

Chemistry 1215 Make up Lab
Enthalpy of Neutralization

Objective

In this experiment you will determine the molar enthalpy of neutralization of an acid.

Introduction

The study of energy and its transformations is known as thermodynamics. Thermochemistry is the branch of thermodynamics that relates to chemical reactions and energy changes involving heat. Most thermochemical studies are conducted in a laboratory where the transfer of heat can be carefully monitored in a closed system. The measurement of heat transfer is called calorimetry. The device in which heat transfer is measured is called a calorimeter. A calorimeter can be a sophisticated device that isolates the reaction from its surroundings or it can be a simple device in which the reactants are in constant, close physical contact with the surroundings. In either case, it is important that temperature and heat transfer can be easily monitored. The reactants contained in a calorimeter are defined as the system. The solvent in which the reactants are dissolved, the calorimeter itself including the thermometer, and any air that is in contact with the solution are defined as the surroundings. When the reagents are mixed they react. Any heat generated in an exothermic reaction is transferred to the surroundings (the solvent, the calorimeter, and the air). An endothermic reaction must, conversely, draw heat from the surroundings. In order to determine the amount of heat that is absorbed by the calorimeter it is advisable that the calorimeter be calibrated (see part A below).

Heat transfer causes the temperature of a system and its surroundings to change due to absorption or release of heat. The change in temperature, ΔT , can be measured and used to calculate the heat absorbed or released by the reaction. Heat, Q , is then used to calculate the change in Enthalpy, ΔH . To obtain the temperature change it is necessary to measure the initial temperature of the system/surroundings and also to determine the final, maximum temperature after the reaction. The temperature at the time of mixing cannot be determined directly because the reaction doesn't happen instantaneously, neither is the heat of the reaction instantly transferred to the surroundings (mainly the solvent) where it can be measured. There is also a delayed response in the thermometer. To compensate for these time delays, the temperature of the reactants is measured before mixing and then the temperature change is monitored at timed intervals after mixing. The actual value of the final temperature is then determined by constructing a time post reaction versus temperature graph. The temperature at the time of mixing, T_{max} or T_{final} is determined by fitting a line through the data points and extrapolating back to the time of mixing (see Figure 1 for an example).

Procedure

Part A. Calibration of the Calorimeter

1. Place one 6 to 8 ounce Styrofoam cup inside another. This is the calorimeter. Weigh the calorimeter and record the mass on your data sheet.
2. Attach a medium ring to a ring stand to support the calorimeter. Attach a clamp above the ring to hold a digital thermometer. Suspend the thermometer so its tip will be immersed in the water but it will not touch the sides or the bottom of the calorimeter. Remember that the thermometer can easily puncture the Styrofoam cup. If this happens you will have to start over.
3. Measure 50 mL of distilled water in a graduated cylinder and pour it into the calorimeter. Weigh the calorimeter again and record the mass on your data sheet.

4. Weigh a 150 mL beaker and record its mass. Pour a 50. mL portion of distilled water into this beaker and weigh it again. Heat the water in the beaker to 45 +/- 3 °C. Remove the beaker from the heat source and place it on an insulated pad.
5. For a period of **two minutes**, measure the temperature of the water in the calorimeter at **30 second intervals**. Record each measurement on the data sheet. At **two minutes** measure the temperature of the hot water also and immediately pour the hot water into the calorimeter. Stir briefly and, at **two and a half minutes**, begin measuring and recording the temperature of the mixture **every 30 seconds** for the next **seven and one half minutes** (a total of 10 minutes of measurements).
6. Empty the calorimeter and dry it with a paper towel. You will use this calibrated calorimeter in part B of the experiment.

Part B. Measurement of the Enthalpy of Neutralization

Use the following systems: (I) NaOH(aq)/HCl(aq), (II) NaOH(aq)/H₂SO₄(aq) or NaOH(aq)/H₃PO₄(aq). Each pair of students will measure the enthalpy of neutralization of two different systems. Remember to record the exact molarities of the solutions used as listed on the labels.

