# Experiment 9
# Specific Heat

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Name:



Date:

## Key Objectives

1. Understand the equation $q = ms\Delta$T, what each variable represents and typical units.
2. Solve problems using $q = ms\Delta$T.
3. Difference between heat and temperature.
4. Use of Significant Figures in calculations.

## Discussion

Calorimetry is the science of measuring heat. We will use a calorimeter to measure the amount of heat transferred from an unknown metal to water. By knowing the value of the specific heat of water we will then be able to calculate the specific heat of the unknown metal and identify it based on a comparison to known values. In addition we will be able to work on our graphing skills. A basic discussion of calorimetry can be found in Hein Ch. 4.5 (p. 71) and in McMurry Ch. 8.8 (p. 311).

The **Temperature** of an object is a measure of how rapidly the atoms composing an object are moving. The faster the atoms move, the higher the temperature. Temperature is an intensive property that does not depend on the amount of matter present, thus the temperature of a cup of coffee and a bathtub full of water can be the same. Temperature is generally measured in degrees Celsius (℃), Fahrenheit (℉), or Kelvin (K).

**Heat** is defined as the transfer of thermal energy, which is associated with the random motion of atoms and molecules, between two bodies that are at different temperatures. Heat is an extensive property that does depend on the amount of matter present, thus the heat content of cup of water is very different from the heat content of a bathtub full of water. Heat is generally measured in energy units as joules (J) or calories (cal) where 4.184 joules = 1 calorie. The calorie is defined as the amount of energy required to heat 1 gram of water 1 ℃.

The **Specific heat** of a substance is an intensive property that relates the temperature and heat of an object. It is defined as the quantity of heat required to raise 1 gram of a substance by 1 ℃ and has units of (J/g·℃, cal/g·℃, or J/mol·℃). The relationship between heat (q), specific heat (s), mass (m) and a temperature change ($\Delta t$ or $t_f - t_i$) can be expressed mathematically as:

$$q = m \cdot s \cdot \Delta T \tag{4}$$

The change in temperature of a substance is often expressed using the greek letter delta ($\Delta$) “which means the change in”. This can also be expressed as the final temperature ($t_f$) minus the initial ($t_i$) of an object. Knowing 3 of the variables in the equation above allows us to solve for the fourth variable. A fact we will make use of in this experiment.

Based on our definitions of specific heat and joules/calories, the specific heat of water is exactly 4.184 J/g·℃ or 1.00 cal/g·℃. Knowing this value we will be able to determine the specific heat of a known metal and an unknown metal. We will do so by heating the metal to a known temperature and then placing it in contact with water at a known temperature. The heat from the metal will be transferred to the water raising the temperature. Using the final measured temperature of the water we will be able to determine the amount of heat transferred from the metal to the water and thus calculate the specific heat of the metal. The following equations show the relationships that allow us to determine the specific heat of the metal. Variables with a subscript "w" refer to the water while a subscript "m" will refer to our metal.

$$q_w = m_w \cdot s_w \cdot (\Delta t_w) \tag{5}$$
$$q_m = m_m \cdot s_m \cdot (\Delta t_m) \tag{6}$$

We can combine the above equations into a single equation by realizing that all of the heat that the water absorbed had to come from the metal sample, thus:

$$q_w = q_m \tag{7}$$
$$m_w \cdot s_w \cdot (\Delta t_w) = m_m \cdot s_m \cdot (\Delta t_m) \tag{8}$$

Figure 9.1 shows the rough setup for the experiment and Table 9.1 shows the values measured in the experiment, because we know all the values for water, we can calculate $q_w$ and using equation 7 we then know $q_m$ and can calculate the specific heat of the metal.

| **Variable** | **Water** | **Metal** |
|---|---|---|
| m | measured | measured |
| s | measured | ?? |
| $t_f$ | same value | |
| $t_i$ | measured | measured |
| $q$ | same value | |

Table 9.1: Values measured in the experiment.

