

# Chapter 3

## Calorimetry - Specific Heat and Latent Heat

Name:\_\_\_\_\_ Lab Partner:\_\_\_\_\_ Section:\_\_\_\_\_

### 3.1 Purpose

The purpose of this experiment is to study the relationship between heat and temperature. Calorimetry will be used to investigate specific heats of materials and the latent heat associated with a phase change.

### 3.2 Introduction

The temperature of a system is closely related to its internal thermal energy. In general, this thermal energy can be described in terms of several macroscopic thermodynamic variables such as temperature and pressure. A decrease in an object's temperature represents a decrease in the object's thermal energy. Since energy must be conserved, the thermal energy that leaves the object as heat will increase the thermal energy of the surrounding environment. The relationship between the temperature change of an object and the resulting heat flow is:

$$\Delta Q = mc\Delta T = mc(T_f - T_i) \quad (3.1)$$

where  $\Delta T$  is the temperature change of the object and  $\Delta Q$  is the heat flow. Heat flow is positive for heat flowing into the system and negative for heat flowing out of the system. The quantity  $c$  is the specific heat of the object and depends on the properties and composition of the object. The above equation applies to systems which are not undergoing a change of state or phase transition. For example, equation 3.1 applies to the heat flow in an object which remains solid as the temperature changes. Table 3.1 gives the specific heat for various materials.

Aluminum	0.22
Copper	0.09
Iron	0.11
Diamond	0.12
Silicon	0.17
Lead	0.03
Water	1.00

Table 3.1: Specific heat of materials in  $\frac{\text{calories}}{\text{gram K}}$

When an object undergoes a phase transition, its internal energy changes, but its temperature does not. For example, as a piece of ice melts at  $0^\circ\text{C}$ , it becomes liquid water, which is also at  $0^\circ\text{C}$ . There is no temperature change, but energy (in the form of heat) must be added to the system to change the ice from a solid to a liquid phase. The energy is used to overcome the binding energy of the water molecules which holds them together in solid form. The heat (thermal energy) required for an object's phase transition is:

$$\Delta Q = mL \tag{3.2}$$

where  $L$  is the object's latent heat and  $m$  is the mass undergoing the phase transition. It varies with the type of material and the nature of the phase transition. For a transition from solid to liquid,  $L$  is known as the latent heat of fusion,  $L_f$ , and for a liquid to gas transition, it is known as the latent heat of vaporization,  $L_v$ . For water, the latent heat of fusion is  $L_f = 79.6$  calories/gram.

## 3.3 Procedure

In this lab we will first verify equation 3.1 for several different materials and then use this relation to determine the specific heat of an unknown material. In the second part, we will verify equation 3.2 for an ice-to-water transition.

### 3.3.1 Verifying the Specific Heat Equation

#### Special Cautions:

- Be careful when handling hot objects, especially boiling water.
- Allow temperatures to completely stabilize before measuring.

Shown in Figure 3.1 is the equipment which will be used for this experiment. The apparatus consists of a Styrofoam calorimeter cup, various metal samples, a digital thermometer, a hot water bath and ice.



Figure 3.1: Equipment for this lab including the Styrofoam calorimeter, metal samples, water baths and digital thermometer

- Weigh your Styrofoam calorimeter while it is empty and then fill it  $\frac{3}{4}$  full with room-temperature tap water. Weigh the container again to determine the mass of the water inside. Insert a digital thermometer and record the water temperature,  $T_{i,water}$ .

Mass of Styrofoam calorimeter \_\_\_\_\_  
 Mass of water ( $m_{water}$ ) \_\_\_\_\_  
 Initial temperature of water ( $T_{i,water}$ ) \_\_\_\_\_

- Take your calorimeter over to the boiling pots and using tongs, remove a piece of aluminum from the boiling pots and quickly place it in your calorimeter. You may use the thermometer to stir, but do not insert any other objects. Once the temperature has stabilized (thermal equilibrium reached), record the temperature of the metal plus water,  $T_f$ .

Equilibrium temperature ( $T_f$ ) \_\_\_\_\_

- Remove the piece of aluminum and weigh it.

