CH 221 Fall 2022:

"Calorimetry" *(online)*

Lab *- Instructions*

Note: **This is the lab for section W1 of CH 221 only.**

- *If you are taking section 01 or section H1 of CH 221*, please use this link: http://mhchem.org/s/8a.htm

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Step One:

Watch the lab video for the "Calorimetry" lab, found here: **http://mhchem.org/w/8.htm**
Record the data found at the ***end*** of the lab video on page Ib-8-7.

Step Two:

Complete pages Ib-8-7 through Ib-8-14 using the "Calorimetry" video and the actual lab instructions on pages Ib-8-2 through Ib-8-5. Include your name on page Ib-8-7!

Step Three:

Submit your lab (pages Ib-8-7 through Ib-8-14 *only* to avoid a point penalty) **as a *single* PDF file to the instructor via email (mike.russell@mhcc.edu) on Wednesday, November 30 by 11:59 PM.** I recommend a free program (ex: CamScanner, https://camscanner.com) or a website (ex: CombinePDF, https://combinepdf.com) to convert your work to a PDF file.

If you have any questions regarding this assignment, please email (mike.russell@mhcc.edu) the instructor! Good luck on this assignment!

Calorimetry

Thermal energy, usually called heat, is one of the most familiar forms of energy. We observe this form of energy when it is passed from an object of higher temperature to one at a lower temperature when the objects are in contact. Heat flow can be measured using a device called a **calorimeter**. A calorimeter is a device that is insulated from the surroundings so that essentially no heat can flow in or out of the device. Within the calorimeter, heat can be transferred from one system to another and this transfer causes a temperature change.

Specific Heat of an Unknown Metal

When heat flows into a substance, the temperature of the substance increases. The quantity of heat, **q**, required to cause a temperature change ΔT of any substance varies directly with the mass, **m**, of the substance such that:

$$q = mC\Delta T$$

The **specific heat, C,** can be considered the amount of heat required to raise the temperature of one gram of a pure substance by one degree Celsius. The calorie is a unit of heat as well as the joule. The **specific heat of water** is 1.000 calorie/g ˚C which equals **4.184 J/g ˚C**. The joule (J) is directly related to mechanical work and is the S.I. unit of energy; hence, we shall use the joule almost exclusively.

The specific heat of a metal can be easily measured with a calorimeter. A weighed amount of metal is heated to a specific temperature and is quickly added to a measured amount of water at a known temperature in a calorimeter. The metal loses heat to the water and eventually the metal and water equilibrate at a temperature above the original temperature of the water but below that of the hot metal. If we assume no heat loss to the surroundings or the walls of the container, the heat lost by the hot metal should equal the heat gain of the water. For heat flow *q*,

$$q_{\text{water}} = -q_{\text{metal}} \quad \text{(the negative sign indicates the opposite flow of the heat)}$$

If we now express the heat flow in terms of specific heat (C) for both the metal as well as the water we get:

$$(C_{\text{water}})(m_{\text{water}})(\Delta T_{\text{water}}) = -(C_{\text{metal}})(m_{\text{metal}})(\Delta T_{\text{metal}}) \qquad \textit{equation A}$$

Knowing the specific heat of water we can use this equation to solve for the specific heat of the metal. The specific heat of a metal is related to its molar mass by a simple relationship. Dulong and Petit discovered that 25 joules is required to raise the temperature of one mole of many metals by 1 ˚C. This relationship, shown below, is known as the **Law of Dulong and Petit**:

$$\text{Molar Mass (g / mol)} = 25 / C_{\text{metal}} \text{ (J/g ˚C)} \qquad \textit{equation B}$$

In part A of this lab you will determine the specific heat and molar mass of an unknown metal.

Heat of Reaction and Hess's Law

When a physical or chemical change occurs, it is usually accompanied by a change in the heat content (**enthalpy**) of the material in question. Enthalpy (**H**) is defined as the heat content of a given set of conditions, called a **state**. Since there is only one value of enthalpy for any given state, the enthalpy is one of a number of thermodynamic variables called **state functions**. Because many factors internally contribute to the enthalpy of a substance there is no way to measure the enthalpy of a pure substance. Instead we can determine the change in the enthalpy (**ΔH**) when a chemical or physical change occurs. When a chemical reaction occurs in water solutions, the situation is similar to that which is present when a hot metal sample is put into water. As in the specific heat experiment the heat flow for the reaction mixture is equal in magnitude but opposite in sign to that for the water.

$$q_{\text{reaction}} = -q_{\text{water}} \qquad \textit{and} \qquad \Delta H_{\text{reaction}} = q_{\text{reaction}} / \text{mol}$$

By measuring the mass of the water used as solvent, and by observing the temperature change that the water undergoes, we can find q_{water} and therefore $\Delta H_{\text{reaction}}$. An increase in water temperature indicates that heat is given off by the reaction; the reaction is **exothermic**, and $\Delta H_{\text{reaction}}$ is negative. Conversely, if the temperature decreases, heat is absorbed by the reaction from the surroundings, the reaction is **endothermic**, and $\Delta H_{\text{reaction}}$ is positive.

