CHM151L Extra Credit Assignments:

There are three possible extra credit assignments possible:

1. Titration of Household Products
2. Molar Mass of a Metal (old experiment 7)
3. Thermochemistry Experiment (old experiment 8)

Each experiment is worth a maximum of 20 points each. These experiment should only be done once you have completed all the normal experiments with a pass. In order to get full credit you must do excellent work and have your data initialed by your TA in the same period the work was done and this “raw data page” must be attached to the work. Good luck and have fun doing the experiments listed below! Feel free to do any or all of them.
Titration of Household Products (1-25 pts extra credit)

Comparison of Common Household Products

In this experiment you will be given two different brands of a household product to analyze for percent by mass of active ingredient (see table below). Take your two smallest beakers to your TA where you will be assigned two brands of one product type to analyze (assignment based on last digit of packet number). The standard NaOH (about 0.1 M) prepared in Experiment 6 can be used for the STD NaOH if you have enough left over. Otherwise the chemistry stockroom will provide you with standard NaOH and HCl solutions that can be used as your titrant (both solutions are approximately 0.2 M, the exact molarity will be provided). Take a flask to the fume hood to get the standard solution you need and be sure to record the exact molarity of the NaOH or HCl. Indicators will be available in the lab.

**Do at least two titrations on each brand** following the instructions in the table below. **Be sure to weigh out the amount of product used for each titration** to the nearest mg (even liquids). The sample does not have to be the exact same weight noted and should be adjusted in additional trials such that the volume of titrant used is between 20 to 24 mL if possible. Dissolve the sample in about 30 mL of distilled water. If more than 25 mL of titrant is needed, take a final buret reading, refill the buret, and continue the titration. The total volume would be the sum of the volumes delivered. Calculate the percent by weight of active ingredient for your product. Devise a report format similar to the report sheet for Experiment 6, part C. **Show all data collection and calculated values. Use correct significant figures.**

**Determine the percent by mass of active ingredient for each trial and the median and the range for each brand.**

The report for this extra credit should include a one-paragraph introduction stating the experimental objectives, a one-paragraph summary of your procedure, your results in the lines provided, and a conclusion that completely answers all questions asked. Your work must be neat, understandable, and correct for you to get full credit.

**Be sure to discuss your precision and accuracy for each brand and why your work resulted in this kind of precision and accuracy.** The range between trials for each brand could be used to estimate precision. A literature value may be found on the container of the product or looked up online in order to comment on accuracy. Comment on any sources of error or experimental problems and how they might relate to these conclusions.

<table>
<thead>
<tr>
<th>Household Products for Acid or Base Analysis and Comparison</th>
<th>Product</th>
<th>Active Ingredient</th>
<th>Approx. Amt. of Product to Use for first trial</th>
<th>Indicator</th>
<th>Titrant</th>
<th>Last Digit of Packet No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drain cleaner</td>
<td>NaOH</td>
<td>0.15 g</td>
<td>Methyl Red</td>
<td>STD HCl</td>
<td></td>
<td>0 or 1</td>
</tr>
<tr>
<td>Ammonia cleaner</td>
<td>NH3</td>
<td>2 g (2 mL)</td>
<td>Methyl Red</td>
<td>STD HCl</td>
<td></td>
<td>2 or 3</td>
</tr>
<tr>
<td>Baking soda</td>
<td>NaHCO3</td>
<td>0.3 g</td>
<td>Methyl Orange</td>
<td>STD HCl</td>
<td></td>
<td>4 or 5</td>
</tr>
<tr>
<td>Substance</td>
<td>Chemical Formula</td>
<td>Amount</td>
<td>Phenolphthalein</td>
<td>Standard NaOH</td>
<td>pH Range</td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td>------------------</td>
<td>----------</td>
<td>-----------------</td>
<td>---------------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>Toilet bowl cleaner</td>
<td>HCl</td>
<td>0.8 g (0.8 mL)</td>
<td>Phenolphthalein</td>
<td>STD NaOH</td>
<td>6 or 7</td>
<td></td>
</tr>
<tr>
<td>Vinegar</td>
<td>HC2H3O2</td>
<td>4 g (4 mL)</td>
<td>Phenolphthalein</td>
<td>STD NaOH</td>
<td>8 or 9</td>
<td></td>
</tr>
</tbody>
</table>
Titration of Household Products

Outline Experimental Procedure and Objectives (attach if necessary):

____________________________________________________________________________________
____________________________________________________________________________________
____________________________________________________________________________________
____________________________________________________________________________________
____________________________________________________________________________________
____________________________________________________________________________________
____________________________________________________________________________________
____________________________________________________________________________________

Household Product Assigned: ___________________________ Active Ingredient: ___________________________

