Specific Heat Capacity

Purpose

Under the assumption of conservation of energy, you will calculate the specific heat capacity of an aluminum cylinder.

Introduction and Theory

Specific heat capacity (in SI units) is the amount of heat (J) to change the temperature of 1.00kg mass of an object by 1.00°C (or 1.00K). In this lab, we use the conservation of energy and the equation of heat transfer $Q = mc\Delta T$ to determine the specific heat capacity of a metal cylinder. We will heat up the metal cylinder close to 100 °C and then put it inside a cup filled with cold water (Case 1) and warm water (Case 2) respectively. When the cylinder and the water reach thermal equilibrium, they both have the same final temperature. Conservation of energy implies that the heat energy lost by the metal cylinder equals the heat energy gained by the water. We assume perfect insulation in the calculation of finding the specific heat capacity of the cylinder, so no heat energy transfers between the system (metal cylinder and the water) and the environment.

The following notations are used in this lab:

T_h = initial (hot) temperature of the heated metal cylinder (close to 100°C),
T_c = initial temperature of the water in the insulated cup,
T_f = final equilibrium temperature after putting the heated metal cylinder in water in the insulated cup,
m_metal = mass of the metal cylinder,
m_cup = mass of the insulated cup,
m_water = mass of the cold/warm water in the insulated cup,
c_metal = specific heat capacity of the metal cylinder,
c_water = specific heat capacity of water (4186. J/kg K).

A metal cylinder is heated to temperature T_h (in a hot water bath) and then placed into colder water with initial temperature T_c. The total amount of heat gained by the water is

$$Q_\mathrm{water} = m_\mathrm{water} \cdot c_\mathrm{water} \cdot (T_\mathrm{f} - T_\mathrm{c}).$$

The total amount of heat lost by the metal cylinder is

$$Q_\mathrm{metal} = m_\mathrm{metal} \cdot c_\mathrm{metal} \cdot (T_\mathrm{h} - T_\mathrm{f}).$$

Since $Q_\mathrm{water} = Q_\mathrm{metal}$,

$$m_\mathrm{water} \cdot c_\mathrm{water} \cdot (T_\mathrm{f} - T_\mathrm{c}) = m_\mathrm{metal} \cdot c_\mathrm{metal} \cdot (T_\mathrm{h} - T_\mathrm{f})$$

Solving for c_metal, we have

$$c_\mathrm{metal} = \frac{m_\mathrm{water} \cdot c_\mathrm{water} \cdot (T_\mathrm{f} - T_\mathrm{c})}{m_\mathrm{metal} \cdot (T_\mathrm{h} - T_\mathrm{f})} \qquad \text{------------------------ [1]}$$

Thus, we find the experimental value of the specific heat capacity of the metal cylinder.

Apparatus

Two-pan balance, Vernier thermometer, glass thermometer, an insulated stainless steel cup, an aluminum cylinder, a small hot plate, a glass beaker, small tongs and a stopwatch.

Draw a labelled diagram of the experimental set up. List all apparatus used in this lab, including the metal cylinder with its identifying number.

Figure 1
An aluminum cylinder heated in a beaker of hot water on a hot plate (with a liquid thermometer).

Figure 2
Use Vernier thermometer (connected to LoggerPro) to measure the temperature of colder water with a heated metal cylinder. The cup should be covered by the lid with thermometer through the mouth-hole.

Procedure and Data

1. Caution! There should be a glass beaker of hot water on a small hot plate on your desk. The hot plate should be set at level 5 and kept it on at all times. A liquid thermometer is in the hot water to measure the hot water temperature (See Figure 1).

2. Use the two-pan balance to measure the mass of your empty insulated cup m_{cup} and the mass of the metal cylinder m_{metal}. Then, for Case 1, fill the cup about 60% full of cold water from the sink and measure the mass of cup and water together. What is the mass of the water m_{water}? Measure, calculate and record all the masses (with uncertainty) in a single data table.

3. After measuring the mass of the cylinder, use the tongs to put the cylinder gently in the glass beaker with hot water. Check the temperature of the hot water. Make sure the temperature is way above 80°C (See Figure 1).

