**Determination of the Specific Heat of a Penny**

**Background**

**Thermodynamics** is the study of energy and its transformations; of particular interest is the relationship between heat and work. One of the fundamental tools in thermochemistry, a branch of thermodynamics, is calorimetry. Calorimetry is the measurement of heat flow.

When heat is transferred to an object, the temperature of the object increases. When heat is removed from an object, the temperature of the object decreases. The relationship between the heat \( q \) that is transferred and the change in temperature \( \Delta T \) is

\[
q = C \Delta T = C ( T_f - T_i )
\]

The proportionality constant in this equation is called the heat capacity \( C \). The heat capacity is the amount of heat required to raise the temperature of an object or substance one degree. The temperature change is the difference between the final temperature \( T_f \) and the initial temperature \( T_i \).

A calorimeter is the vessel in which these thermodynamic measurements are made. Calorimeters are designed to be well insulated, so no heat is gained from or lost to the surroundings. If no heating element is used to introduce heat in the system, the total heat transferred \( q \) for the entire calorimeter system must equal zero. The total heat can be split into heats for each component in the system.

Imagine an experiment in which cold copper pennies are dropped into a calorimeter containing water at room temperature. The copper pennies will gain, which will be lost by the calorimeter and water. Because no heat enters or leaves the system from the calorimeter, the heat balance for this experiment is

\[
0 = q = q_{Cu} + q_{cal} + q_w
\]

In this case \( q_{Cu} > 0 \), because the copper ball will gain heat from the calorimeter and water. Similarly \( q_{cal} < 0 \) and \( q_w < 0 \), because both the calorimeter and the water will lose heat.

The basic strategy in calorimetry is to use a temperature change and a heat capacity to determine a heat. In this experiment, all substances have the same final temperature \( T_f \), but not all substances have the same initial temperature. The copper pennies are initially at temperature \( T_{Cu} \) while the calorimeter and water are initially at temperature \( T_i \).

\[
q_{Cu} = m_{Cu} s_{Cu} ( T_f - T_{Cu} )
\]

\[
q_{cal} = C_{cal} ( T_f - T_i )
\]

\[
q_w = m_w s_w ( T_f - T_i )
\]
Where $m_{Cu}$ is the mass of the pennies, $s_{Cu}$ is the specific heat of a penny, $C_{cal}$ is the specific heat of the calorimeter also known as the calorimeter constant, $m_w$ is the mass of water and $s_w$ is the specific heat of water, 4.184 J/g°C. The heat capacity of the calorimeter must be obtained from a separate calibration experiment. The temperatures $T_{Cu}$, $T_i$, and $T_f$ can be measured experimentally as can the masses of the copper and water ($m_{Cu}$ and $m_{ci}$). The only unknown property in the above equations is the specific heat capacity of the penny.

$$s_{Cu} = \frac{- (C_{cal} + m_w s_w) (T_f - T_i)}{m_{Cu} (T_f - T_{Cu})}$$

**Experimental**

- Part 1. Determine the heat capacity of the calorimeter using hot and cold water.
- Part 2. Determine the specific heat capacity of a penny.

**Determining the specific heat capacity of the calorimeter.**

To determine the specific heat capacity or the calorimeter (a.k.a. the calorimeter constant), the temperature change measured upon the addition of 2 known masses of water. The heat is ideally exchanged between the water. Any heat exchange unaccounted for will be attributed to the calorimeter.

Place 25 mL of water in the Styrofoam cup and measure the temperature. Place 25 mL of ice water (25 g) in a 50 mL beaker (no ice). Measure the temperature of the ice water. Use separate thermometers. Add the ice water to the Styrofoam cup, cover the cup and insert the thermometer. Record the temperature every 30 seconds until you either reach a steady low value or you record an increase in temperature. This low temperature is $T_f$.

$$q_{cw} = q_{cal} + q_{ww}$$

$$s_w m_{cw}(T_f - T_{ic}) = C_{cal} (T_f - T_{iw}) + s_w m_{ww}(T_f - T_{iw})$$

$$C_{cal} = \frac{s_w m_{cw}(T_f - T_{ic}) - s_w m_{ww}(T_f - T_{iw})}{(T_f - T_{iw})}$$

$$C_{cal} = \frac{(4.184 \text{ J/g°C})(25 \text{ g})[(T_f - T_{ic}) - (T_f - T_{iw})]}{(T_f - T_{iw})}$$
Where $T_f$ is the final temperature, $T_{ic}$ is the initial temperature of the ice water, and $T_{iw}$ is the temperature of the room temperature water. The masses of the warm and cold water were the same, 25 g, and the specific heat for warm and cold water are the same so both of these quantities were factored out.

Perform this experiment twice and use the average value for the calorimeter constant.

**Determining the specific heat capacity of a penny.**

Weigh 10 pennies and immerse them in ice water. Let stand for 5 minutes so that the pennies are at the temperature of the water. Prepare the calorimeter by placing 50 mL of water and start recording the temperature. When the temperatures of the pennies and room temperature water have stabilized, record the temperature of each. Remove the pennies from the ice water and place them into the calorimeter. Cover the calorimeter and monitor the temperature every 30 seconds until the temperature stabilizes at a low value or starts to increase. This low temperature is $T_f$. The specific heat of the pennies is calculated from:

$$\frac{- (C_{cal} + m_w s_w) (T_f - T_i)}{m_{Cu} (T_f - T_{Cu})}$$

Where $m_w$ is 50 g, $m_{Cu}$ is the mass of the pennies, $s_w$ is 4.184 J/g°C, $T_i$ is the temperature of the room temperature water, $T_{Cu}$ is the temperature of the ice water.

Perform this experiment twice and report the average.