

CALORIMETRY – EXPERIMENT A

ENTHALPY OF FORMATION OF MAGNESIUM OXIDE

INTRODUCTION

This experiment has three primary objectives:

1. Find the heat capacity (C_p) of a calorimeter and contents (calibration).
2. Determine the ΔH_{rxn} , the enthalpy of reaction, in kJ/mol for several different reactions, including the reaction of an unknown with a solution of HCl.
3. Calculate the ΔH_f , the enthalpy of formation, of MgO using Hess' Law (in kJ/mol).

We will assume that the energy exchanged between the calorimeter and the surroundings during and following the reactions is small and at a slow, constant rate. You will become familiar with calorimetry concepts, computer data collection, and calculations.

BACKGROUND

Calorimetry measures the energy that a reaction produces or consumes. For example, the major difference between gasoline grades is the octane number. Unleaded gas has an octane of 86, while Super Unleaded gas has a higher octane. Calorimetry could be used to measure the heat or energy produced when gasoline is burned. More heat (energy) would be produced by the super unleaded gas so it would have a higher enthalpy compared to just unleaded gas. Calorimetry could be used to see if a gasoline station is selling the grades of gasoline it advertises.

The calories in food have also been measured by calorimetry (hence the term calories). Usually this is a measurement of calories (cal) per gram of food. Remember that calories are easily convertible to joules (J) and grams can be converted to moles if it is a pure chemical.

Enthalpy, represented by the symbol **H**, is a property chemists use to describe the heat flow into or out of a system in a constant-pressure process. This is often the case since most processes that are carried out are exposed to the atmosphere as are the reactions carried out in this course. The enthalpy of a reaction, ΔH_{rxn} , is defined as the difference between the enthalpies of the products and the enthalpies of the reactants. In other words, it is the change in energy for a given amount of a given reaction. The enthalpy of formation, ΔH_f is defined as the enthalpy or heat change that results when one mole of a compound is formed from its elements. The **standard enthalpy of formation** is defined as the enthalpy of formation measured at 1 atm such that the elements are in their **standard state**.

If a reaction is **exothermic**, heat will be released, and the temperature of the system or reaction mixture will rise. (In this experiment the heat and temperature rapidly increase and then slowly decrease as heat is lost to the surroundings.) For **endothermic** reactions heat will be absorbed or used and the temperature will decrease. In this experiment we will use the experimentally measured enthalpy of reaction for a series of exothermic

reactions and Hess' Law to determine the heat of formation for magnesium oxide (MgO). We will also determine the enthalpy of reaction for an unknown metal oxide with an acid. **For this experiment pressure will be constant so Enthalpy of Reaction and Heat of Reaction (ΔH_{rxn}) are assumed to be the same.**

The enthalpy of reaction, ΔH_{rxn} , can be calculated using the equation:

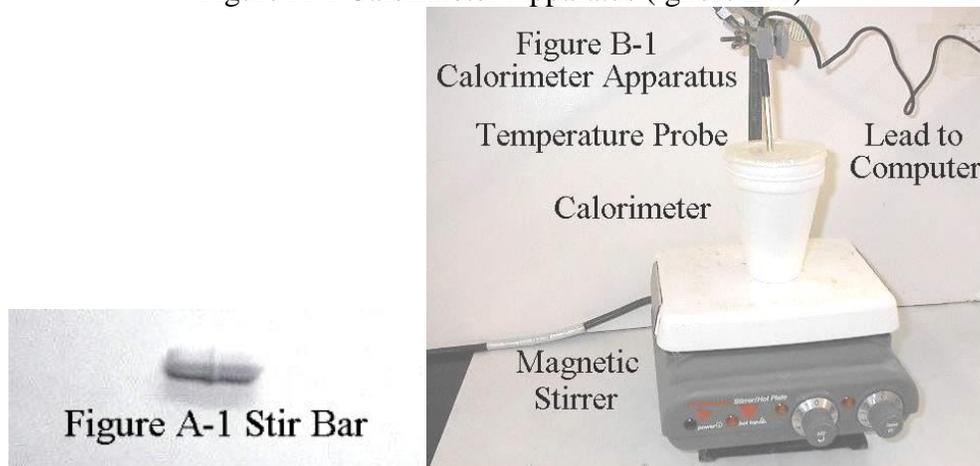
$$\Delta H_{rxn} = \frac{-(Cp)(\Delta T)}{n} = \frac{-(\frac{kJ}{^{\circ}C})(^{\circ}C)}{mol} = \frac{-kJ}{mol} \quad \mathbf{A-1}$$

Where n is the moles of limiting reagent, ΔT ($^{\circ}C$) is the change in temperature in of the calorimeter's contents, and Cp ($kJ/^{\circ}C$) is the heat capacity of the calorimeter. The value for n can be determined knowing the amounts of starting material. The ΔT for a reaction can be calculated using the temperatures before and after the reaction or the initial and final temperatures. The **heat capacity, Cp**, of the calorimeter has to be experimentally determined by doing a reaction where the ΔH_{rxn} is known. The heat capacity of the calorimeter is primarily due to the solution in the cup.

