Heat and Temperature Change Experiment*

Notes to instructor are in italics. You may wish to delete these before posting the experiment. There is an accompanying video demo of the experiment.

OBJECTIVE

The purpose of this experiment is to explore heat transfer using a simple coffee cup calorimeter. We will examine two separate processes: one that transfers heat to the surroundings, and one that absorbs heat from the surroundings.

Learning outcomes:
After performing this experiment, students will be able to:

- *relate energy, temperature change and specific heat capacity*
- *articulate the basic principles of calorimetry as a method of determining the heat evolved or taken in by a system*

MATERIALS from your kit ***(Details, as well as possible substitutions in brackets)***

- Styrofoam cup calorimeter, consisting of two large (240 mL) nested styrofoam cups
- Thermometer *(Fisher lollipop thermometer, Cat S04823 was used. It reads to 1 decimal place. This thermometer was chosen over some of the alternatives because the button battery is not easily removed – an important consideration for a home lab. A digital meat thermometer can be substituted, but they typically only read to the nearest degree)*
- Stirring rod *(could use a plastic spoon or a chopstick)*
- Weighing boats *(could substitute a square of wax paper)*
- Balance *(small pan type digital balances are available online for approximately $20. Ours was 500 g x 0.01g)*
- 100 mL graduated cylinder *(Could use a measuring cup with mL markings, although precision of reading will be affected)*
- Scoopula *(could substitute with a teaspoon)*

MATERIALS from home **(you'll be supplying these)**

- Small (500 mL) bottle of household vinegar
- Box of baking soda
- Small raw egg, in shell
- Slotted spoon
- Saucepan with cover

BACKGROUND

The study of Chemistry would be incomplete without looking at how energy changes in the course of a physical process or a chemical reaction. One way to exchange energy is to transfer **heat**. Heat is something that flows from a hotter object to a colder object, (and never the other way around!) When we are measuring the transfer of heat, we always pay attention to the **system** and its **surroundings.** The system is typically the process we are following, such as a chemical reaction, and the surroundings are everything else, but chiefly the part of the universe that can either absorb heat from or transfer heat to, the system.

For many reactions and processes, a convenient way to measure the amount of heat transferred is by using a coffee-cup calorimeter. The calorimeter consists of a pair of Styrofoam coffee cups (the extra cup provides extra insulation to prevent loss of heat to the room) and water. A reaction or a process (e.g. dropping an ice cube into the water), are the system. The water (or, to be more precise, the water plus the calorimeter) are the surroundings. The most important equation involved when a certain amount of heat, **q** is transferred from the system (sys) to the surroundings (surr) is the following:

$$q_{surr} = -q_{sys}$$

For example, if a piece of hot metal is dropped into the calorimeter and 1500 J, or 1.5 kJ of heat is transferred from the hot metal to the cool water surrounding it, then we can say that

$$q_{surr} = +1.5 \text{ kJ and } q_{metal} = -1.5 \text{ kJ}$$

The 1.5 kJ of heat transferred is the *same amount of heat*, but for the metal it is heat lost (q negative) and for the surroundings (water and calorimeter), it is heat gained (q positive)

We can determine q_{surr} in the lab by measuring the initial and final temperatures of the water, and by determining the mass of the water used. We can calculate q of the surroundings using the equation

$$q = mc\Delta T$$

Where m is the mass of the water in the calorimeter,

$$\Delta T = T_{final} - T_{initial}$$

and the quantity c is the *specific heat capacity* of the water; in other words, the amount of heat required by one gram of water in order to increase its temperature by 1°C or by 1K. For water, we have the following:

$$c_{water} = 4.184\ J \cdot g^{-1} \cdot {}^{\circ}C^{-1}$$

Once we have determined q_{surr}, we know q_{sys}, because it is the same amount of heat as q_{surr}, but with the opposite sign.

