Measurement of Heat of Reaction: Hess' Law

Enthalpy

Heat is associated with nearly all chemical reactions. In such instances, the reaction either liberates heat (exothermic) or absorbs heat (endothermic). When a reaction is carried out under constant pressure (as in an open beaker) the heat associated with the reaction is known as enthalpy. The symbol for enthalpy is ΔH. It is most often too difficult to directly measure the enthalpy change for a reaction. What can be done is to measure the heat change that occurs in the surroundings by monitoring temperature changes. Conducting a reaction between two substances in aqueous solution, allows the enthalpy of the reaction to be indirectly calculated with the following equation.

$$q = C_p \times m \times \Delta T$$

The term q represents the heat energy that is gained or lost. C_p is the specific heat of water, m is the mass of water, and ΔT is the temperature change of the reaction mixture. The specific heat and mass of water are used because water will either gain or lose heat energy in a reaction that occurs in aqueous solution.

Hess's Law

Germain Hess (1802-1850) discovered the principle of how the enthalpy value for a given reaction can be calculated from the enthalpy values of other reactions. This principle (Hess's law) states that the enthalpy change for a reaction depends on the products and reactants and is independent of the pathway or the number of steps between reactants and products. In other words, if a reaction is carried out in a series of steps, ΔH for the reaction will be equal to the sum of the enthalpy changes for the individual steps. Therefore, the enthalpy change for a given reaction is calculated by adding the individual chemical equations and taking the sum of the enthalpy changes associated with each of these individual chemical equations.

Sample Hess's Law Problem

Use the thermochemical equations given below to calculate the enthalpy change for the following reaction.

$N_2O_4(g) \rightarrow 2NO_2(g) \quad \Delta H = ?$

(#1) $N_2(g) + 2O_2(g) \rightarrow 2NO_2(g) \quad \Delta H = +66.36\ kJ$
(#2) $N_2(g) + 2O_2(g) \rightarrow N_2O_4(g) \quad \Delta H = +9.16\ kJ$

$N_2O_4(g) \rightarrow N_2(g) + 2O_2(g) \quad \Delta H = -9.16\ kJ$
$\underline{N_2(g) + 2O_2(g) \rightarrow 2NO_2(g) \quad \Delta H = +66.36\ kJ}$
$N_2O_4(g) \rightarrow 2NO_2(g) \quad \Delta H = +57.2\ kJ$

Objectives

In this experiment, the temperature change of two reactions will be measured, and Hess's law will be used to determine the enthalpy change, ΔH of a third reaction. You will use a Styrofoam cup nested in a beaker as a calorimeter, as shown below in Figure 1. For purposes of this experiment, you may assume that the heat loss to the calorimeter and the surrounding air is negligible. Experimental results will then be compared to accepted values.

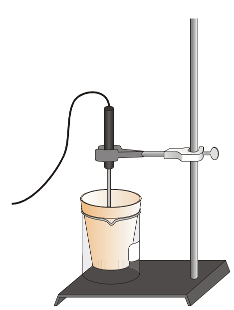

Figure 1

Materials

Vernier computer interface
Computer
Temperature Probe
Styrofoam cup calorimeter
250 mL beaker
50 mL or 100 mL graduated cylinders
2.0 M hydrochloric acid solution
2.0 M sodium hydroxide solution
2.0 M acetic acid solution
ring stand
utility clamp
glass stirring rod

Pre-Lab Exercise

1. The first reaction (#1) to be investigated is a neutralization between an aqueous solution of sodium hydroxide and an aqueous solution of hydrochloric acid, yielding aqueous sodium chloride and water. The thermochemical equation for this reaction is given as follows.

(#1) $NaOH(aq) + HCl(aq) \text{--->} NaCl(aq) + H_2O(l) \quad \Delta H = -55.89 \text{ kJ}$

Write the **net ionic equation** with the corresponding enthalpy value (ΔH) for reaction #1.

2. The second reaction (#2) to be investigated is a neutralization between an aqueous solution of sodium hydroxide and an aqueous solution of acetic acid, yielding aqueous sodium acetate and water. The thermochemical equation for this reaction is given as follows.

(#2) $NaOH(aq) + HC_2H_3O_2(aq) \text{--->} NaC_2H_3O_2(aq) + H_2O(l) \quad \Delta H = -56.14 \text{ kJ}$

Write the **net ionic equation** with the corresponding enthalpy value (ΔH) for reaction #2.

