Experiment 18

Additivity of Heats of Reaction: Hess's Law

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.

$$Na^+(aq) + OH^-(aq) + H^+(aq)\ ) + Cl^-(aq) \longrightarrow H_2O(l) + Na^+(aq) + Cl^-(aq) \quad \Delta H_3 = ?$$

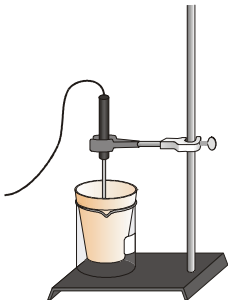

Figure 1

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.

ROLES

Project Manager	
Quality Control Manager	
Materials Manager	

PRE-LAB EXERCISE

In the space below, combine two of the above equations algebraically to obtain the third equation. Indicate the number of each reaction on the shorter lines.

_____ _____

_____ _____

_____ _____

MATERIALS

LabPro or CBL 2 interface	100 mL of water
TI Graphing Calculator	4.00 g of solid NaOH
DataMate program	ring stand
Temperature Probe	utility clamp
50 mL of 1.0 M NaOH	stirring rod
50 mL of 1.0 M HCl	Styrofoam cup
100 mL of 0.50 M HCl	250-mL beaker

PROCEDURE

Reaction 1

1. Obtain and wear goggles.

2. Plug the Temperature Probe into Channel 1 of the LabPro or CBL 2 interface. Use the link cable to connect the TI Graphing Calculator to the interface. Firmly press in the cable ends.

3. Turn on the calculator and start the DATAMATE program. Press CLEAR to reset the program.

4. Set up the calculator and interface for the Temperature Probe.
   a. If the calculator displays TEMP (C) in CH 1, proceed directly to Step 5. If it does not, continue with this step to set up your sensor manually.
   b. Select SETUP from the main screen.
   c. Press ENTER to select CH 1.
   d. Select TEMPERATURE from the SELECT SENSOR menu.
   e. Select the Temperature Probe you are using (in °C) from the TEMPERATURE menu.
   f. Select OK to return to the main 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. Select START to begin data collection and obtain the initial temperature, t_1. Monitor temperature (in °C) on the calculator screen. 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 until the temperature has maximized and then begun to drop. Record the maximum temperature, t_2.

9. Data collection will stop after 10 minutes (or press the STO▶ key to stop *before* 10 minutes has elapsed).

10. To confirm the initial (t_1) and final (t_2) values you recorded earlier, 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 below the graph.

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 ENTER to return to the main screen. Repeat Steps 6-11, 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 ENTER to return to the setup screen. Repeat Steps 6-11, initially measuring out 50.0 mL of 1.0 M HCl (instead of water) into the Styrofoam calorimeter. In Step 7, 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.*

ANALYZE AND APPLY

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.

Remember to include an appropriate conclusion—restate findings and discuss possible sources of error.

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			kJ/mol
11. Accepted value			kJ/mol

12. Percent error	%