Heat capacity (Cp) has units of $kJ/^{\circ}C$. Physically, this means that it takes the value of the Cp in energy to raise the calorimeter by $1^{\circ}C$. For example, if a calorimeter has a Cp of $0.200\ kJ/^{\circ}C$, the calorimeter, including its contents, must absorb $0.200\ kJ$ of energy to increase $1^{\circ}C$. A $20\ kJ/^{\circ}C$ calorimeter increases $1^{\circ}C$ with one hundred times more energy, or $20\ kJ$. Cp varies depending on the substance or system and describes how much energy is needed to change the temperature of that substance or system. The Cp of an ocean is huge (compared to a drop of water) such that the oceans of the world maintain the earth at temperatures that support life.

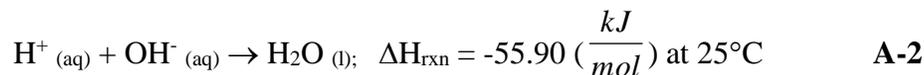
In this experiment, the calorimeter is defined as two nested styrofoam cups, the lid, magnetic stir bar, and the temperature probe tip, plus the $60.0\ mL$ of the reaction mixture (mainly water). In order for the heat capacity of the calorimeter to remain constant, all of these must be present.

Figure A-1 Calorimeter Apparatus (ignore B-1)



NOTE: If less than $60\ mL$ of reaction mixture was added, it would take less energy to increase the calorimeter and contents by $1^{\circ}C$. In other words, the heat capacity would decrease. If more than $60\ mL$ of the mixture was added, more energy would be needed to increase the calorimeter and contents by $1^{\circ}C$. The heat capacity is then increasing.

Most importantly the volume of reaction mixture must remain constant because of the large heat capacity of water. We want the C_p to remain constant because it is the standard by which we can calculate unknown ΔH_{rxn} values in reactions 1, 2, and 4. The C_p is determined in the reaction of HCl with NaOH, using the known enthalpy (energy/mole) for a strong acid/strong base reaction:



Rearranging equation A-1 we can use this ΔH_{rxn} to solve for C_p .

$$C_p = \frac{-(\Delta H_{\text{rxn}})(n)}{\Delta T} = \frac{\left(55.90 \frac{\text{kJ}}{\text{mol}}\right)(\text{mol})}{^\circ\text{C}} = \frac{\text{kJ}}{^\circ\text{C}} \quad \text{A-3}$$

A value for ΔT in $^\circ\text{C}$ can then be determined for a known amount of moles (n). Once the C_p is known we can use it to calculate ΔH_{rxn} for other reactions where ΔT has been experimentally determined. Please look in your textbook under calorimetry or thermodynamics for more information on these concepts. The explanation to determine ΔT is in the experimental section below.

EXPERIMENTAL

This experiment essentially has three parts. In the first lab period, the data to determine the enthalpy of reaction for $\text{Mg} + \text{HCl}$ and $\text{MgO} + \text{HCl}$ will be collected (one trial on each). During the second lab period, data will be collected to calculate the C_p using the reaction of NaOH with HCl (two trials). Also, the enthalpy of reaction for the Exp. An unknown reacting with HCl will be determined (two trials). The trials for the C_p and unknown should be run in the same lab period.

Be sure to label each graph carefully with your name, section, date, reaction & trial, mass of reactant, etc. Note that the ΔH_{rxn} is not done until after C_p is determined the second week. Tape graphs into your notebook as you print them.

