Physical Chemistry I Laboratory #3
CHM301L-01
Fall 2020

Finding the heat capacity of metals and the enthalpy of an acid-base reaction

A teaching experiment produced by

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Concepts to explore in this lab:

- Enthalpy of reaction
- Specific heat of a substance
- Calorimetry
- Heat

Course learning goals to accomplish:

- Interpret the signs use for work, heat, change of energy of the universe and surroundings.
- Apply the first law of thermodynamics to thermochemistry.
- Derive the function for enthalpy and apply it to chemical processes reactions.

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Calorimetry is a chemistry technique used to measure the amount heat (q) involved in a chemical or physical process. The amount of heat absorbed or released by a pure substance depends on its a) mass (m), b) specific heat capacity (c_{sp}, which is the amount of heat required to raise the temperature of 1 gram of substance by 1°C), and c) initial (T_i) and final (T_f) temperatures. The specific heat capacity for a few substances are given in Table 1. The equation that relates these quantities with the heat amount absorbed or released is the following:

Table 1. Specific heat for different substances at atmospheric pressure.

Material	Specific heat capacity (J/kg K)
Water	4186
Ice	2090
Steam	2010
Aluminium	900
Iron	448
Glass	837
Copper	387

$$q = m \times c_{sp} \times (T_f - T_i) \qquad \text{eq. 1}$$

The calorimeter is the device used to carry out calorimetry measurements. A calorimeter can be a Styrofoam cup (Figure 1) with thick walls that act as isolating walls, so heat will not be lost to the environment outside the cup during the measurement. The calorimeter itself can absorb heat from the system inside it; for this reason, it is necessary to measure the heat capacity of the calorimeter, which is the quantity of heat absorbed by the calorimeter for each 1°C rise in temperature.

Figure 1. Calorimeter.

The heat released by a chemical reaction can be measured also using the calorimetry technique; since the measurement is carried out at constant pressure, the heat measured is the enthalpy of the reaction. In this laboratory, we are measuring the enthalpy of an acid-base reaction. One common example of an acid is hydrochloric acid which is produced in the human stomach. This acid is generated in the digestion process; but with heavy meals, the stomach may generate excess hydrochloric acid, and the result is a burning sensation in the chest. When this occurs, people usually take antacids to neutralize the acid. These contain a base such as magnesium hydroxide Mg(OH)2 or aluminum hydroxide Al(OH)3. The neutralization reaction in the first case is:

$$2\,HCl_{(aq)} + Mg(OH)_{2\,(aq)} \rightarrow MgCl_{2\,(aq)} + 2H_2O_{(l)} \qquad \text{eq. 2}$$

The aqueous chemical reaction is carried out inside the cup by mixing two solutions that contain the main chemical species; the temperature is measured before the mixing and until the minimum or maximum values of the temperature start returning to its initial value. The change on enthalpy for the reaction can be calculated as:

$$\Delta H_{rxn} = \frac{q_{rxn}}{\#\,moles\ of\ limiting\ reactant} \qquad \text{eq. 3}$$

One of the ideas to keep in mind while doing calorimetry, it is the conservation of energy. Energy cannot be created or destroyed, but it can be exchanged; therefore, in calorimetry equation 4 is always truth. The key in calorimetry calculations is to define the system and the surrounding.

$$q_{released} + q_{absorbed} = 0 \qquad \text{eq. 4}$$

PART ONE

Pre-experiment Questions (write answers on your notebook)

1. Watch the videos "Calorimetry" and What Is Differential Scanning Calorimetry (DSC), and write bullet points of important facts about calorimetry and DSC. The videos are posted in brightspace.

General Protocol (Read entire protocol before starting the experiment)

Note: Read entire protocol before starting the experiment and make sure you write good notes in your notebook.

