| 300 | 295.6 | 295.0 | 295.1 |
| 305 | 295.7 | 295.1 | 295.2 |
| 310 | 295.7 | 295.1 | 295.1 |
| 315 | 295.7 | 295.1 | 295.3 |
| 320 | 295.6 | 295.0 | 295.4 |
| 325 | 295.7 | 295.1 | 295.2 |
| 330 | 295.7 | 295.1 | 295.4 |
| 335 | 295.6 | 295.0 | 295.3 |
| 340 | 295.7 | 295.1 | 295.3 |
| 345 | 295.7 | 295.0 | 295.3 |
| 350 | 295.7 | 295.1 | 295.3 |
| 355 | 295.7 | 295.1 | 295.3 |
| 360 | 295.7 | 295.1 | 295.4 |
| 365 | 295.7 | 295.1 | 295.4 |
| 370 | 295.7 | 295.3 | 295.4 |
| 375 | 295.9 | 295.4 | 295.4 |
| 380 | 295.7 | 295.3 | 295.4 |
| 385 | 295.8 | 295.3 | 295.4 |
| 390 | 295.6 | 295.3 | 295.5 |
| 395 | 295.9 | 295.4 | 295.5 |
| 400 | 295.7 | 295.2 | 295.5 |
| 405 | 295.7 | 295.3 | 295.5 |
| 410 | 295.7 | 295.4 | 295.5 |
| 415 | 295.7 | 295.3 | 295.5 |
| 420 | 295.8 | 295.3 | 295.6 |
| 425 | 295.8 | 295.3 | 295.5 |
| 430 | 295.8 | 295.4 | 295.6 |
| 435 | 295.8 | 295.4 | 295.5 |
| 440 | 295.8 | 295.4 | 295.6 |
| 445 | 295.9 | 295.4 | 295.5 |
| 450 | 295.9 | 295.6 | 295.6 |
| 455 | 295.8 | 295.4 | 295.6 |
| 460 | 295.9 | 295.5 | 295.6 |
| 465 | 295.8 | 295.5 | 295.5 |
| 470 | 295.9 | 295.5 | 295.6 |
| 475 | 295.8 | 295.4 | 295.7 |
| 480 | 295.9 | 295.5 | 295.9 |
| 485 | 295.9 | 295.5 | 295.6 |
| 490 | 295.9 | 295.5 | 295.7 |
| 495 | 295.9 | 295.5 | 295.8 |
| 500 | 295.9 | 295.7 | 295.6 |
| 505 | 295.9 | 295.6 | 295.8 |
| 510 | 295.9 | 295.7 | 295.7 |
| 515 | 295.9 | 295.4 | 295.8 |
| 520 | 296.0 | 295.6 | 295.7 |
| 525 | 295.9 | 295.6 | 295.8 |
| 530 | 296.0 | 295.5 | 295.7 |
| 535 | 296.0 | 295.6 | 295.8 |
| 540 | 296.0 | 295.6 | 295.7 |
| 545 | 296.0 | 295.6 | 295.8 |
| 550 | 295.9 | 295.6 | 295.8 |
| 555 | 296.0 | 295.6 | 295.8 |
| 560 | 296.2 | 295.7 | 295.8 |
| 565 | 296.1 | 295.6 | 295.8 |
| 570 | 296.0 | 295.7 | 295.8 |
| 575 | 296.2 | 295.6 | 295.9 |
| 580 | 296.1 | 295.7 | 295.8 |
| 585 | 296.2 | 295.7 | 295.8 |
| 590 | 296.1 | 295.7 | 295.9 |
| 595 | 296.1 | 295.6 | 295.9 |
| 600 | 296.1 | 295.7 | 295.9 |
| * Temperature Reading from Data Logger – (K ± 0.1) | | | |

Qualitative Data for Conducting Experiment

1. The calcium hydroxide was only partially soluble in water. When stirring with stirrer, powdered solid could still be felt at the bottom of the cup. After experiment, when emptying the cup, I saw the calcium hydroxide powder was still present at the bottom of the polystyrene cup. Therefore, experiment wasn't and couldn't be completed until all reactant disappears
2. The initial temperature for a second and third trial and all consecutive experiments was a little (about 0.5 K) higher than the previous. This is because, there wasn't enough time to wait for the polystyrene cup to completely return to room temperature. Additionally, since most reactions conducted were exothermic, the temperature of the surrounding was affected mildly.
3. In Barium Hydroxide reaction, the temperature swings/more unpredictable. This may be due to the limited solubility of Barium Hydroxide.
4. For Reaction 2, I only conducted each experiment for 300 seconds instead of the previous 600 seconds and only 2 trials. I did this, because I noticed from the reactions I had already conducted, that the reaction had a stable and predictable curve coming back to room temperature. Therefore, 300 seconds were sufficient. Additionally, since this was a secondary experiment, doing this was appropriate and would allow more than enough opportunity to collect the required data
5. If a trial did not support the others conducted, I re conducted the reaction again in order to get both reliable and correct data. This went well for the second reactions that I conducted and made my results unquestionable.
6. Each solid had different solubility, therefore, there was a difference in both rate of reaction and heat evolved.

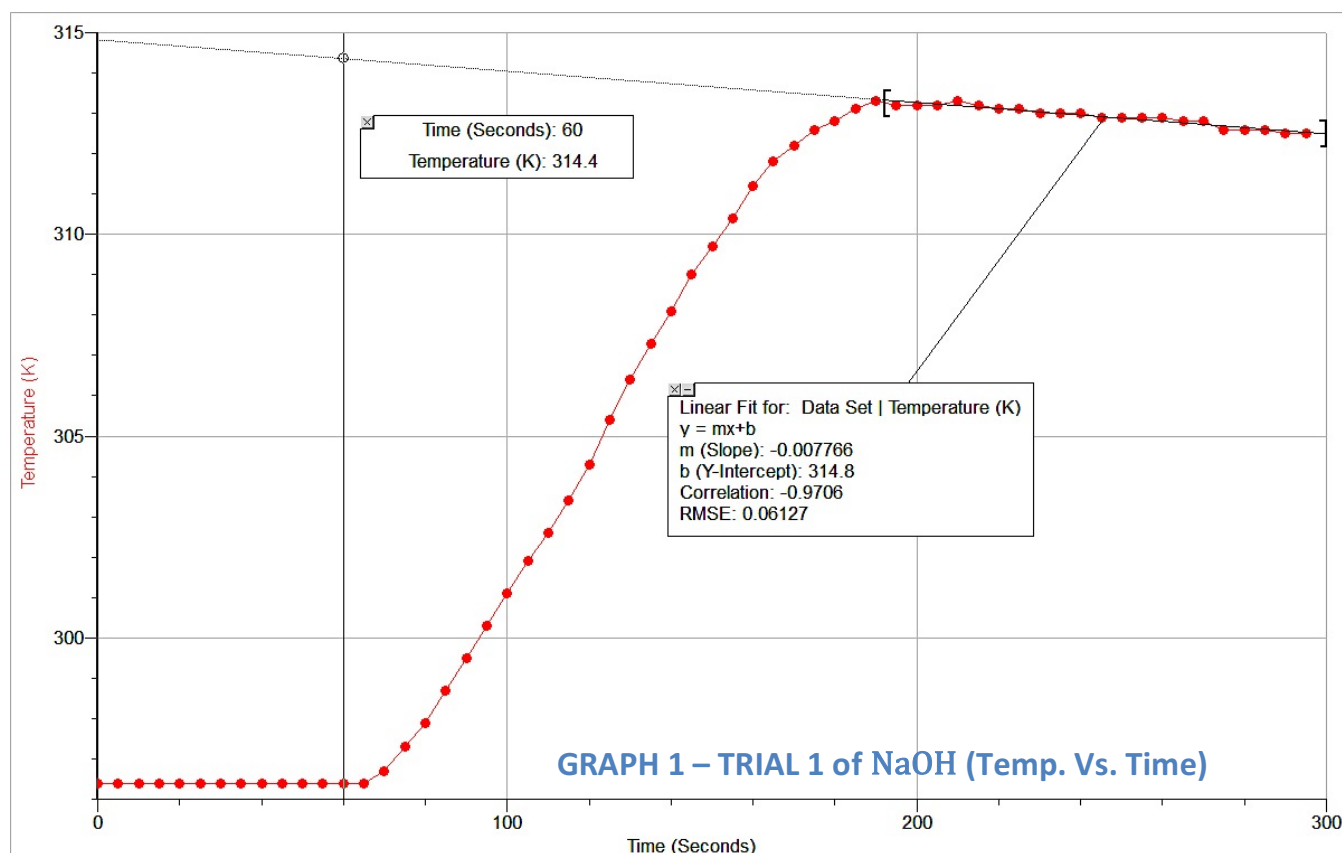
ASPECT 2 & 3: *PROCESSING and PRESENTING RAW DATA*

