Lab 5

Specific and Latent Heats of Solids

Experimental Objectives

- By measuring properties such as the final temperature of an isolated system that consists of hot and cool materials, you can compute the specific heat of an unknown material and, if this is verifiable, then you will have proven the equations related to the specific heat.
- By measuring properties of an isolated system such as the mass of ice that melts in the presence of other materials, you can compute the latent heat of water and, if this is verifiable, then you will have proven the equations related to the latent heat.

When multiple substances at different temperatures are placed in thermal contact, the hotter substances lose energy (heat) while the colder ones gain energy (heat) until thermal equilibrium is reached. It is assumed that the sum of the heat lost by the warmer objects is equal to the sum of the heat gained by the others:

$$-Q_{\text{lost}} = Q_{\text{gained}} \tag{5.0.1}$$

Notice that Equation (5.0.2) says that when you heat the shot, it not only "gets warmer" (increases temperature), but it *also* "heats up" (gains energy). These are *not the same*, but they are very closely related. The relation between the heat content (or internal energy) and the change of temperature is

$$Q = m\,c\,\Delta T \tag{5.0.2}$$

where m is the mass of the substance, ΔT is the change in the temperature, and c is the specific heat. (The product mc is also known as the "water equivalent.") The specific heat of a substance is a measure of the molecular activity within the material. Measurements of specific heats have played an important role in helping us to understand the nature of matter.

Furthermore, the relation between the heat content and a change of phase is

$$Q = mL \tag{5.0.3}$$

where L is called the latent heat. There is a latent heat associated with each phase change.

- **Latent heat of fusion,** L_f, refers to the heat associated with the liquid/solid phase change.
- **Latent heat of vaporization,** L_v, refers to the heat associated with the vapor/liquid phase change.

For example, given one ice cube (5 g) at $-10°$ C, which is to be warmed to $30°$ C, we must ***warm*** the ice to the melting point, ***melt*** it, and then ***warm*** the *melted ice* some more. (There are three separate terms.) The heat required to do so is

$$\begin{aligned} Q &= mc_{\text{ice}}\,\Delta T + mL_f + mc_{\text{water}}\,\Delta T \\ Q &= (5\,\text{g})(c_{\text{ice}})[(0°\ \text{C}) - (-10°\ \text{C})] + (5\,\text{g})L_f \\ &\quad + (5\,\text{g})(c_{\text{water}})[(30°\ \text{C}) - (0°\ \text{C})] \end{aligned}$$

This expression gives the amount of heat required (Q_{gained}) regardless of how the ice is warmed. It does address the heat lost (Q_{lost}) by whatever warmed the ice.

5.1 Specific Heat Pre-Lab Exercise

A few days before doing this lab, you should download the pre-lab worksheet and do the math to remind yourself how the propagation of uncertainty works. If you did not learn this last semester, then this is your opportunity! A PDF version of the pre-lab worksheet alone can be downloaded from SHprelab.pdf (29 kB). A PDF version of the pre-lab with room for *your data* can be downloaded from SHprelab-data.pdf (37 kB).

The point of this worksheet is to walk you through the measurements and calculations for the Specific Heat lab in order to help you decide how to analyze the data and develop a thoughtful report. When you calculate the specific heat based on measurements from the lab, you will use Equation (5.0.1):

$$-Q_{\text{brass}} = Q_{\text{Alcup}} + Q_{\text{water}}$$
$$-m_b c_b \Delta T_b = m_a c_a \Delta T_a + m_w c_w \Delta T_w$$

solving this for c_b, we get:

$$c_b = \frac{m_a c_a \left(T_f - T_{ia}\right) + m_w c_w \left(T_f - T_{iw}\right)}{-m_b \left(T_f - T_{ib}\right)}$$

The "error analysis" for this lab is somewhat more involved than most of the previous labs. In order to ensure your familiarity with the process, there is a Pre-Lab worksheet appended to the end of the lab manual. It is the last page so that you can tear it off without ruining the rest of the manual. Please use the formula above and the worksheet as a guide to calculate the specific heat, c of brass based on the measurements provided on the worksheet.
After you have completed the calculations, you should answer the pre-lab questions below in your lab notebook. These are written specifically to point out the comparisons that you will need to make when you write up your analysis of the data.

5.1.1 Pre-Lab Questions

1. When calculating Q_w, does one of the terms, ΔT_w, m_w, or c_w, have a significantly larger relative uncertainty? If so, what is it about that measurement that made that uncertainty large while the others were small? Is this uncertainty improvable?

2. When calculating Q_a, does one of the terms, ΔT_a, m_a, or c_a, have a significantly larger relative uncertainty? If so, what is it about that measurement that made that uncertainty large while the others were small? Is this uncertainty improvable?