1. Prepare and weigh the empty calorimeter as in steps A-1 and A-2.
2. Weigh a clean and dry 50 mL beaker and record its mass on your data sheet. Using a 50 mL graduated cylinder, pour 50 mL of NaOH solution into this beaker. Reweigh the beaker with its contents and record the mass on your data sheet. Measure and record the temperature of the base solution.
3. Using a clean and dry 50 mL graduated cylinder measure 50 mL of acid solution and pour it into the calorimeter. Weigh the calorimeter containing the acid and record its mass.
4. Measure the temperature of the acid. If the temperature of the acid and the base are not within 0.5 °C of each other, either heat or cool the base (use a hot plate or an ice bath) do not add water or ice directly to the base or you will change both the mass and the concentration of the base.
5. Measure the temperature of the acid at 30 second intervals for two minutes. Record the measurements. At the two minute mark, mix the base with the acid in the calorimeter. Stir briefly with a glass stirring rod. At the two and one half minute mark, begin measuring and recording the temperature of the mixture at 30 second intervals for the next 12.5 minutes (a total of 15 minutes of measurements).
6. Discard the contents of the calorimeter into the sink. Rinse the sink and the calorimeter with tap water and dry the calorimeter with a paper towel. Rinse and dry the thermometer.
7. Set up the calorimeter assembly again and repeat steps 1-6 with a second base-acid system.

Calculations

I. Calorimeter Constant

The heat, Q_{cal} , gained by the calorimeter is calculated according to equations 1 and 2.

$$Q_{cal} = (\text{heat lost by the hot water}) - (\text{heat gained by the cold water}) \quad \text{Equation 1}$$

Or, stated mathematically,

$$Q_{cal} = (m_{hot})(\Delta T_{hot})(s_{water}) - (m_{cold})(\Delta T_{cold})(s_{water}) \quad \text{Equation 2}$$

$$\begin{aligned} \text{Where: } (\text{heat lost by the hot water}) &= (m_{hot})(\Delta T_{hot})(s_{water}) \\ (\text{heat gained by the cold water}) &= (m_{cold})(\Delta T_{cold})(s_{water}) \end{aligned}$$

And:

m_{hot} = mass of the hot water

s_{water} = the specific heat of water = 4.183 J/(g·K)

m_{cold} = mass of the cold water

$\Delta T_{\text{hot}} = T_{\text{max}} - T_{\text{hot}}$

$\Delta T_{\text{cold}} = T_{\text{max}} - T_{\text{cold}}$

T_{max} is the maximum temperature of the water mixture after mixing the hot and cold water. It is obtained by graphing time versus temperature for the calibration data and extrapolating back to the time of mixing. (See Figure 1 below).

The heat capacity, C_{cal} , of the calorimeter (also called the calorimeter constant) is calculated according to Equation 3.

$$C_{\text{cal}} = Q_{\text{cal}} / \Delta T_{\text{cold}} \quad \text{Equation 3}$$

II. Enthalpy of Neutralization

- a. The heat, Q , released by the reaction is calculated from Equation 4

$$Q = -(m_{\text{sol}})(s_{\text{sol}}) + C_{\text{cal}}(\Delta T_{\text{sol}}) \quad \text{Equation 4}$$

Where: $m_{\text{sol}} = m_{\text{acid}} + m_{\text{base}}$ = mass of the solution in the calorimeter

s_{sol} = specific heat of the solution in the calorimeter (see Table 1)

C_{cal} = the calorimeter constant (see Equation 3)

$\Delta T_{\text{sol}} = (T_{\text{max sol}} - T_i)$ temperature change of the solution during the reaction

And $T_i = (T_{\text{acid}} + T_{\text{base}})/2$ = average temperature of the acid and the base before mixing

$T_{\text{max sol}}$ = extrapolated maximum temperature of the reaction mixture after mixing

- b. Molar Enthalpy of Neutralization

$$\Delta H = Q/n \quad \text{Equation 5}$$

Where: n = the number of moles of the limiting reagent in the reaction. Identify the limiting reagent from the molarities of the starting acid and base and the volume of each solution.

Table 1

Solution, concentration	Specific heat, J/g K
Aqueous NaCl, 1.0 M	3.89
Aqueous Na ₂ SO ₄ , 1.0 M	3.76
Aqueous Na ₃ PO ₄ , 1.0 M	3.80

Example

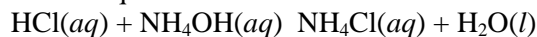
Find the molar enthalpy for the reaction in which 50.0 mL of 1.00 M hydrochloric acid is neutralized with 50.0 mL of 1.10 M aqueous ammonia solution. The initial temperatures of the acid and the base before mixing were both 20.0°C. The graphically extrapolated maximum temperature (see Figure 1 and Table 2) of the reaction mixture was 25.5 °C. The specific heat of

the reaction mixture, 0.50 M aqueous ammonium chloride, is 3.92 J/g·K. The calorimeter constant was previously determined to be 40.0 J/K.