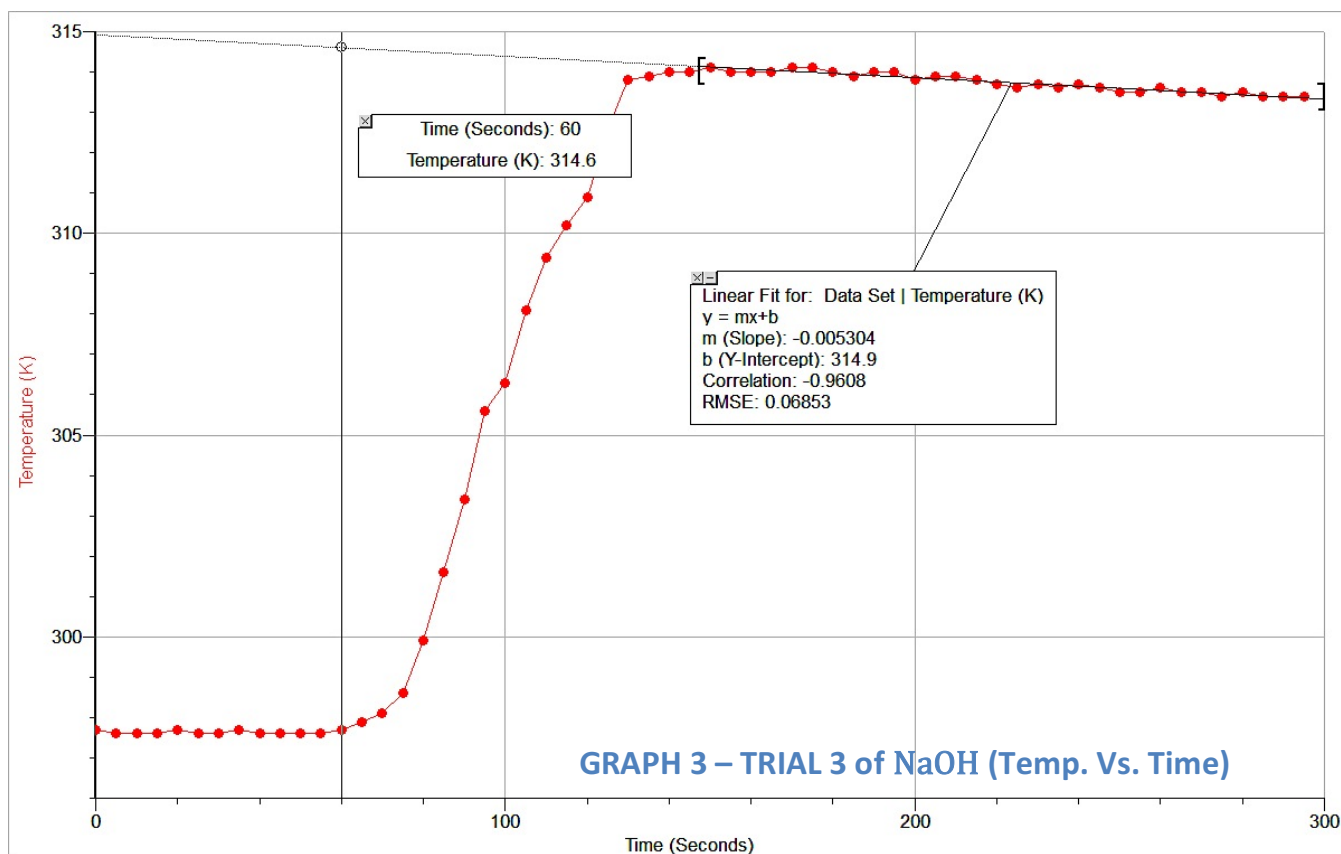
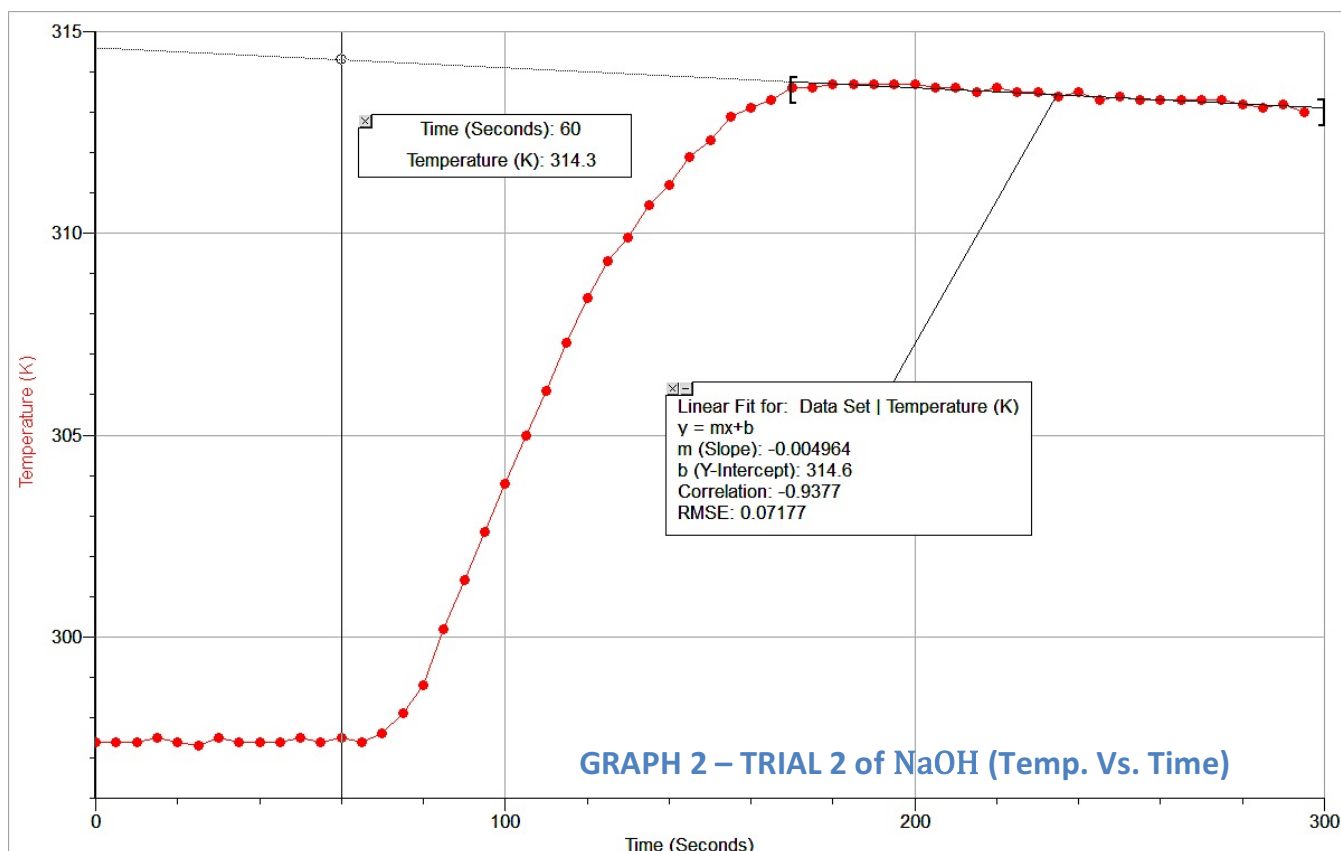
Using the data collected above, individual graphs were made for each trial, with temperature against time. Each graph was extrapolated, to calculate temperature with minimum energy lost to surroundings. Additionally, graphs were made with all three trials together, to evaluate both the accuracy and precision of readings relative to each other.

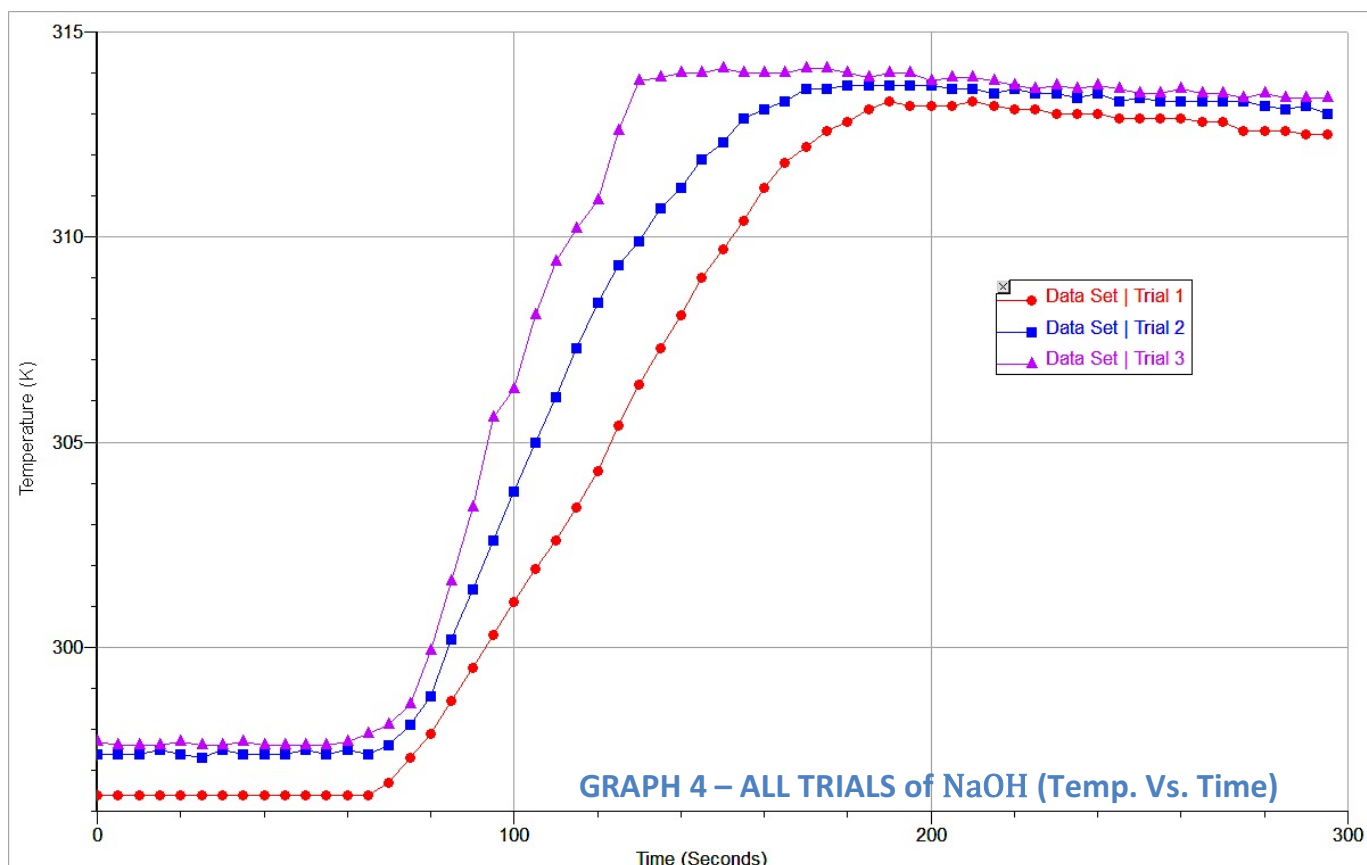
After each set of trials is extrapolated, a table of final maximum temperatures is created, to be used later in order to calculate enthalpy.

The linear fit described in the graph is the line that fits the data points when the liquid starts cooling or heating after attaining its maximum or minimum temperature respectively. It is this line that is extended to time=60s (since this was when the sample was added), and the corresponding value of temperature is found.

Graphs for NaOH







From the combined graphs, we can see that the “room temperature” or rather the container temperature at the start of the experiment between the three trails consecutively increased, but by small, and almost insignificant amounts. This variation will not lead to any great systematic or random errors because change of temperature is what will finally be used.

