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Thermochemistry: Heat of Neutralization and Hess's Law [Chemistry]

Kevin Mark
CUNY La Guardia Community College

Phil Mercier
CUNY La Guardia Community College

Janet Gonzalez
CUNY La Guardia Community College

Burl Yearwood
CUNY La Guardia Community College

General Chemistry 1- SCC 201
Biology/ Environmental Science
Natural Sciences Department, LaGuardia Community College, CUNY
Kevin Mark, Phil Mercier, Janet Gonzalez, Burl Yearwood

Assignment Title
Thermochemistry: Heat of Neutralization and Hess's Law

The General Chemistry 1 (SCC 201) course has been designated for the core competency of Inquiry and Problem Solving along with the Written Communication Ability. These abilities are best observed in the laboratory section of the course where SCC 201 students are asked to submit weekly written lab reports that range in chemistry topics from chemical structures to the chemical analysis of polluted environments. SCC 201 will be implementing a new experiment in the laboratory portion of the course entitled, "Thermochemistry: Heat of Neutralization and Hess's Law." The design of the experiment incorporates many elements of LaGCC's Core Competencies and Communication Abilities, as well as programmatic and course learning objectives both on the departmental and college levels. Natural Sciences major STEM students who successfully complete the thermochemistry lab and write a corresponding satisfactory lab report, will have engaged in two of the program goals, four of the student learning objectives and seven of the course objectives. The SCC 201 course lies in the midpoint Core Competency program curriculum map for both the Biology and Environmental Science programs and accounts for 3.5% of the final SCC 201 grade. Students will spend 3 hours completing the experiment in lab and in addition spend an estimated 3-4 hours completing the lab write-up. This lab was developed in the Natural Sciences programmatic integration CTL mini-grant seminar. The creation of the lab involved an initial discussion with members of the chemistry programmatic team to outline a common theme between SCC 201, SCC 202 and SCC 251. It was agreed upon that the central topic of thermodynamics would be implemented throughout the designated labs.

List the Program Goal(s) that this assignment targets	**List the Student Learning Objective (s) that this assignment targets**	**List the Course Objectives(s) that this assignment targets**	**Write a short description of the pedagogy involved in executing this assignment**
1. To provide extensive hands-on training in laboratory techniques and develop and utilize analytical skills to conduct scientific research	SLO1. Students will be able to frame scientific questions and generate testable hypothesis SLO2. Students will be able to engage in hands-on laboratory work and develop laboratory skills SLO3. Students will be able to collect, analyze, interpret and infer from data	1. Describe and explain the fundamental chemical concepts of matter and energy, chemical nomenclature, solution concentrations, energy relationships in chemical reactions 2. Demonstrate an understanding of the quantitative nature of chemistry and the mathematical methods involved by being able to use the SI measurement system, carry out unit conversions, employ the mole concept in chemical calculations, determine solution concentrations, solve problems based on balanced chemical equations	This is both a hands on and a written assignment that will investigate the use of calorimetry and Hess's Law to broaden the students' understanding of thermochemistry. Students will compose a protocol to examine the heat of neutralization and compare it with a standard value. This assignment reinforces the SCC 201 lecture curriculum while at the same time providing students the opportunity to apply knowledge.

		and determine heats of reactions 3. Perform basic laboratory skills such as the proper handling of chemicals, identification and use of standard laboratory equipment such as thermometers and glassware for quantitative measurement 4. Analyze and represent experimental data in tables and graphs, interpret experimental results and write laboratory reports 5. Demonstrate an understanding of safety procedures in the laboratory 6. Use computer applications in the study of chemistry including internet-based chemistry research, data analysis and graphing using Microsoft Excel and	

2. To provide skills to enable students to communicate scientific information through written, oral and digital formats	SLO4: Students will be able to communicate effectively in written format	computer based self-study	

Rubric for Abstract, Data, and Discussion
Experiment:

Name		Excellent	Good	Fair	Poor	Score
Purpose of Experiment 5 pts	State the goal or purpose of the experiment (2 pts)					
	What method or technique was used to inspect the problem (2 pts)					
	Manufacturer's name and model for specific equipment or instruments used (1 pt)					
Data 8 pts	Accurately present the data in tables, graphs, charts, plots or pictures. All axis must be properly labeled, for example Temp (ºC), or volume (drops or ml). (3 pts)					
	Use of the right equations (3 pts)					
	Proper reference given for images not drawn by you (2 pts)					
Discussion 10 pts	What were your results, what do the results mean in terms of the experiment? Do the results agree with your expectations? Are there any patterns you can see in the data, what does that mean? (5 pts)					
	Do you need more experiments to corroborate your results or other techniques to make further conclusions? What are the limitations of the technique(s)					

	used? (5 pts)					
	Summary of the results in numbers or percentages or characteristics or variables (3pts)					
References **2 pts**	ACS reference style (2 pt) **DO NOT use the lab manual as a source**					