Hess's law further states that when two or more chemical equations are *combined* to produce a balanced chemical equation, the enthalpy changes combined in the same manner will yield the enthalpy change of the new reaction. This will enable us to determine the enthalpy change for a reaction that may not be easily performed in the laboratory, i.e. the enthalpy of formation of acetylene gas (C_2H_2).

The reaction we are trying to determine is:	$2\,C(s) + H_2(g) \rightarrow C_2H_2(g)$	$\Delta H = ?$
By taking 2 x the heat of formation of CO_2:	$2\,C(s) + 2\,O_2(g) \rightarrow 2\,CO_2(g)$	$\Delta H = -787.0$ kJ
$^1/_2$ x the heat of formation of H_2O:	$H_2(g) + {}^1/_2\,O_2(g) \rightarrow H_2O(l)$	$\Delta H = -285.8$ kJ
Reverse the heat of combustion of C_2H_2:	$2\,CO_2(g) + H_2O(l) \rightarrow C_2H_2(g) + {}^5/_2$	$\Delta H = +846.1$ kJ

The **sum** of these enthalpies is **-226.7 kJ**, which is the enthalpy of formation of acetylene.

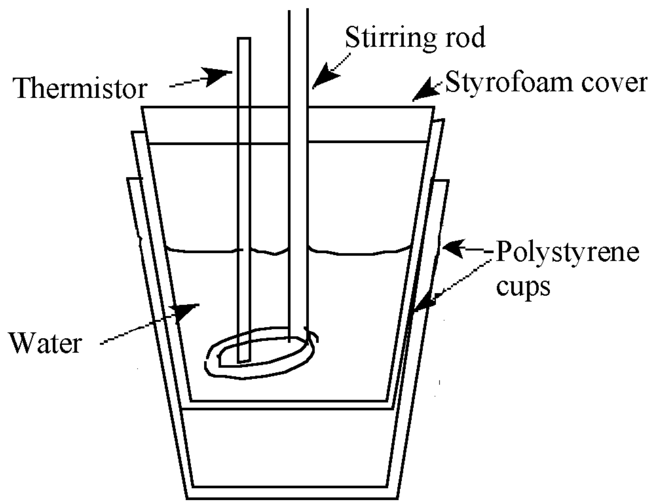
In this experiment we will measure the enthalpy change for the reaction of a metal, zinc, with acid to produce a zinc salt. We will then measure the enthalpy change for zinc oxide reacting with the same acid. From these two reactions along with the value for the reaction of hydrogen with oxygen, one can determine the *heat of combustion of zinc metal* (or the **heat of formation for zinc oxide**):

$Zn(s) + 2\,HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$	ΔH_1 (1)
$ZnO(s) + 2\,HCl(aq) \rightarrow ZnCl_2(aq) + H_2O(l)$	ΔH_2 (2)
$H_2(g) + {}^1/_2\,O_2(g) \rightarrow H_2O(l)$	$\Delta H_3 = -285.8$ kJ
$Zn(s) + {}^1/_2\,O_2(g) \rightarrow ZnO(s)$	$\Delta H_4 = ?$

As before in the last experiment, you can use a calorimeter to determine the heats (***q***) of reaction and enthalpies for reactions ***1*** and ***2***, above. Combining these enthalpy values with the enthalpy of formation for water (equation ***3***, above), one can use Hess's Law to calculate the heat of formation for Zinc Oxide (equation ***4***.)

PROCEDURE: Part A: SPECIFIC HEAT of an UNKNOWN METAL

1. Assemble the calorimeter as diagrammed. The calorimeter consists of two nested polystyrene coffee cups with a Styrofoam cover. There are two holes in the cover, one for the **thermistor** (which records temperature when connected to a **Vernier LabQuest** apparatus) and one for the glass stirrer provided for this experiment. Weigh the dry calorimeter to 0.001 g. Add about 40 mL of tap water and reweigh the calorimeter and water.



2. Fill a 600 mL beaker 2/3 full with tap water and heat it to boiling. While waiting for the water to boil, weigh a sample of dry metal to the nearest 0.001 g. Return the metal to the dry test tube and clamp the test tube in the boiling water bath so that the metal is below the water line.

3. Record the temperature of the boiling water bath using the LabQuest thermistor probe. Remove the thermistor from the boiling water bath and wipe off all the hot water before placing it in the calorimeter. Record the temperature of the water in the calorimeter.

