Specific Heat Capacity
Experiment 19

PURPOSE:

In this experiment, you will measure the specific heat capacity of an unknown metal and identify it based on this property.

INTRODUCTION:

A large part of chemistry is studying and understanding the physical and chemical changes that matter undergoes. The driving force for most chemical and physical changes is energy, often in the form of thermal energy (heat). Temperature and heat are not the same quantity. The temperature of an object is an indicator of the amount of thermal energy it "possesses", but heat is a measure of the transfer of energy to or from an object.

The **heat capacity** (***C***) of an object is defined as the quantity of heat required to change an object's temperature by one unit of temperature (usually 1 ^{o}C or 1 K). The heat capacity is dependent on the *amount* of a sample present as shown in Figure 1, and is thus an *extensive property*: a larger amount of sample requires more heat than a smaller amount of the same substance to raise the substance's temperature by one unit. In addition to the amount of substance present, the *kind* of substance has a direct bearing on its heat capacity. The same amounts of different substances usually have different heat capacities, and heat capacity is often used for samples of a fixed size. It would be more convenient if the heat capacity depended only on the type of material, and not the amount of material. If heat capacity were an intensive property, independent of the amount of substance, it could be used as an analytical tool to identify a substance, much like density.

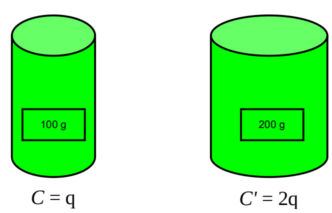

Figure 1. Heat required for 1 ^{o}C change in temperature showing dependence of heat capacity, *C*, on amount of substance.

In order to overcome the fact that heap capacity varies with the amount of a substance, chemists often use the **specific heat capacity** (**C_s**) also known as the specific heat. The specific heat capacity of a substance is defined as the amount of heat required to raise the temperature of 1 gram of the substance by 1^{o}C.

The relationship between the thermal energy (q) and specific heat capacity may be expressed as

$$q = m \cdot C_s \cdot \Delta T \qquad [1]$$

In this laboratory experiment, a calorimeter is used to measure the specific heat of an unknown metal. A calorimeter is an apparatus used to measure the heat released or absorbed by a physical or chemical process. The calorimeter used here is composed of a pair of stacked Styrofoam coffee-cups with a lid (see Figure 3 in the Procedure section). The lid has two holes, one for a thermometer and the other for a stirring wire, and helps minimize heat loss to the atmosphere. In addition to measuring the specific heat of the unknown metal, it will be identified based on the comparison of its specific heat capacity and a list of possible candidates (see Table 1 below).

The specific heat can be determined by immersing a known mass of warm metal of a known temperature into a known volume of water, at a known, lower temperature. Heat energy will flow from the hot metal to the water until, after a period of time, the water and metal achieve the same temperature. Since the calorimeter is thermally isolated, the heat *lost* by the metal and the heat *gained* by the water can be assumed to be equal, and can be represented as

$$q_{water} = -\, q_{metal} \qquad [2]$$

The negative sign in Equation 2 comes about because the metal loses heat and by convention, the flow of heat out of a body is a negative quantity. Combining equations [1] and [2] we can obtain

$$-(C_{s,\text{metal}} \times m_{\text{metal}} \times \Delta T_{\text{metal}}) = (C_{s,\text{water}} \times m_{\text{water}} \times \Delta T_{\text{water}}) \qquad [3]$$

Table 1. Specific heat capacities of various metals.

Metal	**Specific Heat Capacity, C_s (J/g·°C)**		**Metal**	**Specific Heat Capacity, C_s (J/g·°C)**
Lead	0.129		Cobalt	0.421
Gold	0.129		Nickel	0.444
Tungsten	0.132		Iron	0.449
Platinum	0.133		Chromium	0.450
Neodymium	0.191		Manganese	0.479
Tin	0.228		Titanium	0.522
Silver	0.235		Potassium	0.757
Strontium	0.306		Aluminum	0.897
Copper	0.385		Magnesium	1.02
Zinc	0.388		Sodium	1.23

PROCEDURE:

1. Obtain two nested coffee-cups. Zero the balance and weigh the empty, dry cups to the nearest 0.01 g. Add approximately 50 mL of water to the cups and determine the mass of water by difference. Assemble the coffee-cup calorimeter as shown in Figure 2. First, insert the thermometer into the split stopper, and slide the stopper toward the top of the thermometer. Next, slide the thermometer into the center hole of the calorimeter lid. Place the ring stand clamp on the stopper, and adjust the clamp on the ring stand to where it will hold the thermometer bulb about 1 cm from the bottom of the cup. Finally, insert the stirrer in the second hole of the lid with the loop encircling the bulb of the thermometer. Wait approximately 5 minutes before recording the temperature of the water to the nearest 0.1 ^{o}C.

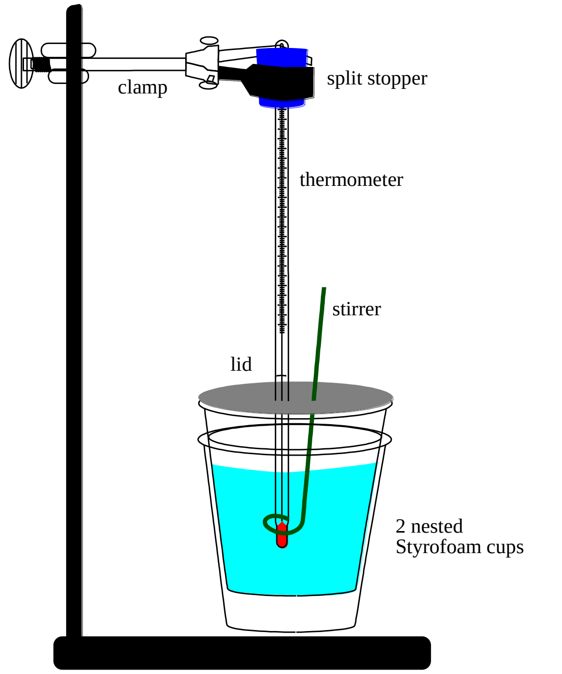

Figure 3. The coffee-cup calorimeter setup

2. Measure the mass of a weighing boat or paper, add approximately 30 g of an unknown sample of metal, and obtain the mass of the metal by difference. Transfer the sample into an appropriately sized test tube, ensuring that no sample is lost.

3. To a 250-mL beaker, add approximately 150 mL of water and bring to a rolling (but not violent!) boil. Once the water is boiling, immerse the test tube containing the metal into the water using a clamp to support the test tube. After ~10 minutes in the boiling water, the sample inside the test tube and the boiling water should be at the same temperature. Record the temperature of the water to the nearest 0.1 ^{o}C. Transfer the thermometer to the calorimeter, and allow it to come to the same temperature that was recorded earlier.

4. *Quickly* transfer the hot metal in the test tube to the calorimeter containing the water. *Take care to not splash any water out of the calorimeter!* Immediately replace the lid, thermometer and stir wire, and record the temperature at time zero. Gently stir the water with the wire and record the temperature in 15 second intervals until the temperature decreases for at least five measurements. This may take a few minutes. It is extremely important that the water be constantly stirred throughout the experiment. Finally, record when the temperature is at a maximum, which will be immediately before the temperature begins to descend.

5. Using your data, compute the specific heat capacity (C_s) of the unknown sample, using equation [3]. Also report the percent error from the value listed in Table 1. The specific of water, $C_{s,\text{water}}$, is 4.18 J/g^{o}C.

$$\%\ \text{error} = \frac{(\text{your value - true value})}{\text{true value}} \times 100$$