Experiment 6
CALORIMETRY

INTRODUCTION

Calorimetry is the measurement of how much heat is gained or released by a system as a chemical reaction occurs within it. The heat lost or gained in a chemical reaction is the heat of reaction. The laboratory device in which quantities of heat can be measured is called calorimeter.

There are two types of calorimeters: the bomb calorimeter and the open calorimeter. In a bomb calorimeter, the volume of the system is constant. The heat measured equals the change in the internal energy of the system. In an open calorimeter, the pressure of the system is constant. The heat measured equals the change in the enthalphy of the system. The type of reaction being studied determines what type of calorimeter is to be employed.

Heats of reaction may be classified into more specific categories. The heat of formation is the thermal change involved in the formation of one mole of a substance from the elements. The heat of combustion is the amount of heat liberated per mole of substance burned. The heat of solution of a substance is the thermal change that accompanies the dissolving of a substance in a solvent. The heats of vaporization, fusion, and sublimation are related to the thermal changes that accompany changes in state. The heat of neutralization is the thermal change associated with the reaction of an acid and a base. The heat of dilution is the thermal change involved when additional solvent is added to a concentrated solution. There are many types of heats of reaction besides those mentioned.

Heat measurements are made by mixing known amounts of reactants in a calorimeter and letting them react. The heat evolved or absorbed by the reaction is equal to the heat absorbed or evolved by the calorimeter. In an exothermic reaction, the chemical reaction gives off heat to the surroundings. The heat is absorbed by the calorimeter and its temperature rises. In an endothermic reaction, the chemical reaction absorbs heat from the surroundings. The heat is absorbed from the calorimeter and its temperature falls.

The SI unit of energy is the joule (J) and one calorie (cal) is equal to 4.184J. One calorie is the amount of heat required to raise the temperature of one gram of water by one degree Celsius. The joule and the calorie are relatively small units for measurements of thermochemical values. Such values are frequently reported in kilojoules (kJ) and kilocalories (kcal). One kilojoule is equal to 1000 J and one kilocalorie is equal to 1000 cal.

The heat capacity (C) of a given mass of a substance is the amount of heat required to raise the temperature of the mass by one degree Celsius. Specific heat (s) is the amount of heat required to raise the temperature of one gram of the substance by one degree Celsius. Therefore, heat capacity is the product of the mass of the substance and its specific heat. The specific heat of water is 4.184 J/g-°C.

The quantity of heat lost or gained (q) is determined by the temperature change (ΔT), the mass of the substance (m), and its specific heat (s):

$$\mathbf{q = ms\Delta T = C\Delta T}$$

In the experiment, a chemical reaction is carried out in aqueous solution in a styrofoam-cup calorimeter and the temperature change is measured. Styrofoam is a good heat insulator, so there is very little heat transfer between the cup and the surrounding air. Because the reaction mixture is maintained under atmospheric pressure, the quantity of heat measured is at constant pressure.

OBJECTIVES

1. To compute the heat capacity of a styrofoam-cup calorimeter
2. To compute the heat of neutralization of 1.0 M hydrochloric acid and 1.0 M sodium hydroxide, the heat of dilution of concentrated sulfuric acid, and the heat of solution of solid ammonium chloride

LIST OF CHEMICALS

100 mL 1M hydrochloric acid
100 mL 1M sodium hydroxide
6 mL concentrated sulfuric acid
5.34 g ammonium chloride
4 drops phenolphthalein
distilled water

LIST OF APPARATUS

2 thermometers, 2 styrofoam-cup calorimeters, 10-mL graduated cylinder, 50-mL graduated cylinder, iron stand, iron ring, Bunsen burner, wire gauze, electronic balance, 150-mL beaker

SAFETY PRECAUTION: Concentrated sulfuric acid, hydrochloric acid, and sodium hydroxide cause skin and eye burns. They are corrosive chemicals. If you get any chemical on your skin, immediately rinse it off with plenty of water.

