Determining the Enthalpy of a Chemical Reaction

All chemical reactions involve an exchange of heat energy; therefore, it is tempting to plan to follow a reaction by measuring the enthalpy change (ΔH). However, it is often not possible to directly measure the heat energy change of the reactants and products (the system). We can measure the heat change that occurs in the surroundings by monitoring temperature changes. If we conduct a reaction between two substances in aqueous solution, then the enthalpy of the reaction can 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. Furthermore, according to a principle known as Hess's law, the enthalpy changes of a series of reactions can be combined to calculate the enthalpy change of a reaction that is the sum of the components of the series.

In this experiment, you will measure the temperature change of two reactions, and use Hess's law to determine the enthalpy change, ΔH of a third reaction. You will use a polystyrene foam cup nested 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.

OBJECTIVES

- Use Hess's law to determine the enthalpy change of the reaction between aqueous ammonia and aqueous hydrochloric acid.
- Compare your calculated enthalpy change with the experimental results.

Figure 1

MATERIALS

Vernier computer interface
computer
Logger *Pro*
Temperature Probe
Stir Station
magnetic stirring bar
Electrode Support
polystyrene foam cup
400 mL beaker
50 mL or 100 mL graduated cylinders
2.0 M hydrochloric acid, HCl, solution
2.0 M sodium hydroxide, NaOH, solution
2.0 M ammonium chloride, NH_4Cl, solution
2.0 M ammonium hydroxide, NH_4OH, solution
fume hood

PRE-LAB QUESTIONS

You will conduct the following three reactions in this experiment. In the space provided below, write the balanced net ionic reaction equations from the descriptions. Use the table of thermodynamic data in your text (or another approved resource) to calculate the molar enthalpy of the reactions.

Reaction 1: An aqueous solution of sodium hydroxide reacts with an aqueous solution of hydrochloric acid, yielding water.

Reaction 2: An aqueous solution of sodium hydroxide reacts with an aqueous solution of ammonium chloride, yielding aqueous ammonia, NH_3, and water.

Reaction 3: An aqueous solution of hydrochloric acid reacts with aqueous ammonia, NH_3, yielding aqueous ammonium chloride.

Reaction	Balanced reaction equation	ΔH (kJ/mol)
1		
2		
3		

PROCEDURE

1. Obtain and wear goggles. It is best to conduct this experiment in a fume hood, or in a well-ventilated room.

2. Connect a Temperature Probe to Channel 1 of the Vernier computer interface. Connect the interface to the computer with the proper cable. Use an Electrode Support to suspend the Temperature Probe from a Stir Station, 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

4. Set up the equipment.

   a. Nest a polystyrene foam cup in a beaker and measure 50.0 mL of 2.0 M HCl solution into the cup. **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*.
   b. Place the beaker with the nested polystyrene foam cup on the base of the Stir Station and add a magnetic stirring bar to the cup.
   c. Set the Stir Station so it is stirring at a slow speed.
   d. Lower the Temperature Probe into the HCl solution. Ensure that the Temperature Probe is not struck by the magnetic stirring bar.

5. Measure out 50.0 mL of NaOH solution, but do not add it to the HCl solution yet. **DANGER**: *Sodium hydroxide solution,* NaOH: *Causes severe skin burns and eye damage. Do not breathe mist, vapors, or spray*.

6. Conduct the reaction.

   a. Click ▶ Collect to start data collection and obtain the initial temperature of the HCl solution.
   b. After three or four readings have been recorded at the same temperature, add the 50.0 mL of NaOH solution to the polystyrene foam cup all at once. Stir the mixture throughout the reaction.
   c. Data collection will end after three minutes. If the temperature readings are no longer changing, you may terminate the trial early by clicking ■ Stop.
   d. Click Statistics, . 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.
   e. Record the initial and maximum temperatures in your data table.

7. Rinse and dry the Temperature Probe, polystyrene foam cup, and stirring bar. Dispose of the solution as directed.

Part II Conduct the Reaction Between Solutions of NaOH and NH_4Cl

8. Measure out 50.0 mL of 2.0 M NaOH solution into a nested polystyrene foam cup. Add the magnetic stirring bar and lower the tip of the Temperature Probe into the cup of NaOH solution. Set the Stir Station to stir gently.

9. Measure out 50.0 mL of 2.0 M NH_4Cl solution, but do not add it to the NaOH solution yet. *Ammonium chloride*, 2.0 M, NH_4Cl: **WARNING**: *Causes skin and eye irritation*.

10. Conduct the reaction.

    a. Click ▶ Collect to begin the data collection.

    b. After three or four readings have been recorded at the same temperature, add the 50.0 mL of NH_4Cl solution to the polystyrene foam cup all at once. Stir the mixture throughout the reaction.

    c. Data collection will end after three minutes. If the temperature readings are no longer changing, you may terminate the trial early by clicking ■ Stop.

    d. Examine the graph as before to determine and record the initial and maximum temperatures of the reaction.

11. Rinse and dry the Temperature Probe, polystyrene foam cup, and stirring bar. Dispose of the solution as directed.

Part III Conduct the Reaction Between Solutions of HCl and NH_4OH

12. Measure out 50.0 mL of 2.0 M HCl solution into a nested polystyrene foam cup. Add the magnetic stirring bar and lower the tip of the Temperature Probe into the cup of HCl solution. Set the Stir Station to stir gently.

13. Measure out 50.0 mL of 2.0 M NH_4OH solution, but do not add it to the HCl solution yet. **DANGER**: *Ammonium hydroxide solution,* NH_4OH: *Do not eat or drink when using this product—harmful if swallowed. Causes severe skin burns and eye damage. May cause respiratory irritation. Do not breathe mist, vapors or spray.*

14. Conduct this reaction in a fume hood or in a well-ventilated area. Repeat Step 10 to conduct the reaction and collect temperature data.

DATA TABLE

	Reaction 1	Reaction 2	Reaction 3
Maximum temperature (°C)			
Initial temperature (°C)			
Temperature change (ΔT)			

POST LAB QUESTIONS / DISCUSSION

1. 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.

2. Calculate the enthalpy change, ΔH, for each reaction in terms of kJ/mol of each reactant.

3. Use your answers from 2 above and Hess's law to determine the experimental molar enthalpy for Reaction 3.

4. Use Hess's law, and the accepted values of ΔH in the Pre-Lab Exercise to calculate the ΔH for Reaction 3. How does the accepted value compare to your experimental value?

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