EQUIPMENT AND MATERIALS:

1. Temperature probe connected to computer via analog to digital interface box
2. Vernier Data Logger software
3. Calorimeter (two nested styrofoam cups and lid labeled with your bin number)
4. Thermometer
5. Stirrer-hot plate and teflon stir bar
6. Spatula and electronic balance
7. 25 mL graduated cylinder (or 25 mL pump dispenser)
8. Various sizes of beakers and erlenmeyer flasks
9. 10 mL volumetric pipet or 10 mL pipettor
10. Wash bottle filled with pure water

CHEMICALS:

1. 3.0M Hydrochloric acid (**3033**) HCl - about 200mL needed
2. ~5.0M Sodium Hydroxide (**3034**) NaOH - see carboy for exact concentration, about 30 mL needed
3. Magnesium (**0220**) Mg turnings - about 0.20g needed
4. Magnesium oxide (**1011**) MgO - about 1.0 g needed
5. Unknown A-xxxx (**1012**) in your unknown packet - need at least 2-3 grams

SAFETY CONCERNS:**Risk Assessment-Moderate to High (due to corrosive liquids)**

1. The HCl and NaOH are corrosive. The unknown and MgO are mildly corrosive and some are powders so avoid contact with solids and dust. Avoid contact, wear eye protection at all times when working with these chemicals, and wash hands after handling them. Do not rub your eyes when using these chemicals. Any small spills should be cleaned up immediately with a damp sponge.
2. Any contact with HCl or NaOH should be rinsed for 15 minutes with water.
3. All solid and liquid chemical waste should be disposed of in the "Corrosive Liquids" container.
4. Goggles required. Lab coat or apron and gloves are recommended but not required.

EXPERIMENTAL PROCEDURE:**FIRST LAB PERIOD****The Determination of ΔH_{rxn} of Mg with HCl and MgO with HCl**

NOTE: If these links are not present, click on the icon, "Vernier Programs" and then "Data Logger". Change the time to 400 seconds.

NOTE: Use the same, calorimeter, computer-temperature probe, and thermometer for every lab period if possible.

Calibration of the Temperature Probe:

Startup procedure

- Select "Start", "Programs", "Chemistry Applications" and then click on "CHM152L-A Calorimetry".

Calibration Check Procedure

- Find your thermometer and three beakers 100mL or bigger. The beakers do not need to be clean.
- Fill one beaker 2/3 full with ice and add cold water to make a slush.
- Fill another beaker 2/3 full with hot tap water.
- Put the temperature probe tip and thermometer bulb together so they touch and place them into the hot beaker and let sit for one minute. The temperature can be

A two point calibration will need to be done using hot and ice water if either the temperature of hot or ice water are not within $\pm 0.5^\circ\text{C}$ of the temperature measured with the thermometer. Your TA will provide with a procedure to calibrate the temperature probe.

NOTE: Only one trial is needed for this reaction.

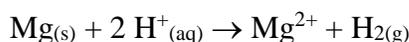
Avoid adding extra heat from hands, hot plate-stirrer; make sure the hot plate heat is turned off.

Why should you measure the mass of Mg this way?

read below the graph. You do not need to click on the collect button. Record the temperatures. If the temperatures are not within $\pm 0.5^\circ\text{C}$, see your TA.

- Put the temperature probe and thermometer into the cold beaker and let sit for one minute. You do not need to push the collect button. Record the temperatures. If the temperatures are not within $\pm 0.5^\circ\text{C}$, see your TA.
- Be sure to check the calibration again at the beginning of the second lab.

Mg Reaction. Determining the Enthalpy for Reaction (ΔH_{rxn}) of Mg with HCl (H^+):

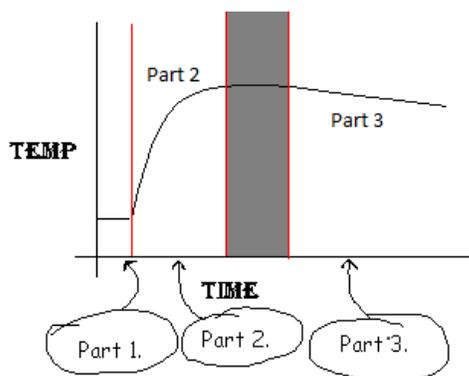


- Clean a teflon stir bar, 50 mL beaker, 25mL and 50mL graduated cylinder and wash bottle.
- Add 25.0 mL of 3.0 M HCl (use pump dispenser, ok to check volume with 25mL graduated cylinder) and 35.0 mL of pure water to the calorimeter.
- Put the temperature probe in through the lid and place the lid on the calorimeter. **Secure the probe with a clamp so that its tip is in the water and off the calorimeter bottom. Don't allow the stir bar to hit the probe tip (see fig.A-1).**
- Stir the solution with a teflon stir bar (**Do not heat.**) Set stirrer so the solution is mixed vigorously but slow enough so that it is not splashed.
- Put between 0.15 to 0.20 g (not 1.5) of Mg metal turnings into a clean, dry 50 mL beaker. Record both the beaker's mass and the mass of the beaker and Mg.
- Click the "Collect" button at the top of your screen to start graphing the temperature. **Do not** add Mg turnings yet.
- After about one minute, add the metal Mg turnings without removing the temperature probe from the solution. (Crack the lid open, add Mg _(s), and then close the lid, it is ok if residual Mg sticks to the inside of the beaker since you will reweigh it later to see how much Mg was added to the calorimeter). If any Mg is stuck on the sides of the calorimeter above the liquid carefully swirl the solution (holding the cup in your hand) to dissolve it.
- **Reweight and record the mass of the beaker that contained the Mg turnings. Subtract this mass from the mass of the beaker and Mg to get the mass of Mg used.**