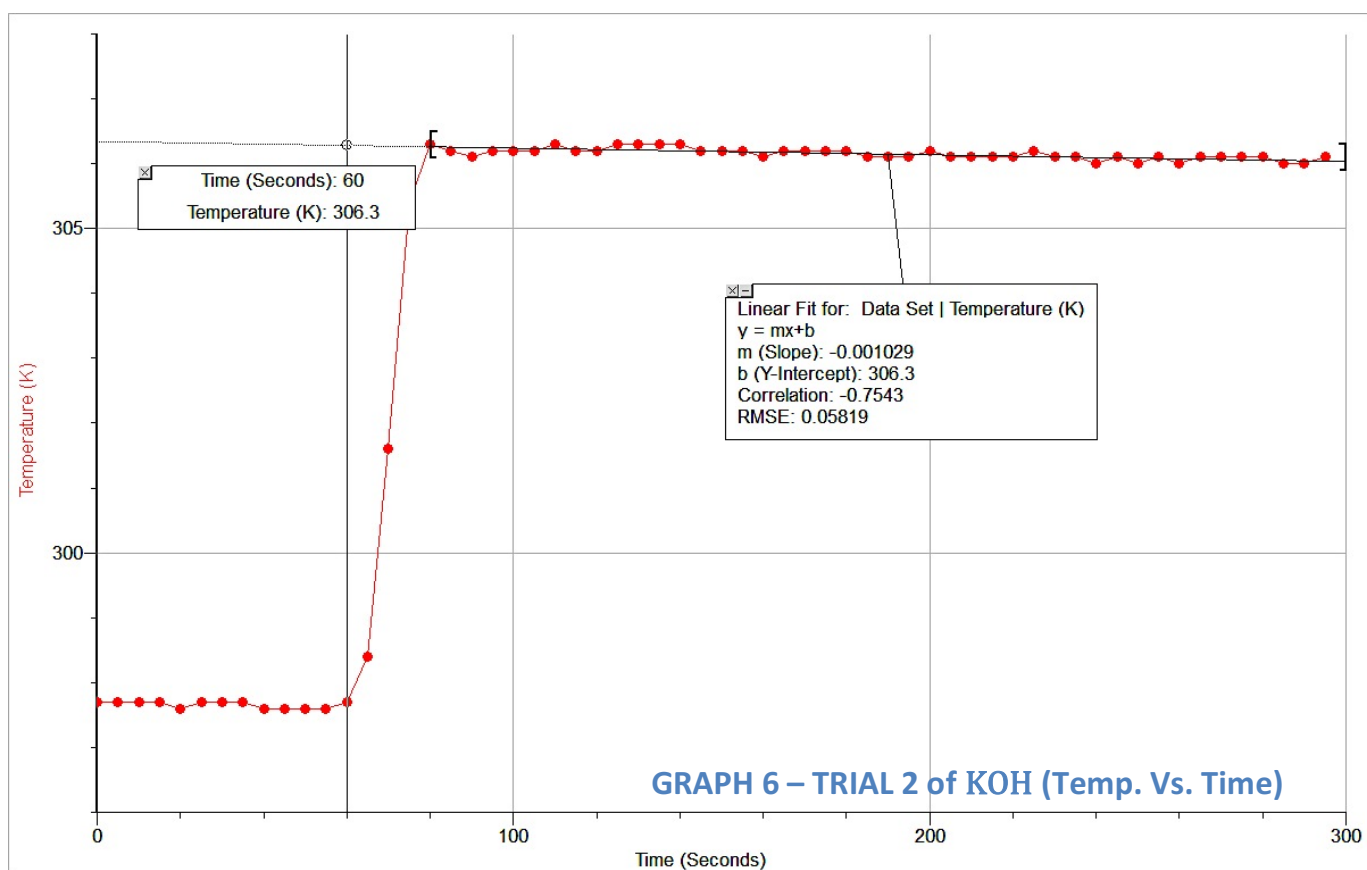
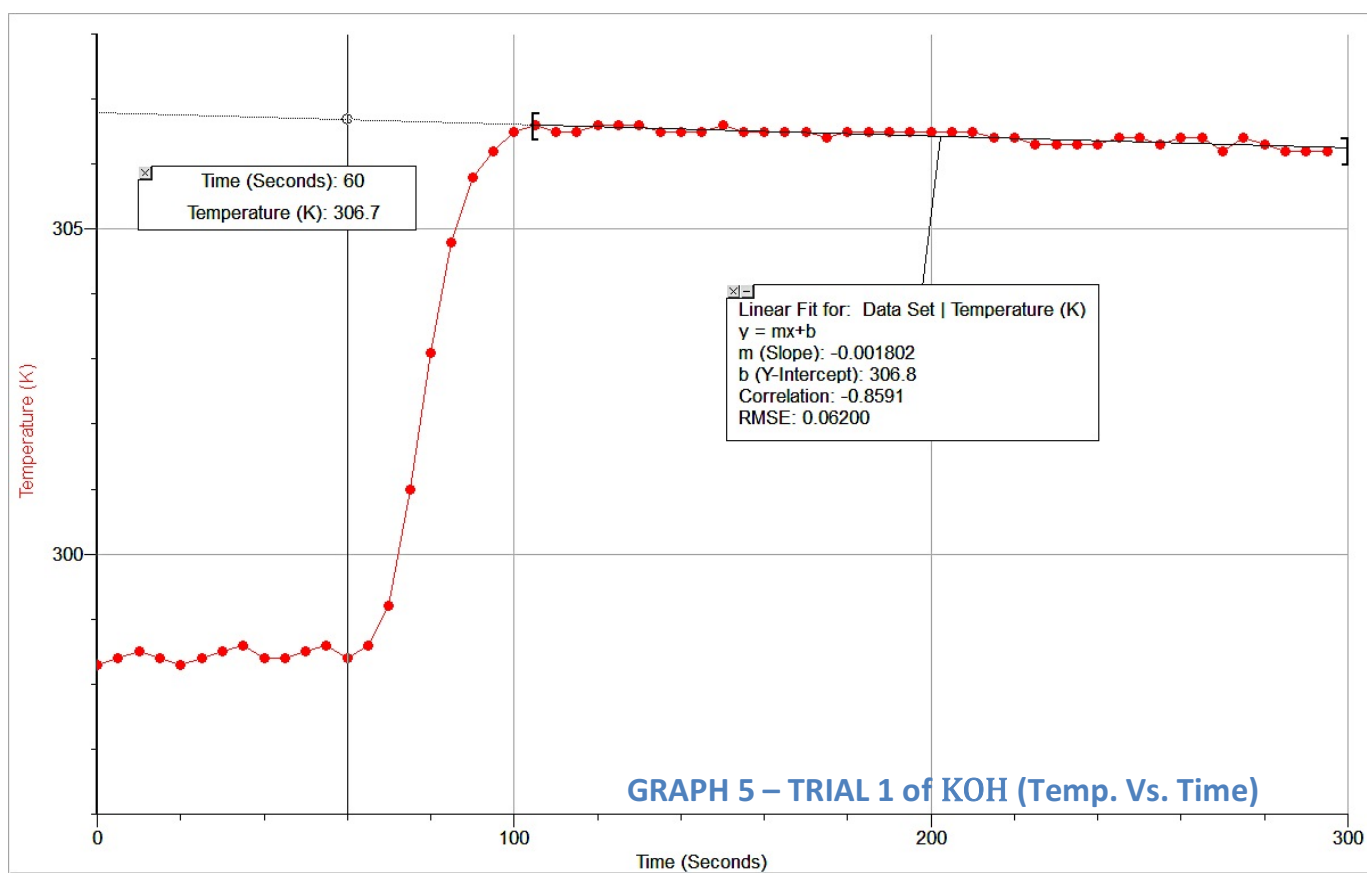
It can also be noticed that the three trials, reached about the same maximum temperature which means that the data is precise. However, the reactions took different times to reach this maximum, as seen by the three different curves. The 3rd trial especially took the smallest amount of time.

