Experiment 6 – Calorimetry

Materials Needed to Complete This Experiment

Note to Student: Please review this video before you begin the lab. ....(https://youtu.be/VG41qjaHDhM)

- 20 pennies or other coins (about 50 g)
- One ice cube (about 20 g)
- ≈10 g of Na_2CO_3(s) from Experiment 4
- Scale that holds up to 200.0 g with 0.01 g accuracy
- Temperature tester
- Distilled water
- Towel (cloth or paper) for drying lab ware
- Goggles
- 50 mL beaker, 100 mL beaker, 250 mL beaker

Common Lab Procedures/Skills in This Lab (new skills in bold)

1. Calorimetry to determine the heat of dissolving of Na_2CO_3 .... (https://youtu.be/Qyb2jJrs8zw)
2. Equilibrate to room temperature*
3. Record the mass*
4. Record the temperature*
5. Calorimetry to determine the heat of fusion of water .... (https://youtu.be/uNFL086pCjY)
6. Calorimetry to determine the specific heat capacity of a metal .... (https://youtu.be/sCnjAth---Y)
7. Calculate the heat of dissolving of Na_2CO_3.. (https://youtu.be/X-r2pyILp3g)
8. Calculate the heat of fusion of water.. (https://youtu.be/oAfpW-Ku6TM)
9. Calculate the specific heat capacity of a metal .... (https://youtu.be/ch-3GS_koRI)

INTRODUCTION

This experiment is an introduction to thermochemistry. Thermochemistry involves the exchange of energy as heat. Thermodynamics can be seen in everyday experiences. Have you noticed when you are in a crowded room with lots of people you will start to feel really warm and start sweating? This is the process your body uses to cool itself off. Heat from your body is transferred to the sweat. As your sweat absorbs more and more heat, it evaporates from your body, transferring heat to the air, which heats up the air temperature of the room. Following this experiment, you will have a better understanding of the reasons behind these and other thermal phenomena.

Calorimetry is one way to measure the amount of heat transferred in a chemical reaction, and a calorimeter is the tool used to measure this heat. A simple calorimeter is typically made from two Styrofoam coffee cups, with one inside the other and an insulating cover. In this experiment, you will use a plastic beaker as your calorimeter. During the experiment, we will assume that all of the heat energy stays within the calorimeter. This is equivalent to assuming that the calorimeter is a perfect insulator.

When two substances having different temperatures come into contact, the energy in the form of heat is exchanged between them until they reach a thermal equilibrium (the same temperature). If they are insulated from their surroundings, the amount of heat lost from the hotter substance equals the heat gained by the colder one.

Heat is only exchanged between the things that are in the calorimeter. For example, when a cold metal is added to room temperature water, the cold metal will absorb heat from the room temperature water. The symbol for heat is q with units of J or kJ. In this example,

$$q_{metal} = - q_{water} \qquad (1)$$

The negative sign is present because one material is taking in heat while the other material is giving off heat. For the experiments in this lab, the negative sign is always necessary.

The specific heat of a substance is the heat required to raise the temperature of one gram of the substance one degree. All substances have characteristic specific heats. The equation for the heat q of a substance that changes temperature is

$$q = m\,(C_s)\,\Delta T = m\,(C_s)\,(T_f - T_i) \qquad (2)$$

In the case of the cold metal absorbing heat from the room temperature water, each material has an expression like equation 2,

$$m_{metal}\,(C_{s,metal})\,(T_f - 0°C) = -\,m_{water}\,(C_{s,water})\,(T_f - T_i) \qquad (3)$$

In the experiment, the only variable that will not be measured or looked up is $C_{s,metal}$. You will solve for $C_{s,metal}$.

When a reaction is involved, the equation for q looks different,

$$q_{rxn} = \Delta H_{rxn}(mol_{reacted}) \qquad (4)$$

While the units of q are J or kJ, the units of ΔH_{rxn} are J/mol or kJ/mol. The units are often one way to tell a "q" apart from a "ΔH_{rxn}". When a reaction gives off heat, the reaction is exothermic and the sign of ΔH_{rxn} is negative. The solution then warms up and increases in temperature.