NOTE: If data gathering stops before reaching 350-400 seconds click on "Collect" and then "Append to Latest" to restart collecting data. **Do not move the calorimeter or delete or stop the program! You can also get help from your TA!**

- Continue graphing data until a linear line (part 3 in Figure A-2) is made. (At about 350 to 400 seconds.)
- Adjust graph scale (autoscale) and then do a linear fit (refer to Figure A-3). Generate line 2 by selecting the linear part of the graph and doing a linear fit. Under analyze use the interpolate tool to find the starting time of the reaction and the corrected temperature at this time. The time could also be used for x in $y=mx+b$ to determine the final temperature (T_f). The following graphs explain this process.
- Point the cursor at the flat part of the graph before the reaction starts to determine T_i and subtract this from T_f to determine the change in temperature, $T_f - T_i = \Delta T$. Calculate these values for every graph done for exp. A.
- Label the graph by clicking on the graph title. **Edit the title to include your last name, experiment title-Reaction Mg + HCl, date, section letter, and exact mass of Mg used.**
- Save the graph on your "Z" drive, my documents, or a thumb drive using a logical file name and print it.
- Write the values for T_f , T_i , and ΔT directly on this printed graph.
- Clean and dry the calorimeter, temperature probe, and the 50 mL beaker.

Explanation of the Graph: Below is a general temperature vs. time graph representative for all reactions trials done for this experiment. (Figure A-2) It is divided into three parts.



NOTE: the dark band between Part 2 and Part 3 is a transition area that is not usable for data analysis. The linear regression is done on part 3 to the right of this dark area!

Figure A-2. A general temperature vs. time graph

Part 1. This is the initial temperature. Only one reactant is in the solution and so our reaction is not happening. (For example, for Mg, only 25.0 mL of HCl and 35.0 mL of water are in the solution.) Between part 1 and part 2 the reactants are mixed together.

Part 2. The temperature is changing rapidly. Both reactants are now in the solution and are reacting to give off heat. (For example, for Mg, this is

because the Mg turnings are added to the solution.) Somewhere within the blocked out region the reaction stops.

Part 3. The reaction has already stopped. Since the calorimeter isn't a perfect insulator, heat is lost to the environment and, as a result, the temperature decreases. The temperature should be constantly decreasing. (For example, for Mg, all of the Mg has been converted to Mg^{2+} .)

How do you get Temperature Change (ΔT) in $^{\circ}C$? ΔT is equal to the extrapolated final temperature minus the solutions initial temperature so $\Delta T = T_f - T_i$. Below is the same general graph from figure 1, but it has been extrapolated to find T_f (Figure 2). T_f can also be determined by doing a linear regression on the linear, right hand side of the curve (part 3) to determine the slope and y-intercept of line 2 and then solving for the temperature using the time at the start of the reaction (line 1).

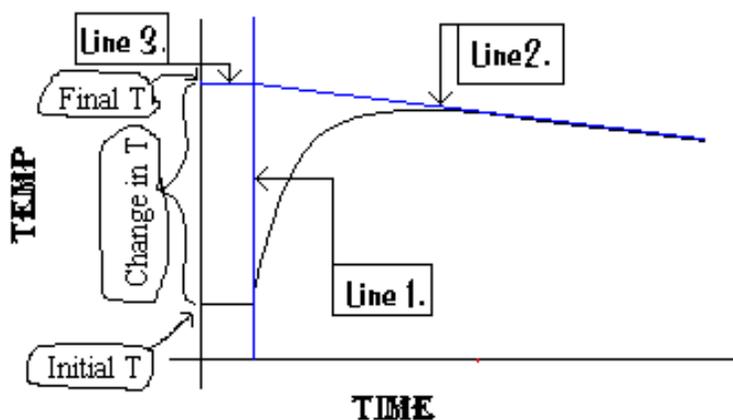


Figure A-3. Extrapolation of a Temperature vs. Time Graph to Find ΔT .