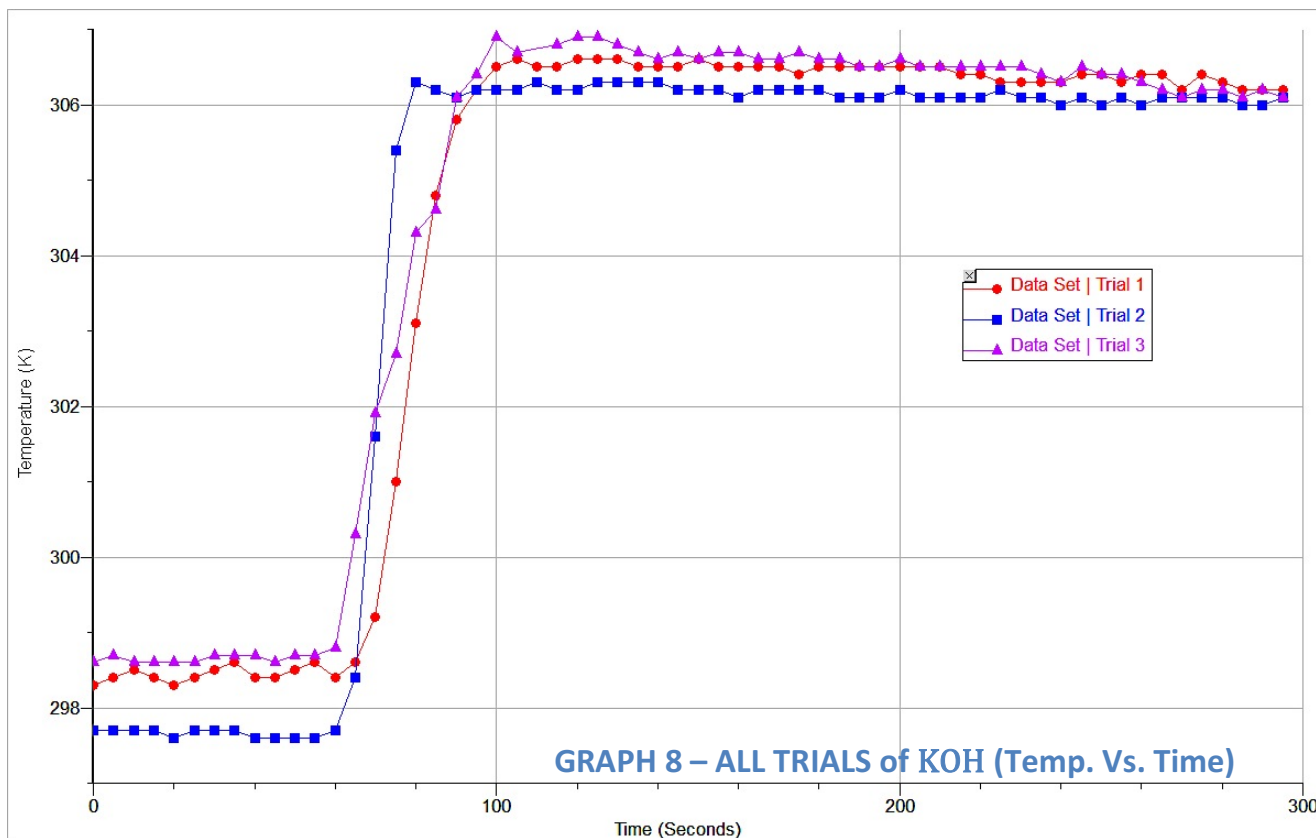
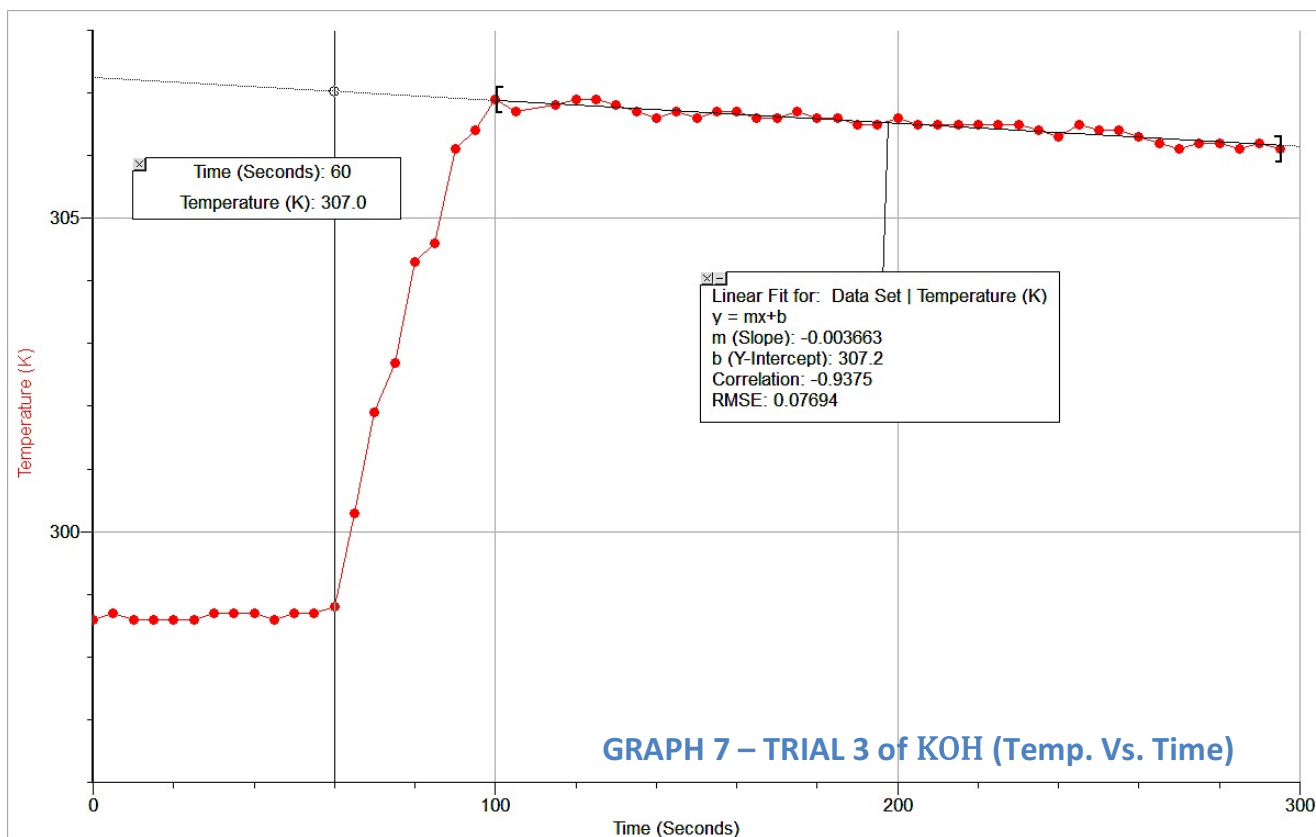
Finally singular graphs were extrapolated to further reduce the error caused due to loss of heat to surroundings. The data obtained is summarized below.

Summary Table –

| | Max. Temp. Reached (K) | Room Temperature | Extrapolated Temp. (K) | Absolute Uncertainty | Change in Temperature |
|-----------|------------------------|------------------|------------------------|----------------------|-----------------------|
| Trial 1 | 313.3 | 296.4 | 314.4 | 0.1°C | 18 |
| Trial 2 | 313.7 | 297.4 | 314.3 | 0.1°C | 16.9 |
| Trial 3 | 314.1 | 297.6 | 314.6 | 0.1°C | 17 |
| % Uncert. | ≈ 0.25% | ≈ 0.43% | ≈ 0.25% | | ≈ 1% |

Graphs for KOH





First we notice from the combined graphs that the room temperature was not exactly constant, however, again it does not make much of a difference since the change in temperature is being calculated here. However, it does create a slight difference, as the warmer the container is from room temperature, the less affect heat has on its final temperature, because at higher temperatures, heat loss has a greater effect.

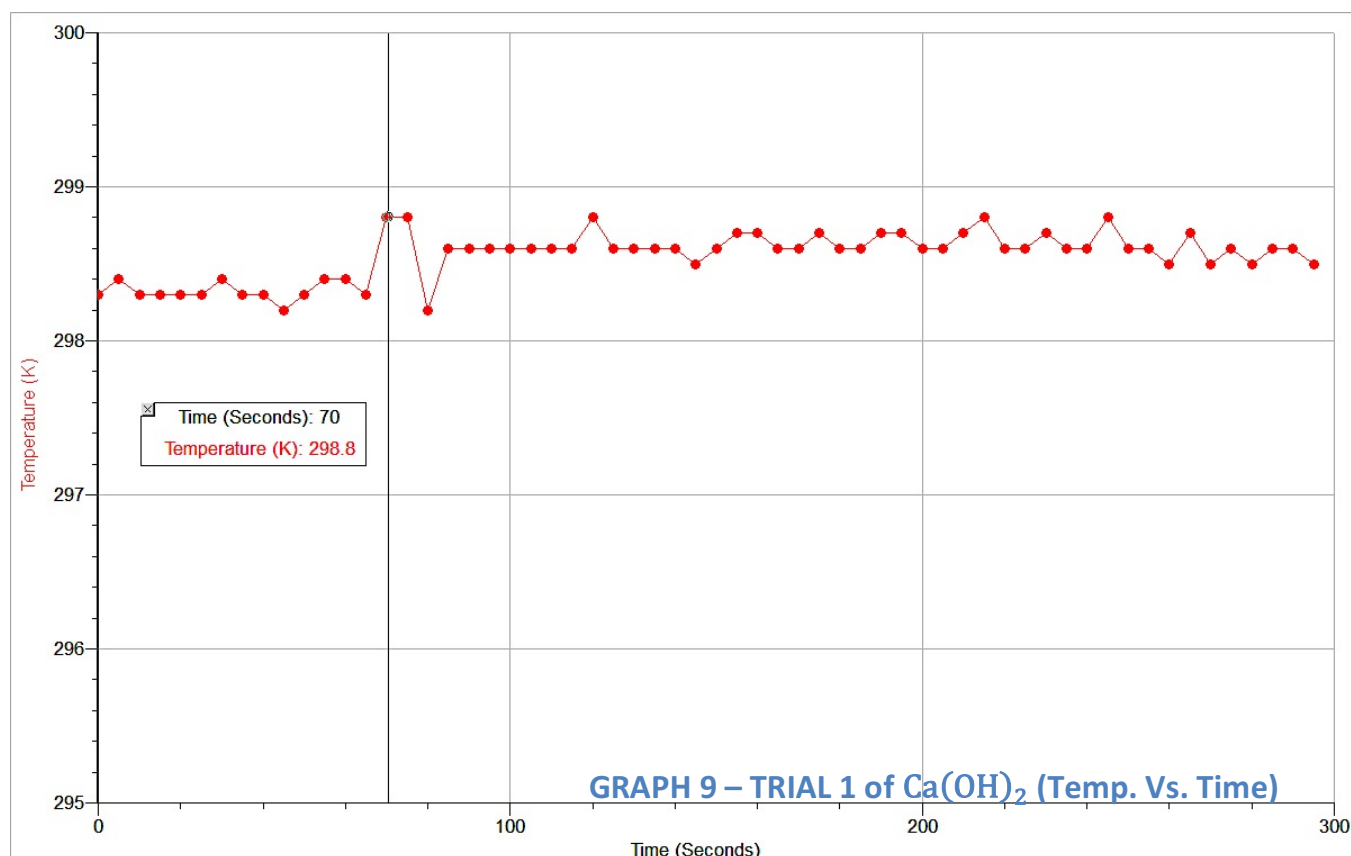
Since the temperatures reached in this experiment were lower than the one with NaOH, less heat was lost to the surrounding. This can also be seen by the minute change in maximum temperature and extrapolated temperature. Whereas in NaOH, the difference was about 0.4K, in this, the difference is one 0.1K.

