Calorimetry

1 Purpose

The temperature of an adiabatic system will be measured as it undergoes various heat transfers due to changes of state, electrical work, and contact with a warmer or cooler body.

2 Theory

A calorimeter is considered an adiabatic system where the net heat transfer in or out of a calorimeter is zero. Inside the calorimeter the sum of the heat gained by any elements of the system plus the sum of the heat lost by the rest of the elements of the system must equal to zero.

$$Q_{gained} + Q_{lost} = 0 \tag{1}$$

In this experiment the system will consist of a piece of ice, water, an aluminum cup, a thermometer, and a ceramic resistor with an electric current.

The amount of heat Q_{ice} absorbed by ice during the melting process is given by:

$$Q_{ice} = L_f m_{ice} \tag{2}$$

where $L_f = 334\text{J/g}$ is the latent heat of fusion (melting) of ice, and m_{ice} is the mass of the ice.

The amount of heat absorbed by the melted ice water Q_{ice_wat}, water Q_{wat}, and aluminum cup Q_{alum_cup} and released by the hot body Q_{hot_body} is given by:

$$Q = mc\Delta T \tag{3}$$

where m is the mass, c is the specific heat capacity, and ΔT is the resulting temperature change of each element (ice_wat, wat, alum_cup, hot_body) of the system.

The amount of heat absorbed by the ceramic resistor/thermometer Q_{res_therm} is given by:

$$Q_{res\_therm} = C_{res\_therm} \Delta T_{res\_therm} \tag{4}$$

where C_{res_therm} is the heat capacity of the ceramic resistor/thermometer.

The ceramic resistor will be part of an electrical circuit where an external electric force (due to an external power supply) will move charges around the circuit, that is, electrical work will be performed on the system. This electrical work is converted to heat while the charges collide with the atoms of the ceramic resistor. The heat equivalent of this electrical work is given by:

$$Q_{res\_h\_equi} = -\int iV dt = -\int P_e dt \quad (5)$$

where i is the electrical current in the circuit, V is the voltage across the resistor, and t is the total time that charges are in motion in the circuit. The product of iV gives the electrical power in [J/s] or [W] (watts).

The law of calorimetry states that

$$Q_{ice} + Q_{ice\_wat} + Q_{res\_therm} + Q_{wat} + Q_{alum\_cup} + Q_{hot\_body} + Q_{res\_h\_equi} = 0 \quad (6)$$

3 Procedure

Heat capacity of the ceramic resistor/thermometer

1. Calibrate both thermometers such that they indicate the same temperature using the Calculate function of the Capstone software.
2. Measure the mass of the inner aluminum cup of the calorimeter. Make sure it is dry.
3. We will experimentally determine the heat capacity of the ceramic resistor/thermometer. Tare the balance with the empty aluminum cup and add more or less 140 g (at least 1/2 filled) of water to your aluminum cup. Let the water reach thermal equilibrium with the environment.
4. Start capstone, insert the resistor/thermometer and record the temperature of the water. When finished taking the temperature, stop capstone, and take out the resistor/thermometer, and measure precisely the mass of the water and aluminum cup.
5. Insert the resistor/thermometer in boiling water and let reach thermal equilibrium.
6. Quickly introduce the hot resistor/thermometer into the water of the calorimeter. Careful not to introduce too much boiling water to the calorimeter with the resistor and thermometer. Rock the calorimeter gently. At the point where the temperature reaches a maximum after dropping, record the final temperature of the water.
7. Fill-out the following table.

m_{cup} (dry) [g]	T_i (water) [°C]	m_{cup} (with water) [g]	T_i (therm/res boiling water) [°C]	T_f (water+therm/res) [°C]

Table 1: Determination of $C_{ther/res}$

Calorimetry prediction

1. Fill out the following table as you do each procedure.

(metal)	m_{met} [g]	m_{wat} [g]	T_i (wat) [°C]	$m_{ice+pap}$ [g]	m_{pap} [g]	T_f (wat) [°C]