Line 1. This line represents the time when the reactants were mixed and so the start of the reaction.

Line 2. This line helps us model what the final temperature would be if the reaction and temperature measurement were instantaneous. It compensates for the heat lost from the calorimeter so that we can determine the final temperature if the reaction and temperature measurement were instantaneous. This line is important because it compensates for heat lost to the environment while temperature is measured during and after the reaction.

Line 3. This line is drawn at a right angle to line 1 to intersect the point where lines 1 and 2 meet. It is there to help read the final temperature, T_f , at the y-axis. The interpolate function can also be used to get T_f .

Calculation: Temperature Change (ΔT) in $^{\circ}\text{C}$ and mol of Mg

IMPORTANT: For nearly all calculations in this manual the value you are calculating will be in bold print.

In this reaction you were trying to find the ΔH_{rxn} for reaction of Mg with HCl. **Unfortunately all of the calculations cannot be done until the Cp in equation A-1 is found after doing the NaOH reaction.** The limiting reagent is Mg, so find the moles of Mg.

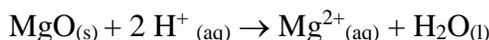
$$n = \left| \frac{\text{Mass Mg (g)}}{\text{molar mass Mg (g)}} \right| = \frac{g \text{ Mg}}{\text{MM of Mg}} = \text{mol Mg} \quad \text{A-4}$$

where g Mg is grams of Mg and **MM of Mg is the molar mass of Mg** ($\frac{\text{g}}{\text{mol}}$). Now n is found. Find ΔT by as noted earlier but you should be able to do the extrapolation using a printed graph as shown in figure A-3 draw all lines with a pen and a ruler. **Label T_i (initial), T_f (final), and ΔT on your graph. All temperatures are in $^{\circ}\text{C}$. Do not convert to Kelvin (K)!**

NOTE: Only one trial is needed for the MgO reaction.

NOTE: **Never click on "New Graph" when starting a new trial.** Instead just close the program and then reopen it. If you do click on "New Graph" the time scale will decrease to 200 seconds. **Do not move the calorimeter or delete or stop the program if it does stop early! Get help from your TA!**

MgO Reaction. Determination of the Enthalpy for Reaction (ΔH_{rxn}) of MgO with HCl:



- Add 25.0 mL of 3.0 M HCl and 35.0 mL of pure water to the calorimeter.
- Clean the temperature probe by thoroughly spraying with your wash bottle into a large waste beaker.
- Put the temperature probe in the calorimeter as was done before and vigorously stir the solution (but don't splash) with a Teflon stir bar. (Do not heat)
- Put between 1.0 to 1.2 g of MgO powder into a clean, dry 50 mL beaker. Record the mass of both the beaker and the beaker with MgO.
- If Data Logger is open close it and select "Start", "Programs", "Chemistry Applications" and then click on "CHM152L-A Calorimetry".
- Click the "Collect" button at the top of the screen to start graphing the temperature. **Do not** add MgO powder yet.
- After about one minute, add the white MgO powder without removing the temperature probe from the solution. (Crack the lid open, add $\text{MgO}_{(s)}$, and then close the lid. If any MgO is stuck on the sides of the calorimeter above the liquid carefully swirl the solution (holding the cup in your hand) to dissolve it). It's ok if a residual amount of powder remains in the beaker since it will be reweighed later to determine the amount transferred to the calorimeter.

- Reweigh the beaker (with traces of MgO powder not transferred) and subtract this from the mass of the beaker and MgO to determine the actual amount of MgO transferred to the calorimeter.
- Continue graphing data until a linear line (part 3 of figure A-2) is made, then click on Stop at the top of the screen. (at about 350 to 400 seconds.)
- Adjust scale of graph, do a linear fit, and find the ΔT as was done for Mg rxn.
- Label the graph by clicking on the graph title. **Include your last name, experiment title-Reaction MgO + HCl, date, section letter, and mass of MgO used.**
- Save the trial on your “Z” drive, my documents, or a thumb drive and print it.
- **Clean and rinse all glassware, the calorimeter and temperature probe.**
- **Before leaving, trim graphs to size and tape into the notebook, and have TA sign and date notebook.**

Calculations:

These are the same calculations as described for the Mg reaction. The calculations are now for the reaction of MgO_(s) with HCl_(aq). The limiting reagent is MgO so find the moles of MgO.

