Experiment 3
Specific Heat & Heats of Transformation

In this experiment you combine materials at different temperatures and wait until the mixture reaches a final common temperature at thermal equilibrium. You model the heat exchange process within the mixture using calorimetry, which is an application of conservation of energy using the idea that heat is a form of energy. The calorimetry analysis allows you to determine some of the thermal properties of the materials. The specific heat capacity is a measure of how heat added to / lost by a material results in a rise / fall of temperature. The latent heat of transformation is a measure of how heat added to / lost by a material results in a change of state, or phase change.

Preliminaries.

In most cases, when heat energy \( Q \) is added to an object initially at temperature \( T_i \), the object’s temperature increases to a final temperature \( T_f \). The temperature rise depends on the mass \( m \) of the object and the type of material of which the object is composed. The relationship incorporating these ideas is

\[
Q = mc (T_f - T_i) \quad \text{(eq. 1)}
\]

where \( c \) is the specific heat capacity of the material.

Figure 1: Heat Flow Sign Convention

Eq. 1 also describes the thermal behavior of an object when heat is removed. In this case, the final temperature is less than the initial temperature, giving a negative result for the heat \( Q \). The sign of the heat energy \( Q \) is positive when heat is added and negative when heat is removed. This convention is shown in Figure 1.

In some cases, heat energy \( Q \) can be transferred to an object without having a temperature change occur. These cases occur when there is a phase change or change of state (examples are ice becoming water and dry ice becoming carbon dioxide vapor). The heat energy transferred in a phase change is directly proportional to the mass \( m \) changing its phase, the material and the type of phase change (boiling, melting, etc.). The relation is

\[
Q = \pm mL \quad \text{(eq. 2)}
\]

where \( L \) is the latent heat of transformation appropriate for the type of phase change taking place. In using eq. 2, the sign must be chosen appropriately according to the sign convention discussed above. As an example, if the object is melting, heat is being added so that the plus sign is correct. The opposite is true if the object is freezing.

If objects at different temperatures are brought into contact in an insulated container they will transfer heat energy among themselves until thermal equilibrium is achieved. In thermal equilibrium, all temperatures equalize and remain constant thereafter. Hot objects cool off to the equilibrium temperature and the cold objects warm up. The hot objects lose heat energy and the cold ones gain heat energy. Objects may also change phase in their approach to thermal equilibrium, resulting in heat gains and losses. The heat energy gained and lost by the initially cold and hot objects can be expressed in terms of their masses, specific heats, latent heats, and temperature changes through eqs. 1 and 2. The net heat energy transfer for the system as a whole is zero if the system is isolated. This statement may be written symbolically by eq. 3, where \( Q_i \) represents one of the possible heat exchanges (due to different objects, changes in temperature, changes in phase) as the system progresses from its initial state to thermal equilibrium.

\[
\sum Q_i = 0 \quad \text{(eq. 3)}
\]

This is a direct consequence of viewing heat as a form of energy and applying conservation of
energy. The heat energy gains in parts of the system exactly balance the heat energy losses in other parts. Eq. 3 is a conservation of energy equation describing the processes in which the algebraic sum of all the relevant heat exchanges is zero.

The determination or use of thermal properties of the materials in a system consisting of objects exchanging heat is called calorimetry. Calorimetry experiments are generally difficult to analyze due to a source of error which is difficult to quantify – heat exchange between the system and its surroundings.

Various steps can be taken to minimize this problem. First, the system can be as thermally insulated as possible. This is accomplished by placing the system in a calorimeter. The calorimeter used in these experiments is shown in Figure 2. The components of the system are assembled inside an aluminum cup set inside a bigger aluminum cup. The air space between the two provides the thermal insulation. The inner cup, however, is in thermal contact with its contents and must be considered part of the system. A lid on the container limits heat flow out the top. Second, the shorter the duration of the experiment, the less time for heat exchange. Once the components of the system are combined, the experiment needs to run as quickly as possible. Gently swirling the system contents (by holding the outer cup in your hand with the bottom of the outer cup staying in contact with the table and gently swirling the entire calorimeter in small slow circles) speeds the distribution of heat. This results in a more rapid approach to thermal equilibrium. Third, start with elements which have initial temperatures on either side of the temperature of the environment. That way, some heat flows from the hotter object to the environment at the same time that other heat flows from the environment to the colder object; i.e., thermal energy is both gained and lost to the environment which reduces the net heat exchange between the system and its surroundings.