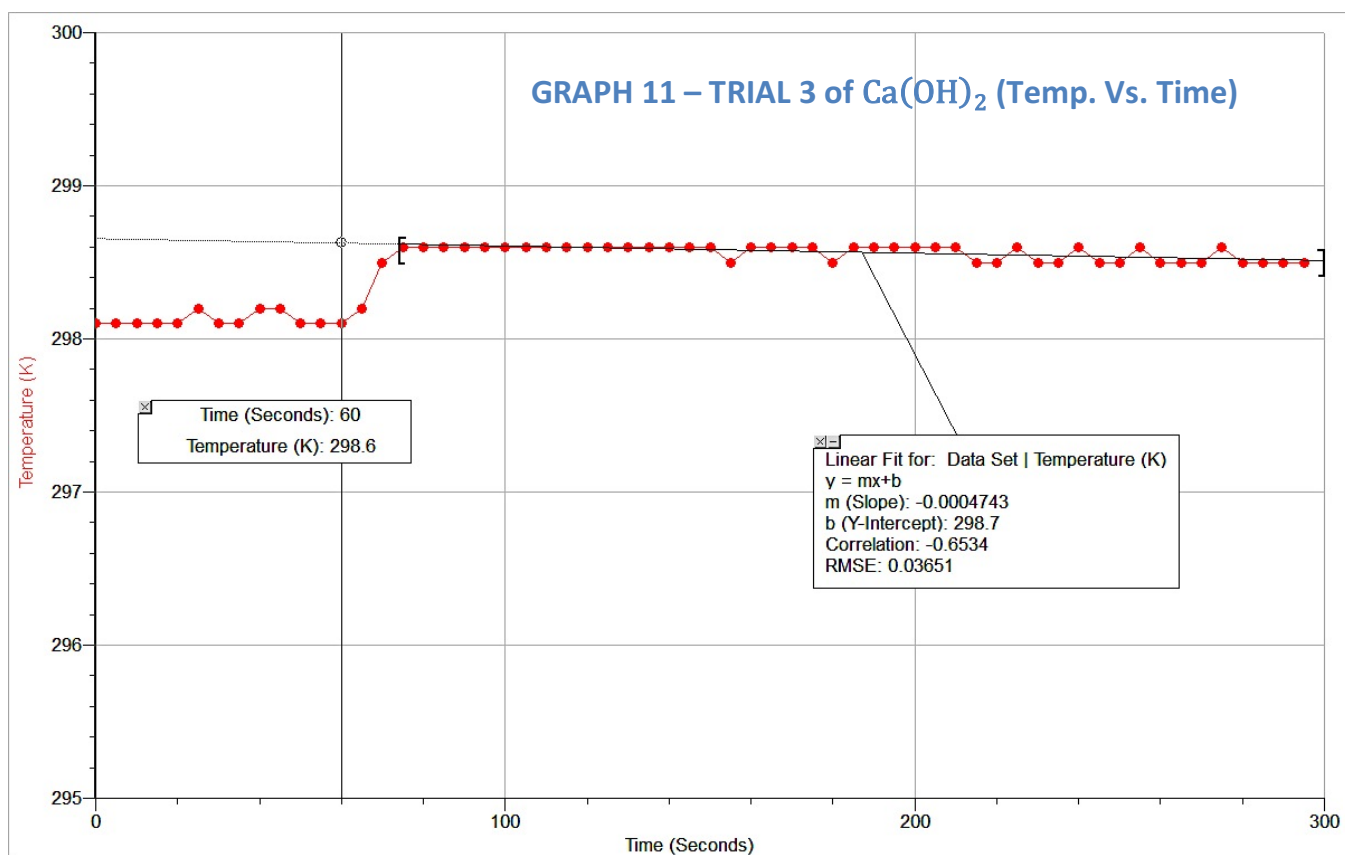
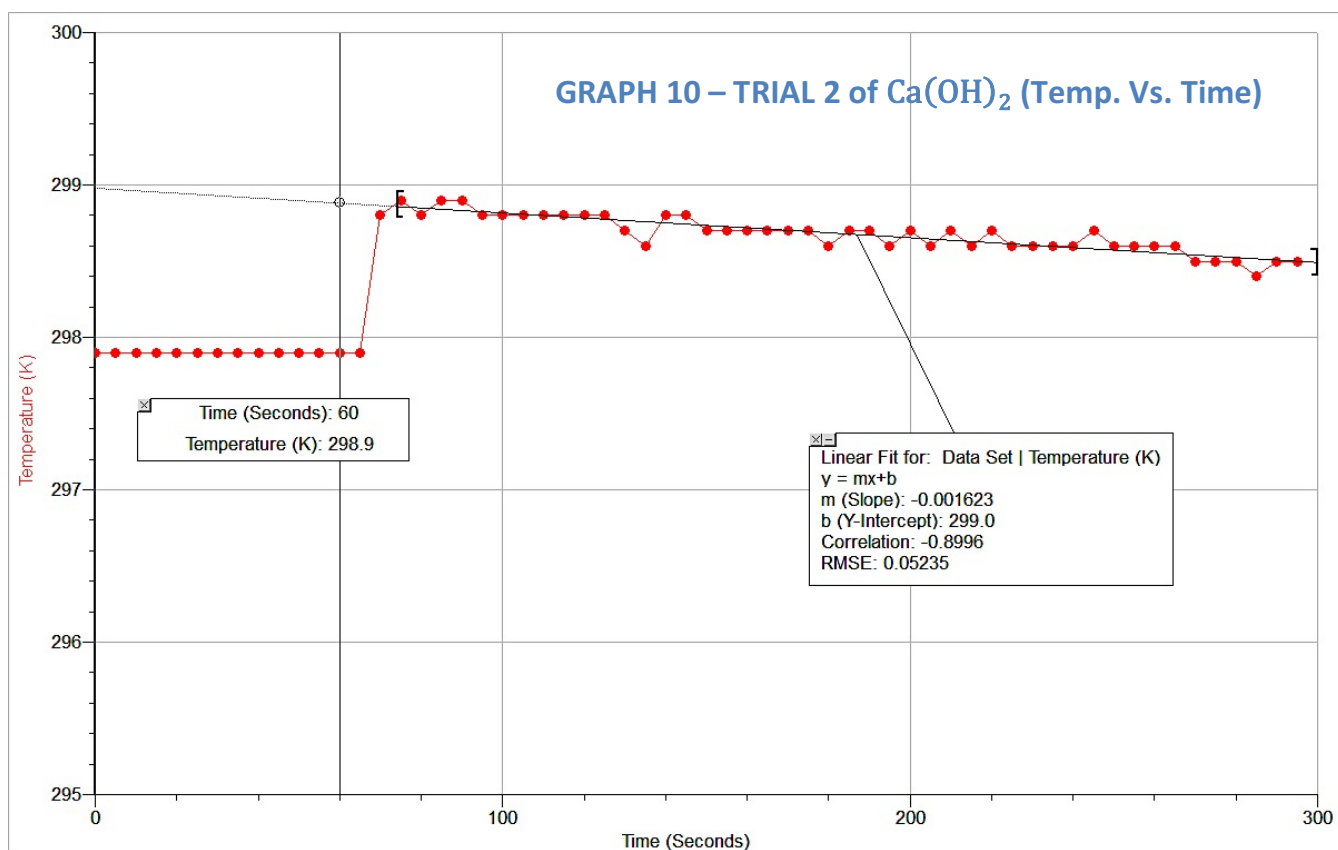
Finally singular graphs were extrapolated to further reduce the error caused due to loss of heat to surroundings. The data obtained is summarized below.

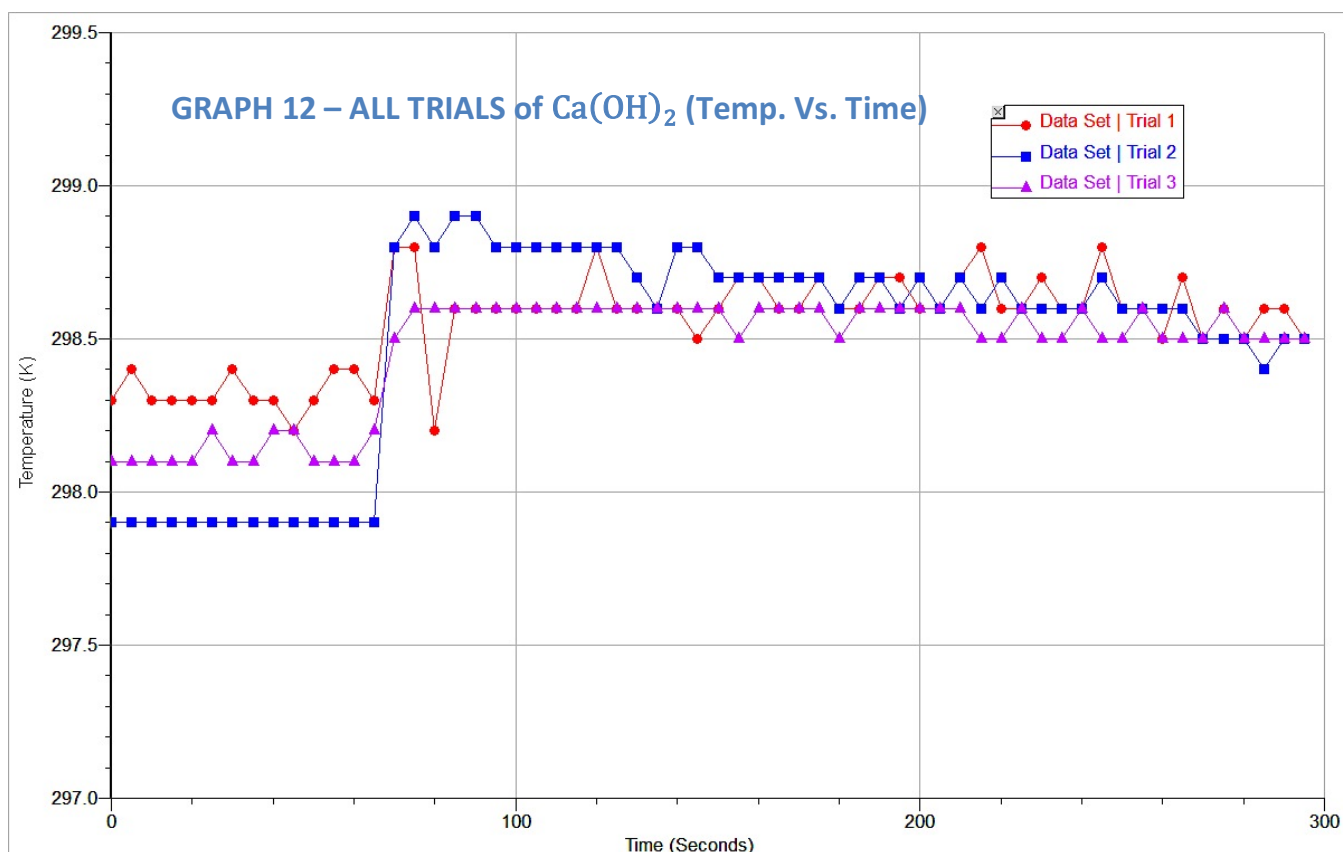
Summary Table –

| | Max. Temp. Reached (K) | Room Temperature | Extrapolated Temp. (K) | Absolute Uncertainty | Change in Temperature |
|-----------|------------------------|------------------|------------------------|----------------------|-----------------------|
| Trial 1 | 306.6 | 298.4 | 306.7 | 0.1°C | 8.3 |
| Trial 2 | 306.3 | 297.7 | 306.3 | 0.1°C | 8.6 |
| Trial 3 | 306.9 | 298.6 | 307.0 | 0.1°C | 8.4 |
| % Uncert. | ≈ 0.30% | ≈ 0.40% | ≈ 0.30% | | ≈ 2.5% |

Graphs for $\text{Ca}(\text{OH})_2$







The problem that was seen in this experiment was the limited solubility of calcium hydroxide. This proved to be a big problem, as it limited the change in temperature, so the rise in temperature was barely noticeable. Additionally, we don't know what percentage of the sample dissolved to result in that temperature. Hence, it has to be assumed that the whole sample reacted. This will add inaccuracy to enthalpy calculations conducted later.