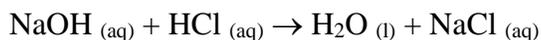
$$n = \text{mol MgO} = \frac{\text{g MgO}}{\text{MM of MgO}} \quad \text{A-5}$$

Now n (mol of MgO) is found using the mass of MgO (g MgO) and the molar mass of MgO (MM of MgO). Extrapolate your printed graph to find ΔT .

SECOND LAB PERIOD

Determination of the Cp and ΔH_{rxn} of an unknown with HCl

NaOH + HCl Reaction. Determination of Cp:



- Clean a 25 mL graduated cylinder, 10 mL volumetric pipet, a spatula, a 50 mL beaker, and a wash bottle.
- Add 25.0 mL pure water and 10.00 mL of NaOH to the calorimeter and measure its temperature.

NOTE: Check the calibration of temperature probe and calibrate if needed.

Remember: 10.00 mL is more precise than 25.0 mL. (cont.)

(cont.) What kind of glassware should you use for this? _____

NOTE: Never click on “New Graph” to start a new trial. Instead just close the program and then reopen it. If you do click on “New Graph” the time scale will decrease to 200 seconds. Do not move the calorimeter or delete or stop the program if it does stop early! Get help from your TA!

NOTE: Be sure to record the exact NaOH molarity of the carboy.

NOTE: At least two Cp trials need to be done. Avoid adding extra heat from your hands or hot plate.

NOTE: At least 2 trials also need to be done for reaction of HCl with the unknown. Avoid adding extra heat from hands, hot plate, etc

NOTE: If your unknown is sticky see your TA.

NOTE: The unknown metal oxide is assumed to have a formula weight of 120.0 g/mol !

- Measure out 25.0 mL of 3.0 M HCl and use an ice or hot water bath to adjust its temperature so that it is within $\pm 0.5^\circ\text{C}$ of the NaOH solution. Do not get any of the NaOH solution in the HCl solution. Rinse and dry your thermometer between solutions.
- Put the temperature probe in the calorimeter and stir the solution with a teflon stir bar. (Do not heat)
- Click the Collect button at the top of the screen to start graphing the temperature probe. **Do not** add HCl solution yet.
- After about one minute, add the 3.0 M HCl without removing the temperature probe from the solution. (Crack the lid open, add $\text{HCl}_{(\text{aq})}$, and close the lid.)
- After about 10 seconds, briefly swirl the solution.
- Continue graphing data until a linear line (Figure A-2: see part 3 of this figure) is made. (At about 350 to 400 seconds.)
- Adjust scale of graph, do a linear fit, and find the ΔT as was done before.
- Label the graph by clicking on the graph title as before. Enter your last name, experiment title, date, section letter, and **NaOH with HCl, Trial 1 or 2, and molarity of NaOH.**
- Save the run on your “Z” drive, my documents, or a thumb drive and print it.
- Clean, rinse, and dry the calorimeter and temperature probe.
- Repeat this once.

Enthalpy of Reaction (ΔH_{rxn}) of HCl with an Unknown Metal Oxide:

- Add 25.0 mL of 3.0 M HCl and 35.0 mL of pure water to the calorimeter.
- Clean the temperature probe by rinsing well with your wash bottle into a 600 mL beaker.
- Put the temperature probe in the calorimeter and vigorously stir the solution with a teflon stir bar but avoid splashing. (Make sure the heat is off)
- Before using your unknown, make sure it is a powder. If it is clumpy, grind it up in a clean, dry mortar and pestle. Put between 1.0 to 1.2 g of unknown powder into a clean, dry 50 mL beaker. Record mass of beaker & contents.
- Click the "Collect" button at the top of your screen. Your temperature probe will display the data it is collecting on the graph. **Do not** add the unknown yet.

NOTE: Never click on "New Graph" to start a new trial. Instead just close the program and then reopen it. If you do click on "New Graph" the time scale will decrease to 200 seconds. **Do not move the calorimeter or delete or stop the program if it does stop early! Get help from your TA!**