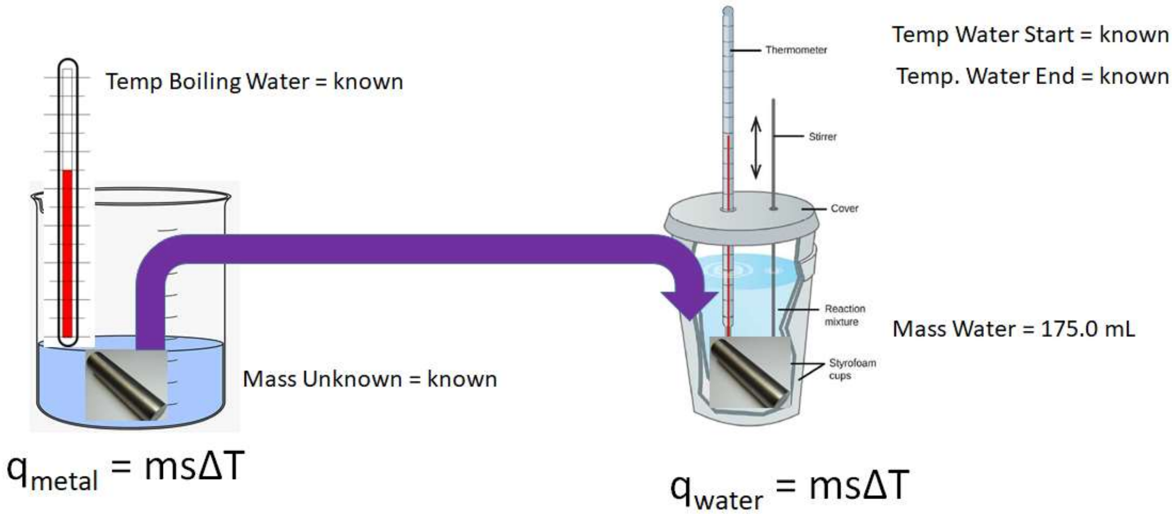


Figure 9.1: Experimental setup for finding the specific heat of an unknown metal. credit: author

## Procedure

Read the entire procedure before beginning the experiment. Day one you will use a known sample (most likely Copper (Cu) to test the accuracy and precision of the measurement. Day two you will repeat the experiment on on unknown sample and calculate its specific heat and using Table 9.2 try to determine its identity.

1. Be sure to record all measured values with the appropriate number of significant figures and unit. Be sure to show all calculations required.

2. Obtain a known metal sample (most likely Copper (Cu)) from your instructor and record the name of the known in the results section.

3. Weigh the known metal sample. Record it in the results section.

4. Construct the apparatus shown in Figure 9.2a. Place the metal sample carefully in the beaker (do not drop it, you might break the beaker) before placing the thermometer in. Use the smaller thermometer and be sure to clamp the thermometer in place. Adjust the height above the flame to ensure rapid heating.

5. Fill the beaker with tap water so the height of the water is a least 2 inches higher than the top of the metal sample.

6. Begin heating the water in the beaker and continue with the next step(s). As you are working, check the water frequently and note when it starts to boil. Turn down the burner, but keep the water gently boiling. Do not do step 11 until the water has been boiling for about 10 minutes and the temperature of the metal object has stabilized.

7. Obtain a calorimeter (Figure 9.2b) and record the mass of the inner cylinder on your data sheet.

8. Add approximately 50 mL of water to the calorimeter (enough to cover the metal sample) by no

more than 1/2 inch. Use the minimum amount of water to cover the sample so the measured change in temperature will be as large as possible. Record the mass of the calorimeter + the water.

9. Use a cardboard cover to trap heat and slide the thermometer through it, clamp a large thermometer carefully and make sure the water will cover the mercury bulb. Adjust it so that it hangs suspended just above the bottom of the calorimeter, but will be covered by the water. Clamp it to a ring stand to prevent it from falling over.

10. Measure the initial temperature of the water in the calorimeter. Use a second ring stand to secure the thermometer in place.

11. After the water in the beaker has been boiling for 10 minutes and the temperature of the metal sample has been stable for 5 minutes record the temperature in the results section. Remove the thermometer from the test tube and set it aside.

12. Using tongs, transfer the metal sample from the boiling water to the calorimeter. It is important that the transfer take place quickly and that no water is transferred along with the metal. Be sure to remove the thermometer from the calorimeter and set it carefully aside so you don't break it when you place the metal sample in the calorimeter. Try to minimize splashing. Be sure not to confuse the two thermometers.

13. Once the metal sample is in the calorimeter, quickly place the cover on and the thermometer in the water. Stir gently by swirling the calorimeter. Watch the temperature of the water in the calorimeter, and note the peak temperature. If the temperature does not reach a maximum value and decrease then record the temperature when it has been stable for one minute.

14. Calculate the specific heat of your unknown sample. Compare the sample to the known value. If you are within 0.05 J/g·℃ of the correct value continue to the next step. If you were not accurate enough on the first trial of your known metal consult your instructor and perform a second trial.