Titrant Used: ______________________________________

Purity of Active Ingredient (% by mass) in the Household Product

<table>
<thead>
<tr>
<th></th>
<th>Brand One</th>
<th>Brand One</th>
<th>Brand Two</th>
<th>Brand Two</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Mass of sample (g)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final buret reading (mL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial buret reading (mL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume Titrant delivered (mL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moles of Titrant (remember at end pt. mol Titrant = mol Active Ingredient)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of Active Ingredient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent by mass of Active Ingredient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Median % by mass: Brand One: ___________________________ Brand Two: ___________________________
Example Calculations:

Analysis and Conclusion

Comparing the trials for each brand, were the results for one brand more or less accurate than the other? Explain:

____________________________________________________
____________________________________________________
____________________________________________________

Was one set of trials more or less precise than the other? Explain.

____________________________________________________
____________________________________________________
____________________________________________________

What are the implications of these results?

____________________________________________________
____________________________________________________
____________________________________________________

What are some sources of errors in this experiment and how could the experiment be improved?

____________________________________________________

Assigned TA Signature ___________________________ Date____ (leave paper with TA).
Molar Mass of a Metal

Experiment Seven: Extra Credit

Introduction
You have been introduced to the concept of the "mole" in lecture and have used this concept in previous experiments. You have also become familiar with the concept of molar mass and have used it as a conversion factor when calculating the number of moles present in a given mass of a substance. So far, when you have needed a molar mass (molecular mass or atomic mass for an element), you have been able to obtain it by adding together molar masses from a table. However, this procedure cannot be used when working with an unknown substance. The formula of such a substance is, of course, unknown, and it is necessary to determine its molar mass experimentally.

Gram molar mass or molar mass is defined as the number of grams in one mole of a substance. Thus, whenever the number of moles in a given mass of substance can be experimentally determined, the molar mass of that substance can be calculated. For example, if 0.0264 moles were found to be present in 3.69 grams of an unknown substance, the molar mass of that substance could be calculated as follows:

\[
\text{molar mass of unknown substance} = \frac{3.69 \text{ grams}}{0.0264 \text{ moles}} = 140 \text{ g/mole}
\]

There are many ways to determine the number of moles in a given mass of substance. If an unknown substance is a gas, can be easily changed to a gas, or can produce a gas in a reaction, the simplest method is to measure the volume of the gas. For ideal gases, the volume does not depend on the type of substance present, but only the temperature, the pressure, and the number of moles present. Thus, if the volume of a given mass of gas at a known temperature and pressure can be determined, the number of moles present in that quantity of gas can be calculated.

Calculating the Number of Moles in a Given Sample of Gas
The Ideal Gas Law, \(PV = nRT\), is an equation relating the pressure (P), volume (V), absolute temperature (T), and number of moles (n) to each other. The value of the ideal gas constant (R) depends on the units used in expressing the variables. The value of 0.08206 liter-atm/K-mole is most often used and is appropriate when indicating pressure in atmospheres, volume in liters, and temperatures in Kelvin (absolute). Since volume is frequently measured in milliliters, pressure in torr (mm of Hg) and temperature in degrees Celsius (ºC), these quantities must be converted to the proper units before the Ideal Gas Law can be used with R. The following problem illustrates the use of the Ideal Gas Law to calculate the number of moles in a given volume of a gas at a specified temperature and pressure.

Sample Problem:
A sample of gas was collected and found to have a volume of 152 mL at an atmospheric pressure of 677.7 mm Hg and a temperature of 32.0ºC. How many moles of gas are present? First the pressure must be corrected for the vapor pressure of water since
the gas was collected over water. Use the information at the bottom of page 73 the vapor pressure of water is 37.7 mm Hg at 32.0ºC so the corrected pressure (P) would be 677.7 – 37.7 = 642 mm Hg. The pressure, volume, and temperature are then converted to the units of R and plugged into the ideal gas law, PV = nRT, rearranged to solve for n, the number of moles:

\[ n = \frac{PV}{RT} \]

\[ P = 642.0 \text{ mm Hg} \times \frac{1 \text{ atm}}{760 \text{ mm Hg}} = 0.845 \text{ atm} \]

\[ V = 152 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.152 \text{ L} \]

\[ T (K) = 32.0^\circ + 273 = 305.0 K \quad (0^\circ C = 273K) \]

The molar mass can be calculated by dividing the mass of the sample by the moles.

**The Experiment**

**Risk Assessment:** Moderate to high when using the 6M HCl and producing hydrogen gas. Moderate otherwise.

Note: There is a video on the experimental procedure for this experiment on the CHM151L homepage that you should view before doing this experiment.