4. Remove the test tube from the boiling water bath, quickly wipe excess water off the outside of the test tube. Pour the hot metal into the calorimeter without causing the water to splash (tilt the calorimeter). While stirring the water in the calorimeter, monitor the temperature until it remains steady or begins to fall. Record the temperature when it has stabilized.

5. Dry the metal sample, return it to the large test tube and heat it again in the boiling water. **Repeat** the experiment.

Part B: HEAT of REACTION: HESS'S LAW – *all waste should go in a waste container!*

Zinc Reaction

1) Using a graduated cylinder, add about 75.0 mL of 6.00 M HCl in the dry calorimeter. Determine the mass of the HCl solution in the calorimeter to 0.001 g, then record the temperature.
2) Weigh about 0.65 g of Zn to the nearest 0.001 g.
3) Add the metal to the calorimeter, stir and record the highest temperature (when it stabilizes.)

Zinc Oxide Reaction

4) Perform a similar experiment using 75.0 mL of 6.00 M HCl and 1.2 g zinc oxide.

CALCULATIONS for Part A:

1. For each trial, calculate the specific heat of the metal. Use "equation A" on the front page of this lab.
2. Determine the **average** specific heat and deviation in **parts per thousand**.
3. **Estimate the molar mass** using the law of Dulong and Petit (equation B, front page). What is the identity of your metal?

CALCULATIONS for Part B:

1. Calculate the heat change (q) for the Zn and ZnO reactions.
   Example for q_{Zn}: **q_{Zn} = -(Heat capacity of HCl)(g HCl *solution*)(ΔT)** *notice the negative sign!*
   ***Heat capacity** for HCl is 3.86 J/g·˚C. Assume the **density** of the HCl solution is 1.00 g/mL (if needed.)

2. Calculate the heat of reaction (ΔH) for the Zn and ZnO reactions. Watch the sign of your value!
   Example for Zn: **ΔH = q_{Zn} / mol Zn**

3. Write balanced equations for the two reactions performed in lab, including your experimentally determined ΔH. *Hint:* See the second page of this lab, towards the bottom.

4. Use Hess's Law to determine the heat of formation for zinc oxide: $Zn_{(s)} + \frac{1}{2} O_{2\,(g)} \rightarrow ZnO_{(s)}$ (***Hint**:* See the second page of this lab, towards the bottom! You will need the heat of formation for water to calculate the heat of formation for zinc oxide.)

5. Look up the value for the heat of formation of $ZnO_{(s)}$ in your text. Calculate your **percent error**.
   Percent error = absolute value{ (actual - experimental) / actual }*100%. Remember to explain (in your conclusion) any discrepancies.

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Calorimetry

YOUR NAME: ______________________________

DATA: *Watch the video (***http://mhchem.org/w/8.htm***) to acquire these values using the data at the very end:*

PART A:

Trial 1

metal sample (g): ____________

initial temperature of metal (°C): ____________

water sample (g): ____________

initial temperature of water (°C): ____________

final temperature of metal plus water (°C): ____________

Trial 2

metal sample (g): ____________

initial temperature of metal (°C): ____________

water sample (g): ____________

initial temperature of water (°C): ____________

final temperature of metal plus water (°C): ____________

PART B:

Zinc

mass Zn (g): ____________

Volume HCl (mL): ____________

initial temperature of HCl (°C): ____________

final temperature of solution (°C): ____________

Zinc Oxide

mass ZnO (g): ____________

Volume HCl (mL): ____________

initial temperature of HCl (°C): ____________

final temperature of solution (°C): ____________

<u>Part A Calculations</u>: *Determining the Specific Heat of an Unknown Metal*

Show all work, use significant figures and circle the final answer for full credit.

- Use the data from Part A to calculate the **specific heat of the metal for both trial #1 and trial #2** (two separate calculations.) *Hint:* Use **equation A** on page I-8-2 to solve for C_{metal}. Use this page and the following page to show ***all*** calculations; attach additional pages of work if necessary.
- Find the **average specific heat** of your metal and the **parts per thousand** (http://mhchem.org/ppt).
- Use the **Law of Dulong and Petit** (**equation B** on page I-8-2) to estimate the molar mass of the unknown metal and then predict it's identity using the periodic table.

Part A Calculations (continued, if needed):

Trial #1 Specific Heat of Unknown Metal (J g^{-1} K^{-1}): ____________________________

Trial #2 Specific Heat of Unknown Metal (J g^{-1} K^{-1}): ____________________________

Average Specific Heat of Unknown Metal (J g^{-1} K^{-1}): ____________________________

Parts Per Thousand: _____________________________________

Molar Mass of Unkonwn Metal using the Law of Dulong and Petit (g/mol): ___________

Probable identity of the Unknown Metal (name and symbol): __________________________

Part B Calculations: *Heat of a Reaction / Hess's Law*

For the Zn reaction:

1. Assuming that the density of the HCl solution is **1.00 g/mL**, calculate the mass (g) of the HCl solution for the Zn reaction. *Hint:* this will be a number larger than twenty grams!