<u>Measuring temperature with the Pasco probe and the datalogger:</u>

Instrumentation:

- PASCO Spark LXi Datalogger
- Pasco Wireless temperature
- Cables: one charger

Instrument setup and data collection instructions:

- Turn on the Datalogger (tablet)
- Setup the tablet to the wifi, pick NDM_GuestNet and accept the conditions
- Press the return 
- Select SPARKvue
- Turn on the temperature probe
- In choose path, select Sensor Data
- On the left, you will see the name of your wireless device; for example, 197-137 temperature. Select that probe by pressing on it. (note: it should say connecting)
- Then, on the right side select the Graph in templates.
- A new window will open and the Datalogger is ready to start collecting data
- When you are ready to start, press the start green button.
- To stop, press the red square button.
- If you want to zoom up into the graph, you can use touch the screen using two fingers.
- To start a new data collection, press start again; if you want to temporarily remove the previous data plot, you can uncheck Run 1.
- When you finish you can just press the multiple windows-button in the tablet and then close all. Then turn off both the Datalogger and the temperature probe.

<u>Measuring the heat capacity of a calorimeter:</u>

The easiest way to find the amount of heat your calorimeter will absorb is to study the mixing of "warm" and "cold" water. The water at higher temperature will release heat to its surroundings inside the calorimeter; in this case, the surroundings are the "cold" water and the internal walls of the calorimeter. In equation 1, the amount of heat transferred depends on the mass of the substance, so it is required to measure the exact mass of water "hot" and "cold" you pour into the calorimeter.

- Find the mass of your calorimeter.
- Add the cold water (room temperature) into the calorimeter and find the mass again.
- Measure an equal volume of hot water and transfer it to a beaker; find the mass of the water and the beaker. Measure the temperature of the hot water.

- Cover the calorimeter with the lid and insert the temperature probe through the lid to start recording the temperature of the cold water; carefully place a magnetic stirrer in the calorimeter and turn on the stirrer in a low setting.
- Add the hot water into the calorimeter, close it and keep recording the temperature until it starts going down.
- Measure the mass of the beaker after pouring the hot water into the calorimeter.

Measuring the heat capacity of a metal:

- Measure the mass of the metal and describe the physical properties of it.
- In a beaker, boil water such that you can suspend and completely immerse the metal piece in the water without the metal touching the beaker walls.
- Suspend and fully immerse the metal piece in the boiling water and keep it there for 5-10 minutes. Meanwhile, add room temperature DI water (enough that will cover completely the metal piece standing up) to the calorimeter and find the mass.
- Close the calorimeter, stir slowly and start recording the temperature.
- Carefully place the metal piece in the calorimeter, close it and keep recording the temperature until it starts decreasing.

Measuring the enthalpy of a reaction:

- Add the basic solution to the calorimeter, find the mass of the solution and the calorimeter.
- Close the calorimeter, stir slowly and start recording the temperature.
- Measure the calculated volume of the acid, pour it in a beaker and measure the mass.
- Carefully add the acidic solution and keep recording the temperature until it starts decreasing.
- Measure the mass of the beaker after pouring the acidic solution in the calorimeter.

Experiment

2. Discuss with the class what calorimetry is, the types and what are the differences between those.

Calorimeter's Heat capacity:

3. Follow the general protocol for measuring the heat capacity of the calorimeter and collect the values for mass and temperature as instructed.
4. In this experiment (numeral 3), define the system and the surroundings. Explain.
5. Predict the sign of the heat released or absorbed by the system and the surroundings in this experiment. Explain.

Metals' heat capacity:

6. Choose a metal cylinder to work with, make sure you select one that your classmates have not worked with yet.
7. Follow the general protocol for measuring the heat capacity of a metal and collect the values for mass and temperature as instructed.
8. In this experiment (numeral 7), define the system and the surroundings. Explain.
9. Predict the sign of the heat released or absorbed by the system and the surroundings in this experiment. Explain.

Thinking About the Data

10. Using Python, plot in a separate graph the data for temperature and time you collected in each experiment, give each graph a title and axis labels.

11. Using the guidance from Appendix A, find the values of ΔT for both experiments. Write down the linear equations for both data sets and show your calculation to find the initial and final temperatures.