**Determination of Molar Mass of Calcium and an Unknown Metal**

The reaction of calcium with water was studied in experiment 3. A gas was produced during the reaction. You will carry out an experimental procedure to measure the molar mass of calcium metal using the ideal gas law (PV=nRT) and the reaction of a known mass of Ca with water. The moles of Ca can be calculated from the volume of hydrogen (H\(_2\)) gas collected using the ideal gas law. The moles of the two are equal because:

\[ \text{Ca} + \text{H}_2\text{O} \rightarrow \text{CaO} + \text{H}_2 \]

The molar mass (in g/mol) can then be determined by dividing the grams of Ca used by the moles of H\(_2\) produced.

**Caution:** Avoid handling the calcium metal with your hands. Instead use crucible tongs or a test tube clamp. Keep any gas produced away from open flames in case it is hydrogen (very flammable!) and vent this gas in a fume hood. Wear goggles at all times in the lab.
Procedure to Determine Molar Mass of Calcium (be sure to watch the video):

1. Obtain a gas collection apparatus and a 100mL graduated cylinder for experiment 7 from your workstation glassware locker and make sure it works with a 6 inch test tube.
2. Obtain and weigh a 0.05-0.07g piece or amount of Ca to a precision of 0.001g and place in a clean, dry vial. Avoid touching Ca with bare skin.
3. Place about 2mL of RO water in your six inch test tube.
4. Fill a 100mL graduated cylinder completely with tap water and place it up-side-down in a 600mL beaker that is about 2/3 full of water so no air is in the graduated cylinder. This can be done in the tap water tub for exp. 7 by the sink.
5. Assemble the apparatus shown below.

6. Now tilt the test tube closer to a near horizontal position but keep the liquid in the end of the test tube, remove the stopper, place the metal in the tube, put the stopper back in to make a tight seal, and rock the tube to get the metal in the RO water in the tube.
7. Wait until the reaction is complete and record the temperature of the water in the beaker and the atmospheric pressure with today’s date from the board.
8. Remove the gas collection apparatus from the graduated cylinder/beaker.
9. Now match the water levels in the beaker and graduated cylinder by moving the graduated cylinder up and down until the levels match. Use the 4L beaker if needed to do this. Record the volume.
10. Keeping the graduated cylinder in the 600 mL beaker take it to the hood and release the hydrogen gas.
11. The solution in the test tube should be placed in the corrosive waste bucket.
12. Subtract the vapor pressure of water from the atmospheric pressure to correct for the water vapor present inside the graduated cylinder. The vapor pressure of water is dependent on water temperature. Use the table below, or for a more precise correction, use the table on the board in the lab to determine the water vapor pressure:
Vapor Pressure of Water

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (mm Hg)</td>
<td>12.8</td>
<td>13.6</td>
<td>14.5</td>
<td>15.5</td>
<td>16.5</td>
<td>17.5</td>
<td>18.6</td>
<td>19.8</td>
<td>21.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>24</th>
<th>25</th>
<th>26</th>
<th>27</th>
<th>28</th>
<th>29</th>
<th>30</th>
<th>31</th>
<th>32</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (mm Hg)</td>
<td>22.5</td>
<td>23.8</td>
<td>25.2</td>
<td>26.7</td>
<td>28.3</td>
<td>30.0</td>
<td>31.8</td>
<td>33.7</td>
<td>35.7</td>
</tr>
</tbody>
</table>

13. Use the corrected vapor pressure to calculate the moles of hydrogen present (see page 72 earlier in the lab manual). Use this and the mass of calcium to calculate the molar mass of calcium in g/mol knowing that the moles of hydrogen will be equal to moles of Ca that reacted. Compare this molar mass to the one listed in the periodic table. Calculate the error and then the percent error between the two molar masses and then answer the questions.

Procedure to Determine the Molar Mass of the Unknown:
1. The unknown for experiment 7 from your unknown packet will contain a metal for which you will determine the molar mass (will not match periodic table).
2. Use the same procedure used for calcium except use the unknown instead of the Ca and 6M HCl

   Caution: 6M hydrochloric acid is corrosive so wear goggles and rinse with water immediate in case of contact with skin.

   Instead of the distilled water in the test tube. Use a pump dispenser to place 2.0 mL of 6.0M HCl (hydrochloric acid) in the six inch test tube. Dispose of the used 6M HCl in the corrosive waste bucket in the hood.
3. Adjust the sample mass to maximize the volume collected, and/or change the size of the graduated cylinder to provide greatest precision. Repeat this procedure two more times with 2.0mL of fresh 6M HCl for each trial. (hint: use ratios)
4. Clean the apparatus and any graduated cylinders and return them to your glassware workstation before the end of the lab period. DO NOT STORE THEM IN YOUR LOCKER BINS! Doing so will cost you 5 points.
5. Complete the calculations for each trial knowing they are the same as for Ca except the reaction is slightly different:

   \[ M + 2HCl \rightarrow MCl_2 + H_2 \]

where M is your metal unknown. Show all data and calculations on your report sheet.