$$1. Q = -[(m_{\text{sol}})(s_{\text{sol}}) + C_{\text{cal}}](\Delta T_{\text{sol}})$$

$$\text{or } Q = -(50.0 \text{ g} + 50.0 \text{ g})(3.92 \text{ J/g}\cdot\text{K}) + 40.0 \text{ J/K}(298.15\text{K} - 293.15\text{K}) = -2160 \text{ J} = -2.16 \text{ kJ}$$

2. The reaction equation is:



$$n \text{ NH}_4\text{OH} = (50.0\text{mL})(1.0\text{L}/1000\text{mL})(1.10 \text{ mol/L}) = 5.50 \times 10^{-2} \text{ mol}$$

$$n \text{ HCl} = (50.0 \text{ mL})(1.0 \text{ L}/1000\text{mL})(1.00 \text{ mol/L}) = 5.00 \times 10^{-2} \text{ mol}$$

therefore, HCl is the limiting reagent.

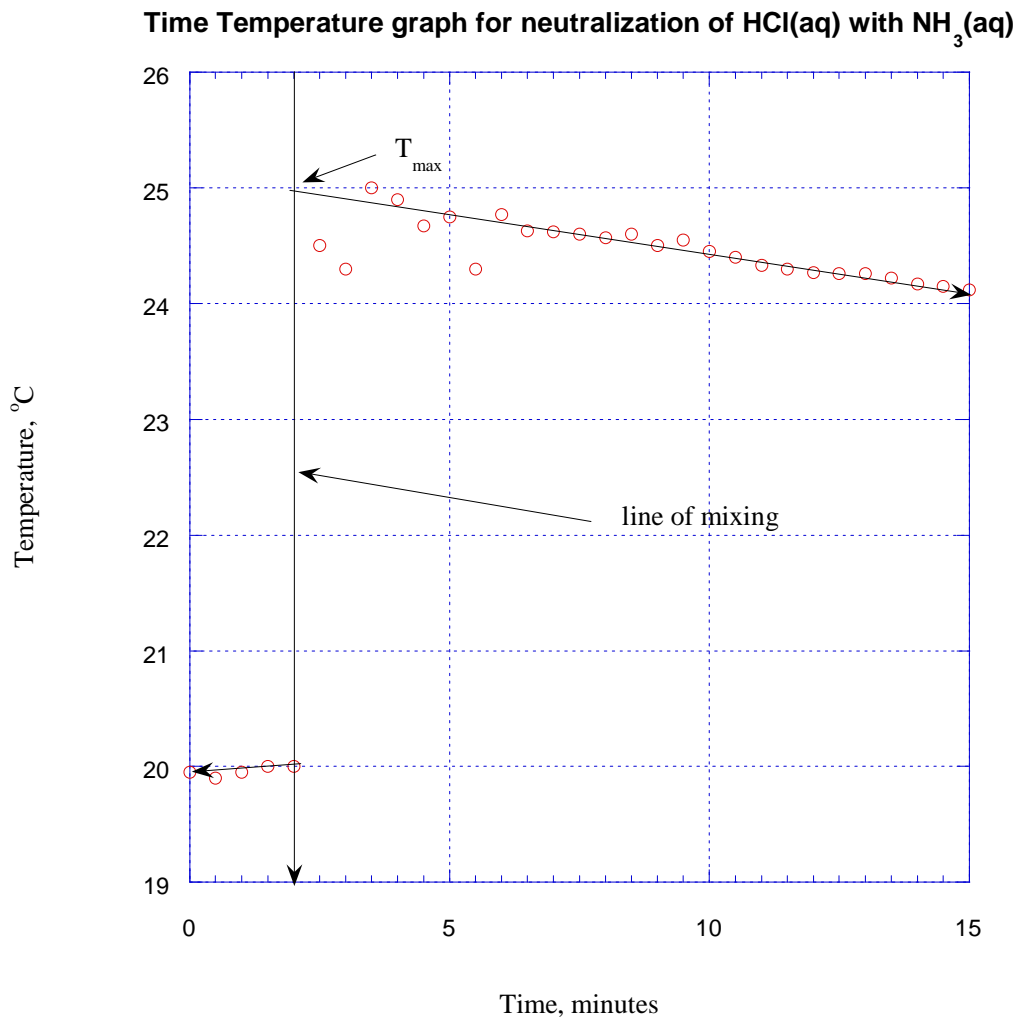
$$3. \Delta H = Q/n$$

$$\text{or } \Delta H = (-2.16\text{kJ})/(5.0 \times 10^{-2}\text{mol}) = 53.2 \text{ kJ/mol}$$