Calorimeter's Heat capacity:

12. Using the ΔT values you found in numeral 11, calculate the amount of heat released by the "hot" water.
13. Using the ΔT values you found in numeral 11, calculate the amount of heat absorbed by the "cold" water.
14. Using your definitions in numeral 4, re-write equation 4 given in the introduction of this lab guide to represent the heat released and absorbed by the system and the surroundings in this experiment.
15. Using the new equation from numeral 14, calculate the heat capacity of your calorimeter. (note: use the same calorimeter for the rest of your experiments!)
16. Discuss numerals 12-15 with another group and then with your professor.

Metals' heat capacity:

17. Using the ΔT values you found in numeral 11, calculate the amount of heat absorbed by the water.
18. Using the ΔT values you found in numeral 11, calculate the amount of heat absorbed by the calorimeter
19. Using your definitions in numeral 8, re-write equation 4 given in the introduction of this lab guide to represent the heat released and absorbed by the system and the surroundings in this experiment.
20. Using the new equation from numeral 19, calculate the heat capacity of the metal. Identify the metal by comparing the value you calculated with the ones in the following table.

Specific Heat Capacities for Common Materials at 20°C	
Material	Specific Heat Capacity, J/g°C
Air	1.00
Aluminum	0.895
Asphalt	0.92
Brass	0.380
Carbon dioxide	0.832
Copper	0.387
Ethyl alcohol	2.45
Gold	0.129
Granite	0.803
Iron	0.448
Lead	0.128
Sand	0.29
Silver	0.233
Stainless steel	0.51
Water (liquid)	4.18
Zinc	0.386

21. Collect the specific heat values for all metals and organize them in a table that includes the atomic number. Is there any tendency? Explain.
22. Discuss numerals 17-21 with another group and then with your professor.

PART TWO

Pre-experiment Questions (write answers on your notebook)

23. Find out which the main components in milk magnesia and white vinegar are and their concentrations.
24. Write down the acid-base reaction that will occur if you mix milk magnesia and white vinegar, make sure you balance the chemical equations.
25. Calculate the molar concentrations of the main species in milk magnesia and white vinegar.
26. What type of solutions are milk magnesia and vinegar?
27. Use your textbook to look up the enthalpy of formation of <u>all</u> the chemical species involved in the reaction between milk magnesia and acetic acid. Take into account the state of matter of each species.

Experiment

Enthalpy of an acid-base reaction:

28. In this experiment, you will neutralize 30.0 mL of milk magnesia. Calculate the volume of vinegar you need to completely neutralize milk magnesia.
29. Follow the general protocol for measuring the enthalpy of a reaction and collect the values for mass and temperature as instructed.

30. In this experiment (numeral 29), define the system and the surroundings. Explain.
31. Predict the sign of the heat released or absorbed by the system and the surroundings in this experiment. Explain.

Thinking About the Data

32. Using Python, plot the data for temperature and time you collected in the neutralization experiment, give the graph a title and axis labels.

Enthalpy of an acid-base reaction:

33. Using the ΔT value you found in numeral 32, calculate the amount of heat absorbed by the water.
34. Using the ΔT value you found in numeral 32, calculate the amount of heat absorbed by the calorimeter.
35. Using your definitions in numeral 30, re-write equation 4 given in the introduction of this lab guide to represent the heat released and absorbed by the system and the surroundings in this experiment.
36. Using the new equation from numeral 35, calculate the heat released by the reaction.
37. Calculate the molar enthalpy of the reaction ($\Delta H_{rxn}^{experimental}$) in kJ/mol.
38. Collect the molar enthalpy of the reaction from all groups and find an average (($\Delta \overline{H}_{rxn}^{experimental}$), if necessary, remove outliers before calculating the average.
39. Is the neutralization reaction endo- or exo-thermic?
40. The enthalpy of reaction (ΔH_{rxn}) can be calculated according to equation 5, where ΔH_f^o is the change of enthalpy of formation for either the products or the reactants and ν is the number of moles of each species.