So to summarize the calculations for the molar mass of calcium or the unknown:
1. \( n = \frac{PV}{RT} \) where \( R = \text{Gas Law Constant of 0.08206 L-atm/°K-mol} \)
2. \( P = (\text{Barometric Pressure on Board - Vapor Pressure Water}) \times 1 \text{ atm/760 mmHg} \)
3. \( V = (\text{Volume Hydrogen Gas collected in mL}) \times 1\text{L/1000mL} \)
4. \( T = \text{Temperature of Water °C + 273} \)
5. Solve for \( n \).
6. Molar Mass = Mass sample in grams/n

The percent error for Ca is

\[ \frac{\text{(measured molar mass Ca – true molar mass Ca)}}{\text{true molar mass Ca}} \times 100\% \]

When doing the calculation check for the unknown, use the corrected pressure for the calculation check and be sure to enter values using the requested units.
Extra Credit - Experiment 7
Molar Mass of a Metal

Experimental

Determination of the Molar Mass of Calcium

Outline Experimental Procedure:

______________________________________________________
______________________________________________________
______________________________________________________
______________________________________________________
______________________________________________________
______________________________________________________
______________________________________________________
______________________________________________________

Risk Assessment:

TA Signature and Date for Procedure & Risk Assessment: 

Data, Observations, and Calculations (must show all data and calculations):

_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________

Molar Mass of Calcium (g/mol)

True Molar Mass of Calcium From Periodic Table (g/mol)

Difference Between Molar Masses (Error)

Percent error in Molar Mass Measurement

What measurement(s) caused the greatest error in the determination of the molar mass?

_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________

How could you improve your experimental procedure for determining the molar mass of calcium?

_________________________________________________________________________________
Molar Mass of Unknown: Data and Calculations (must show all data and example calculation):

Mass of Unknown Metal (g)  __________  __________  __________

Barometric pressure (mmHg); don’t use in calc. check  __________  __________  __________

Vapor pressure water (mmHg); don’t use in calc. check  __________  __________  __________

Corrected Barometric pressure (mmHg)  __________  __________  __________

Temperature of water (°C)  __________  __________  __________

Volume of gas collected (mL)  __________  __________  __________

Number of moles of gas collected (mol)  __________  __________  __________

Molar mass of unknown metal (g/mol)  __________  __________  __________

Median molar mass of unknown /mole __________  
* For Unknown # 7- _________*

Calculate the range for the molar mass of unknown metal: __________ g/mol

List the experimental errors that might have caused this range:

How could the procedure to determine the molar mass of the unknown be improved?

__________________________________________

__________________________________________

Please note that this report sheet will not be graded unless these question are answered on a sheet of paper and printout of the completed calculation check are stapled to this sheet.
Experiment Eight: Thermochemistry Extra Credit (1-20 pts)

Introduction

Heat is a form of energy possessed by all matter. The total heat content (or enthalpy) of a sample of matter at any given temperature is impossible to determine. Only the change in heat content associated with a change in physical state, a change in temperature, or a chemical reaction for a given substance can be determined.

Heat is measured in units of calories. A calorie can be roughly defined as the quantity of heat energy required to raise the temperature of 1 gram of water by 1 degree Celsius. The specific heat of 1.00 cal/ºC-g while iron has a specific heat of only 0.11 cal/ºC-g. This means that it takes approximately one-tenth as much heat to raise the temperature of 1g of iron by 1ºC as it does to raise the temperature of 1g of water by 1ºC. It also means that a given amount of heat will raise the temperature of 1g of iron approximately ten times more than it will raise the temperature of 1g of water.

When samples of matter at different temperatures are brought into contact, heat transfers from the sample at the higher temperature to that at the lower one until the temperatures become equal. Some substances however transfer heat very poorly. For example, when hot coffee is poured into a styrofoam cup, heat does not transfer to the styrofoam of the cup easily. Consequently styrofoam is a good insulator. Coffee stays warm longer in a styrofoam cup than it would in a metal cup, because a metal is a relatively good conductor of heat and therefore contributes to the heat loss.

When liquids or solids at different temperatures are mixed inside of an insulated container like a styrofoam cup, the final temperature reached for the mixture depends upon the initial temperatures of the components, the mass of each component, and finally the specific heat of each component. An insulated container of this sort can be used to construct a simple calorimeter.

When phase changes occur, for example, the melting (fusion) of a solid like ice or the boiling (vaporization) of a liquid like water, a certain constant quantity of heat is required per gram of substance. Such quantities of heat are called heats of fusion or heats of vaporization.