3. The third reaction (#3) to be studied is the complete dissociation of an aqueous solution of acetic acid. It can be represented as follows.

(#3) $HC_2H_3O_2(aq) \rightarrow H^{1+}(aq) + C_2H_3O_2^{1-}(aq)$

Using Hess' law and the enthalpy of reaction data (Δ*H*) for the **net ionic equations** from reactions #1 and #2, calculate the enthalpy of reaction (Δ*H*) for reaction #3.

Procedure

1. Put on your chemical splash-proof safety goggles.

2. Connect a Temperature Probe to Channel 1 of the Vernier computer interface. Connect the interface to the computer with the proper cable. Use a utility clamp to suspend the Temperature Probe from a ring stand, as shown in Figure 1.

3. Start the Logger *Pro* program on your computer. Open the file "13 Enthalpy" from the *Advanced Chemistry with Vernier* folder.

Part I Conduct the Reaction Between Solutions of NaOH and HCl (Reaction #1)

4. Nest a Styrofoam cup in a 250 mL beaker (see Figure 1). Measure 50.0 mL of 2.0 M HCl solution into the cup. Lower the tip of the Temperature Probe into the HCl solution. **CAUTION:** *Handle the hydrochloric acid with care. It can cause painful burns if it comes in contact with the skin.*

5. Measure out 50.0 mL of 2.0 M NaOH solution, but do not add it to the HCl solution yet. **CAUTION:** *Handle the sodium hydroxide solution with care.*

6. Conduct the reaction.
   a. Click [Collect] to begin the data collection and obtain the initial temperature of the HCl solution.
   a. After three or four readings have been recorded at the same temperature, add the 50.0 mL of NaOH solution to the Styrofoam cup all at once. Stir the mixture throughout the reaction.
   b. Data collection will end after three minutes. If the temperature readings are no longer changing, you may terminate the trial early by clicking [Stop].
   c. Click the Statistics button, [STAT]. The minimum and maximum temperatures are listed in the statistics box on the graph. If the lowest temperature is not a suitable initial temperature, examine the graph and determine the initial temperature.
   d. Record the initial and maximum temperatures in your data table.

7. Rinse and dry the Temperature Probe, Styrofoam cup, and the stirring rod. Dispose of the solution as directed.

Part II Conduct the Reaction Between Solutions of $HC_2H_3O_2$ and NaOH (Reaction #2)

8. Measure out 50.0 mL of 2.0 M $HC_2H_3O_2$ solution into the nested Styrofoam cup (see Figure 1). Lower the tip of the Temperature Probe into the cup of $HC_2H_3O_2$ solution.

9. Measure out 50.0 mL of 2.0 M NaOH solution, but do not add it to the $HC_2H_3O_2$ solution yet.

10. Conduct the reaction.
   e. Click [Collect] to begin the data collection.
   f. After three or four readings have been recorded at the same temperature, add the 50.0 mL of NaOH solution to the Styrofoam cup all at once. Stir the mixture throughout the reaction.
   g. Data collection will end after three minutes. If the temperature readings are no longer changing, you may terminate the trial early by clicking [Stop].
   h. Examine the graph as before to determine and record the initial and maximum temperatures of the reaction.

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

Name:	Group Members:

Data Table

	Initial Temperature (°C)	**Maximum Temperature (°C)**	**Temperature Change (ΔT) (°C)**
Reaction #1 **$NaOH(aq) + HCl(aq) \text{--->} NaCl(aq) + H_2O(l)$**			
Reaction #2 **$NaOH(aq) + HC_2H_3O_2(aq) \text{--->} NaC_2H_3O_2(aq) + H_2O(l)$**			

Data Analysis

A. Calculate the amount of heat energy, *q*, produced in each reaction. Use 1.03 g/mL for the density of all solutions. Use the specific heat of water, 4.18 J/(g•°C), for all solutions.

	***q* (J)**
Reaction #1	
Reaction #2	

B. Calculate the enthalpy change, ΔH, in **kJ** in terms of the **net ionic equations** for reactions #1 and #2.

	ΔH (kJ)
Reaction #1	
Reaction #2	

C. Use the values from B above and Hess's law to determine the experimental enthalpy for Reaction #3.

D. Using the calculated ΔH value from the Pre-Lab Exercise assignment as the accepted value of ΔH for Reaction #3, calculate the percent error of the experimental value.

E. Does this experimental process support Hess's law? Suggest ways of improving your results.