

## Specific Heat

### Equipment

|                            |                           |         |
|----------------------------|---------------------------|---------|
| 1                          | Quad Temperature Sensor   | PS-2143 |
| 1                          | Density Set               | ME-8569 |
| 1                          | Calorimeter Cup and Lid   |         |
| Required but not included: |                           |         |
| 1                          | 550 Universal Interface   | UI-5001 |
| 1                          | Centigram Balance         |         |
| 1                          | Hot Plate                 |         |
| 2                          | Beaker, 600 ml            |         |
| 1                          | Graduated Cylinder, 50 ml |         |
| 1                          | Scissors                  |         |
| 1                          | Thread (1 meter)          |         |
| 2                          | Paper Clip                |         |
|                            | Ice (500 ml)              |         |
|                            | Water (500 ml)            |         |
|                            | Paper Towels (1 roll)     |         |
| 3                          | Coffee Stirrers           |         |

### Introduction

In this activity you will use a temperature sensor to measure the temperature change of a volume of warm water when a cold piece of metal is placed in it. Your data will be used to determine the total amount of heat transferred from the warmer water to the cold metal, which will in turn be used to determine the specific heat of the metal sample.



Figure 1: Equipment

## Background

The specific heat,  $c$ , of a substance describes the amount of thermal energy (heat) that a single gram of the substance must absorb in order to change its temperature by one degree Celsius (or Kelvin).

The specific heat of water, for example, is  $c_w = 4.186 \text{ J/g}^\circ\text{C}$ . That is: 4.186 J of heat are needed to raise the temperature of 1g of water by  $1^\circ\text{C}$ . In general, we have:

$$Q = mc\Delta T \quad (1)$$

where  $Q$  is the thermal energy (heat) required to produce a temperature change  $\Delta T$  in a material with a specific heat  $c$  and a mass  $m$ .

If there is no loss into the environment, when a cold metal is added to warm water, the heat gained by the metal ( $Q_M$ ) must equal the heat lost by the water ( $-Q_W$ ) and we have:

$$Q_M = -Q_W \quad (2)$$

$$m_M c_M \Delta T_M = -m_W c_W \Delta T_W$$

Solving for the specific heat of the metal gives:

$$c_M = \frac{-m_W c_W \Delta T_W}{m_M \Delta T_M} \quad (3)$$

## Setup

1. Connect the stainless-steel temperature probe to port #1 on the Quad Temperature sensor and then connect the sensor to either of the PASPORT channels on the 550 interface.
2. For this activity you will be using only the gold and silver-colored rectangular metal samples from the ME-8569 Density Set. Each of the two samples has a small hole drilled through it that will be used to attach a piece of thread to help lift the samples during data collection without touching them with your hands.

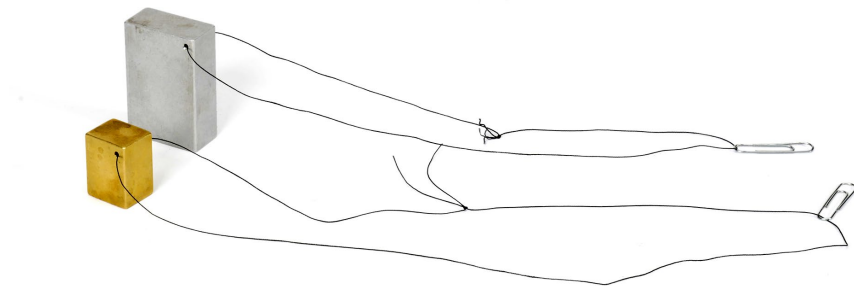


Figure 2: Metal Samples

3. Run a small piece of thread (~50 cm) through the hole in each metal sample and tie the ends of the string to create a loop similar to Figure 2. Attaching a paper clip to the loop will create a small handle to help when lifting the samples.
4. Fill one 600 ml beaker with ice, and then add enough water to the ice to just cover it. Place both metal samples into the ice bath and hang the string and paper clips over the side of the beaker. Leaving the metal samples in the ice bath will eventually cool them to about 0 °C.
5. Fill the other 600 ml beaker with approximately 300 ml of water and place the beaker onto the hot plate. Turn on the hot plate and set it to a medium-high heat setting.
6. In PASCO Capstone, create a Digital display and select the Temperature. Set the sample rate to 1 Hz. Change the Sampling Mode to Fast Monitor.
7. The goal is to heat the water in the beaker to approximately 60 °C, but no hotter. Monitor the temperature of the warm water by placing the temperature probe into the water and clicking the Monitor button.
8. When the temperature of the warm water reaches 60 °C, switch off the hot plate and click stop in the Sampling Control Bar below (Fast Monitor Mode).