Part A of this experiment involves the determination of the quantity of heat required to melt 1 g of ice. This is defined as the “heat of fusion of ice”. Weighed quantities of hot water and ice at known temperatures (hot water about 50ºC and ice at 0ºC) are mixed in 2 nested styrofoam cups (calorimeter) to do this. The inner cup is covered with a plastic lid and a thermometer is inserted through a hole in the lid. The cups are swirled until the ice melts and the final temperature of the contents is recorded.

Heat is transferred from the hot water to the cold ice until the ice melts. The cold water produced from the melted ice is then warmed from 0ºC by heat transferred from the hot water. This system has a final temperature between 0ºC and the initial temperature of the "hot water" (assuming sufficient hot water is present to melt all the ice). This is true because no external heat is added and no internal heat is lost through the styrofoam insulator. Under these conditions, the heat transferred in calories is equal to the number of grams of hot water used multiplied by its specific heat multiplied by the number of degrees it is cooled. This must also be the amount of heat absorbed by the ice in melting plus the
heat absorbed by the liquid water that is formed. The heat absorbed during melting is equal the mass of the ice in grams multiplied by the (presently unknown and to be determined) heat of fusion of water. The heat required to warm the cold water (from the melted ice) is equal to the mass of the cold water (equal the mass of ice that melted) multiplied by its specific heat multiplied by the number of degrees that it is warmed. In summary,

\[
\text{Heat Lost by Hot Water} = \text{Heat Absorbed by Water Initially Present as Ice}
\]

\[
\text{Heat Lost by Hot Water} = \text{Heat to Melt Ice} + \text{Heat to Warm Cold Water from Melted Ice}
\]

\[
(m_i)(1.00 \text{ cal/g}^{\circ}C)(T_f - T_i) = (m_i)(H_f) + (m)(1.00 \text{ cal/g}^{\circ}C)(T_f - T_i)
\]

where \(m_i\) = mass of hot water in grams, \(m_i\) = mass of ice in grams, \(T_f\) = the final temperature that is measured, \(T_h\) = the initial temperature of the hot water (in degrees celsius), and \(T_i\) = the temperature of the ice. The heat of fusion \((H_f)\) is the only unknown in the above equation and it can be solved for as follows:

| Heat Absorbed by Solid and Cold Liquid | = | Heat Lost by Hot Liquid |
| Heat to Melt Solid + Heat to Warm | = | Heat Lost by Hot Liquid |
| Liquid from Solid |
| Heat to Melt Solid | = | Heat Lost by Hot Liquid – Heat to Warm Liquid from Solid |
| Heat of Fusion | = | Heat to melt Solid |
| Mass of Solid |

For example, determine the heat of fusion for a metal that has a melting point of 20.0ºC and a specific heat of 0.100 cal/gºC from the following data. If 10.00 g of the solid metal at 20.0ºC is put in 50.0 g of hot liquid metal at 50.0ºC, the metal melts and the final temperature of the system is 40.0ºC. Solution:

Heat Lost by Hot Liquid = Specific Heat (T)(Mass)
= \((0.100 \text{ cal/g}^{\circ}C)(50.0 - 40.0)\text{ºC})(50.00g)\)
= 50.0 cal

Heat to Warm Liquid from Solid = (Specific Heat of Compound)(T)(Mass)
= \((0.100 \text{ cal/g}^{\circ}C)(40.0 - 20.0)\text{ºC})(10.00g)\)=20.0 cal

Heat to Melt Solid Metal = 50.0 - 20.0 cal = 30.0 cal

Heat of fusion = 30.0 cal / 10.0 g
= 3.00 cal / g

Please note that the specific heat for water is 1.00 cal/gºC not the 0.100 list for the metal in this example problem.

Part B of this experiment involves the determination of the heat of neutralization of a monoprotic acid by a base. The reaction of a strong acid with a strong base is very
exothermic. The amount of energy released per mole of acid or base neutralized (reacted) is a constant called the heat of neutralization and has units of cal/mole. When such a reaction is conducted under insulated conditions, the heat released by the reaction raises the temperature of the reaction medium. If the mass, temperature change, and specific heat of the medium is known, the amount of heat produced can be calculated.