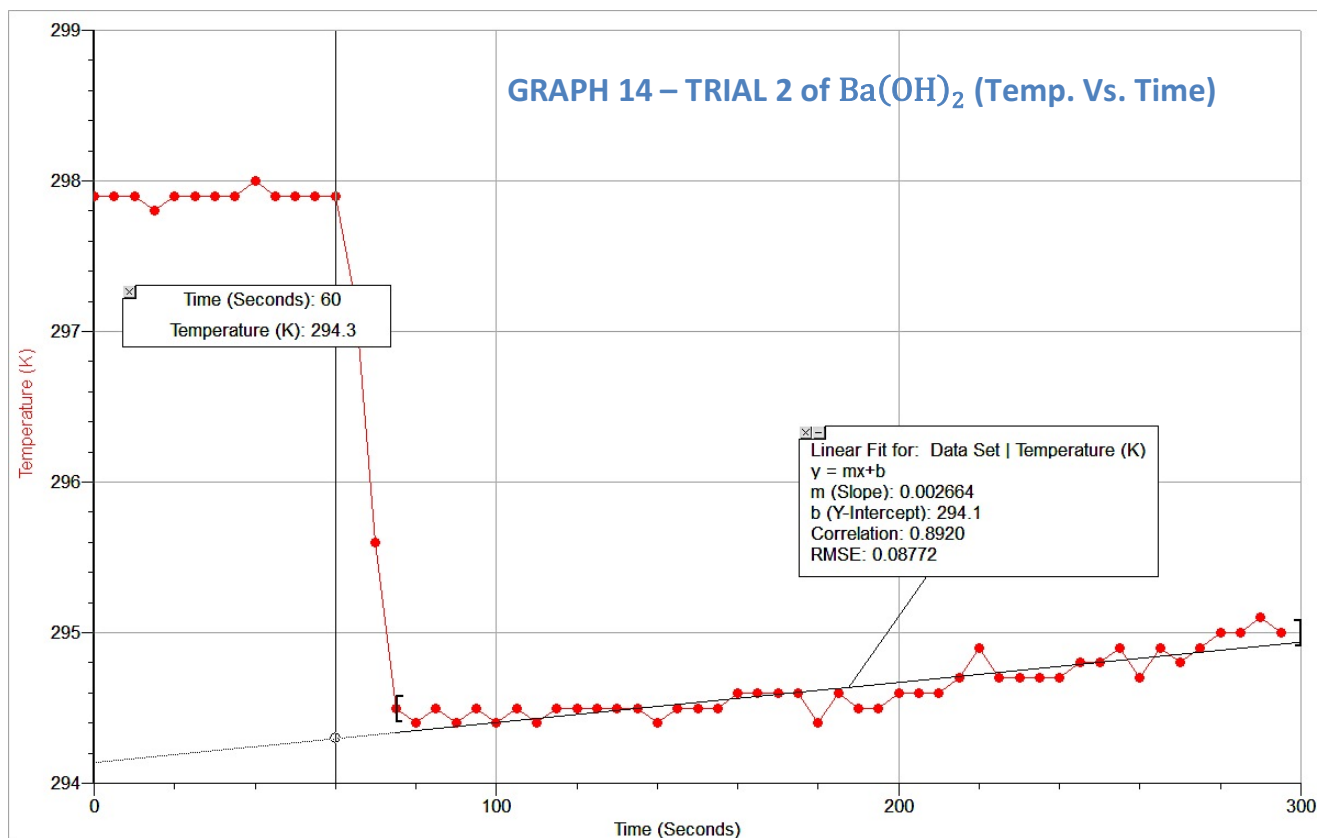
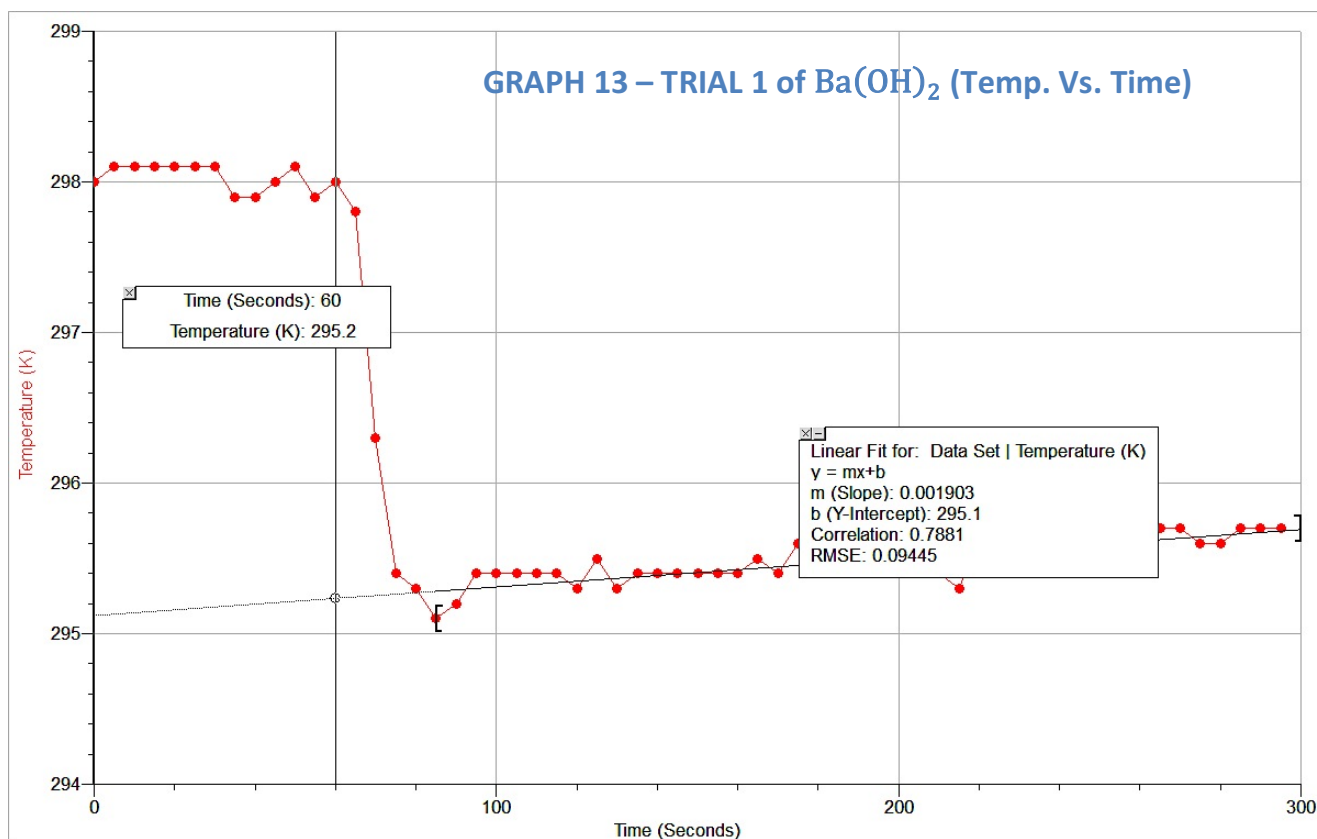
Since the temperatures reached in this experiment were even lower in this experiment compared to the previous two, the change from maximum temperature to extrapolated temperature is even lesser, often being exactly the same. This also proves that the higher the temperatures, hence the further the object from thermal equilibrium, the more heat energy is lost to the surroundings.