Procedure.

Caution: This lab uses boiling water and steam. Do not let the boiling water or steam touch your skin or clothes.

Part A. The Specific Heat of Copper

You add hot copper to cool water in the calorimeter and bring to equilibrium in order to determine the specific heat of copper.

- Determine the mass of the inner aluminum cup \( m_{Al} \) of the calorimeter and of the copper mass \( m_{Cu} \). Record these values.

- Securely tie a sting to your copper mass using the shallow channel machined around one end. The string allows you to be able to lower it slowly into your hot-water bath, and remove it from the hot-water bath without touching the mass.

- Heat the copper mass by placing it in the steel beaker and fill with enough water so that the copper is completely submerged. Turn the hotplate on your table on to HIGH and set the beaker on it until the water is boiling for several minutes.

- Fill the inner cup of the calorimeter with just enough cool water (about 5-10 °C below room temperature) so that the copper, when added, is completely submerged. Weigh the partially filled cup in order to determine the mass \( m_w \) of the water. Record this value.

- Determine the temperature of the water/calorimeter \( T_w \) and of the copper \( T_{Cu} \). Record these values.
- Quickly add the copper to the water, cover, and start to gently and slowly swirl the calorimeter until the temperature rises to its maximum value. This is the final, equilibrium temperature $T_{eq}$. Record this value.

- Starting with eq. 3, determine the specific heat of copper. There are three heat exchange $Q$'s to be added – for water $Q_w$, for aluminum $Q_{Al}$, and for copper $Q_{Cu}$.

- The standard value for the specific heat of copper is 385 J/(kg °C). Determine the percent error of the experimental value from the standard value.

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**Part B. The Latent Heat of Fusion of Ice**

You add ice to warm water in the calorimeter and bring to equilibrium in order to determine the latent heat of fusion of ice.

- Determine the mass of the inner aluminum cup $m_{Al}$ of the calorimeter. Record this value.

- Heat some water slightly (about 5-10 °C above room temperature) by mixing tap water with a small amount of hot water from the provided coffee pots. Fill the inner cup of the calorimeter with the warm water to about one third full. Weigh the partially filled cup in order to determine the mass $m_w$ of the water. Record this value.

- Take the calorimeter over to the freezer. Determine the temperature of the water / calorimeter $T_w$ and of the ice / freezer $T_{ice}$. Record these values.

- Quickly add two pieces of ice (we want about 15 to 20 g of ice) to the water in the calorimeter cup. Use a water to ice ratio of about three by volume, making sure that the ice is immersed. Take care not to add too much ice as we want all of the ice added to be able to fully melt. Cover the calorimeter and start stirring until the temperature falls to its minimum value. This is the final, equilibrium temperature $T_{eq}$. Record this value.

- Weigh the cup of water plus ice to determine the mass of ice added $m_{ice}$. Record this value.

- Starting with eq. 3, determine the latent heat of fusion of ice. There are three heat exchange $Q$’s to be added – for water $Q_w$, for aluminum $Q_{Al}$, and for ice $Q_{ice}$. Be careful in taking into account the change in phase.

- The standard value for the latent heat of fusion of pure ice is $3.33 \times 10^5$ J/kg. Determine the percent error of the experimental value from the standard value.

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**Questions** (Answer clearly and completely).
1. Why should the initial temperature of the copper be as high as reasonably possible?

2. Why is it important that you transfer the hot copper to the calorimeter quickly and begin to stir immediately?

3. Why is it important that copper be completely submerged underwater in the calorimeter?

4. Why should the initial temperature of the water be cooler than room temperature? *Hint:* though we use a calorimeter to minimize the interaction with the environment, this interaction is not negligible. How does the cool water help to minimize this? You may want to refer back to the preliminary discussion preceding the lab.

5. How did you know when the final equilibrium temperature was reached during the copper experiment?

6. In the ice experiment (part B), why should initially warm water be used? Your answer should be along the same lines as your answer to question #4.

7. Why is it critical that all of the ice has melted?
To Turn In

- All data and calculations for Part A, neatly presented and organized
- All data and calculations for Part B, neatly presented and organized
- Answers to all questions posed in the Questions section

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