Additivity of Heats of Reaction: Hess's Law

Introduction:

In this experiment, you will use a Styrofoam-cup calorimeter to measure the heat released by three reactions. One of the reactions is the same as the combination of the other two reactions. Therefore, according to Hess's Law, the heat of reaction of the one reaction should be equal to the sum of the heats of reaction for the other two. This concept is sometimes referred to as the *additivity of heats of reaction.* The primary objective of this experiment is to confirm this law. The reactions we will use in this experiment are:

(1) Solid sodium hydroxide dissolves in water to form an aqueous solution of ions.

$$NaOH_{(s)} \longrightarrow Na^+_{(aq)} + OH^-_{(aq)} \quad \Delta H_1 = ?$$

(2) Solid sodium hydroxide reacts with aqueous hydrochloric acid to form water and an aqueous solution of sodium chloride.

$$NaOH_{(s)} + H^+_{(aq)} + Cl^-_{(aq)} \longrightarrow H_2O_{(l)} + Na^+_{(aq)} + Cl^-_{(aq)} \quad \Delta H_2 = ?$$

(3) Solutions of aqueous sodium hydroxide and hydrochloric acid react to form water and aqueous sodium chloride.

$$Na^+_{(aq)} + OH^-_{(aq)} + H^+_{(aq)} + Cl^-_{(aq)} \longrightarrow H_2O_{(l)} + Na^+_{(aq)} + Cl^-_{(aq)} \quad \Delta H_3 = ?$$

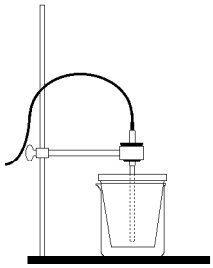

Figure 1

You will use a Styrofoam cup in a beaker as a calorimeter, as shown in Figure 1. For purposes of this experiment, you may assume that the heat loss to the calorimeter and the surrounding air is negligible. Even if heat is lost to either of these, it is a fairly constant factor in each part of the experiment, and has little effect on the final results.

PRE-LAB EXERCISE

Combine reactions (1) and (3) from above to obtain reaction (2). Show this work as the FIRST CALCULATION in the Results section of your lab report.

MATERIALS

LabQuest Interface
Temperature Probe
50 mL of 1.0 M NaOH
50 mL of 1.0 M HCl
100 mL of 0.50 M HCl
100 mL of water
4.00 g of solid NaOH
100 mL of water
250-mL beaker
ring stand
utility clamp
stirring rod
Styrofoam cup

PROCEDURE

Reaction 1

1. Obtain and wear goggles.

2. Plug the Temperature Probe into Channel 1 of the LabQuest. Turn on the LabQuest (it may take a while to load the system software). It should auto-recognize the temperature probe.

3. The LabQuest is a touch-screen device. Touch the image of a dial in the upper left-hand corner to go to data collection modes.
    a) For"Mode" select "Time Based"
    b) "2" samples per second, 0.5 s/sample
    c) Duration: 180 seconds
    d) Click "OK" to go back to data collection screen.

5. Use a utility clamp to suspend a Temperature Probe from a ring stand as shown in Figure 1.

6. Place a Styrofoam cup into a 250-mL beaker as shown in Figure 1. Measure out 100.0 mL of water into the Styrofoam cup. Lower the Temperature Probe into the solution.

7. Weigh out about 2 grams of solid sodium hydroxide, NaOH, and record the mass to the nearest 0.01 g. Since sodium hydroxide readily picks up moisture from the air, it is necessary to weigh it and proceed to the next step without delay. **CAUTION**: *Handle the NaOH and resulting solution with care.*

8. Click the green "start" arrow in the lower left-hand corner to begin data collection. to begin data collection. It may take several seconds for the Temperature Probe to equilibrate at the temperature of the solution. After three or four readings at the same temperature have been obtained, add the solid NaOH to the Styrofoam cup. Using the stirring rod, stir continuously. As the reaction proceeds, you may find it more interesting to observe the graphing. You can switch back-and-forth between the graph, temperature, and data table using the left-most icon on the upper right-hand corner.