3. When calculating the numerator, does one of the terms, Q_w or Q_a, have a significantly larger uncertainty? If so, which measurement caused that uncertainty to be large? (See questions 1 and 2.)

4. When calculating the denominator, does one of the terms, ΔT_b or m_b, have a significantly larger relative uncertainty? If so, which measurement caused that uncertainty to be large? Is this uncertainty improvable?

5. Which term, $(Q_w + Q_a)$ or $m_b \Delta T_b$, had the largest relative uncertainty? What is it about that measurement that made that uncertainty large while the others were small? Is this uncertainty improvable?

6. Which measurement ultimately caused the size of δc to be as large as it was? Is there a way to reduce the relative uncertainty by planning the experiment differently? For example, should you use a different mass of water or of metal? Should you start at a different temperature? Should the final temperature be higher or lower? How might one accomplish this?

7. When you do any experiment, a significant component of the analysis should be devoted to the question: For each measurement, if you measured the value to be higher than the true value, then how does this affect the final result? To that end, for this case, answer the following:

(a) If all masses are skewed high by the scale, then is c affected?

(b) If all temperatures are skewed high by the thermometer, then is c affected?

(c) If some heat escaped into the atmosphere, lost to the experiment, then how does this affect the final temperature of the mixture and how does this affect the final value of c?

5.2 The Specific Heat Capacity of an Unknown Metal

The following considerations should allow you to experimentally determine (with uncertainty) the specific heat of the metal and, from that, the composition of the metal. Use these questions to determine your procedure, with notes about where to be careful. Verify the procedure with the professor before beginning the experiment.

1. We would like the metal to be at some warm, stable, and uniform temperature. Can you imagine what convenient temperature we can warm the metal to which satisfies these three conditions? Hint: In order for the cylinder to be at a uniform temperature, it must sit in this environment for some short time; since we don't know the temperature of a burner, we can't just place the metal on the burner itself.

2. We would like the water to be at some cool, stable, and uniform temperature. Can you imagine what convenient temperature we can maintain for the water which satisfies these three conditions? HINT: The container for the water must also be in thermal equilibrium with the water before the unknown metal is added.

Note 5.2.1 (Assumption)**.** The aluminum cup is always at the same temperature as the water.

1. The specific heat is an inherent property of a material. Since the cup is aluminum, you can easily find it's specific heat with a CRC, or a textbook, or it may also be stamped onto your equipment.

2. When the metal and water (with container) are placed in thermal contact, they must be isolated from the external environment. With what equipment will this be done? (See your lab table.)

3. If some hot metal is held in the air, it cools down. What happens to the heat when hot metal is exposed to the air? Can we easily measure the heat lost to the air? How will this affect your experimental technique?

4. Think about Equation (5.0.2) and the likely values of c for the water and for the unknown metal. If there are equal masses of water and metal, then where (roughly) do you expect the final temperature to be (closer to T_i for water or T_i for metal)? What if you have more water?

5. If the final temperature is far from room temperature and the calorimeter is not well insulated, then where will the actual final temperature be? If the final temperature value is wrong in this way, then will your calculated c for the metal be wrong too high or wrong too low?

5.3 The Latent Heat of Fusion for Water

The following considerations should allow you to experimentally determine (with uncertainty) the latent heat of water. Use these questions to determine your procedure, with notes about where to be careful. Verify the procedure with the professor before beginning the experiment.

1. We would like the water to be at some warm, stable, and uniform temperature. Can you imagine what convenient temperature we can maintain for the water which satisfies these three conditions?

2. We would like the ice to be at some cool, stable, uniform, and known temperature. Can you imagine what convenient temperature we can maintain for the ice which satisfies these three conditions? HINT: Most freezers are colder than freezing.

Note 5.3.1 (Assumption)**.** The aluminum cup is always at the same temperature as the water.

1. When the ice and water (with container) are placed in thermal contact, they must be isolated from the external environment. With what equipment will this be done? (See your lab table.)

2. You will need to know the mass of the ice added. If you take the time to weigh it on a scale, it will melt. How can we determine the mass of the ice added without explicitly placing it on the scale before adding to the water?

3. Based on the expected value of the latent heat of fusion for water, how much ice should you use compared to the amount of water that you have?

4. When you add the ice, the mL term should only include the mass of the ice that will melt in the water. If you add water with your ice, then this value of m will not be accurate. How does this fact affect your procedure for adding ice?

5. If the final temperature is far from room temperature and the calorimeter is not well insulated, then where will the actual final temperature be? If the final temperature value is wrong in this way, then will your calculated L be wrong too high or wrong too low?

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A PDF version might be found at spheat.pdf (125 kB)