2. Calculate the change in temperature (ΔT) for the zinc reaction.

3. Using a *heat capacity* of 3.86 J g^{-1} K^{-1} , find q_{Zn} using the equation:

$$q_{Zn} = -(\textit{heat capacity}\ \text{of HCl})(\text{g HCl solution})(\Delta T)$$

4. Calculate the moles of Zn (**mol Zn**) used using the grams of Zinc used and the molar mass of Zn.

5. Find the heat of reaction for the Zn reaction (**ΔH_{Zn}**) ***in kJ/mol*** using the equation:

$$\Delta H_{Zn} = q_{Zn} / \text{mol Zn}$$

For the ZnO reaction:

1. Assuming that the density of the HCl solution is **1.00 g/mL**, calculate the mass (g) of the HCl solution for the ZnO reaction. *Hint:* this will be a number larger than twenty grams!

2. Calculate the change in temperature (ΔT) for the zinc oxide reaction.

3. Using a *heat capacity* of 3.86 J g^{-1} K^{-1} , find q_{ZnO} using the equation:

$$q_{ZnO} = -(\textit{heat capacity} \text{ of HCl})(\text{g HCl solution})(\Delta T)$$

4. Calculate the molar mass for zinc oxide (g/mol).

5. Calculate the moles of ZnO (**mol ZnO**) used using the grams of zinc oxide used and the molar mass of zinc oxide.

6. Find the heat of reaction for the ZnO reaction (**ΔH_{ZnO}**) ***in kJ/mol*** using the equation:

$$\Delta H_{ZnO} = q_{ZnO} / \text{mol ZnO}$$

Hess's Law:

1. Use your previously calculated values of $\mathbf{\Delta H_{Zn}}$ and $\mathbf{\Delta H_{ZnO}}$ to complete the missing values in the equations below:

$Zn(s) + 2\ HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$ ΔH_{Zn} (kJ/mol) = ___________________

$ZnO(s) + 2\ HCl(aq) \rightarrow ZnCl_2(aq) + H_2O(l)$ ΔH_{ZnO} (kJ/mol) = ___________________

$H_2(g) + {}^1/_2\ O_2(g) \rightarrow H_2O(l)$ ΔH_3 (kJ/mol) = -285.8 kJ

2. Use Hess's Law and the three equations above (ΔH_{Zn}, ΔH_{ZnO}, ΔH_3) to find ΔH_f for the following equation:

$Zn(s) + {}^1/_2\ O_2(g) \rightarrow ZnO(s)$ ΔH_f (kJ/mol) = ___________________

3. Look up the value of ΔH_f for ZnO in your textbook (or here: **https://mhchem.org/thermo**). Calculate the percent error (% error) using the *actual* value (from the textbook or table) and your *experimental* value (answer #2 above.) Why are the two values not equal? Explain briefly.

Percent error = absolute value{ (actual - experimental)/ actual }*100%

Postlab Questions:

Show all work, use significant figures and circle the final answer for full credit.

1. A metal sample weighing 45.23 g is heated to 100.00 ˚C. It is placed in 38.64 g of water in a calorimeter at 25.25 ˚C. At equilibrium, the temperature of the water and metal is 33.05 ˚C. Calculate the specific heat of the metal.

2. When 0.5000 g of Zn are added to 50.00 mL of 6.00 M HCl, the temperature of the solution rises from 20.00 ˚C to 32.56 ˚C. Using the assumptions and procedures recommended in Part B of this lab concerning the HCl density and specific heat, calculate $\boldsymbol{q_{Zn}}$ and $\boldsymbol{\Delta H_{Zn}}$ for the reaction.

Postlab Questions: *Continued*

3. Calculate the enthalpy change for the allotropic transformation of graphite into diamond using the following data:

C (graphite) $+ O_2(g) \rightarrow CO_2(g)$ $\Delta H = -390.5$ kJ

C (diamond) $+ O_2(g) \rightarrow CO_2(g)$ $\Delta H = -393.5$ kJ

4. Using the following equations:

$C(s) + 2\,Cl_2(g) \rightarrow CCl_4(g)$ $\Delta H^0 = -135.4$ kJ

$H_2(g) + Cl_2(g) \rightarrow 2\,HCl(g)$ $\Delta H^0 = -184.6$ kJ

$2\,H_2(g) + C(s) \rightarrow CH_4(g)$ $\Delta H^0 = -74.8$ kJ

Calculate the standard enthalpy of reaction for the process:

$CH_4(g) + 4\,Cl_2(g) \rightarrow CCl_4(g) + 4\,HCl(g)$ $\Delta H^0 = ?$