15. Obtain an unknown sample and determine its specific heat. Do 2-3 trials (as time permits) on the unknown sample.

16. Ask your instructor for permission to start.

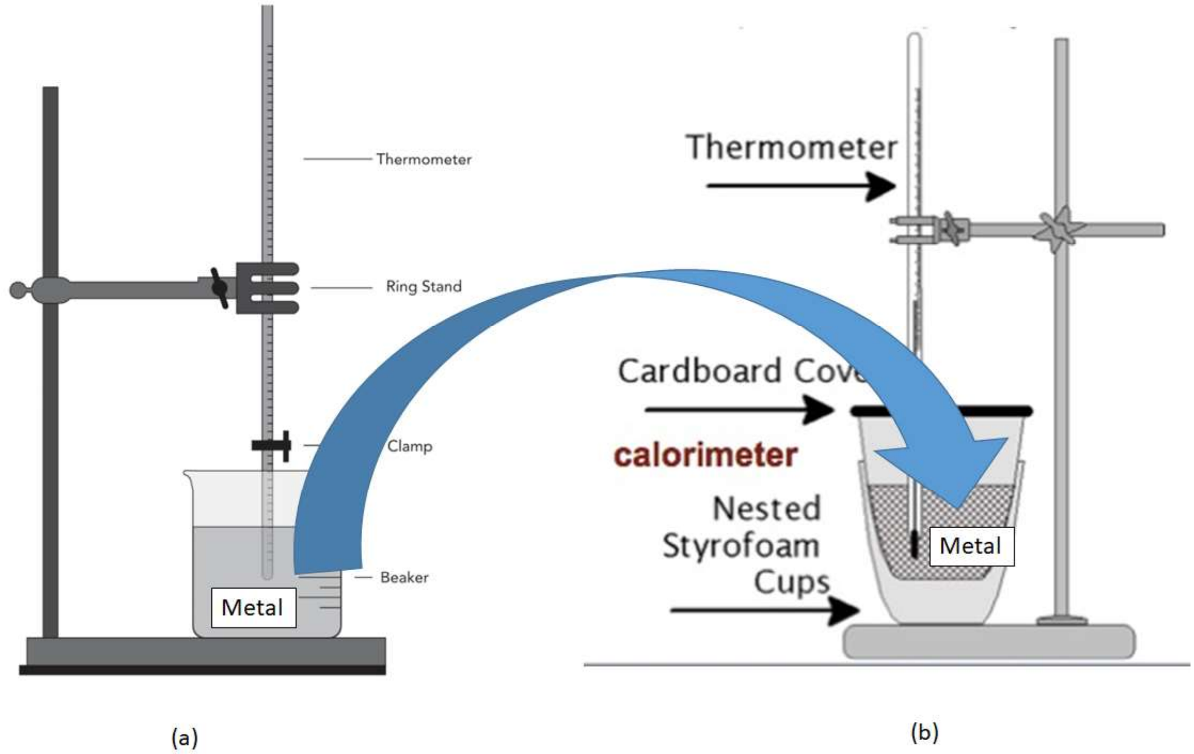


Figure 9.2: (a) Heat the metal in a beaker then transfer the metal to the (b) calorimeter and measure the temperature change. credit: (a) https://seedsconnections.org (b) https://chemdemos.uoregon.edu/demos/Comparing-Specific-Heats-of-Metals

| Metal | Atomic Mass (amu) | Specific Heat (J/g·°C) |
|---|---|---|
| Aluminum | 26.98 | 0.900 |
| Brass | N/A | 0.380 |
| Copper | 63.55 | 0.385 |
| Gold | 197.0 | 0.131 |
| Iron | 55.85 | 0.451 |
| Lead | 207.2 | 0.128 |
| Magnesium | 24.305 | 1.02 |
| Silver | 107.9 | 0.237 |
| Tin | 118.7 | 0.222 |
| Zinc | 65.39 | 0.390 |

Table 9.2: Specific Heat of Selected Metals

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## Results

### A. Known Metal Sample - Data

| | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|
| 1. Identity of known metal | ________ | ________ | ________ |
| 2. Uncertainty in mass measurements: | ________ | ________ | ________ |
| 3. Mass of metal sample: | ________ | ________ | ________ |
| 4. Mass of calorimeter: | ________ | ________ | ________ |
| 5. Mass of calorimeter + water: | ________ | ________ | ________ |
| 6. Uncertainty in temperature measurements (heating appratus): | ________ | ________ | ________ |
| 7. Uncertainty in temperature measurements (calorimeter): | ________ | ________ | ________ |
| 8. Initial temperature of water in calorimeter: | ________ | ________ | ________ |
| 9. Initial temperature of metal sample: | ________ | ________ | ________ |
| 10. Final temperature of water and metal: | ________ | ________ | ________ |

## B. Known Metal Sample - Calculations

Show example calculations for Trial 1 in the space provided below.

| | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|
| 1. Mass of Water: | ________ | ________ | ________ |
| 2. Change in temperature of water: | ________ | ________ | ________ |
| 3. Change in temperature of metal: | ________ | ________ | ________ |
| 4. Heat gained by water: | ________ | ________ | ________ |
| 5. Heat lost by metal: | ________ | ________ | ________ |
| 6. Specific Heat of Metal (Experimental): | ________ | ________ | ________ |
| 7. Average Specific Heat: | | ________ | |
| 8. Theoretical specific heat of metal: | | ________ | |
| 9. Calculate the Percent Error using the following formula: $\left\lvert\frac{\text{Actual Value}-\text{Measured Value}}{\text{ActualValue}}\right\rvert * 100\ \%$ | ________ | ________ | ________ |

## C. Unknown Metal Sample - Data and Results

| | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|
| 1. Identity of unknown metal | ________ | ________ | ________ |
| 2. Mass of metal sample: | ________ | ________ | ________ |
| 3. Mass of calorimeter: | ________ | ________ | ________ |
| 4. Mass of calorimeter + water: | ________ | ________ | ________ |
| 5. Initial temperature of water in calorimeter: | ________ | ________ | ________ |
| 6. Initial temperature of metal sample: | ________ | ________ | ________ |
| 7. Final temperature of water and metal: | ________ | ________ | ________ |
| 8. Mass of Water: | ________ | ________ | ________ |
| 9. Change in temperature of water: | ________ | ________ | ________ |
| 10. Change in temperature of metal: | ________ | ________ | ________ |
| 11. Heat gained by water: | ________ | ________ | ________ |
| 12. Heat lost by metal: | ________ | ________ | ________ |
| 13. Specific Heat of Metal (Experimental): | ________ | ________ | ________ |
| 14. Average Specific Heat: | | ________ | |
| 15. Which element is your metal made from: | | ________ | |
| 16. Explain why you chose the above metal (as opposed to other possibilites): | | | |
| 17. Theoretical specific heat of metal: | ________ | ________ | ________ |
| 18. Calculate the Percent Error using the following formula: $\left\lvert \frac{\text{Actual Value}-\text{Measured Value}}{\text{ActualValue}} \right\rvert * 100\ \%$ | ________ | ________ | ________ |

## Post Lab Questions

1. Why is it more accurate to weigh the mass of the calorimeter and the calorimeter + water instead of simply measuring the mass of water in a beaker and pouring it into the calorimeter?

2. Why do we want the water in the calorimeter to barely cover the metal sample (but not entirely fill up the calorimeter)?

3. Why do we want to be careful not to mix up which thermometer we use to measure the metal sample and which we use to measure the temperature in the calorimeter?

4. What effect does the initial temperature of the water in the calorimeter have on the change in temperature of the water after the hot metal sample is added, consider the following two scenario's.

   4(a) For instance what if you used water at 5°C in your calorimeter instead of room temperature water? Explain.

   4(b) What if a mixture of ice and water was used? Explain.

5. Based on **YOUR** experimental data, which was better, the precision or the accuracy? Explain.

6. In this experiment you measured the specific heat of your known and unknown three times. Why did you do this?

7. Bob heats 25.00 grams of an unknown metal in a calorimeter from 18.0℃ to 23.0℃ using 500.0 J of heat. What is the specific heat of the metal? 7. ____________

8. Bob's brother heated up $2.5 \times 10^3$ L of Sulfuric Acid from 15.00℃ to 39.0℃. How many nJ of heat did he use? The specific heat of Sulfuric Acid is 2.59 $\mathrm{J/g\,^{\circ}C}$.

8. ____________

9. Bob's sister uses $2.45 \times 10^4$ J of energy to heat a copper pan weighting 250 grams. If the final temperature of the pan was 600.℃ what was the initial temperature of the pan?

9. ____________

10. Bob's father heated a metal bar weighting 50.0 grams to 200.0℃ and placed it in a calorimeter containing 75.00 grams of water at an initial temperature of 30.0 ℃. If the final temperature of the metal object in the water was 45.0℃ what is the specific heat of the metal?

10. ____________

Name: ____________________________ Class: ______________ Date: ______________

## Prelab Questions

1. Why are we measuring the specific heat of a known compound (Cu - Copper) before we measure it for an unknown compound?

2. How much energy (in kJ) is required to heat a cup of coffee (mostly water) weighing 0.50 lbs from 25 ℃to 75 ℃?

3. What is the final temperature of a gold sample weighing 10.5 grams which absorbs 814 J of energy if it starts at 20.0 ℃? Explain.

4. A metal sample weighing 32.250 g was heated to 100.0 ℃ , then quickly transferred to a calorimeter containing 53.247 g of water at 18.0 ℃. The temperature of the water increased to 20.6 ℃. Calculate the specific heat of the metal in J/g·℃. (Hint: where did all the heat lost by the metal go?)

This is the back of the page, totally uninteresting.