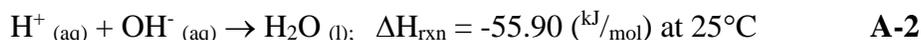
- After about one minute, add the white unknown powder without removing the temperature probe from the solution (Crack the lid open, add the weighed unknown, and then close the lid. If any the unknown is stuck on the sides of the calorimeter above the liquid carefully swirl the solution, holding the cup in your hand, to dissolve it). It is ok if a residual amount of powder remains in the beaker since it will be reweighed later to determine the amount transferred to the calorimeter.
- Reweigh the beaker with unknown powder not transferred into the calorimeter. Continue graphing data until a linear line (part 3 in fig A-1) is made and then click on "Stop". (At about 350 to 400 seconds.)
- Adjust the scale of graph, do a linear fit, and find the ΔT as was done before.
- Label the graph by clicking on the graph title. Enter in your last name, experiment title, date, section letter, **Unknown with HCl, Trial 1 or 2, & mass unknown.**
- Save the run on your "Z" drive, my documents, or a thumb drive and print it.
- Do a second trial after cleaning the cup and probe.
- **Clean and rinse all glassware and the temperature probe.**
- **Before leaving, trim graphs to size and tape into the notebook, and have TA sign and date notebook.**

Calculation: Cp

The calibration of the calorimeter is now complete! Cp can now be calculated and used for all other calculations. First solve for the moles of NaOH (limiting reagent).

$$(\text{mol/L NaOH}) * (\text{L NaOH}) = \text{mol NaOH} = n$$

Where M is molarity (exact molarity on carboy) and L is liters of NaOH that was used. (You need to convert from mL). Now that we have n (mol of NaOH) plug it into equation A-3. Also called the enthalpy of neutralization (ΔH_{rxn}) of a strong base by a strong acid is a constant -55.90 kJ/mol at 25°C . This is shown by reaction A-2.



With this value, the moles of limiting reactant (n), and after determining ΔT from your graphs by extrapolation, the equation A-3 becomes a simple plug and chug.

$$C_p = \frac{-(\Delta H_{\text{rxn}})(n)}{\Delta T} = \frac{(55.90 \frac{\text{kJ}}{\text{mol}})(\text{mol})}{^\circ\text{C}} = \frac{\text{kJ}}{^\circ\text{C}} \quad \text{A-3}$$

Repeat this calculation for the second trial and calculate the median, range, and relative percent range (see p. I-18) for your Cp.

Calculation: Heat of Reaction (ΔH_{rxn}) for Mg and MgO

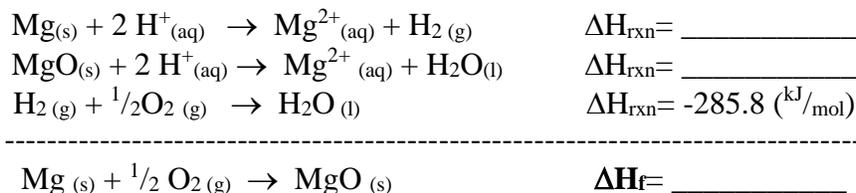
Use the mean (average) Cp value for the calculation of ΔH_{rxn} for both Mg and MgO. If the two Cp values differ by more than ± 0.02 you may want to run a third trial to determine a more precise value. Calculate the median of the Cp values. Now the Enthalpy for Reaction (ΔH_{rxn}) of Mg with HCl can be calculated using the ΔT and moles of Mg previously calculated and plugging them into the equation below using the Cp determined above.

$$\Delta H_{rxn} = \frac{-(Cp)(\Delta T)}{n} = \frac{-\left(\frac{kJ}{^{\circ}C}\right)(^{\circ}C)}{mol} = \frac{kJ}{mol} \quad \text{A-1}$$

Now repeat this calculation using the data for MgO to determine the ΔH_{rxn} of MgO.

Calculation: Molar Enthalpy of Formation of Magnesium Oxide, ΔH_f :

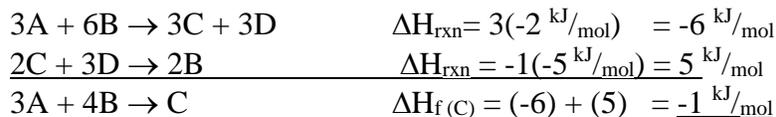
Using Hess' Law to combine the calculated ΔH_{rxn} values and a known ΔH_{rxn} (-285.8 kJ/mol), the ΔH_f (MgO) can be calculated:



Example: Let say the ΔH_{rxn} for the below equations was determined experimentally.



When the first equation is multiplied by three, and the second equation is flipped around, this equation becomes solvable.



Notice how chemical D and some of B and C cancel out because they are on opposite sides of the first and second chemical equation.

Once the ΔH_f (MgO) is calculated look up the literature value (ΔH_f° , the Standard Molar Enthalpy of Formation for $\text{MgO}_{(s)}$), using your textbook or the internet and calculate the error and percent error (see p. I-18) and record in your notebook and on the unknown report sheet.