You will measure the heat of reaction (called heat of neutralization) when an unknown strong acid (HX) reacts with a strong base (sodium hydroxide, NaOH) in a water solution. Since an aqueous strong acid solution contains H⁺ (aq) and an aqueous strong base solution contains OH⁻ (aq), the heat change will be that due to formation of water.

\[ \text{H}^+ (\text{aq}) + \text{OH}^- (\text{aq}) \rightarrow \text{H}_2\text{O} (l) + \text{heat} \]

Example: 110 mL of 1.00 M NaOH are mixed with 50.0 mL of 2.00 M HCl. Both solutions were initially at 20.1°C; the final temperature of the solution (specific heat = 0.960 cal/g°C) after the reaction is 30.3°C (y intercept from the graph); thermometer correction factor is 1.020 (see below). The final mass of the solution is 161.000 g. The energy released by the reaction and the moles of limiting reagent are needed to calculate the heat of neutralization.

\[
\begin{align*}
\text{Temp. Change} & = (30.3-20.1)^\circ\text{C} = 10.2 \, ^\circ\text{C} \\
\text{Corrected Temp. Change} & = (10.2 \, ^\circ\text{C})(1.020) = 10.4 \, ^\circ\text{C} \\
\text{Heat release} & = (0.960 \text{ cal/g}^\circ\text{C})(161.000 \text{ g})(10.4 \, ^\circ\text{C}) = 1607 \text{ cal} \\
\text{Moles NaOH} & = (0.1100 \text{ L})(1.00 \text{ mol/L}) = 0.110 \text{ mole NaOH} \\
\text{Moles HCl} & = (0.0500 \text{ L})(2.00 \text{ mol/L}) = 0.100 \text{ mole HCl}
\end{align*}
\]

HCl would therefore be the limiting reagent (0.110 mol NaOH > 0.100 mol HCl), and the heat of neutralization would be,

\[
\text{Heat of Neutralization} = \frac{\text{heat released}}{\text{moles limiting reagent}} = \frac{1607 \text{ cal}}{0.100 \text{ mol}} = 1.61 \times 10^3 \frac{\text{cal}}{\text{mol}}
\]

The Experiment

Risk Assessment: Moderate to High due to corrosives, 2M NaOH and exp. 8 unknown (strong acid).

Thermometer Calibration Check

Since the measurement of temperature is the greatest source of error in this experiment, special care needs to be taken to insure that your thermometer is functioning correctly and that it is read to ±0.1°C. Checking its calibration will do this. First check and make sure there are no breaks in the alcohol column inside the thermometer. If there are any breaks trade the thermometer in for a new one at the lab prep stockroom (room 216). An easy way to calibrate the thermometer is to compare the temperature difference measured by your thermometer in ice water (0°C) to boiling water (93°C at 7,000 feet). Fill a beaker half full with ice and add a little cold water to make a slush mixture. First position the thermometer such that the bulb is about in the center of the water/ice mixture. After 60 seconds measure the temperature. Gently stir the mixture with the thermometer and recheck the
temperature. If the temperature is constant record it to ±0.1°C on your report sheet, otherwise repeat this process until the temperature you measure for cold water is constant. If temperature is not within ±2°C of zero, check with your TA. Repeat this process with water heated to a rolling boil in a 400 mL beaker. Take care to keep the tip of the thermometer in the center of the boiling water. **The bulb of the thermometer should always be place in the center of liquids for good measurements.**

Calculate the difference in temperature between the ice water and boiling water. This difference should be 93°C. If you determine that the error in temperature change of your thermometer to be greater than ±4.0°C from 93°C, label the thermometer with a piece of tape noting the temperature change. Trade in your thermometer for a more accurate one at the lab prep stockroom window (room 216).

The measurement of temperature is difficult such that when the unknown is analyzed a correction factor will be used to make up for any differences in thermometer calibration. The correction factor (CF) can be calculated by dividing 93°C by the temperature difference between boiling water and ice water measured above:

\[
CF = \frac{93}{\text{Measured Temp Difference}}
\]

CF will be used to correct the temperature change measured in determining the heat of neutralization of the unknown, but will not be needed for the heat of fusion calculations.

**Determination of the Heat of Fusion of Water**

Obtain 100 mL of hot water from the hot water tap. Heat the water in a beaker to 50-55°C if necessary using a hot plate. Weigh the empty calorimeter (2 clean, dry nested styrofoam cups covered by a plastic lid available on the side shelf) on the balance. Transfer about 75 mL (using a beaker) of the hot water (40°C-55°C) to the inner cup; place the cover on the calorimeter and reweigh it to determine the mass of the hot water. Record the temperature of the hot water to the nearest 0.1°C using a thermometer inserted through the hole in the lid.

Add the crushed ice (assume that the temperature of ice is 0°C, try to avoid adding liquid water when you add ice) available on the side shelf (ask your TA if none is in lab), a few pieces at a time and swirl until the temperature is between 15°C and 20°C. Keep the lid on the calorimeter as much as possible during this period. As soon as the last pieces of ice are gone, read the lowest temperature reached by the thermometer (to the nearest 0.1°C) and record it as the final equilibrium temperature, T_f. Weigh the calorimeter and contents again to determine the mass of the ice added and record the data on the Report Sheet. Calculate the heat of fusion for water using 1.00 cal/g°C for the specific heat of water. Do two trials, and report the average value.
Determining the Molar Heat of Neutralization of an Unknown Monoprotic Acid (HX)

The unknown for this experiment (8-XXXX) can be checked out from the lab prep stockroom (216). All chemical waste for this experiment should be placed in the liquid corrosives bucket in the hood.

