Additivity of Heats of Reaction: Hess's Law

In this experiment, you will use a polystyrene foam 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.

$$NaOH(s) \rightarrow Na^{+}(aq) + OH^{-}(aq) \quad \Delta H_1 = ?$$

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

$$NaOH(s) + H^{+}(aq)\ ) + Cl^{-}(aq) \rightarrow H_2O(l) + Na^{+}(aq) + Cl^{-}(aq) \quad \Delta H_2 = ?$$

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

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

You will use a polystyrene foam 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.

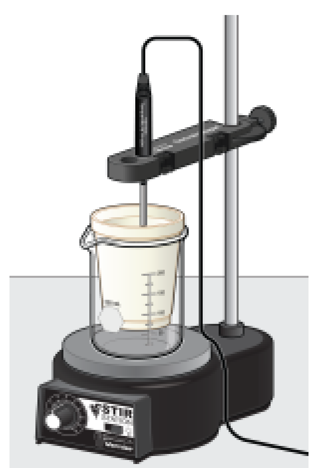

Figure 1

OBJECTIVES

- Combine equations for two reactions to obtain the equation for a third reaction.
- Use a calorimeter to measure the temperature change in each of three reactions.
- Calculate the heat of reaction, ΔH, for the three reactions.
- Use the results to confirm Hess's law.

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.

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MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis app
Vernier data-collection interface
Temperature Probe
Stir Station and magnetic stirring bar
Electrode Support
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
polystyrene foam cup
400 mL beaker
100 mL graduated cylinder

PROCEDURE

Reaction 1

1. Obtain and wear goggles.

2. Connect the Temperature Probe to the data-collection interface, and then connect the interface to your Chromebook, computer, or mobile device. Launch Graphical Analysis.

3. Place a polystyrene foam cup into a 400 mL beaker as shown in Figure 1. Measure out 100.0 mL of water into the polystyrene foam cup. Add a magnetic stirring bar to the cup. Place the beaker on the Stir Station and start stirring at a gentle speed.

4. Use an Electrode Support to suspend a Temperature Probe from a Stir Station and lower the Temperature Probe into the solution. The stirring bar should not strike the Temperature Probe.

5. Weigh out about 2 g 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. **DANGER**: *Sodium hydroxide solution,* NaOH: *Causes severe skin burns and eye damage. Do not breathe mist, vapors, or spray*.

6. Click or tap Collect to start data collection and obtain the initial temperature, t_1. Monitor temperature (in °C) on the 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 polystyrene foam cup. Stir continuously until the temperature has maximized and then begun to drop. Record the maximum temperature, t_2.

7. Data collection will stop after 3 minutes, or you can stop data collection before 3 minutes have elapsed if the maximum temperature has been recorded.

8. 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.

9. Rinse and dry the Temperature Probe and polystyrene foam cup. Dispose of the solution as directed by your instructor.

Reaction 2

10. Repeat Steps 4–9, using 100.0 mL of 0.50 M hydrochloric acid, HCl, instead of water. Use the same amount of solid NaOH as before. **DANGER**: *Hydrochloric acid solution,* HCl: *Causes severe skin and eye damage. Do not breathe mist, vapors, or spray. May cause respiratory irritation. May be harmful if swallowed*. **Note**: The previous data set is automatically saved.

Reaction 3

11. Repeat Steps 4–9, initially measuring out 50.0 mL of 1.0 M HCl (instead of water) into the polystyrene foam calorimeter. In Step 5, 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 polystyrene foam cup. **Note**: The previous data set is automatically saved.

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:

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

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. Δ*H*	kJ	kJ	kJ
8. Moles of NaOH	mol	mol	mol
9. Δ*H*/mol	kJ/mol	kJ/mol	kJ/mol
10. Experimental value (kJ/mol)			
11. Accepted value (kJ/mol)			
12. Percent error (%)			