Transfer of Heat by Radiation

Introduction

Heat energy is transferred through three different processes: conduction, convection, and radiation. Conduction is a thermal process in which heat energy is transferred from a hot object to a colder object through direct contact (Figure 1). Convection is a thermal process in which heat energy is transferred from one place to another through the movement of fluids (Figure 2). Radiation is a thermal process in which heat energy is converted to electromagnetic radiation (photons) which are emitted from an object's surface (Figure 3). These photons, in turn, can heat other objects similar to how the Sun heats the Earth's surface.

In this lab you will explore how heat energy is lost by a hot object and show how radiation is affected by the different surfaces of a hot object.

Equipment

<table>
<thead>
<tr>
<th>Qty</th>
<th>Items</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Quad Temperature Sensor</td>
<td>PS-2143</td>
</tr>
<tr>
<td>1</td>
<td>Radiation Cans</td>
<td>TD-8570A</td>
</tr>
<tr>
<td></td>
<td>Required, but not included:</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Balance</td>
<td>SE-8723</td>
</tr>
<tr>
<td>1</td>
<td>Beaker, 1000 mL (Only 1 needed)</td>
<td>SE-7288</td>
</tr>
<tr>
<td>1</td>
<td>Beaker tongs</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Insulating Pads</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Safety goggles</td>
<td></td>
</tr>
<tr>
<td>1L</td>
<td>Hot water</td>
<td></td>
</tr>
<tr>
<td>1L</td>
<td>Ice, cubes or crushed</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>550 Universal Interface</td>
<td>UI-5001</td>
</tr>
<tr>
<td>1</td>
<td>PASCO Capstone software</td>
<td></td>
</tr>
</tbody>
</table>

Optional: Aluminum Foil
Temperature Calibration

1. Prepare the three flexible white Fast Response Probes by inserting each one through a hollow tube (included with the Quad Temperature Sensor) and taping them as shown in Figure 4. You can use a coffee stirrer (see Figure 4), or any plastic or wooden rod and tape the thermistor to the side of the rod. Be sure the thermistor at the end of each probe is not inside the tube, or covered with tape.

2. Connect the three temperature probes to the Quad Temperature Sensor using ports 1, 2, and 3 on the sensor. Then connect the Quad Temperature Sensor directly to the interface, or use a PASPort extension cable.

3. Prepare an ice bath (1 L of mostly ice and a little water) in the beaker. Temporarily tape all three of the temperature probes together so they will be in the same place in the bath, but do not tape over the thermistors at the ends of the probes. Put all the probes into the ice water and gently stir them around the ice. Continue to gently stir through the next step.

4. In Capstone, open Calibration in the toolbar at the left. Choose to calibrate all three of the temperature probes, using a one standard (1 point offset) calibration. For the first calibration point, set the standard value to 0°C, and set the current value to the standard value. Review the calibration and then finish it.

5. Remove the sensors from the water. Remove the tape holding them together. Dry the sensors well using paper towels or other towels, and set the dry sensors on the table.

Safety:
* Each group member should wear safety goggles while performing this experiment.
* Always use insulating pads or beaker tongs, as needed, when handling or moving hot water containers and hot plates, including the radiation cans used in this experiment.
Procedure

1. In Capstone, set the sample rate to 20 Hz. Create a graph of Temperature 1 vs. time. Add plot areas with Temperature 2 and Temperature 3 on the vertical axis.

2. Fill the beaker with hot water.

3. Place insulating pads on the lab table (away from any hot plate, if used), and then set the silver, black, and white radiation cans on the insulating pads approximately 30 cm apart.

4. Be sure to use the beaker tongs or insulating pads when handling the hot radiation cans or beaker. Have one group member use beaker tongs to hold the silver can in place, and then another group member carefully fill the can with 300 mL of hot water from the beaker. In the same manner, fill the white can and the black can each with 300 mL of hot water.

5. Put the temperature probe 1 in the silver can, probe 2 in the black can, and probe 3 in the white can. Let the taped end act as a hook as shown in Figure 5.

   Immediately start recording.

6. While recording, constantly and gently stir the water with the temperature probe. Observe the starting temperatures of the three cans. Are the starting temperatures the same? If not, which can is hotter and why is there a difference between the two starting temperatures?

7. Stop recording data after the temperature has dropped to about halfway between the starting temperature and room temperature.

8. Create a table as shown below. Create User-Entered Data sets called “Can Color”, “Can+Water Mass” with units of g, and “Can Mass” with units of g. Then create a calculation in the last column:

   \[
   \text{Water Mass} = [\text{Can+Water Mass (g)}] - [\text{Can Mass (g)}]
   \]

<table>
<thead>
<tr>
<th>Can Color</th>
<th>Can+Water Mass (g)</th>
<th>Can Mass (g)</th>
<th>Water Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9. Use the balance to measure the mass of each can with the water in it and record the masses in Table I. Then measure and record the mass of each can without water. The water masses should be approximately equal for the three cans. If a can has significantly less water, it will cool significantly more quickly, and so you should take this into account in your analysis in the next step.
Analysis

1. To precisely compare cooling rates of the three cans: Examine the plots of Temperatures 1 (silver can), 2 (black can), and 3 (white can) vs. Time. Then:
   
   a. Choose a starting temperature that works for each plot. Use the coordinate tool and on each plot to place a cursor at the time corresponding to this starting temperature.
   
   b. Use the delta tool on each plot to measure how long it took to cool by 15°C, for example. It is important to compare each can between the same two temperatures.
   
   c. Which can cools the fastest? The slowest?

2. When the cans were cooling, which processes were involved in transferring heat? See Figures 1, 2, and 3. Which process do you think was dominant? Explain your reasoning.

3. When the cans were cooling, did they cool faster at the beginning of the experiment or toward the end of the experiment? Why?

Further Study

1. Tightly wrap all three of the cans with aluminum foil and tape the foil closed. See Figure 6.

2. Put hot water in all the cans and record the cooling as before.

3. How does the cooling compare to the cans without the foil? Explain why

Conclusions

1. In general, what color can cools the fastest? Was one of the colors much faster than the others?

2. If you want something to keep warm, what kind of surface should you put on its outer surface?

3. Why are radiators on cars black?

4. Why do you wrap a potato in foil after baking it?