Table 2: Calorimetry prediction

2. Dry your ceramic resistor and the aluminum cup.
3. Measure the mass of your piece of metal. Record the type of metal. Add the metal to boiling water with an attached string.
4. Tare the balance with the empty aluminum cup and add more or less 140 g (at least 1/2 filled) of water to your aluminum cup and record the precise mass of water.
5. Take a 10g-15g piece of ice from the cooler and let it reach 0°C and start melting.
6. Set the DC voltage of the power supply in capstone to the maximum as indicated by your ceramic resistor. **But do not start the power supply.**
7. Add the resistor and thermometer to the aluminum cup and water and **start capstone (Record)**.
8. Obtain a temperature profile for at least 5 minutes and at thermal equilibrium record the initial temperature of the system.
9. Dry your piece of ice and measure the mass of the ice and a piece of paper towel placed first on the balance.
10. Dry the ice again with the paper towel placed on the balance and carefully add the ice to the water of the aluminum cup. Gently and continually rock the calorimeter to help achieve a quasistatic equilibrium. Measure the mass of the slightly wet paper towel.
11. When the ice has stopped melting and the temperature has started to increase, carefully add the hot piece of metal. Try not to splash and lose any water of the calorimeter. Gently and continually rock the calorimeter.
12. When the temperature has more or less stabilized, set the power amplifier to ON. And continue to gently rock the calorimeter.
13. The area under and over the $T = T_{amb}$ line and the temperature versus time curve is measured in captone as the temperature integral. Notice that initially when the ice is added the temperature integral is negative. Stop the experiment when the temperature integral becomes positive. At that point record the water temperature and stop recording capstone and turn the the power supply to OFF.

14. Screencapture the complete capstone window and save both graphs as pictures. Save the temperature versus time data and the power versus time data.

4 Interpretation of Results

1. Using the values of Table 1, calculate the mass of water in the cup and the mass of the aluminum cup. Using the specific heat of water $4.186\frac{J}{g°C}$ and of the aluminum cup $0.900\frac{J}{g°C}$, the initial and final temperature of the water and aluminum cup, solve for the effective heat capacity (C_{res_therm}) of the ceramic resistor/thermometer. Use

$$Q_{wat} + Q_{alum\_cup} + Q_{res\_therm} = 0 \tag{7}$$

$$m_{wat}\ c_{wat}\ (T_f - T_i) + m_{alum\_cup}\ c_{alum\_cup}\ (T_f - T_i) + C_{res\_therm}\ (T_f - 100°C) = 0 \tag{8}$$

2. Include a graph of temperature versus time for your calorimetry prediction experiment. According to your graph, how many seconds did it take to melt the ice?

3. Using values of Table 2, the total mass of paper and ice minus the mass of the wet paper towel gives the mass of the ice introduced to the calorimeter. Determine the mass of the ice. Calculate the heat Q_{ice} gained by the ice due to melting using $Q = L_f m_{ice}$. $L_f = 334$J/g is the latent heat of fusion (melting) of ice and m_{ice} is the mass of the ice. Calculate the rate of absorption of heat due to the ice, $\frac{Q_{ice}}{\Delta t}$, where Δt is the time that it took the ice to melt. Given this rate of absorption, approximately how long would it take to cool down an 8-ounce glass of water at 20°C to 4°C when ice is added?

4. What is the heat equivalent $|Q_{res\_h\_equi}|$ of the electrical work calculated by capstone? Include a graph of the electrical power $P_e = iV$ versus time in Excel and use Excel to numerically calculate the area under the $P_e = iV$ versus t graph. Does the area correspond to the value calculated by capstone? Substantiate your answer with the percentage difference.

5. Using your values from interpretations 1, 3, and 4, and the specific heat of your particular hot metal, use equation 6 to predict the final temperature of the water when the power supply is turned off. Recall that the $Q_{res\_h\_equi}$ is negative as the heat generated by the resistor is lost by the resistor.

6. Compare your prediction with the experimental value using the percentage difference. List the possible sources of error in this experiment. Are you convinced of the law of calorimetry?