## Procedure

1. Place the temperature probe into the ice bath so that the tip of the probe is touching the gold-colored metal sample (Metal 1). Click the monitor button in the control panel to begin monitoring the temperature of Metal 1 in the digits display to the right.
2. When the temperature measurement comes to equilibrium (stops changing), click stop in the control panel, and then record the temperature value shown in the digits display.
3. Use the balance to measure the mass of the calorimeter cup, without its lid, to the nearest 0.01 g and record the value.
4. Use the graduated cylinder to measure 150 ml of warm (~60 °C) water, and then pour the warm water into the calorimeter cup.
5. Measure the mass of the calorimeter cup with water to the nearest 0.01 g and record the value. Using the Calorimeter Mass and Cal+Water Mass values, calculate the mass of the water.
6. Put the lid on the calorimeter cup. Place the temperature probe into the warm water inside the calorimeter by inserting the probe through the hole in the calorimeter lid. Gently swirl the water in the calorimeter for about 15 seconds to equilibrate the temperature inside the calorimeter.

7. In Capstone, change the Sampling Mode to Continuous Mode and change the sample rate to 5 Hz. Create a graph of Temperature vs. Time.
8. Click the record button in the control panel below to begin recording data, and continue to record data for about 20 seconds.

*The next step must be done quickly!*

9. Using the paper clip and string, remove the gold-colored metal sample from the ice water bath. **DO NOT TOUCH THE METAL WITH YOUR HANDS!** Using paper towels, quickly dry off the metal and then lower it into the calorimeter cup and replace the calorimeter lid making sure that the very tip of the temperature probe is submerged in the calorimeter water and not in direct contact with the metal sample.
10. Gently swirl the calorimeter cup until the temperature inside the cup comes to equilibrium. Then click stop.
11. Remove the metal sample from the calorimeter cup and completely dry it using paper towels.
12. Use the balance to measure the mass of the metal sample to the nearest 0.01 g and record the value.
13. Use the Coordinates Tool in the graph to determine the initial temperature of the water just before you added the metal sample. Record this value.
14. Use the Coordinates Tool in the graph to determine the final (equilibrium) temperature of the water once it has come to equilibrium. Note that since the water loses heat to the air and the foam cup, the temperature will continue to decrease. Look for the temperature where the data begins to look linear. Record this value.

## Analysis

1. Using the data you recorded and Equation 3, calculate the specific heat of Metal 1. Show your work and record your results. Be certain to use correct units. Note that the specific heat for aluminum is given below:

| Metal           | Specific Heat (J/g°C) | Metal    | Specific Heat (J/g°C) |
|-----------------|-----------------------|----------|-----------------------|
| Silver          | 0.233                 | Tungsten | 0.134                 |
| Zinc            | 0.387                 | Aluminum | 0.900                 |
| Stainless Steel | 0.500                 | Lead     | 0.128                 |

2. The gold-colored Metal 1 is made of brass which has a theoretical specific heat equal to  $c_{\text{brass}} = 0.380 \text{ J/g}^\circ\text{C}$ . Calculate the percent error in your experimental value using the equation below. Record your result.

$$\% \text{ error} = \frac{|\text{Theoretical} - \text{Experimental}|}{\text{Theoretical}} \times 100\% \quad (4)$$

3. In your opinion, what are the three largest sources of potential error in your experimental value for  $c_{\text{Metal1}}$ , and briefly explain how these sources of error can be avoided for future trials.

### Application

1. Using the same set-up and data collection procedure as you did with the brass sample, repeat this experiment using the silver-colored sample, recording all your data values into the tables next to "Metal 2".
2. Using the data and Equation 3, calculate the specific heat of Metal 2. Record your results.
3. Based on your calculated value from the previous question, and the table of common metals and their specific heat values in the Analysis section, what type of metal do you think your Metal 2 sample is?
4. Calculate the percent error in your experimental values for sample using Equation 4. Record your results.

### Conclusions

1. How did the percent error in your experimental value for  $c_{\text{Metal2}}$  compare to the percent error in your experimental value for  $c_{\text{Metal1}}$ ? Why do you think the percent error was larger for one of the metal samples?
2. If both of your values for specific heat,  $c_{\text{Metal1}}$  and  $c_{\text{Metal2}}$ , are too low, how would you explain it?
3. What does the specific heat tell you about how easy it is to change the temperature of a material?
4. Why is it so important to the earth that the specific heat of water is so high? Hint: Of what is the Earth's surface mostly composed?