PROCEDURE

A. Preparation of the Two Styrofoam-Cup Calorimeters

A styrofoam-cup calorimeter consists of two styrofoam cups nested together with a cover. A hole is made in the cover for the insertion of the thermometer. Label the calorimeters with 1 and 2. Make sure that the two thermometers will not interchange. Refer to Figure 1.

Note: Be sure that the two thermometers have the same calibration. It is preferable to use a thermometer with a graduation line equivalent to one degree Celsius because you can read the temperature better.

Figure 1. Styrofoam-cup calorimeters

B. Determination of the Heat Capacity of Calorimeter 1

1. Place 50 mL of cold water (distilled water at room temperature) in calorimeter 1. Put the cover and determine its temperature (T_{cold}) by immersing the thermometer for one minute.

2. Place 50 mL of hot water with temperature between 55°C and 60°C in calorimeter 2. Put the cover and determine its temperature (T_{hot}) after one minute.

3. Immediately pour the hot water in calorimeter 2 to the cold water in calorimeter 1. Cover and determine the highest temperature (T_{final}) reached.

4. Make 2 trials.

5. **Waste Disposal:** Dispose the water to the sink.

6. Calculate the heat lost by the hot water in joules. The specific heat of water is 4.184 J/g-°C. The density of water is 1 g/mL. The mass of the water is the product of its volume and density.

$$q_{hot} = m_{hot}s(T_{final} - T_{hot})$$

Note: Heat (q) is negative when it is lost by the system and it is positive when it is gained by the system.

7. Compute the heat gained by the cold water in joules.

$$q_{cold} = m_{cold}s(T_{final} - T_{cold})$$

8. Determine the heat gained by calorimeter 1 in joules by applying the law of conservation of energy.

$$q_{hot} + q_{cold} + q_{calorimeter\ 1} = 0$$
$$q_{calorimeter\ 1} = -q_{hot} - q_{cold}$$

9. Calculate the heat capacity of calorimeter 1 in J/°C by dividing the heat gained by calorimeter 1 by the temperature change of the cold water.

$$C_{calorimeter\ 1} = q_{calorimeter\ 1} / (T_{final} - T_{cold})$$

10. Compute the average heat capacity of calorimeter 1 in J/°C. This average heat capacity of calorimeter 1 will be used in parts C, D, and E of the experiment.

C. Heat of Neutralization of 1.0M Hydrochloric Acid and 1.0 M Sodium Hydroxide

1. Place 50 mL of 1.0 M NaOH in calorimeter 1. Cover and get the temperature (T_{NaOH}) after one minute.

2. Place 50 ml of 1.0 M HCl in calorimeter 2. Put the cover and read the temperature (T_{HCl}) after one minute.

3. Pour the HCl in calorimeter 2 to the NaOH in calorimeter 1. Stir using the thermometer and record the highest temperature (T_{final}) reached.

4. Make 2 trials.

5. **Waste Disposal:** Dispose the solution to the sink.

6. Calculate the initial temperature using $T_{initial} = (T_{NaOH} + T_{HCl})/2$.

7. Compute the heat gained by the mixture in joules. Assume that the density and the specific heat of the mixture are the same as that of water. The total volume of the mixture is 100 mL.

$$q_{mixture} = m_{mixture}s\ (T_{final} - T_{initial})$$

8. Determine the heat gained by calorimeter 1 in joules.

$$q_{calorimeter\ 1} = C_{calorimeter\ 1}(T_{final} - T_{initial})$$

9. Calculate the heat of neutralization in joules by applying the law of conservation of energy.

$$q_{neutralization} + q_{mixture} + q_{calorimeter\ 1} = 0$$
$$q_{neutralization} = -q_{mixture} - q_{calorimeter\ 1}$$

10. Compute the heat of neutralization per mole of water formed in kJ/mole H_2O.

    Note: The number of moles of NaOH is 0.05 mole and that of HCl is also 0.05 mole. The number of moles is determined by multiplying the volume in liter by the molarity of the solution. Since the two reactants are in stoichiometric proportion, there is no excess reactant. The number of moles of the water produced from the reaction is 0.05 mole. The chemical equation is $HCl + NaOH \rightarrow NaCl + H_2O$.