For this experiment, the $\Delta H_{dissolving}$ for Na_2CO_3 will be negative because the solution will warm up. The entire expression for this experiment is,

$$\Delta H_{dissolving}(mol_{Na_2CO_3}) = -\,m_{soln}\,(C_{s,soln})\,(T_f - T_i) \qquad (5)$$

In this experiment three processes involving heat transfer will be studied. In part A, you will determine the enthalpy of dissolving, $\Delta H_{dissolving}$, of a salt. In part B, you will determine the enthalpy of fusion, ΔH_{fusion}, of water. In part C, you will measure the specific heat of a metal.

PRELAB QUESTIONS

1. What is the relationship between heat and calorimetry?

2. Write a balanced equation for the dissolution process of sodium carbonate.

3. A metal sample weighing 53.4 g and at a temperature of 120.5°C was placed in 48.6 g of water in a calorimeter at 23.2°C. At equilibrium, the temperature of the water and metal was 35.4°C.

   a. What was ΔT for the water?
   b. What was ΔT for the metal?
   c. Calculate the specific heat of the metal.

4. What is the difference between specific heat and heat capacity?

PROCEDURE – You will work on this lab independently (no lab partners).

Before beginning the experiment, record ✎ the mass of 20 pennies (or other coins ≈ 50 g) and place the coins into a 100 mL beaker that you then place into the freezer portion of your refrigerator. *(Note, your calculations will be much easier if you select only one-coin denomination for your fifty grams of coins.)*

A. Calorimetry to determine the heat of dissolving of Na_2CO_3 .... (Video 1 Procedure/Skill 1 above)

1. Equilibrate 400 ml of distilled water to room temperature.

2. Record ✎ the mass of the 50 ml beaker.

3. Put ≈10 g solid Na_2CO_3 into the 50 mL beaker. Record ✎ the mass of the 50 mL beaker + Na_2CO_3.

4. Record ✎ the mass of a clean, dry 250 mL beaker.

5. Place about 100 g distilled water into the 250 mL beaker. Record ✎ the mass of the beaker + water.

6. Record ✎ the temperature of the water. Note, this is your initial temperature of your water, T_i.

7. Pour the solid Na_2CO_3 into the 250 mL beaker. While gently stirring using the temperature tester, record ✎ the temperature of the water in the beaker every 30 seconds until the temperature of the water has reached a maximum (while still stirring) for 3 minutes or more. It will take a few minutes for the Na_2CO_3 to dissolve, this is okay. The whole process will take at least 10 minutes but should not take longer than 20 minutes. This is T_f.

8. Pour out the contents into the sink. Rinse the beaker. Dry the beaker thoroughly.

Note to student

If you did not see a temperature change you will need to repeat the decomposition of sodium bicarbonate, $NaHCO_3$. In Experiment 4, part A. (Decompose sodium bicarbonate, $NaHcCO_3$ of the procedure.) Then repeat Part A of this experiment.

B. Calorimetry to determine the heat of fusion of water .... (Video 2 Procedure/Skill 5 above)

1. Record ✎ the mass of a clean, dry 250 mL beaker.

2. Place about 100 g distilled water into the 250 mL beaker. Record ✎ the mass of the beaker + water.

3. Record ✎ the temperature of the water. This is your initial temperature of your water, T_i.

4. Add an ice cube from your freezer into the water. While gently stirring using the temperature tester, record ✎ the temperature of the water in the beaker every 30 seconds until the temperature of the water has reached a minimum (while still stirring) for 3 minutes or more. This will take at least 10-20 minutes but should not take longer than 20 minutes. This is T_f.

5. Take the temperature tester out of the water. Shake off any excess water back into the beaker. Record ✎ the mass of the beaker + water + ice.