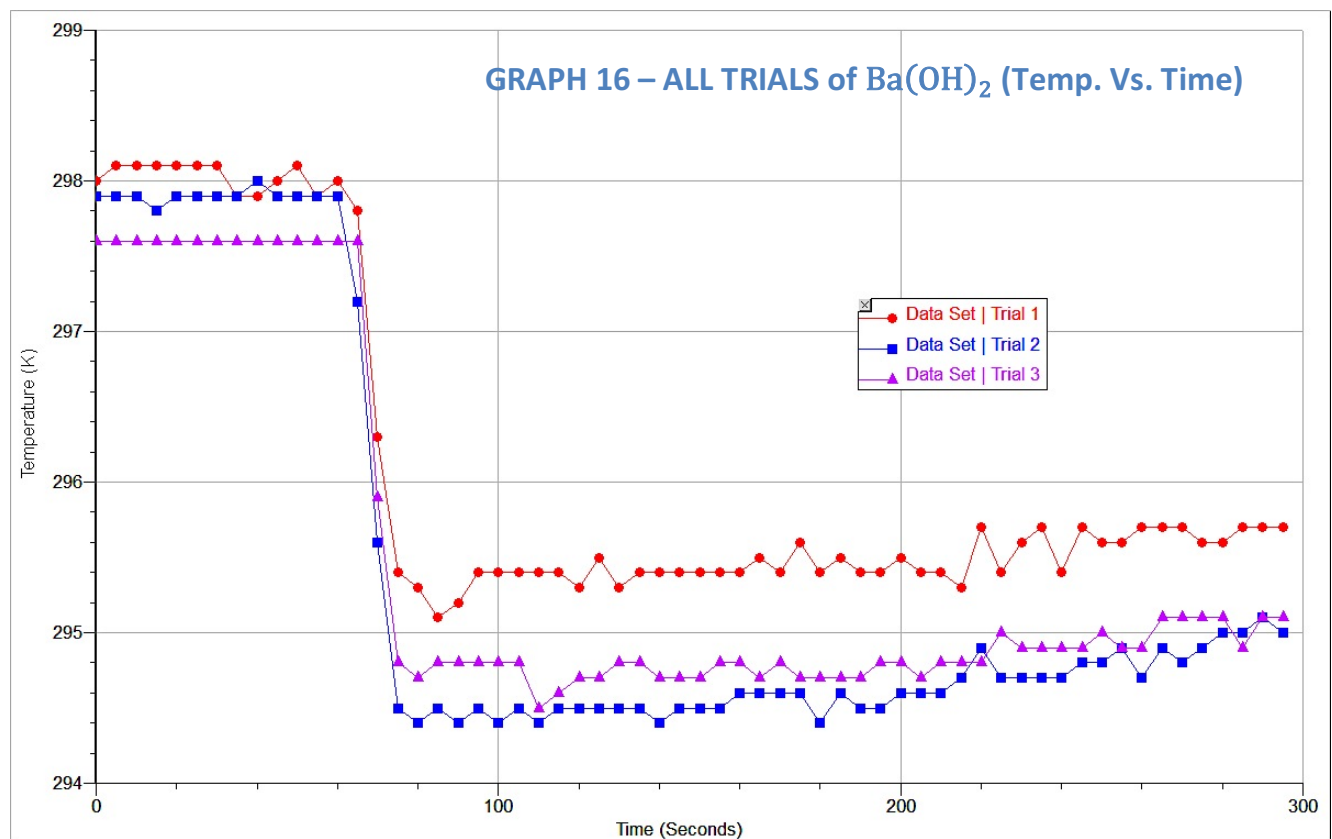
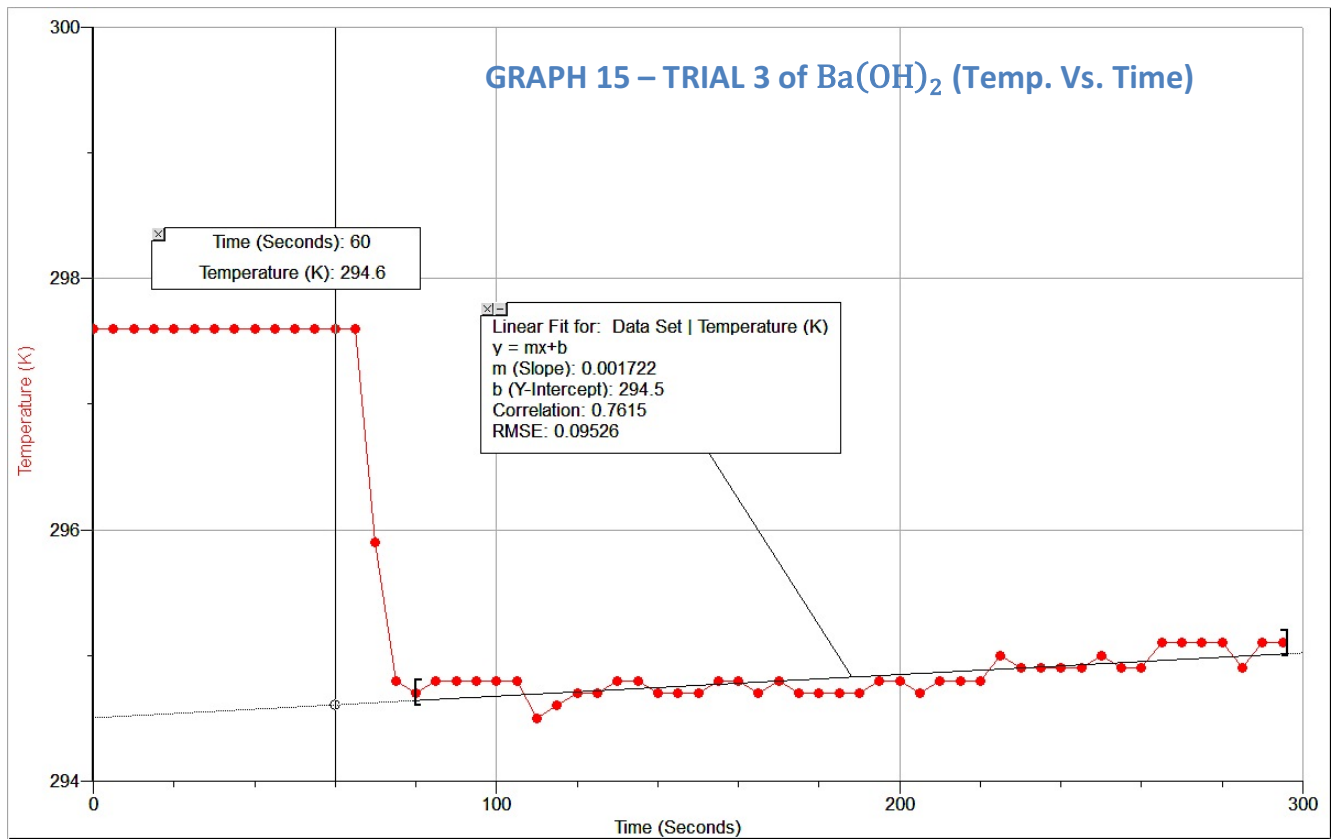
Finally, it is alarming that the percentage uncertainty is 20% for this experiment, but it seems right due to the reasons below and the low change in temperature, which could be negligible or significant. The data obtained is summarized below.

Summary Table –

| | Max. Temp. Reached (K) | Room Temperature | Extrapolated Temp. (K) | Absolute Uncertainty | Change in Temperature |
|---------|------------------------|------------------|------------------------|----------------------|-----------------------|
| Trial 1 | 298.8 | 298.3 | 298.8 | 0.1°C | 0.5 |
| Trial 2 | 298.8 | 297.9 | 298.9 | 0.1°C | 1.5 |
| Trial 3 | 298.6 | 298.1 | 298.6 | 0.1°C | 0.5 |
| % unce. | ≈ 0.38% | ≈ 0.40% | ≈ 0.38% | | ≈ 20% |

Graphs for Ba(OH)₂





Of the four experiments, this was the only endothermic reaction, where heat was taken in instead of given out. Hence, the temperature of the surrounding reduced rather than increased, unlike the other experiments.

Surprisingly, some of the extrapolated temperatures are higher than the minimum temperature, because normally, a lower extrapolated temperature would be expected. This hints that the lowest temperature recorded could have been an odd point.

Additionally, from the combined graphs, it can be seen that even though trial 1 did not have that much of a higher room temperature, the minimum temperature it could attain was less than the other two trials. This trial, hence could have been privy to random errors, or the mass of solid used in this trial could have been less. From table 1 above, we see that its mass was similar to trial 3, however, did not manage to attain a minimum point similar to trial 3.

Summary Table –

| | Min. Temp. Reached (K) | Room Temperature | Extrapolated Temp. (K) | Absolute Uncertainty | Change in Temperature |
|---------|------------------------|------------------|------------------------|----------------------|-----------------------|
| Trial 1 | 295.2 | 298.0 | 295.2 | 0.1°C | 2.8 |
| Trial 2 | 295.4 | 297.9 | 294.3 | 0.1°C | 3.6 |
| Trial 3 | 294.5 | 297.6 | 294.6 | 0.1°C | 3.0 |
| % unce. | ≈ 0.45% | ≈ 0.40% | ≈ 0.46% | | ≈ 6% |

Table 2: Summary of all important information collected for calculations

| | | REACTION (With Water) | | | |
|---------------------------|---------|--------------------------|---------------------------|-------------|-------------------|
| | | Mass (grams) | Volume (cm ³) | ΔTemp. (K) | % uncer. in temp. |
| <i>NaOH</i> | Trial 1 | 4.800 | 60 | 18 | ≈ 1% |
| | Trial 2 | 4.550 | 60 | 16.9 | |
| | Trial 3 | 4.324 | 60 | 17 | |
| <i>KOH</i> | Trial 1 | 2.380 | 60 | 8.3 | ≈ 2.5% |
| | Trial 2 | 2.362 | 60 | 8.6 | |
| | Trial 3 | 2.573 | 60 | 8.4 | |
| <i>Ca(OH)₂</i> | Trial 1 | 4.780 | 60 | 0.5 | ≈ 20% |
| | Trial 2 | 4.893 | 60 | 1.5 | |
| | Trial 3 | 4.785 | 60 | 0.5 | |
| <i>Ba(OH)₂</i> | Trial 1 | 4.834 | 60 | 2.8 | ≈ 6% |
| | Trial 2 | 4.818 | 60 | 3.6 | |
| | Trial 3 | 4.795 | 60 | 3.0 | |
| % Uncertainty | | 0.05% | 1% | | |

Annotated Calculations and Uncertainty

STEP 1: Calculating heat energy evolved from the above information in Table 2. Heat Energy in Joules

The heat energy evolved is absorbed by the surrounding. In this case, the liquid medium that the reaction is occurring in is considered the surrounding. Hence the heat evolved can be calculated by the heat absorbed by the water, and hence the increase in temperature of the water as summarized in table 2. The equation for heat energy required to increase the temperature of an object is given by the equation –

$$\Delta H = m \cdot c \cdot \Delta T$$

Where m represents the mass of the object/medium, c is the specific heat capacity of that object – the energy required to raise the temperature of the object by 1K and ΔT , which is the change in temperature.

This process however lends itself to some uncertainty, because not all the heat evolved is absorbed by the medium.

In the experiments above, the volume of water used is constant at 60 cm³. This volume has to be converted to mass in order to use in the equation.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \gg \text{Mass} = \text{Density} \times \text{Volume}$$

Hence, since the density of water is 1g·cm⁻³ -

$$\text{Mass} = 1\text{g}\cdot\text{cm}^{-3} \times 60\text{ cm}^3 = 60\text{g} \pm 1\%$$

The percentage uncertainty remains the same because the volume was simply multiplied by a constant. The specific heat capacity of water is 4.1855J·g⁻¹K⁻¹. This hence transforms the equation above to –

$$\Delta H = 60\text{g} \cdot 4.1855\text{J}\cdot\text{g}^{-1}\text{K}^{-1} \cdot \Delta T$$

Now the heat energy evolved can be simply calculated by plugging in the change in temperature values recorded in Table 2. The percentage uncertainty becomes the 1% added to the % of uncertainty in the temperature values (as included in Table 2). Hence for NaOH, the uncertainty of heat evolved becomes 2%.

| | | REACTION (With Water) | | |
|---------------------------|---------|--------------------------|-----------------|------------------------------|
| | | Δ Temp. (K) | Heat Evolved | % uncert. in Heat Evolved |
| <i>NaOH</i> | Trial 1 | 18 | 4520 | $\approx 1\%$ |
| | Trial 2 | 16.9 | 4244 | |
| | Trial 3 | 17 | 4269 | |
| <i>KOH</i> | Trial 1 | 8.3 | 2084 | $\approx 2.5\%$ |
| | Trial 2 | 8.6 | 2160 | |
| | Trial 3 | 8.4 | 2110 | |
| <i>Ca(OH)₂</i> | Trial 1 | 0.5 | 126 | $\approx 20\%$ |
| | Trial 2 | 1.5 | 377 | |
| | Trial 3 | 0.5 | 126 | |
| <i>Ba(OH)₂</i> | Trial 1 | 2.8 | 703 | $\approx 6\%$ |
| | Trial 2 | 3.6 | 904 | |
| | Trial 3 | 3.0 | 753 | |

STEP 2: Finding the number of moles of reactant that dissolved in the fixed volume of water.

The number of moles have to be calculated from mass, because standard enthalpy values describe heat of a reaction, in moles and kilojoules. The simple equation to convert mass to moles is –

$$n(\text{moles}) = \frac{\text{mass}}{\text{molar mass}}$$

The molar mass however is specific to each compound. The molar mass, is the mass in grams that a mole of the compound would weigh. This is found by adding the atomic mass of the individual elements that make up the compound, in the correct order.

