Specific Heat of Solids

Objectives

These lab activities will focus on concepts of thermodynamics in materials. You should read all the steps in each part before you start.

We will measure the specific heat of different solid samples. The simulation allows us to develop an understanding for how temperature changes and phase changes may be expressed in terms of heat energy.

For the following activities, you will use a physics simulation program. Visit: https://uglabs.physics.ucr.edu/ for lab downloads and links.

Introduction

The amount of thermal energy (heat) required to raise the temperature of an object is determined by the heat capacity of the object. The heat capacity is defined as the amount of energy required to raise the temperature of an object by one Kelvin:

\[ Q = C \Delta T \]

where \( Q \) is the amount of heat energy, \( C \) is the heat capacity, and \( \Delta T \) is the change in temperature.

The heat capacity changes depending on the mass of the object we are considering. It is convenient to introduce a quantity that does not depend on the mass of the object, but only on the material of the object. This quantity is the specific heat, which is defined as the heat capacity per unit mass. Twice as much material (mass-wise) will have twice as much heat capacity, but the specific heat
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will remain the same for all objects made of the same material. The specific heat is related to the heat capacity as:

\[ c = \frac{C}{m} \]

When a substance changes state (solid to liquid, or liquid to gas, or solid to gas) there will be a transfer of heat associated with the change of internal energy in that substance. The heat energy absorbed by the material goes to breaking the bonds (potential energy) that hold the atoms/molecules together to form the solid or liquid. **There is no change in temperature associated with the change of state, it can (mathematically) be treated separately from heat associated with changes in temperature (as described above).** The heat of transformation depends on how much material is present, so:

\[ Q = mL \]

where \( m \) is the mass of the material, and \( L \) is the latent heat or heat of transformation. For example, the solid (ice) to liquid transformation of water has a latent heat of \( L_{\text{fusion}} = 3.33 \times 10^5 \text{ J/kg} \). Note that the temperature of the ice remains at 0º C (273 K) while the heat is being absorbed by the ice.

The relationship between the heat lost by the sample and that gained by the melting ice is:

\[ Q = m_{\text{ice}}L_{\text{fusion}} = -m_{\text{water}}c_{\text{water}}(T_f - T_i) \]

Molar Specific Heat:

The *Equipartition of Energy Theorem* states that every atom in a solid has a specific heat equal to \( k_B/2 \) for every allowed kind of motion (called degrees of freedom). In a solid at high temperatures, the atom can move in the \( x, y, \) and \( z \) directions and also vibrate in the same three directions, giving a total of six degrees of freedom. Therefore, the specific heat of each atom is \( 3k_B \). For a solid containing an Avogadro’s number \( (N_A) \) of atoms \( (i.e. \) one mole of atoms), the molar specific heat should be given by:

\[ c_v = 3k_BN_A = 3R = 25 \text{ J/mol} \cdot \text{K} \]

We will investigate whether the measured specific heats of the metal samples agree with this “Law”.

PHYS 2LB: Lab 2
1. Latent Heat of Ice

We will first explore the latent heat of ice. We shall explore the results of mixing water and ice in a thermally insulated environment (also known as a calorimeter).

1.1: Move the beaker over to the Dispens-o-matic. You are first going to add ice to the calorimeter. Select ice from the top row of the Dispens-o-matic. Then, adjust the temperature to 0°C. Add 50 grams of ice to the beaker (the contents of the beaker will be displayed in the Beaker Info on the far right; see Figure 2). It is okay if you are just close to 50 grams and not exactly, just note how much you have for any calculations. Take this ice and drop it into the calorimeter (See Figure 3).

1.2: Move the beaker over to the Dispens-o-matic. You are going to add water to the calorimeter. Adjust the temperature to 15°C. Add 250 grams of water to the beaker. It is okay if you are just close to 250 grams and not exactly, just note how much you have for any calculations. Take this water and pour it into the calorimeter.

1.3: Wait for the resulting mixture to equilibrate. What is the final temperature of the system? Is that what you expected given the relative masses of the two (i.e. you had five times more water than ice)?
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1.4: The latent heat of fusion is a “hidden place” to store or release energy for an object. So, even though you have five times more water than ice, doesn’t mean that you have energy to completely melt the ice. Using Equation 2, calculate how much water (in grams) it would take to barely melt all of the ice.