11. Determine the average heat of neutralization per mole of water formed in kJ/mole H_2O.

D. Heat of Dilution of Concentrated Sulfuric Acid

1. Place 97 mL of distilled water in calorimeter 1. Cover and read the temperature ($T_{initial}$) after one minute.

2. Using a 10-mL graduated cylinder, measure 3 mL of concentrated sulfuric acid.

3. Pour the acid in the distilled water in calorimeter 1. Cover and record the highest temperature (T_{final}) reached.

4. Make 2 trials.

5. **Waste Disposal:** Add 2 drops of phenolphthalein to the solution. Neutralize the solution by adding dropwise 1M NaOH until the color becomes light pink. Dispose the neutralized solution to the sink.

6. Calculate the heat gained by the mixture in joules. Assume that the specific heat of the mixture is the same as that of water. The density of the concentrated sulfuric acid is 1.83 g/mL.

$$q_{mixture} = m_{mixture}s(T_{final} - T_{initial})$$
$$m_{mixture} = m_{water} + m_{sulfuric\ acid}$$

7. Compute the heat gained by calorimeter 1 in joules.

$$q_{calorimeter\ 1} = C_{calorimeter\ 1}(T_{final} - T_{initial})$$

8. Determine the heat of dilution in joules by applying the law of conservation of energy.

$$q_{dilution} + q_{mixture} + q_{calorimeter\ 1} = 0$$
$$q_{dilution} = -q_{mixture} - q_{calorimeter\ 1}$$

9. Calculate the heat of dilution per mole of concentrated sulfuric acid in kJ/mole H_2SO_4. The molar mass of H_2SO_4 is 98 g/mole.

10. Compute the average heat of dilution per mole of concentrated sulfuric acid in kJ/mole H_2SO_4.

E. Heat of Solution of Ammonium Chloride

1. Place 100 mL of distilled water in calorimeter 1. Place the cover and record the temperature ($T_{initial}$) after one minute.

2. Weigh exactly 2.67 g of ammonium chloride .

3. Put the ammonium chloride in calorimeter 1. Cover and stir using the thermometer to dissolve the solid. Determine the lowest temperature (T_{final}) reached.

4. Make 2 trials.

5. **Waste Disposal:** Dispose the solution to the sink.

6. Calculate the heat lost by the mixture in joules. Assume that the specific heat of the mixture is equal to that of water.

$$q_{mixture} = m_{mixture}s(T_{final} - T_{initial})$$
$$m_{mixture} = m_{water} + m_{ammonium\ chloride}$$

7. Compute the heat lost by calorimeter 1 in joules.

$$q_{calorimeter\ 1} = C_{calorimeter\ 1}(T_{final} - T_{initial})$$

8. Determine the heat of solution in joules by applying the law of conservation of energy.

$$q_{solution} + q_{mixture} + q_{calorimeter\ 1} = 0$$
$$q_{solution} = -q_{mixture} - q_{calorimeter\ 1}$$

9. Calculate the heat of solution per mole of ammonium chloride in kJ/mole NH_4Cl. The molar mass of NH_4Cl is 53.45 g/mole.

10. Compute the average heat of solution per mole of ammonium chloride in kJ/mole NH_4Cl.

REFERENCES

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Nelson, J.H. and Kemp, K.C. (2003). Chemistry: The Central Science (Laboratory Experiments), 9th Edition. Pearson Education, Inc., USA.

Group No.______

Name:	**Date Performed:**
Course & Section:	**Date Submitted:**
Program & Year:	**Professor:**

Experiment 6
CALORIMETRY

A. Preparation of the Two Styrofoam-Cup Calorimeters

No data needed.

