

Experiment #2, The Specific Heat of Aluminum

1 Purpose

1. To review the physical concepts and relationships associated with the flow of heat in and out of materials.
2. To come to a deeper understanding of the principle of conservation of energy as it applies to thermal energy.
3. To determine the specific heat of aluminum in the temperature ranges between boiling water and room temperature water.

2 Introduction

Heat is the energy associated with the thermally excited motion of atoms. When heat energy is added to a substance at constant pressure, its temperature usually rises. The exception to this rule occurs when there is a change of phase (e.g., a solid is changed into a liquid phase or a liquid state is changed into its vapor phase). A phase change occurs without increase or decrease in the substance's temperature.

If an object is isolated from the rest of the universe no heat can flow into or leave that object. As a result its temperature will remain unchanged. If it is brought into thermal contact with another object that is at a different temperature heat will flow out of the object that is hotter and into that which is cooler. As a result the thermal energy of the hotter object will decrease and that of the cooler object will increase. Heat will continue to flow until the temperature of both objects is the same. At this point they are said to be in thermal equilibrium.

The historical unit of heat energy, the **calorie**, was defined as the amount of heat energy needed to raise the temperature of one gram of water by one degree Celsius. The calorie is now defined in terms of the SI unit of energy, the **joule**, by:

$$1 \text{ cal} = 4.184 \text{ J}$$

2.1 Specific Heat

When heat flows into or out of an object its temperature changes. The connection between the change in heat energy and the change in temperature is the specific heat. The heat energy ΔQ needed to raise the temperature ΔT of a substance is related to its mass m according to the formula:

$$\Delta Q = mc\Delta T \tag{1}$$

The specific heat c is defined as the heat energy needed to raise the temperature of one gram of a substance by one degree Celsius ($^{\circ}\text{C}$). In general, the value of the specific heat of a solid substance is predominantly a function of temperature, though small variation of the specific heat occurs due to

variation in pressure or volume. The value of c in Eq. (1) is taken as its average value, \bar{c} , over the temperature interval between its initial and final temperatures, T_i and T_f respectively.

The specific heat of substances varies with the temperature, as for example, the average value of the specific heat of aluminum is 0.17 cal/g-°C between room temperature and liquid nitrogen temperature while it remains essentially constant (0.215 cal/g-°C) from room temperature to 100 °C. In contrast to this, the specific heat of water decreases from 1.00728 cal/g-°C to 0.99795 cal/g-°C in the temperature range 0 to 35°C and then increases to 1.00697 cal/g-°C at 100 °C.

2.4 Determination of the Specific Heat of Aluminum

2.41 In the Temperature Range of 100 °C to 20 °C

In this experiment, the specific heat of aluminum is measured by immersing an aluminum cube of known mass m_{Al} and initial temperature $T_{i,Al}$ (**around 100 °C**) into water of known mass m_w and initial temperature $T_{i,w}$, and measuring the final common equilibrium temperature T_f . If there is no loss or gain of heat energy from the environment by the water or the aluminum cube, the heat **lost** by the aluminum will be equal to the heat **gained** by the water, Eq (2).

$$-\Delta Q_{Aluminum} = \Delta Q_{Water} \quad (2)$$

The minus sign indicates that heat is flowing out of the aluminum cube and into the water. Applying the principle of the conservation of energy, $\Delta Q_{Aluminum} + \Delta Q_{Water} = 0$, and using Eq. (1), one obtains the following equation applicable to this experiment.

$$m_{Al} \bar{c}_{Al} (T_{i,Al} - T_f) = m_w \bar{c}_w (T_f - T_{i,w}) \quad (3)$$

Solving for the specific heat one obtains:

$$\bar{c}_{Al} = \frac{m_w \bar{c}_w (T_f - T_{i,w})}{m_{Al} (T_{i,Al} - T_f)} \quad (4)$$

3 Experimental Apparatus and Procedure

3.1 Experimental Apparatus

- 1 Celsius thermometer
- 2 Aluminum cube
- 3 Water
- 4 Small double Styrofoam cup for water.
- 5 Beaker
- 6 Hot plate
- 7 Digital thermometer
- 8 Double Pan balance

3.2 Procedure

Measurement of the Average Specific Heat of Aluminum in the Temperature Range 100 °C to 20 °C. Enter data in the data sheet located at the end of this write-up.