9. Data collection will stop after 3 minutes. To confirm the initial (t_1) and final (t_2) values, examine the data points along the curve on the displayed graph. As you move the cursor right or left, the time (X) and temperature (Y) values of each data point are displayed.

11. Rinse and dry the Temperature Probe, Styrofoam cup, and stirring rod. Dispose of the solution as directed by your instructor.

Reaction 2

12. Press the "file cabinet" icon and select "Run 2" (Your Run1 data will be preserved in case you need to refer to it later). Repeat Steps 8 - 11, using 100.0 mL of 0.50 M hydrochloric acid, HCl, instead of water. Use the same amount of solid NaOH as before. **CAUTION:** *Handle the HCl solution and NaOH solid with care.*

Reaction 3

13. Press the "file cabinet" icon and select "Run 3" (Your Run 1 and Run 2 data will be preserved in case you need to refer to it later). Repeat Steps 8 - 11, initially measuring out 50.0 mL of 1.0 M HCl (instead of water) into the Styrofoam calorimeter. Instead of solid NaOH, measure 50.0 mL of 1.0 M NaOH solution into a graduated cylinder. After 3-4 temperature readings have been taken to determine the initial temperature of the 1.0 M HCl, add the 1.0 M NaOH solution to the Styrofoam cup. **CAUTION:** *Handle the HCl and NaOH solutions with care.*

Important: When you have completed all data collection, power the LabQuest down by a long press on the power button. You will be asked if you want to save or discard your data. Choose "discard". Carefully disconnect the temperature probe and return both the probe and LabQuest to your instructor.

PROCESSING THE DATA

1. Determine the mass of 100 mL of solution for each reaction (assume the density of each solution is 1.00 g/mL).

2. Determine the temperature change, Δt, for each reaction.

3. Calculate the heat released by each reaction, q, by using the formula:

   $$q = C_p \cdot m \cdot \Delta t \ (C_p = 4.18 \text{ J/g°C})$$

   Convert joules to kJ in your final answer.

4. Find ΔH ($\Delta H = -q$).

5. Calculate moles of NaOH used in each reaction. In Reactions 1 and 2, this can be found from the mass of the NaOH. In Reaction 3, it can be found using the molarity, M, of the NaOH and its volume, in L.

6. Use the results of the Step 4 and Step 5 calculations to determine ΔH/mol NaOH in each of the three reactions.

7. To verify the results of the experiment, combine the heat of reaction (ΔH/mol) for Reaction 1 and Reaction 3. This sum should be similar to the heat of reaction (ΔH/mol) for Reaction 2. Using the value in Reaction 2 as the accepted value and the sum of Reactions 1 and 3 as the experimental value, find the percent error for the experiment.

DATA AND CALCULATIONS

	Reaction 1	Reaction 2	Reaction 3
1. Mass of solid NaOH	_____ g	_____ g	(no solid NaOH mass)
2. Mass (total) of solution	_____ g	_____ g	_____ g
3. Final temperature, t_2	_____ °C	_____ °C	_____ °C
4. Initial temperature, t_1	_____ °C	_____ °C	_____ °C
5. Change in temperature, Δt	_____ °C	_____ °C	_____ °C
6. Heat, q	_____ kJ	_____ kJ	_____ kJ
7. ΔH	_____ kJ	_____ kJ	_____ kJ
8. Moles of NaOH	_____ mol	_____ mol	_____ mol
9. ΔH/mol	_____ kJ/mol	_____ kJ/mol	_____ kJ/mol
10. Experimental value (Reaction #1 + Reaction #3)			_____ kJ/mol
11. Accepted value (***Reaction #2***)			_____ kJ/mol
12. Percent error (Show work)			_____ %