Heats of Reaction – Hess's Law

Overview

Hess's Law states that the energy change for a reaction depends on the enthalpy of the reactants and products and is independent of the pathway of the reaction.

In this experiment you will use calorimetry to measure the heats of reaction for three reactions:

Reaction	Reaction Equation	You will determine:
1	$NaOH(s) \rightarrow Na^{+}(aq) + OH^{-}(aq)$	ΔH_1
	Solid NaOH is dissolved in water	
2	$Na^{+}(aq) + OH^{-}(aq) + H^{+}(aq) + Cl^{-}(aq) \rightarrow Na^{+}(aq) + Cl^{-}(aq) + H_2O(l)$	ΔH_2
	Solutions of NaOH and HCl are mixed	
3	$NaOH(s) + H^{+}(aq) + Cl^{-}(aq) \rightarrow Na^{+}(aq) + Cl^{-}(aq) + H_2O(l)$	ΔH_3
	Solid NaOH is dissolved in a HCl solution	

The third reaction is actually a combination of the first two reactions. Notice that the equation for Reaction 3 can be obtained by adding together reactions 1 & 2. By calculating the heats of reaction for all three reactions you will be attempt to verify Hess's Law:

$$\Delta H_3 = \Delta H_1 + \Delta H_2$$

Purpose

- To measure experimentally the amount of heat absorbed or released during the dissolving of ammonium nitrate and of sodium acetate in water.

Equipment, Materials, and Procedure

Your teacher will provide you with a list of the materials and equipment required for this lab, and the procedures to follow.

SAFETY PRECAUTIONS MUST BE STRICTLY FOLLOWED!

If you are unable to actually perform the experiment, use the following set of experimental data to plot the graphs and answer the questions at the end of the lab.

Summary of Procedures

Reaction 1.

$NaOH(s) \rightarrow Na^{+}(aq) + OH^{-}(aq)$

2.0 g of solid NaOH is dissolved in 100 mL of water. The initial and final temperatures are measured and recorded. The heat of solution is calculated (ΔH_1)

Reaction 2.

$Na^{+}(aq) + OH^{-}(aq) + H^{+}(aq) + Cl^{-}(aq) \rightarrow$
$Na^{+}(aq) + Cl^{-}(aq) + H_2O(l)$

50 mL of 1.0 M hydrochloric acid solution is combined with 50 mL of 1.0 M sodium hydroxide solution. The initial and final temperatures are recorded, and the heat of the reaction is calculated (ΔH_2)

Reaction 3.

$NaOH(s) + H^{+}(aq) + Cl^{-}(aq) \rightarrow Na^{+}(aq) + Cl^{-}(aq) + H_2O(l)$

2.0 g of solid NaOH is dissolved in 200 mL of 0.50 M HCl. The heat of reaction is calculated (ΔH_3)

Data Analysis and Calculations

Record your calculations in Table 2.

Step 1. Calculate the mass of reaction mixture for each reaction. We will assume that the density of the solutions (the HCl and NaOH solutions) have the same density as pure water – 1.0 g/mL. Thus, 100.0 mL will have a mass of 100.0 g.

Reaction 1:
Add the mass of water used + mass NaOH

Reaction 2:
The volume of HCl used will be numerically equivalent to it's mass, expressed in grams.

Add mass NaOH + mass HCl

Reaction 3:

Add the masses of the two solutions:
NaOH + mass HCl

Step 2. Calculate the change in temperature for each of reactions

Steps 3 – 6. Calculate the amount of heat released, in kJ, during each of the reactions, using

$$Q = mc\Delta T$$

Step 7 – 9. These steps convert mass or volume of materials used into moles.

To convert mass of a solid into moles:

$$moles = \frac{mass}{Molar\_Mass}$$

To convert the volume of a solution into moles:

The unit for concentration of solutions is M, which represents mol/L.

moles = Volume of solution (in L) × concentration (in mol/L)

For example: If 55.0 mL of a 1.0 M NaOH solution is used, then

mol = (0.055 L) × (1.0 mol/L) = 0.055 mol

Step 10. Calculate the heat of reaction per mole of NaOH by dividing the heat released (your answer to Step 6) by moles NaOH used (answer to step 9).