6. Pour out the contents into the sink. Dry the beaker thoroughly.

C. Calorimetry to determine the specific heat capacity of a metal .... (Video 3 Procedure/Skill 6 above)

1. Record ✎ the mass of a clean, dry 250 mL beaker.

2. Place about 100 g distilled water into the 250 mL beaker. Record ✎ the mass of the beaker and water.

3. Record ✎ the temperature of the water. This is your initial temperature of your water, T_i.

4. As quickly (yet safely) as possible, take the pennies (or other coins) out of the freezer and place them into the water. While gently stirring using the temperature tester, record ✎ the temperature of the water in the beaker every 30 seconds until the temperature of the water has reached a minimum (while still stirring) for 3 minutes or more.

CALCULATIONS

A. Calculate the heat of dissolving of Na_2CO_3 .... (Video 4 Procedure/Skill 7 above)

1. Assume that all of the heat that the water gained was given off by the dissolving reaction.

$$\text{heat given off by dissolving} = -\text{heat taken in by solution}$$
$$q_{dissolving} = -q_{soln}$$
$$\Delta H_{dissolving}(mol_{Na_2CO_3}) = -m_{soln}\,(C_{s,soln})\,(T_f - T_i)$$

2. Plug in all of the constants and experimental data and solve for $\Delta H_{dissolving}$. The mass of the solution is the sum of the masses of the water and Na_2CO_3. Signs are important: the solution warms up (meaning it is taking in heat), so the dissolving reaction must be giving off heat (exothermic, negative sign).

B. Calculate the heat of fusion of water .... (Video 5 Procedure/Skill 8 above)

1. Assume that all of the heat that left the water was taken in by the ice. After the ice melts, it then warms to the final temperature of the water.

heat taken in by ice (ice melts to water, water warms 0°C to T_f)	=	- heat given off by water (water cools T_i to T_f)
$q_{fusion} + q_{warming}$	=	$- q_{water}$
$\Delta H_{fusion}(mol_{ice}) + m_{ice}\,(C_{s,water})\,(T_f - 0°C)$	=	$- m_{water}\,(C_{s,water})\,(T_f - T_i)$

2. Plug in all of the constants and experimental data and solve for ΔH_{fusion}. This calculation is a bit more complicated than the others because there are two terms on the left-hand side: one term for the heat of fusion and a second term because the melted ice then warms up to T_f. Signs are important: the heat of fusion must be positive because the heat of fusion is the energy taken in by the ice to melt.

C. Calculate the specific heat capacity of a metal .... (Video 6 Procedure/Skill 9 above)

1. Assume that all of the heat that left the water was taken in by the metal.

heat taken in by metal	=	- heat given off by water
q_{metal}	=	$- q_{water}$
$m_{metal}\,(C_{s,metal})\,(T_f - 0°C)$	=	$- m_{water}\,(C_{s,water})\,(T_f - T_i)$

2. Plug in all of the constants and experimental data and solve for $C_{s,metal}$.

POST LAB QUESTIONS

1. Usually in General Chemistry labs, this experiment is done as "Coffee Cup Calorimetry" using Styrofoam coffee cups instead of a plastic beaker. Styrofoam is a better insulator than the plastic beaker. How would using Styrofoam coffee cups instead of a plastic beaker affect your results. Be specific: what would happen to your temperature change for parts A, B, and C of the procedure.

2. Use the conversion and equation sheets or Google to calculate the correct value for the heat of dissolving of Na_2CO_3. Calculate the percent error in your experimental value.

3. Use the conversion and equation sheets or Google to calculate the correct value for the heat of fusion of water. Calculate the percent error in your experimental value.

4. The specific heat capacities of copper, zinc, and nickel are 0.385 J/g°C, 0.39 J/g°C, and 0.440 J/g°C, respectively. Look up the composition of each coin you used and determine an average specific heart capacity for the coins you used based on how many coins of each type you used and their specific heat capacities. Use this value as your correct value. Calculate a percent error in your experimental value.