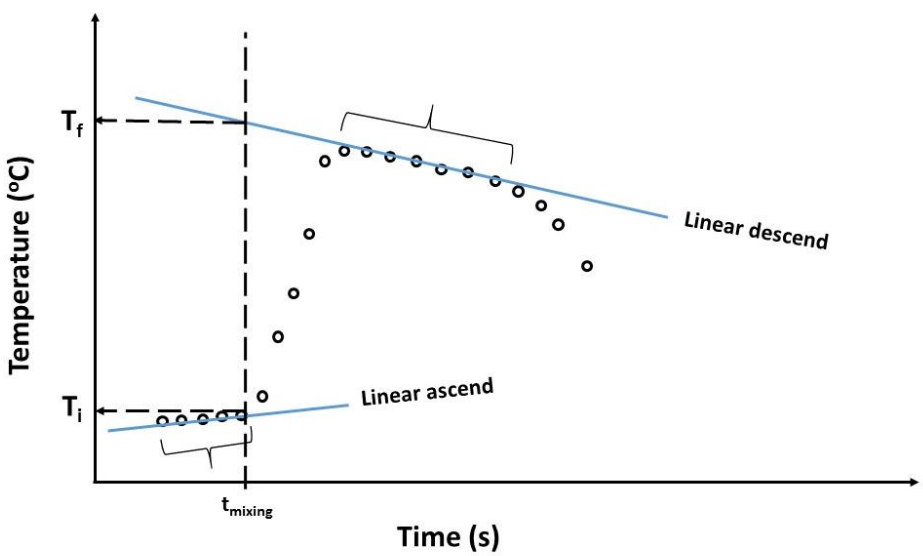
$$\Delta H_{rxn}^{expected} = \sum_{products} \nu \Delta H_f^o - \sum_{reactants} \nu \Delta H_f^o \qquad eq. 5.$$

Using the values of ΔH_f^o that you found (numeral 27), calculate the enthalpy for the reaction between acetic acid and magnesium hydroxide.

41. Calculate the %error for the enthalpy of the reaction and discuss why is not 100%.
42. Discuss with your group if the temperature change can be calculated from the tabulated data (numeral 27) or if it can only be measured experimentally?
43. Discuss with another group your answers from numerals 38-42 and come to a consensus about your answer from numeral 42.
44. If you think ΔT can be calculated, please do so. Otherwise, continue to numeral 45. is this ΔT the same that you obtained experimentally? (*Note: for any calculation make sure you use the same number of moles that you used in the neutralization reaction)*
45. Will the change of temperature for the reaction solution be the same or different if you double the amount of reagents you use? Explain
46. For the three experiments, where is the heat flowing from and to? Explain in detail.
47. Write a few conclusions of what you learnt in this laboratory.

Appendix A: How to measure ΔT?

The temperature change due to the chemical reaction is the main key value to calculate the heat released or gained by the reaction. For this reason, it is important to determine accurately the final and initial temperatures. The determination of the maximum temperature T_f is not obvious because heat exchange occurs between the surroundings and the solution in the calorimeter, both during the reaction and after its completion. A correction for this heat loss is made by an extrapolation of a temperature vs. time curve before and after the reaction as shown in the figure below.



In order to calculate the final temperature of the solution, you need to find the equation for the linear descend of the temperature ($T_{descend} = m * time + b$). (Note: choose only the part of the data that seems linear).

After you find the slope (m) and the intercept (b), you can solve for the value of the temperature (y) at the time of mixing; this value corresponds to T_f.

In order to calculate the initial temperature of the solution, you need to find the equation for the linear ascend of the temperature ($T_{ascend} = m * time + b$). (Note: choose only the part of the data that seems linear).

After you find the slope (m) and the intercept (b) of the linear ascend, you can solve for the value of the temperature (y) at the time of mixing as well; this value corresponds to T_i. Now you can calculate $\Delta T = T_f - T_i$.