4. The metal cylinder is heated by the hot water and needs to be in the hot water for at least 10 minutes. Start the stopwatch to count the time.

5. Plug the Vernier thermometer into CH1 or CH2 on the Vernier interface box.

6. Start the LoggerPro program. The program will automatically detect the Vernier thermometer and load a default data-collection page. Your Vernier thermometer is ready to be used now.

7. Use the Vernier thermometer to measure the temperature T_c of the cold water in your cup (with the cover, see Figure 2). Be sure your Vernier thermometer has reached thermal equilibrium with the water. The uncertainty of the temperature given by the Vernier thermometer is 0.5°C. Record all the temperatures (T_c, T_h and T_f) in a separate data table for each case.

8. In the LoggerPro program, go to “Experiment”, then “Data Collection”. Set the duration to 10 minutes and change the number of samples per minute to 20 samples/minute.

9. Check your stopwatch to see if 10 mins has passed. If so, then the metal cylinder should be in thermal equilibrium with the hot bath of water. Record the temperature of the hot water with the heated metal cylinder T_h from the glass thermometer.

10. Click “Start Data Collection” button ▷ to start collecting data of the water’s temperature.

11. Carefully transfer the hot metal cylinder to the insulated cup, using tongs provided. The tongs themselves should not enter the cold water, as they will transfer an unknown amount of heat to the cold water.

12. Cover the cup with the lid, and put the Vernier thermometer put in the mouth-hole of the lid (See Figure 2).

13. With your Vernier thermometer, **carefully stir the water but <u>do not touch the metal</u>**, while watching the temperature of the water rise.

14. Keep recording the data of the water’s temperature for 10 minutes, even after the water’s temperature rises to the highest temperature T_f.

15. A sketch of the graph (temperature of water vs time) should be included in your lab report. On your graph, label clearly
    - the temperature when the cold water and the thermometer reach thermal equilibrium T_c,
    - the time when the metal is added,
    - the temperature of water when the water reaches thermal equilibrium with the metal T_f,
    - the region showing the cooling to the surrounding after thermal equilibrium (cooling region),
    - and the temperature of water T_end at 10 minutes.

    Note that the highest temperature on the curve is the temperature when the metal and water reach thermal equilibrium. We use this highest temperature as the final temperature T_f.

16. (Optional) Select “File” → “Export as” → “CSV” to save your data for reference. The .csv file can be opened with Microsoft Excel.

17. For Case 2, we repeat the experiment (Steps 2−14) with a cup of <u>warm water</u>, instead of cold water. The temperature of the warm water should be around 40°C. Don’t forget to measure and calculate the mass of the warm water.

There should be two data tables for Case 1 (cold water) and two data tables for Case 2 (warm water). For each case, one data table records the masses and the other table records the temperatures (listed on Page 1).

Calculations

Calculate the specific heat capacity of the metal (aluminum) cylinder c_{metal} with Equation [1] in Case 1 and in Case 2 respectively. Your final result is the average of the two specific heat capacities.

The reference value of the specific heat capacity of aluminum is 896.91 J/(kg·K). Calculate the percentage discrepancy between your result and the reference value.

Conclusions

In complete sentences, report your result (specific heat capacity of the aluminum cylinder) with the correct number of significant figures and units. Compare your result with the reference value.

Discussion

1. We consider a system of a metal cyinder and water in our calculation. What item(s) is/are missing in the heat transfer equation?

2. Is your percentage discrepancy larger than 10%? What caused the discrepancy?

3. How much temperature is dropped ($T_{\text{f}} - T_{\text{end}}$) in the cooling region in Case 1 and Case 2 respectively? In which case did the water cool faster in the cooling region?

4. From your answer in Question 3 above, does the cooling rate relate to the temperature of the water (with a metal cylinder) compared with the room temperature in the lab? Explain your answer. [Hint: You can check the room temperature with the Vernier thermometer.]

After you finish this lab, empty the water out of the cup. Dry all the apparatus and leave them on the desk.

Note:
The reference value of the specific heat capacity of aluminum is from National Institute of Standards and Technology (NIST) Chemistry WebBook.
https://webbook.nist.gov/cgi/cbook.cgi?ID=C7429905&Mask=2&Type=JANAFS&Table=on