Mass of aluminum metal ( $m_{metal}$ ) \_\_\_\_\_

- If we consider the Styrofoam cup to be a perfect insulator, the amount of heat lost from the metal exactly equals the amount of heat entering the water (and raising its temperature.) Using equation 3.1 we can relate the heat gained by the water to the heat lost by the metal.

$$m_{water}c_{water}(T_f - T_{i,water}) = -m_{metal}c_{metal}(T_f - T_{i,metal}) \quad (3.3)$$

The initial temperature of the metal,  $T_{i,metal}$ , is the temperature of the boiling water ( $100^\circ\text{C} = 373 \text{ K}$ ). Solving for  $T_f$  we get:

$$T_f = \frac{m_{\text{metal}}c_{\text{metal}}T_{i,\text{metal}} + m_{\text{water}}c_{\text{water}}T_{i,\text{water}}}{m_{\text{metal}}c_{\text{metal}} + m_{\text{water}}c_{\text{water}}} \quad (3.4)$$

- Calculate the final temperature of the water. (Don't forget to use temperatures in units of Kelvin.) Calculate the percentage difference of the measured and calculated final temperatures.

Final temperature ( $T_f$ ) of water \_\_\_\_\_  
 % difference of calculated and measured values \_\_\_\_\_

- Repeat this measurement for the lead metal.

Mass of Styrofoam calorimeter \_\_\_\_\_  
 Mass of water ( $M_{\text{water}}$ ) \_\_\_\_\_  
 Initial temperature of water ( $T_{i,\text{water}}$ ) \_\_\_\_\_  
 Equilibrium temperature ( $T_f$ ) \_\_\_\_\_  
 Mass of lead metal ( $m_{\text{metal}}$ ) \_\_\_\_\_  
 Final temperature ( $T_f$ ) of water \_\_\_\_\_  
 % difference of calculated and measured values \_\_\_\_\_

- Repeat the measurement in the previous section for the unknown material. This time we will solve equation 3.3 to find the specific heat of the unknown material.

$$c_{\text{metal}} = \frac{m_{\text{water}}c_{\text{water}}(T_f - T_{i,\text{water}})}{m_{\text{metal}}(T_{i,\text{metal}} - T_f)} \quad (3.5)$$

- Using Table 3.1 and your measured specific heat, determine the unknown material and calculate the percentage error with the standard value from the table.

Specific heat of unknown metal \_\_\_\_\_  
 Unknown metal \_\_\_\_\_  
 % error between measured value and table value \_\_\_\_\_

### 3.3.2 Latent Heat of Fusion for Ice

- Fill the cup about  $\frac{1}{3}$  full of room temperature water. Weigh the cup with water and subtract the mass of the cup recorded previously to find the mass of water in the cup. Record the mass of water in the cup.

Mass of water ( $m_{\text{water}}$ ) \_\_\_\_\_

- Record the initial water temperature in your calorimeter,  $T_{i,\text{water}}$ .

Initial temperature of water ( $T_{i,water}$ ) \_\_\_\_\_

- Find a solid ice cube and put in in the cup. Weight the cup with the water and ice. Determine the mass of the ice by subtracting the weight of the cup and water.

Mass of ice ( $m_{ice}$ ) \_\_\_\_\_

- As before, you may use your thermometer to stir. Once the ice has melted and the system has reached thermal equilibrium, record the final temperature,  $T_f$ .

Final temperature ( $T_f$ ) \_\_\_\_\_

- Heat has been taken from the surrounding water to melt the ice. The melted ice then absorbs additional heat from the original mass of water until thermal equilibrium is reached. The heat flow obeys the relation:

$$\Delta Q_{water} = -(\Delta Q_{melt} + \Delta Q_{icewater}) \quad (3.6)$$

where the left side is the heat lost by the water bath, and the right side is the heat needed to melt the ice plus the heat needed to raise the temperature of the melted ice to the equilibrium temperature.

Using equations 3.1 and 3.2 we have:

$$m_{water}c_{water}(T_f - T_{i,water}) = -m_{ice}L_{f,ice} - m_{ice}c_{water}(T_f - T_{i,ice}) \quad (3.7)$$

Solving for  $L_{f,ice}$  we have

$$L_{f,ice} = \frac{m_{ice}c_{water}(T_{i,ice} - T_f) + m_{water}c_{water}(T_{i,water} - T_f)}{m_{ice}} \quad (3.8)$$

- Using your measured temperatures in equation 3.8, calculate the value of  $L_{f,ice}$  and calculate the percentage error using the standard value of  $L_f = 79.6$  calories/gram.

Heat of fusion of ice ( $L_f$ ) \_\_\_\_\_  
% error of measured and standard value \_\_\_\_\_

### 3.3.3 Questions

1. How fast would you have to throw a snowball to completely melt the snowball when it hits a brick wall? Assume all of the kinetic energy is converted into thermal energy when it hits the brick wall. Hint: 1 calorie = 4.18 joules.

## 3.4 Conclusion

Write a detailed conclusion about what you have learned. Include all relevant numbers you have measured with errors. Sources of error should also be included.