**CAUTION:** The unknown is a strong acid (8 M in H⁺) and is corrosive to skin and clothing. Handle the unknown carefully and immediately flush any spills with cold water. The 2 M NaOH is also caustic and should be flushed off skin immediately. Always wear eye protection in the laboratory. Do not rub your eyes while working with corrosives. Wash your hands when you are done working with corrosive chemicals.

Weigh a clean, empty calorimeter on the balance. Remove the lid and add 50.0 mL of 2.00 M NaOH to the calorimeter (measured with a 25 or 50 mL graduated cylinder or pump dispenser provided). Put the lid back on and allow the NaOH in the calorimeter to reach a constant temperature (this will take 2-5 minutes). Record this temperature to ±0.1°C on the Report Sheet. Clean and dry the thermometer and measure the temperature of the acid solution (unknown 8-xxxx). Adjust the temperature of the acid by heating the unknown bottle in your hand or cooling it in cold water.

When the temperature of the two solutions are within 1°C or less of each other, record the temperature of the acid, and clean and dry the thermometer. Remove the lid, quickly add 10.00 mL of the acid solution into the calorimeter using a volumetric pipet, start timing, and place the lid back on the calorimeter. Insert the thermometer and gently swirl the solution for about 20 seconds. Hold the calorimeter securely in your fingertips while swirling, not with your whole hand, to limit heat transfer from your hand to the calorimeter. Record the temperature of the solution to the nearest ±0.1°C at 60 seconds after the addition of the unknown. Take the temperature every 30 seconds for additional readings at 90, 120, and 150 seconds after adding the unknown. Gently swirl the solution for about 10 seconds between each temperature measurement.

Remove the thermometer, dry the outside of the calorimeter with a paper towel, and weigh the calorimeter and contents (the outside of the calorimeter must be dry before it is placed on the balance). Dispose of used acids and bases in the “Corrosive Liquids” container in the hood. The unknown for exp. 8 can be disposed in this container also (wait until the it is grade though). Rinse both the styrofoam cups and used glassware several times with tap water. Make sure the pipet is also rinsed with distilled water.

**Calculations:**

Use the pre-reaction temperature of the 2.00 M NaOH solution as the initial temperature of the mixture before the reaction starts (since there is about 5 times as much of it). To determine the temperature of the solution after the reaction takes place you will first plot the temperatures of the reaction mixture (y axis) measured at 60, 90, 120, and 150 seconds against the time in seconds (x axis) using the Graphical Analysis software available in the chemistry computer labs. Do not plot the temperature of the NaOH.

The y intercept or temperature at time zero is used as final temperature after the reaction takes place to compensate for heat lost from the calorimeter to the surroundings. The y intercept (B) is determined by doing a linear fit. This is done by selecting the points to be used in the linear fit (select points in data table with mouse) and selecting the
linear fit icon (second icon from right on tool bar). Make sure the x-axis (time) starts at zero (click on left hand number on axis and change to zero). Make a graph for each of the two trials done and print them. If the correlation coefficient (COR) is less than 0.8 see your TA. You may need to discard a point. The y-intercept (B) for the following example graph is 35.71°C:

The “Change in temperature during the reaction” would be the y-intercept minus the temperature of the NaOH. This temperature change can then be corrected for differences in thermometers by multiplying it by the correction factor (CF) calculated earlier in the experiment. Use 0.960 cal/g°C for the specific heat of the contents of the calorimeter (mass of NaOH solution and unknown acid), the corrected temperature change, and the solution mass to calculate the “heat released during the reaction”.

Next you must determine whether the OH⁻ in the NaOH solution (50.0 mL of 2.0 mol/L) or the H⁺ in the unknown acid (10.00 mL of 8.00 mol/L in H⁺) is the limiting reagent by calculating the moles of each. The “Number of moles of the limiting reagent” is the smaller of the two. Calculate the “Heat of neutralization” of the unknown acid using the “Heat released during the reaction” and the “Number of moles of the limiting reagent” (hint - look at the units). Refer to the limiting reagent example problem earlier in this experiment and your lecture text for help doing the heat of neutralization calculations if you still have problems. Clean up your work area with a damp sponge. Wash the calorimeter and your glassware. Make sure the volumetric pipet is rinsed several times with tap water and once with distilled water before storing it.