1.5: Repeat steps 1.1 and 1.2, but this time use the mass that you calculated in step 1.4. If you can’t get the mass exactly, then you should round up slightly.

Q1: How much energy (in Joules) does it take to melt 1 kg of ice? How much energy (in Joules) does it take to raise 1 kg of water by 50°C? Which number is greater?

Figure 4 - Bring the calorimeter (or beaker) over to the drain and it will dispense all contents.
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2. Specific Heat of Solids

We will now explore the specific heat of solids. We shall explore the results of mixing water and solids in a thermally insulated environment (also known as a calorimeter).

2.1: Move the beaker over to the Dispens-o-matic. You are going to add iron to the calorimeter. Make sure the temperature is set to 22 C. Add 100 grams of iron to the beaker. It is okay if you are just close to 100 grams and not exactly, just note how much you have for any calculations. Take this iron and drop it into the calorimeter.

2.2: Move the beaker over to the Dispens-o-matic. You are going to add water to the calorimeter. Adjust the temperature to 70 C. Add 150 grams of water to the beaker. It is okay if you are just close to 150 grams and not exactly, just note how much you have for any calculations. Take this water and pour it into the calorimeter.

2.3: Wait for the resulting mixture to equilibrate. What is the final temperature of the system?

2.4: Knowing that in a calorimeter that the heat that leaves the water is equivalent to heat that enters the iron, calculate the specific heat of iron with the data that you have calculated from the simulation.

2.5: The specific heat of iron has been experimentally found to be 450 J/(kg K). Discuss how close your calculation with this simulation came to that value. How much of an uncertainty range do you expect to get when calculating the mystery solids?
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2.6: Repeat steps 2.1 through 2.4, but use Mystery #2 instead of using iron (note you will have to use 105 grams of Mystery #2 because it comes out in chunks of 35 grams).

2.7: Repeat steps 2.1 through 2.4, but use Mystery #3 instead of using iron (note you will have to use 105 grams of Mystery #3 because it comes out in chunks of 35 grams).

2.8: Repeat steps 2.1 through 2.4, but use Mystery #5 instead of using iron (note you will have to use 105 grams of Mystery #5 because it comes out in chunks of 35 grams).

2.9: Using the table below, make an educated guess as to what you think Mystery objects #2, #3, and #5 are. Share your guesses with your lab partner and your TA.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Molecular Weight (g/mol)</th>
<th>c (J/kg*K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>55.9</td>
<td>440</td>
</tr>
<tr>
<td>Tungsten</td>
<td>183.8</td>
<td>130</td>
</tr>
<tr>
<td>Copper</td>
<td>63.5</td>
<td>380</td>
</tr>
<tr>
<td>Aluminum</td>
<td>27.0</td>
<td>900</td>
</tr>
<tr>
<td>Germanium</td>
<td>72.6</td>
<td>320</td>
</tr>
<tr>
<td>Silver</td>
<td>107.9</td>
<td>235</td>
</tr>
<tr>
<td>Titanium</td>
<td>47.9</td>
<td>520</td>
</tr>
<tr>
<td>Scandium</td>
<td>45.0</td>
<td>600</td>
</tr>
</tbody>
</table>

2.10: Now that you have a good idea what all of the objects are, convert from a specific heat to a molar specific heat using the atomic weight of the materials.

Q2: How do the results obtained for the mystery items compare with 3R (R here is the ideal gas constant)? Comment on the differences of your values from 3R, and on any differences between the mystery items?
Pre-Lab Assignment (1 point)

1. What is the difference between heat capacity, specific heat, and latent heat?

2. Two objects A and B both have mass 2kg. Object A has a temperature of 20°C and Object B has a temperature of 50°C. The specific heat of Object A is larger than that of Object B. The two objects are isolated from the environment and are brought into thermal contact with each other and allowed to come to thermal equilibrium. Is the final temperature of both objects greater than, less than, or equal to 35°C? Explain your choice.