Calculation: Heat of Reaction (ΔH_{rxn}) for Unknown

The unknown metal oxide is assumed to have a molar mass of 120.0 g/mol. These are the same calculations as described in the reaction of Mg. The calculations are now for the reaction of unknown with $\text{HCl}_{(aq)}$. The unknown is the limiting reagent.

$$n = \frac{g \text{ unknown}}{120.0 \frac{g \text{ unknown}}{\text{mol unknown}}} = \text{mol unknown}$$

Now use the value for n (mol of unk), the ΔT determined from the graph, the C_p and the equation below to calculate the enthalpy of reaction for the unknown with HCl:

$$\Delta H_{rxn} = \frac{-(Cp)(\Delta T)}{n} = \frac{-\left(\frac{kJ}{^{\circ}C}\right)(^{\circ}C)}{\text{mol}} = \frac{kJ}{\text{mol}} \quad \mathbf{A-1}$$

Calculate this value for each trial and report the median, range, and relative % range.

Fill out the unknown report sheet at the end of this experiment making sure to put the unknown number list on the unknown vial that you used (A-xxxx where xxxx is you unknown number). **DO NOT** use the hazard code at the bottom of the label (HC-1012). Make sure that all calculations are done in your laboratory notebook using dimensional analysis and that the report sheet is complete. Be sure to complete a calculation check! When doing the calculation check, be aware that the heat of reaction is the same as enthalpy of reaction and that these values are negative numbers for exothermic reactions. Get a printout of the calculation check and staple it to the unknown report sheet. Points will be taken off for incomplete report sheets or resubmission/repeats of the unknown. Have your regular TA review the report sheet, sign and date it and give it to them for grading. The report sheet for the unknown must be turned in by the deadline listed in the syllabus to avoid late points. This same process will be used for the unknowns done in experiments D, E and F.

POST LAB QUESTION (In your lab notebook):

Do you trust your results?

Use the following information to answer this question:

- **Your calculated range and relative percent range for the C_p and Heat of Reaction or Enthalpy (ΔH_{rxn}) for the unknown.**
- **Your calculated error and relative error for the Molar Enthalpy of Formation of Magnesium Oxide, ΔH_f .**
- **Possible limitations or error in the measurement of temperature and mass, experimental procedure, and graph interpretation.**
- **Do not say ‘Human Error’, ‘Calculation Error’, or ‘Instrument/Machine Error’ in your answer. These are too broad and nonspecific. Instead, be specific, for example: “It was difficult to choose which points to do the linear regression on since the graph for MgO was not very linear resulting in a possible error in the measurement of T_f ”.**

CALORIMETRY - EXPERIMENT A
CHM 152L REPORT SHEET FOR UNKNOWN A-XXXX

STUDENT'S NAME _____ ID# _____ Dana ID _____

SECTION _____ WORKSTATION # _____ DATE _____ UNKNOWN # A- _____

TEACHING ASSISTANT _____ INSTRUCTOR _____

This report sheet should be turned in to your TA. Do not write the hazard code, which has the form HC-xxxx, for the unknown number. The unknown number can be found on the top of vial label containing the unknown in the format A-xxxx. The unknown number can also be found in the section blue book. Be sure to attach the calculation check to this sheet before submitting for grading.

Staple the original report sheet to the back of the new one for repeats of unknowns.

I. Calibration of Calorimeter – Section Workstation # on Calorimeter _____

C_p Values _____ kJ/°C

Median C_p _____ kJ/°C

Range in C_p _____ kJ/°C Relative Percent Range in C_p _____ % (see p. I-18)

II. Enthalpy or Heat of Reaction: $\text{Mg}_{(s)} + 2 \text{H}^+_{(aq)} \rightarrow \text{Mg}^{2+}_{(aq)} + \text{H}_{2(g)}$

_____ kJ/mol

III. Enthalpy or Heat of Reaction: $\text{MgO}_{(s)} + 2 \text{H}^+_{(aq)} \rightarrow \text{Mg}^{2+}_{(aq)} + \text{H}_2\text{O}_{(l)}$

_____ kJ/mol

IV. Enthalpy or Heat of Formation MgO _____ kJ/mol

Literature Value _____ kJ/mol Error _____ kJ/mol Percent Error _____ %

V. Enthalpy or Heat of Reaction: Unknown Oxide + HCl

Values for Each Trial _____ kJ/mol

Median Value _____ kJ/mol for Unknown # A- _____

Range for Unknown _____ kJ/mol Relative Percent Range Unknown _____ %

TA Signature for Review of This Report Sheet _____ Date _____