PROCEDURE

A. Exothermic process

First, you will be boiling your source of heat, which will be a freshly prepared hard-boiled egg.

Place your egg into a tared weigh boat, and weigh it to two decimal places. Record this mass on your data sheets.

Cook your egg by first placing it in a saucepan and pouring in cool water to cover by approximately 3 cm. Slowly bring the water to a boil over medium heat; when the water is boiling, turn OFF the heat on the stove, cover the saucepan, and remove it from the heat. Let it sit for 12 minutes. At the end of the 12 minutes, record the temperature of the water the egg is sitting in. This is equal to the temperature of the egg just before adding it to the cool water in the calorimeter ($T_{initial,\ egg}$).

While the egg is cooking, prepare your calorimeter.

First, weigh the empty calorimeter on the top-loading balance, and record the mass. Fill the calorimeter with approximately 200 mL cool tap water (using your graduated cylinder…doesn't have to be exact). Now, weigh the calorimeter with the water in it and record the mass. Let this sit until the egg is ready.

Just before the 12 minute mark, take the temperature of this water, and record this as $T_{initial,\ cal}$ on your report sheet. **So you have two initial temperatures: the initial temperature of the egg, and the initial temperature of the tap water.**

Using a slotted spoon, carefully transfer the hard-boiled egg to the calorimeter. Stir the water in the calorimeter with your stirring rod, taking care not to puncture the calorimeter and not to disturb the egg too much. Observe the temperature rise for several minutes and record the maximum temperature before it begins to fall. This temperature is your T_{final}. Record this temperature on your report sheet. **This temperature is T_{final} for both your water AND for the egg. Carry out all necessary calculations, as indicated on your report sheet.**

B. Endothermic process

Using your graduated cylinder, measure out approximately 80 mL of vinegar. Transfer the vinegar to the calorimeter. Weigh the calorimeter with the vinegar in it and record the mass. Record the initial temperature of the vinegar.

Measure and weigh out your baking soda in the following way (you'll be weighing by difference, first weighing the weigh boat with the baking soda, then weighing the empty weigh boat, so by difference you'll know the mass of the baking soda)

- Turn on your balance
- Place a weighing boat on the balance
- Add 1 level tsp baking soda to the weighing boat using scoopula or teaspoon
- Record the mass of the weigh boat plus baking soda on your report sheet

Transfer the baking soda to the calorimeter, and stir the solution, holding the thermometer in the solution, stirring with your stirring rod. Observe the solution carefully for any changes. The temperature should settle down to a steady value after 20 or 30 seconds. Record the *minimum* temperature obtained as $T_{final.}$ After the experiment, weigh the "empty" weighing boat and record that mass. It may have some baking soda still clinging to it, but that doesn't matter, because that amount won't be included in the mass transferred to the calorimeter.

Record your observations and carry out all necessary calculations. When calculating q_{surr}, use the mass of the solution (vinegar plus baking soda) as the mass of the surroundings.

This could be extended for General Chemistry to obtain the reaction enthalpy in kJ/mol

REPORT SHEET

You can either:

- Print out the report sheet, record the measurements as you make them, and show sample calculations by pen directly on the sheet. Once the sheet is ready, either scan it or take a picture of it. You can upload the image using the "assignment" feature on our Moodle site *substitute your learning management system here*. Make sure the image you upload has a jpeg (.jpg) extension. Be sure to include your "selfie", as described in the report sheet.

  or

- Work online on the report sheet, save your word file (save it as yournameheat.doc) and upload the sheet.

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References

Voltz, D. L., Smola, R. Investigating Chemistry through Inquiry, **2009**, Vernier, Beaverton, OR, 2.1.

MarthaStewart.com. How to Make Perfect Hard-Boiled Eggs. http://www.marthastewart.com/354061/perfect-hard-boiled-eggs, retrieved June 5, 2017.

Video clip produced by the Digital Media Zone of Mount Saint Vincent University.