Table 2

Time, minutes	Temperature, °C	Time, minutes	Temperature, °C
0.0	19.95	8.0	24.57
0.5	19.90	8.5	24.60
1.0	19.95	9.0	24.50
1.5	20.00	9.5	24.55
2.0	20.00	10.0	24.45
2.5	24.50	10.5	24.40
3.0	24.30	11.0	24.33
3.5	25.00	11.5	24.30
4.0	24.90	12.0	24.27
4.5	24.67	12.5	24.26
5.0	24.75	13.0	24.26
5.5	24.30	13.5	24.22
6.0	24.77	14.0	24.17
6.5	24.63	14.5	24.15
7.0	24.62	15.0	24.12
7.5	24.60		

Figure 1



Data Sheet
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I. Calibration of the calorimeter

1. Mass of the empty calorimeter _____
2. Mass of calorimeter plus cold water _____
3. Mass of empty beaker _____
4. Mass of beaker plus water _____
5. Temperature of hot water _____
6. Temperature of cold water at 2.0 minutes _____

7. Temperature measurements:

Time, minutes	Temperature, °C	Time, minutes	Temperature, °C	Time, minutes	Temperature, °C
0		3.5		7.0	
0.5		4.0		7.5	
1.0		4.5		8.0	
1.5		5.0		8.5	
2.0		5.5		9.0	
2.5		6.0		9.5	
3.0		6.5		10.0	

II. Enthalpy of Neutralization

- | | Acid 1 | Acid 2 |
|-------------------------------|--------|--------|
| 1. Identity of acid | _____ | _____ |
| 2. Concentration of acid | _____ | _____ |
| 3. Concentration of NaOH | _____ | _____ |
| 4. Mass of empty calorimeter | _____ | _____ |
| 5. Volume of acid | _____ | _____ |
| 6. Mass of calorimeter + acid | _____ | _____ |
| 7. Mass of empty beaker | _____ | _____ |
| 8. Mass of beaker + NaOH | _____ | _____ |
| 9. Temperature of NaOH | _____ | _____ |
| 10. Temperature of acid | _____ | _____ |
| 11. Temperature measurements: | | |

Acid 1 _____

Time, minutes	Temperature, °C	Time, minutes	Temperature, °C	Time, minutes	Temperature, °C
0		5.5		11.0	
0.5		6.0		11.5	
1.0		6.5		12.0	
1.5		7.0		12.5	
2.0		7.5		13.0	
2.5		8.0		13.5	
3.0		8.5		14.0	
3.5		9.0		14.5	
4.0		9.5		15.0	
4.5		10.0			
5.0		10.5			

Acid 2 _____

Time, minutes	Temperature, °C	Time, minutes	Temperature, °C	Time, minutes	Temperature, °C
0		5.5		11.0	
0.5		6.0		11.5	
1.0		6.5		12.0	
1.5		7.0		12.5	
2.0		7.5		13.0	
2.5		8.0		13.5	
3.0		8.5		14.0	
3.5		9.0		14.5	
4.0		9.5		15.0	
4.5		10.0			
5.0		10.5			

III. Results

A. Calibration of the calorimeter

1. Mass of cold water _____
2. Mass of hot water _____
3. ΔT_{cold} _____
4. ΔT_{hot} _____
5. C_{cal} _____

B. Enthalpy of neutralization

- | | Acid 1 | Acid 2 |
|----------------------------|--------|--------|
| 1. Mass of acid | _____ | _____ |
| 2. Mass of NaOH | _____ | _____ |
| 3. ΔT_{sol} | _____ | _____ |
| 4. s_{sol} | _____ | _____ |
| 5. Q | _____ | _____ |
| 6. n | _____ | _____ |
| 7. ΔH | _____ | _____ |

Calculations

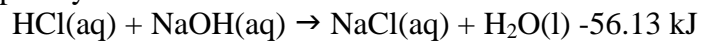
Discussion:

The discussion must contain all of the calculations, applicable graphs (on graph paper) and a detailed statement of and a discussion of your results including an evaluation of the error sources. In your discussion include also a comparison of the enthalpies of neutralization of the two acids.

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Name _____

1. Consider the chemical equation below. Is the reaction endothermic or exothermic? Explain your answer.



2. In the reaction in question 1, how many kJ of energy are produced when 0.041 moles of HCl are neutralized by an excess of NaOH?
3. Neutralization of 0.330 moles of H_2SO_4 by an excess of NaOH produced 66.3 kJ of heat. What is the molar enthalpy of neutralization for H_2SO_4 ?
4. An aqueous solution of Na_3PO_4 is heated from 24.7°C to 35.6°C . How much heat was absorbed by the solution?