SCC 201-Thermochemistry: Heat of Neutralization and Hess's Law

Learning Objectives

Students will be able to: Determine the heat of neutralization of three separate reactions and manipulate the chemical equations to find the heat of neutralization of a fourth reaction (SLO: Students will be able to frame scientific questions and generate testable hypothesis) (Core competency- Inquiry and Problem Solving). Use their experimental ΔH values and compare it to literature values (SLO: Students will be able to frame scientific questions and generate testable hypothesis) (Core competency – Inquiry and Problem Solving). Identify, handle and react acids/bases in a constructed calorimeter apparatus. (SLO: Students will be able to engage in hands-on laboratory work and develop laboratory skills. Measure temperature changes over extended reaction times, generate mixing curves and extrapolate temperature changes to calculate heats of neutralization (SLO: Students will be able to collect, analyze, interpret and infer from data.)(Core competency- Inquiry and Problem Solving). Communicate their change of enthalpy findings through the formal lab report format of: Introduction, Materials, Procedure, Results, Sample Calculations, Discussion and References (SLO: Students will be able to communicate effectively in written format).

Prelab work: Claim, Evidence and Reasoning

Claim Question: If you mix a strong acid with a strong base in a cup, will the temperature of the mixture increase or decrease? Does this correlate to an exothermic or endothermic process?

Evidence Question: How could you measure the before and after mixing of the acid/base to quantify the heat change?

Reasoning Question: What concepts in general chemistry lecture have you learned that you can apply to this experiment?

Background:

A chemical reaction is accompanied by an energy change described as a change in heat content: energy is absorbed (endothermic reaction) or released (exothermic reaction). In general, the breaking of bonds in reactants requires the consumption of energy, and the creation of new bonds in products involves the release of energy. The potential energy that is stored in chemical bonds can be thought of as the heat content of a system, enthalpy. When these chemicals react, a change in energy (absorb or

release of energy) will result in a change in enthalpy, ΔH. The overall change in energy will depend on the unique properties of the reactants and products.

Calorimetry is the study of heat transferred in a chemical reaction. The amount of heat absorbed or released during this thermochemical process is measured by a change in temperature. The device used to measure the change is called a calorimeter (two nested styrofoam cups), where ideally, the calorimeter would not absorb any heat from its surroundings and at the same time not allow any heat from the reaction to escape.
(1) $q = ms\Delta T$ where q = heat , m = mass, s = specific heat ($J\ g^{-1}\ {}^oC^{-1}$) , ΔT = Temperature change. The specific heat of a substance, s, is the amount of heat required to raise the temperature of one gram of a substance by one degree Celsius (an intensive property).

Enthalpy is a property of a substance that can be applied to determine the heat absorbed or released in a chemical reaction. The relationship between enthalpy change and heat is:
(2) $\Delta H = q_p$ where ΔH is the enthalpy change and q is the heat. The "p" in equation 2 denotes that the reaction occurs at constant pressure. This is convenient, as a great deal of reactions are open to a constant atmospheric pressure.

Hess's Law: Unlike mass or temperature, there is no instrument that can measure heat or enthalpy, H. However , an enthalpy change ΔH can be calculated from equation 1. In addition, if a reaction is carried out in a series of steps, ΔH for the overall process is equal to the sum of enthalpy change for each individual step. Let's look at an example- You would like to know the enthalpy change to transform graphite into diamonds. This is an extremely difficult task (aside- need a high activation energy) in the lab but if you know the enthalpy changes when the different forms of carbon reacts with oxygen to produce CO_2, the enthalpy change of graphite to diamond can be calculated:

(1) $2\ C_{(s,graphite)} + 2O_{2\ (g)} \rightarrow 2\ CO_{2\ (g)}$ $\Delta H_1^o = -787$ kJ
(2) $C_{(s,diamond)} + O_{2\ (g)} \rightarrow CO_{2\ (g)}$ $\Delta H_2^o = -396.5$ kJ

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(3) $C_{(s,graphite)} \rightarrow C_{(s,\ diamond)}$ $\Delta H_{overall}^o = ??$ kJ

We simply cannot add equations (1) and (2) to get the $\Delta H_{overall}^o$ equation (3) because there would be three oxygen molecules in the reactants and three carbon dioxide molecules in the products and our overall desired reaction (3) does not contain any O_2 and/or CO_2 molecules. Two possible operations to manipulate the chemical equations so that our overall reaction (3) is attained are to multiply/divide the chemical equation by a coefficient or reverse a chemical reaction. When an operation is done, the

corresponding ΔH^o must undergo the same operation. In our case, we can flip reaction (2) so that $C_{(s,diamond)}$ appears in the products and we can divide equation (1) by a factor of two.

(1) $C_{(s,graphite)} + \cancel{O_2}_{(g)} \rightarrow \cancel{CO_2}_{(g)}$ $\Delta H_1^o = -393.5$ kJ

(Equation (1) divided by 2)

(2) $\cancel{CO_2}_{(g)} \rightarrow \cancel{O_2}_{(g)} + C_{(s,diamond)}$ $\Delta H_2^o = 396.5$ kJ

(Equation (2) flipped)

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(3) $C_{(s,graphite)} \rightarrow C_{(s,\ diamond)}$ $\Delta H_{overall}^o =$ **3 kJ**

Adding $\Delta H_1^o + \Delta H_2^o = \Delta H_{overall}^o =$ **3 kJ**

By altering the chemical equations, multiplying the coefficients (and the corresponding ΔH_1^ovalue) in equation (1) by 0.5 and by reversing equation (2) (and changing the sign of ΔH_2^o) into an endothermic reaction, the oxygen and carbon dioxide molecules cancel when (1) and (2) are added.