B. Determination of the Heat Capacity of Calorimeter 1

	Trial 1	Trial 2
Temperature of Cold Water in ^oC (T_{cold})		
Temperature of Hot Water in ^oC (T_{hot})		
Final Temperature in ^oC (T_{final})		
Heat Lost by the Hot Water in J (q_{hot})		
Heat Gained by the Cold Water in J (q_{cold})		
Heat Gained by Calorimeter 1 in J ($q_{calorimeter\ 1}$)		
Heat Capacity of Calorimeter 1 in J/^oC ($C_{calorimeter\ 1}$)		
Average Heat Capacity of Calorimeter 1 in J/^oC		

Show the computations for the following using the data for trial 1:

1. Heat Lost by the Hot Water

2. Heat Gained by the Cold Water

3. Heat Gained by Calorimeter 1

4. Heat Capacity of Calorimeter 1

5. Average heat Capacity of Calorimeter 1

C. Heat of Neutralization of 1.0M HCl and 1.0M NaOH

	Trial 1	Trial 2
Temperature of NaOH in ^{o}C (T_{NaOH})		
Temperature of HCl in ^{o}C (T_{HCl})		
Temperature of Mixture in ^{o}C (T_{final})		
Initial Temperature in ^{o}C ($T_{initial}$)		
Heat Gained by the Mixture in J ($q_{mixture}$)		
Heat Gained by Calorimeter 1 in J ($q_{calorimeter\ 1}$)		
Heat of Neutralization in J ($q_{neutralization}$)		
Moles of Water Formed		
Heat of Neutralization per Mole of Water Formed in kJ/mole H_2O		
Average Heat of Neutralization per Mole of Water Formed in kJ/mole H_2O		

Show the calculations for the following using the data in trial 1:

1. Initial Temperature

2. Heat Gained by the Mixture

3. Heat Gained by Calorimeter 1

4. Heat of Neutralization

5. Heat of Neutralization per Mole of Water Formed

6. Average Heat of Neutralization per Mole of Water Formed

D. Heat of Dilution of Concentrated Sulfuric Acid

	Trial 1	Trial 2
Temperature of Water in ^{o}C ($T_{initial}$)		
Temperature of Mixture in ^{o}C (T_{final})		
Heat Gained by the Mixture in J ($q_{mixture}$)		
Heat Gained by Calorimeter 1 in J ($q_{calorimeter\ 1}$)		
Heat of Dilution in J ($q_{dilution}$)		
Moles of Concentrated Sulfuric Acid		
Heat of Dilution per Mole of Concentrated Sulfuric Acid in kJ/mole H_2SO_4		
Average Heat of Dilution of Concentrated Sulfuric Acid in kJ/mole H_2SO_4		

Show the computations for the following using the data in trial 1:

1. Heat Gained by the Mixture
2. Heat Gained by Calorimeter 1
3. Heat of Dilution
4. Moles of Concentrated Sulfuric Acid

5. Heat of Dilution per Mole of Concentrated Sulfuric Acid

6. Average Heat of Dilution per Mole of Concentrated Sulfuric Acid

E. Heat of Solution of Ammonium Chloride

	Trial 1	Trial 2
Temperature of Water in ^{o}C ($T_{initial}$)		
Temperature of Mixture in ^{o}C (T_{final})		
Heat Lost by the Mixture in J ($q_{mixture}$)		
Heat Lost by Calorimeter 1 in J ($q_{calorimeter\ 1}$)		
Heat of Solution in J ($q_{solution}$)		
Moles of Ammonium Chloride		
Heat of Solution per Mole of Ammonium Chloride in kJ/mole NH_4Cl		
Average Heat of Solution per Mole of Ammonium Chloride in kJ/mole NH_4Cl		

Show the calculations for the following using the data in trial 1:

1. Heat Lost by the Mixture

2. Heat Lost by Calorimeter 1

3. Heat of Solution

4. Moles of Ammonium Chloride

5. Heat of Solution per Mole of Ammonium Chloride

6. Average Heat of Solution per Mole of Ammonium Chloride