Questions and Conclusions

1. Show that adding together the equations for Reaction 1 and Reaction 2 produce the equation for Reaction 3.

2. Calculate the sum of ΔH_1 and ΔH_2. How does this compare with the experimentally determined value for ΔH_3?

3. Calculate the percent difference between ΔH_3 and ($\Delta H_1 + \Delta H_2$).

$$\text{Percent Difference} = \frac{\Delta H_3 - (\Delta H_1 + \Delta H_2)}{\Delta H_3} \times 100$$

Table 1A. Data recording sheet for Reactions 1 and 3

	Reaction 1 $NaOH (s) \rightarrow Na^+ + OH^-$	**Reaction 3** $NaOH (s) + H^+ + Cl^- \rightarrow Na^+ + Cl^- + H_2O$
Volume H_2O or HCl used (mL)		
Mass of solid + container (g)		
Mass of empty container (g)		
Mass of solid used (g)		
Initial water/HCl temperature (°C)		
Final water/HCl temperature (°C)		
Change in temperature (°C)		

Table 1B. Data recording sheet for Reaction 2.

	Reaction 2 $Na^+ + OH^- + H^+ + Cl^- \rightarrow Na^+ + Cl^- + H_2O$
Volume NaOH solution (mL)	
Volume HCl solution (mL)	
Total solution volume (mL)	
Initial temperature HCl solution (°C)	
Initial temperature NaOH solution (°C)	
Average temperature (°C)	
Final temperature of mixture (°C)	
Change in temperature (°C)	

Sample Data

Use the following sample data if you are not able to perform the experiment.

Table 1A. Data recording sheet for Reactions 1 and 3

	Reaction 1 $NaOH (s) \rightarrow Na^+ + OH^-$	**Reaction 3** $NaOH (s) + H^+ + Cl^- \rightarrow Na^+ + Cl^- + H_2O$
Volume H_2O or HCl used (mL)	98.2	96.6
Mass of solid + container (g)	3.58	3.65
Mass of empty container (g)	1.60	1.60
Mass of solid used (g)		
Initial water/HCl temperature (°C)	18.6	19.0
Final water/HCl temperature (°C)	21.2	25.2
Change in temperature (°C)		

Table 1B. Data recording sheet for Reaction 2.

	Reaction 2 $Na^+ + OH^- + H^+ + Cl^- \rightarrow Na^+ + Cl^- + H_2O$
Volume NaOH solution (mL)	48.6
Volume HCl solution (mL)	47.8
Total solution volume (mL)	
Initial temperature HCl solution (°C)	18.8
Initial temperature NaOH solution (°C)	18.4
Average temperature (°C)	
Final temperature of mixture (°C)	22.0
Change in temperature (°C)	

Table 2. Calculating Heats of Reaction

	Reaction 1 NaOH (s) → Na^+ + OH^-	**Reaction 2** Na^+ + OH^- + H^+ + Cl^- → Na^+ + Cl^- + H_2O	**Reaction 3** NaOH (s) + H^+ + Cl^- → Na^+ + Cl^- + H_2O
1. Total mass of water or solution used			
2. Change in temperature			
3. Specific heat of water	4.18 J/ g·°C	4.18 J/ g·°C	4.18 J/ g·°C
4. Energy absorbed/lost by the ***water*** (J) [Multiply steps 1 × 2 × 3]			
5. Energy absorbed/lost by the ***reaction*** (J) (same as result for step 4, but opposite sign)			
6. Energy absorbed/lost (kJ) (convert answer to step 5 to kilojoules)			
7. Rxn 1: Mass of NaOH used (g) Rxn 2: Volume of NaOH used (L) Rxn 3: Mass of NaOH used (g)			
8. Rxn 1: Molar mass of NaOH (g/mol) Rxn 2: Concentration of NaOH (aq) (mol/L) Rxn 3: Molar mass of NaOH (g/mol)		$\frac{1.0 \text{ mol}}{\text{L}}$	
9. Moles of NaOH actually used (mol) Rxn 1: moles = (g) / (g/mol) Rxn 2: moles = (L) × (mol/L) Rxn 3: moles = (g) / (g/mol)			
10. Heat of Reaction ΔH° (kJ/mol)			