1. Determine the mass of the aluminum cube (m_{Al}). Be sure to place another paper clip on the right pan of the balance.
2. Place water and digital thermometer into a glass beaker. Place the beaker on a hot plate and heat it. Do not use a setting higher than 4 on the hot plate.
3. While the water in the beaker is getting to the boiling point, weigh the small double Styrofoam cup. Fill it with room temperature tap water (about 60-70 g) and weigh it again. Compute the mass (m_w) of the water in the cup.
4. When the boiling water is at approximately 100 °C, place the aluminum cube into the heated water. It should be close to but not necessarily exactly 100°C. (The boiling point temperature changes with the atmospheric pressure. In addition, there may be a small error in the setting of the digital thermometer.)
5. Insert a thermometer into the cup with the tap water, and measure the initial temperature of the tap water ($T_{i,w}$).
6. When the water in the beaker with the cube is boiling vigorously, and the temperature returns to approximately 100 °C, record its initial temperature ($T_{i,Al}$) as 100.0 °C. We will assume the temperature is 100.0 °C as the digital thermometer may have a possible error.
7. Quickly remove the cube and insert it into the cup with the water. **Be very careful not to splash water out of the cup.** This will result in a measurement error.
8. Begin stirring the water once the cube is in. Again, do not splash water out of the cup. When the system attains its highest temperature, measure and record the final equilibrium temperature (T_f) of the water and aluminum cube system.

4 Calculations and Analysis of the Data

4.1 Computation of the Average Specific Heat of Aluminum in the Temperature Range of 100 °C to 20 °C.

1. Use Eq. 4 to determine the experimental average specific heat capacity \bar{c}_{Al} . Assume specific heat of water to be 0.998 cal/g · °C in the vicinity of room temperature. The accepted value is $\bar{c}_{Al} = 0.215 \text{ cal/g} \cdot \text{C}$ in this temperature range. Calculate your percent difference in \bar{c}_{Al} .

Percent difference is given by:

$$\% \text{ difference} = (|\bar{c}_{Al \text{ accepted}} - \bar{c}_{Al \text{ experimental}}| / \bar{c}_{Al \text{ accepted}}) (100\%)$$

This should be a positive value do to the use of the absolute value | |.

5 Questions

1. List various factors, including errors, which might affect your experimental value of the specific heat of aluminum at room temperature.
2. We have ignored the specific heat of the thermometer. Will this make your measurement of the heat capacity of aluminum higher or lower?
3. What type of error would result if the digital thermometers were not properly calibrated? See the appendix on error analysis located at www.physics.umb.edu to help you to answer this question. Same place you download this write-up.
4. Would the final equilibrium temperature be higher or lower if 200.00 grams of tap water was used.
5. Change both values of T_f in Equation (4) by adding your error in measuring temperature. Calculate the value of the specific heat of aluminum with this new value of T_f . Based on the results of this calculation, comment on how this error would affect your experimental results.
6. Using question 5, which term in Equation (4) is most affected by an error in reading the thermometer; $(T_f - T_{i,w})$ or $(T_{i,Al} - T_f)$? We are asking which term has the greatest impact on your calculations of the specific heat if there is an error in reading the thermometer.

6 Conclusion

This section should have a clear statement of the results of the experiment and the extent to which the results are in agreement with the theory being tested. When the experiment results in a measurement of a constant, e.g., the specific heat of aluminum at a given temperature, compare it with its established handbook value. Here, **0.215 cal/g·°C**. Use percent difference for this comparison.

To make this comparison meaningful, you should include the impact of the experimental error on your results. This includes errors in plotting and reading linear graphs when determining their slope and intercept. In addition, please include a statement of what you have learned, a critique of the experiment, and any suggestions you have which you think could improve the experiment or the lab handout.

Specific Heat of Aluminum Data Sheet

3.2 Measurement of the Average Specific Heat of Aluminum in the Temperature Range 100 °C to 20 °C.

Mass of Aluminum Cube (m_{Al}) = _____ g

Mass of the Styrofoam cup = _____ g

Mass of the Styrofoam cup plus water = _____ g

Mass of water (m_w) = _____ g

Initial temperature of Tap Water ($T_{i,w}$) = _____ °C

Initial temperature of Aluminum Cube ($T_{i,Al}$) = 100.0 °C

Final temperature of Water ($T_{f,w}$) = _____ °C

Final temperature of Aluminum Cube ($T_{f,Al}$) = _____ °C

Estimated error in reading balance. $\text{Error}_m = \pm \Delta m =$ _____ g

Estimated error in reading thermometer. $\text{Error}_T = \pm \Delta T =$ _____ °C

Note that error measurements always go into the data section of your lab report.