Mechanical energy includes the kinetic energy of motion and the potential energy of position. At the microscopic level, atoms and molecules are in constant motion and we can speak of the internal energy of an object. If the substance is an ideal gas, the total internal energy is the average kinetic energy of the atoms times the number of atoms. Like kinetic and potential energy, internal energy must be considered for the correct conservation of energy.

Temperature is a measure of the internal energy of matter. It is measured in kelvin (K) or °C (0°C = 273K). For an ideal gas the internal energy $U = (3/2)NkT$, where $N$ is the number of atoms, $T$ is the temperature, and $k$ is a constant equal to $1.38 \times 10^{-23}$ J/K (Boltzmann’s constant).

When two objects are at different temperatures, the hotter object will lose internal energy and cool off, while the cooler object will gain internal energy and heat up. The energy that is transferred from one object to another because they are at different temperatures is called heat. Like work, heat is a process that changes the energy of an object. Like work it could be measured in Joules, but is customarily measured calories (1 cal = 4.186 J). The calorie is the amount of heat required to raise the temperature of water by 1 °C.

The amount of heat needed to raise the temperature of objects depends on the material they are made of. The specific heat, $c$, is the measure of how much heat it takes to raise the temperature of a specific material. Mathematically, the heat, $Q$, is related to the mass, $m$, and change in temperature, $\Delta T$, by:

$$Q = mc\Delta T$$  \hspace{1cm} (1)
Based on the definition of the calorie, water has a specific heat $c_w = 1.00 \text{ cal/g } ^\circ\text{C}$. Some other specific heats are in Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Heat, $c$ (cal/g °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water,</td>
<td>$c_w = 1.00$</td>
</tr>
<tr>
<td>Aluminum,</td>
<td>$c_{Al} = 0.21$</td>
</tr>
</tbody>
</table>

Since energy is conserved, the heat gained by any substance equals the heat lost by another substance. In our experiment, heat will be gained by an aluminum cup of mass $m_{\text{cup}}$ and water $m_w$ as they increase by a temperature $\Delta T_1$. The heat will be lost by a metal slug of mass $m$ as it decreases by a temperature $\Delta T_2$. Eq. (2) below represents the balance of heat gained to heat lost:

$$m_w c_w \Delta T_1 + m_{\text{cup}} c_{Al} \Delta T_1 = m_{\text{slug}} c_{\text{unknown}} \Delta T_2$$

Eq. (3) can be solved for the unknown specific heat of a metal slug.

$$c_{\text{unknown}} = \frac{m_w c_w + m_{\text{cup}} c_{Al}}{m_{\text{slug}} \Delta T_2} \Delta T_1$$

**Apparatus**

A calorimeter is a device designed to measure the exchange of heat between two bodies. It works by minimizing the loss of heat from inside the calorimeter to the outside. The calorimeter in this experiment consists of a large canister with a top that has a small opening that a thermometer fits into. The calorimeter is designed to use air as an insulating buffer.

The smaller inner cup of the calorimeter is made of aluminum and fits into a holder inside the cannister. The large canister will hold air, and the inner cup will contain water that adjusts to room temperature.
A different aluminum (or glass) beaker will hold water and can be placed on a hot plate to bring the water to boiling.

**Apparatus**

Vernier temperature probe and Logger Pro software.
Mass scales
Hot plates
Water pitchers

1. Fill the large aluminum/glass beaker about half full of water and place it on a hot plate, heat it until boiling. Keep the pot on the plate to maintain the water at the boiling point.

2. Weigh and record the mass of each of the three metal slugs labeled B, C, D. Note: Hold the string so its mass is not included.

<table>
<thead>
<tr>
<th>Mass (g)</th>
<th>Slug B</th>
<th>Slug C</th>
<th>Slug D</th>
</tr>
</thead>
</table>

3. Weigh and record the mass of the empty (dry it out if it is wet) small aluminum cup from the calorimeter \((m_{\text{cup}})\). Fill the small aluminum cup from the calorimeter about halfway full of water from the pitcher. Using the string attached to the metal slug, dip the metal slug in the aluminum cup until it is submerged then remove the metal slug and dry it off (you’ll see why this is important later). Now, weigh the cup containing water, and record the mass difference due to the water \((m_w)\) only.

<table>
<thead>
<tr>
<th>Metal Slug B</th>
<th>Empty Cup</th>
<th>Cup + water</th>
<th>Water only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (g)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Place the small aluminum cup in the calorimeter. Place a thermometer probe into the water in the cup and record the temperature every 10 s until the temperature reaches equilibrium and record the final temperature. Note: Reset the time in between samples on the Logger Pro software by clicking the “clock/ruler” icon and selecting 10 seconds per sample and continuous sampling. Remove the thermometer.

Temperature of water: _____________
5. Using the string attached to one of the metal slugs, place the metal slug in the boiling water in the large aluminum/glass beaker on the hot plate (make sure the string does not touch the surface of the hot plate. Leave it in for 5 minutes.

6. Using the string, remove the metal slug from boiling water and quickly place it in the small aluminum cup of water (but NOT in the middle of the cup so it doesn’t block the temperature probe) in the calorimeter. Be careful since the metal slug is at the temperature of boiling water. Place the top on the calorimeter.

7. Insert the thermometer through the small opening in the top. Record the temperature every 10 s while “swishing” the thermometer in the water, until the temperature reaches a MAXIMUM, record this final maximum temperature.

Temperature of metal slug B and water: ______________

8. Repeat steps 3 through 7 for each of the other two slugs.

**Note: You will need redo step 3, starting with a fresh cup of water from the pitcher for each metal slug.**

<table>
<thead>
<tr>
<th>Metal Slug C</th>
<th>Empty Cup</th>
<th>Cup + water</th>
<th>Water only</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass (g)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Temp of water</strong></td>
<td>Temp of water &amp; slug C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metal Slug D</th>
<th>Empty Cup</th>
<th>Cup + water</th>
<th>Water only</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass (g)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Temp of water</strong></td>
<td>Temp of water &amp; slug D</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Data Analysis

9. Make a table of data for each of the three slugs.

10. Find the temperature difference $\Delta T_1$ by subtracting the initial equilibrium temperature in Step 4 from the final equilibrium temperature in step 7.

11. Find the temperature difference $\Delta T_2$ by subtracting the final equilibrium temperature in Step 7 from the boiling temperature 100°C.

12. Find the specific heats with Eq (3). Use the masses measured in steps 2 and 3, the specific heats for water and the aluminum cup from Table 1, and the temperature differences calculated in Steps 10 and 11.

13. Show the specific heats you calculated for each metal slug and the formula (with data filled in) to your TA before you leave the lab.

Refer to the P150A Lab Syllabus for information on the general guidelines for writing an Experimental Lab report.

This week’s Lab report must include the following:

Theory section - Write a description in your own words that describes the relationship between temperature and the internal energy of an object. Explain why different materials (made of different atoms) would require different amounts of thermal energy to change their temperature/internal energy.

Data section—Include your data tables and all the calculations of the specific heats for each of the metal slugs that you used.

There are no Observation Questions for this lab experiment.