Prelab questions:

1. You would like to determine how many calories are in 10 grams of chicken that is served in the LaGCC cafeteria. Using your understanding of a bomb calorimeter (Figure 5.18 in your textbook)
   a) Devise a scheme to find how many calories are in the meat and
   b) Assuming the specific heat of chicken is 3.68 J/g^{0}C and the change in temperature was 1.90^{0}C, how many calories are in 10 grams of chicken?

2. For the following hypothetical reactions:

$2A + 3B \rightarrow C + D$		$\Delta H = -46$ KJ
$E + A \rightarrow C$		$\Delta H = 50$ KJ
$A + 0.5D \rightarrow B$		$\Delta H = 23$ KJ
Overall reaction: $3A + B \rightarrow E$		$\Delta H = ?$

Calculate ΔH for the overall reaction

<u>Your task</u>:

In this lab, you will measure the enthalpy change that occurs in three separate exothermic acid/base reactions involving

a) NaOH and HCl

b) NaOH and CH_3COOH
c) NH_3 and HCl

and calculate the respective enthalpy change for each reaction. For these experiments, you will assume the specific heat of the each reactions is 4.18 J/g ºC and the density of the solutions is 1.0 g/cm^3 .

Materials

Equipment	**Consumables**
One thermometer Two styrofoam cups (calorimeter) One cup lid 50 mL graduated cylinder 250 mL beakers Stirring Rod Timer	1.0 M hydrochloric acid 1.0 M ammonia 1.0 M acetic acid 1.0 M sodium hydroxide eionized water

Procedure development

- Write the objective of your experiment
- State the three acid/base exothermic chemical reactions in your experiment
- State equation(s) you will use to find the change in enthalpy

IN LAB, BEFORE BEGINNING YOUR EXPERIMENT, YOU WILL DEVELOP AND HANDWRITE A PROTOCOL

- Compose a step-by-step procedure to determine ΔH for the reaction of HCl and NaOH. In terms of details, your procedure should be clear to the point where a fellow colleague could read your methodology and repeat the experiment without having to consult with you. Ensure that all of the equipment and consumables are included in the procedure. Number your steps.

Suggestions on writing procedures

- Draw and label your apparatus set-up.
- Indicate how much of each reactant you will use? Should they be the same/different amounts?
- Is there a limiting reagent?
- Decide how many trials you will conduct?
- ***The maximum amount of solution in the calorimeter should not exceed 50 mL at any time***
- Finish your procedure with,
    - "Repeat steps __ to __ for the reactions between NH_3 and HCl "
    - "Repeat steps __ to ___for the reactions between NaOH and CH_3COOH"

- Create labeled data tables to record your data
- Write equation(s) and how will you use them to find the moles of product
- State how will each variable be measured/calculated?

With the collected data, using the enthalpy of neutralization values and in conjunction with Hess's Law, determine ΔH (Joules per mole) for the reaction between ammonia (NH_3) and acetic acid (CH_3COOH) and compare it to the literature value

Notes:

1. Safety measures: Keep in mind all safety rules from the previous experiments and in addition

a) Wear safety eye protection at all times
b) Be aware of the following details regarding the chemicals:

Chemical	**Safety Data Sheet**
Hydrochloric Acid	https://www.fishersci.com/shop/msdsproxy?productName=SA49&
Ammonia	https://fscimage.fishersci.com/msds/00211.htm
Acetic acid	https://fscimage.fishersci.com/msds/00120.htm
Sodium hydroxide	https://fscimage.fishersci.com/msds/21300.htm

c) Dispose of all chemicals in the appropriate waste containers

DO NOT BEGIN EXPERIMENTING UNTIL YOUR INSTRUCTOR HAS SIGNED YOUR PROTOCOL

Results and Calculations:

1. Write the three experimental exothermic reactions and write the balanced chemical equation for the reaction of ammonia with acetic acid (This is the overall ΔH enthalpy change you are determining)
2. Plot three separate "acid/base" mixing graphs (Use Excel or other graphic programs)
3. Extrapolate temperatures, ΔT, from your graph to calculate q for your three neutralizations
4. What is the heat of neutralization ΔH **per mole**

5. Use Hess's law to calculate ΔH for the reaction of ammonia and acetic acid
6. Compare your ΔH value with the literature value. What is the percent error?

Post lab questions/discussion topics:

1. Was your objective met?
2. How are calorimetry and Hess's Law used to find the heat of neutralization of ammonia and acetic acid?
3. Why are the heat of neutralizations values negative?
4. Explain why it is it important to know if energy is being released or absorbed during a chemical reaction?
5. What are some sources of error in your set-up and how can they be reduced to achieve a greater accuracy?