For NaOH –

$$Mr(\text{Na}) = 22.989769$$

$$Mr(\text{O}) = 15.9994$$

$$Mr(\text{H}) = 1.00794$$

$$\text{Therefore, on adding - } Mr(\text{NaOH}) = 39.997$$

Other Molar Masses of compounds used –

$$Mr(\text{KOH}) = 56.1056$$

$$Mr(\text{Ca(OH)}_2) = 74.093$$

$$Mr(\text{Ba(OH)}_2) = 171.34$$

Hence, the moles of reactant is found simply by dividing the Mass in Table 2, with the appropriate molar mass of that compound.

The percentage uncertainty of mass is 0.1%, as described in Table 2. The uncertainty remains same for all final mole values, as the mass is simply being divided by a constant. Hence uncertainty of all moles values is $\pm 0.1\%$.

| | | REACTION (With Water) | | |
|---------------------------|---------|--------------------------|--------------|---------------------------|
| | | Mass | No. of Moles | % uncert. in No. of Moles |
| <i>NaOH</i> | Trial 1 | 18 | 0.120009 | $\approx 0.1\%$ |
| | Trial 2 | 16.9 | 0.113759 | |
| | Trial 3 | 17 | 0.108108 | |
| <i>KOH</i> | Trial 1 | 8.3 | 0.042420 | $\approx 0.1\%$ |
| | Trial 2 | 8.6 | 0.042099 | |
| | Trial 3 | 8.4 | 0.045859 | |
| <i>Ca(OH)₂</i> | Trial 1 | 0.5 | 0.064514 | $\approx 0.1\%$ |
| | Trial 2 | 1.5 | 0.066039 | |
| | Trial 3 | 0.5 | 0.064581 | |
| <i>Ba(OH)₂</i> | Trial 1 | 2.8 | 0.028212 | $\approx 0.1\%$ |
| | Trial 2 | 3.6 | 0.028120 | |
| | Trial 3 | 3.0 | 0.027985 | |

STEP 3: Calculating final Enthalpy of Solution from the heat energy evolved and moles of reactant dissolved.

The heat energies found in Step 1 illustrates the heat evolved for the number of moles specified in Step 2. However, standard enthalpies describe heat energy evolved for 1 mole of reactant, in the reaction.

$$\text{Hence, Standard Enthalpy} = \frac{\text{Heat Evolved}}{\text{No. of Moles } (n)}$$

By dividing the heat evolved calculated in step 1 with the corresponding moles calculated in step 2, enthalpy is calculated in the form of $\text{J}\cdot\text{mol}^{-1}$. This value can further be divided by 1000, to get the values in $\text{kJ}\cdot\text{mol}^{-1}$, as normally stated.

| | | REACTION (With Water) | | | | |
|---------------------------|---------|--------------------------|--------------|------------------|---------------------------|-----------------------|
| | | Heat Change (J) | No. of Moles | Enthalpy (J/mol) | Average Enthalpy (kJ/mol) | % uncert. in Enthalpy |
| <i>NaOH</i> | Trial 1 | 18 | 0.120009 | 37667 | 38.155 | ≈ 1.1% |
| | Trial 2 | 16.9 | 0.113759 | 37308 | | |
| | Trial 3 | 17 | 0.108108 | 39490 | | |
| <i>KOH</i> | Trial 1 | 8.3 | 0.042420 | 49137 | 48.812 | ≈ 2.6% |
| | Trial 2 | 8.6 | 0.042099 | 51301 | | |
| | Trial 3 | 8.4 | 0.045859 | 45999 | | |
| <i>Ca(OH)₂</i> | Trial 1 | 0.5 | 0.064514 | 1946 | 3.198 | ≈ 20.1% |
| | Trial 2 | 1.5 | 0.066039 | 5704 | | |
| | Trial 3 | 0.5 | 0.064581 | 1944 | | |
| <i>Ba(OH)₂</i> | Trial 1 | 2.8 | 0.028212 | 24923 | 27.998 | ≈ 6.1% |
| | Trial 2 | 3.6 | 0.028120 | 32151 | | |
| | Trial 3 | 3.0 | 0.027985 | 26921 | | |

Therefore – Enthalpy of Solution of the four hydroxides are as follows –
 (A negative sign is added for exothermic reactions, reactions that released heat)

$$\Delta H_{(s)}(\text{NaOH}) = - 38.155 \pm 0.42 \text{ kJ}$$

$$\Delta H_{(s)}(\text{KOH}) = - 48.812 \pm 1.27 \text{ kJ}$$

$$\Delta H_{(s)}(\text{Ca(OH)}_2) = - 3.198 \pm 0.64 \text{ kJ}$$

$$\Delta H_{(s)}(\text{Ba(OH)}_2) = 27.998 \pm 1.70 \text{ kJ}$$

CONCLUSION AND EVALUATION

ASPECT 1: *CONCLUDING*

From the enthalpies above, we can conclude a few things regarding the intermolecular forces of the compounds and reactivity of the cations that participated in the reaction. Firstly, since the enthalpy of sodium hydroxide was more endothermic than that of potassium hydroxide, (enthalpy of solution of sodium hydroxide was less negative, where the negative sign shows exothermic reaction), it can be concluded that the hypothesis was correct, since it predicted this.

Hence, we see that the stronger bonds in sodium hydroxide required more energy to break. This meant that its enthalpy was more endothermic than potassium hydroxide's, since potassium hydroxide required less energy, and released more energy. The uncertainty was low in these cases, and could not have led to sodium hydroxide having a more exothermic reaction, since the difference between the enthalpy of the two is far greater than the extents to which the uncertainty would allow the data to migrate to.

The second conclusion we can form is by comparing potassium hydroxide and barium hydroxide. The two hydroxides have similar ionic radii, however the cation in barium hydroxide has a +2 charge, whereas the cation in potassium hydroxide only has a +1 charge. The +2 charge, according to the hypothesis should mean that the enthalpy is more endothermic, because the compound with the +2 cation would require far more energy to break bonds than the +1, because the +2 cation has greater electrostatic forces due to the stronger attraction of negative and positive ions with a +2 charge.

This is supported by the experiments, because barium hydroxide does have a more endothermic reaction than potassium hydroxide. In fact, it has a far greater endothermic reaction than potassium hydroxide, almost differing by 60,000J.

The difference between an increased charge is far greater than the difference of increased ionic radii. From this we can make one of the most important conclusions being, when enthalpy is concerned, the differing charge of two cations in their compounds has a greater effect than any difference in atomic radii. Charge is a dominant factor when compared to atomic radii.

Unfortunately, these conclusions could not be further supported by calcium hydroxide because its experiments into enthalpy of solution had great uncertainties, due to the extremely small change in temperature and the partial solubility. However, by considering literature values found on the Internet, it agrees and reinforces the pattern noticed when considering the above three hydroxides. This might also hint at the trend continuing for all metal hydroxides for the 1st and 2nd group elements.

ASPECT 2&3: *EVALUATING PROCEDURES AND IMPROVEMENTS*

1. The uncertainty was kept at a minimum as an automatic temperature probe and electronic mass balance were used. These apparatus have very low uncertainty. However, the measure of volume had a relatively high uncertainty as it was measured using a graduated cylinder.
2. The uncertainty is very high for calcium hydroxide. This is in part because it is only partially soluble and hence, a large uncertainty is expected and required because the true volume of solid that dissolved to make the solution is not known. Additionally, the large uncertainty is also due to the small change in temperature. The smaller the change in temperature, the larger the uncertainty because the device is less sensitive, relative to the change. The solubility of other compounds could have also affected the final temperature measured and hence enthalpy calculated. This is one of the drawbacks of this experiment.
3. The solubility of some compounds related to others created huge differences in this experiment. Even among potassium hydroxide, sodium hydroxide and barium hydroxide, their slight difference in solubility would have had an affect on the final enthalpy calculated. This was much more significant for calcium hydroxide which had partial solubility and much of the mass added did not dissolve and participate in the reaction. A greater volume of water could have been used to eliminate any difference in solubility. The only problem that arises with this is that, the temperature difference, whether temperature is absorbed or evolved will be much less as there is a larger volume of water to either absorb the heat given off, or evolve the heat required.
4. As seen by the combined graphs, the values of temperature, hence enthalpies are precise. The combined graphs that illustrate data points of all thee trials, have curves that are close to each other. From this, it can be concluded that values were precise. Whether they are accurate or not cannot be inferred from this. However, significant imprecise trials can be seen for Calcium Hydroxide. This is not because the measurements themselves are imprecise, but rather because the scale of the graph taken is small, and every small deviation of 0.1K is represented by a huge spike.
5. The extrapolation also corrected for odd points as seen with Barium Hydroxide, where the extrapolated point was higher than the minimum temperature recorded, because it was an odd point.
6. For the calculation of energy and heat evolved, only the specific heat capacity of the liquid medium: water, was considered. The specific heat capacity and the change in temperature that occurs in the polystyrene cup itself were not investigated. Although polystyrene cup has a high specific heat capacity and is not a heat conductor, hence does not absorb much heat, this would still make a difference in enthalpy. Since not all polystyrene cups are same, and differ based

on thickness and percentage composition, the individual specific heat capacity of the cup would have to be calculated, which is out of scope for this investigation.

7. Experiments evolving heat are compromised due to heat loss to surrounding being major factor. Insulation was used to retain heat, however, several procedures could have been improved to reduce heat loss.
 - a. The procedures were mechanical, involving opening the cap of the polystyrene cup and manually adding the content to the container. Often the cap would not be closed properly, in a hurry to measure the maximum temperature achieved.
 - b. Heat was also lost due to a hole in the cup to introduce the temperature probe.
 - c. Finally, heat measurements could have been made more accurate if a more accurate probe was used. The probe used calculated temperature to one decimal point. One clear advantage of the probe was that it wasn't manual and hence reduced the chances of human error.
8. The heat loss of the experiment due to the reasons above was minimized by the extrapolation of graphs. This analytical tool allowed me to account for some proportion of the heat loss, from when the solid sample was added to the liquid medium.
9. The measurement with the greatest uncertainty is volume, since the most accurate container that could be found was a graduated cylinder. Hence, more accurate method and apparatus could have been used for volume.
10. The strength of cation was observed and a conclusion was formed by considering the enthalpy of solution. Other similar reaction that all four hydroxides undergo could have additionally been used for more data. For example, the hydroxides reaction with hydrochloric acid. By investigating the change in enthalpy due to neutralization. This would have lead to more conclusive evidence for their relative strength in compounds.