Use the computer calculation check for this experiment and attach a copy of it to your report sheet before turning in your results. Record the following values below and turn in the report sheet at the chemistry stockroom for grading.
Experiment 8 – Thermochemistry Extra Credit

Outline Experimental Procedure:

____________________________________________________________________________________
____________________________________________________________________________________
____________________________________________________________________________________
____________________________________________________________________________________
____________________________________________________________________________________

Risk Assessment:_____________________________________________________________________

TA Signature and Date for Procedure & Risk Assessment:_______________________________________

Experimental:

Thermometer Calibration Check:

Temperature of ice water (°C)_________ Temperature of boiling water (°C)______

Temperature change (°C)___________ Correction Factor (93°C + temperature change)_______

Determination of the Heat of Fusion of Water:

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of styrofoam</td>
<td>________________________ g</td>
<td>________________________ g</td>
</tr>
<tr>
<td>calorimeter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of styrofoam</td>
<td>________________________ g</td>
<td>________________________ g</td>
</tr>
<tr>
<td>calorimeter + mass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>hot water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of hot water</td>
<td>________________________ g</td>
<td>________________________ g</td>
</tr>
<tr>
<td>($m_h$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature of hot</td>
<td>________________________ °C</td>
<td>________________________ °C</td>
</tr>
<tr>
<td>water ($T_h$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature of ice</td>
<td>________________________ °C</td>
<td>________________________ °C</td>
</tr>
<tr>
<td>($T_i$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final temperature</td>
<td>________________________ °C</td>
<td>________________________ °C</td>
</tr>
<tr>
<td>of water ($T_f$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature change</td>
<td>________________________ °C</td>
<td>________________________ °C</td>
</tr>
<tr>
<td>of water from ice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>($T_f - T_i$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature change</td>
<td>________________________ °C</td>
<td>________________________ °C</td>
</tr>
<tr>
<td>of hot water ($T_h - T_f$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of calorimeter,</td>
<td>________________________ g</td>
<td>________________________ g</td>
</tr>
<tr>
<td>water, and ice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of ice added</td>
<td>________________________ g</td>
<td>________________________ g</td>
</tr>
<tr>
<td>($m_i$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat lost by the</td>
<td>________________________ cal</td>
<td>________________________ cal</td>
</tr>
<tr>
<td>hot water ($H_{hw}$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat used to warm</td>
<td>________________________ cal</td>
<td>________________________ cal</td>
</tr>
<tr>
<td>the water from</td>
<td></td>
<td></td>
</tr>
<tr>
<td>melted ice ($H_{iw}$)</td>
<td>________________________ cal</td>
<td>________________________ cal</td>
</tr>
<tr>
<td>Heat used to melt</td>
<td>________________________ cal</td>
<td>________________________ cal</td>
</tr>
<tr>
<td>the ice ($H_{iw} - H_{iw}$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat of fusion for</td>
<td>________________________ cal/g</td>
<td>________________________ cal/g</td>
</tr>
<tr>
<td>ice ($H_f$) = ($H_{iw} - H_{iw}$)/ $m_i$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average heat of fusion for ice  ________________________ cal/g

Calculate the range for: Heat of Fusion Water ________________________ cal/g
Determination of the Molar Heat of Neutralization of an Unknown Monoprotic Acid:

<table>
<thead>
<tr>
<th>Description</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of Styrofoam calorimeter(g)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Temperature of 2.00M NaOH, Initial Temperature (C)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Temperature of unknown 8.00M acid (C)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Temperature at 60 seconds (C)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Temperature at 90 seconds (C)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Temperature at 120 seconds (C)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Temperature at 150 seconds (C)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Mass of calorimeter, NaOH and unknown acid (g)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Mass of NaOH solution and unknown acid (g)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Temperature from graph extrapolated back to 0 secs. (C)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Change in temperature during reaction (C)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>(Temperature NaOH or initial temperature – y intercept)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Corrected change in temperature during reaction (C)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>(change in temperature during reaction times correction factor)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Heat released during reaction (cal)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>(specific heat solution = 0.960 cal/g.-ºC,</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Specific heat x mass NaOH solution and acid  x Corrected Change in Temperature)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Number of moles of the limiting reagent (mol)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Heat of neutralization (cal/mol)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Average heat of neutralization(cal/mol)*</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Calculate the range for the Heat of Neutralization _________cal/mol</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Have you done a calculation check? (Yes/No)</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>Why do we extrapolate back to time zero to determine the final temperature?</td>
<td>______________</td>
<td>______________</td>
</tr>
<tr>
<td>What are the major sources of experimental error for this experiment:</td>
<td>______________</td>
<td>______________</td>
</tr>
</tbody>
</table>

*Unkno

_____________cal/mol*  Unknown #________________ **