

# 2 Specific Heat

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- Determine the specific heat of an unknown metal with a simple calorimeter.
- Identify the unknown metal from its specific heat and other physical properties.

## DISCUSSION

The *specific heat* of a substance is defined as the amount of heat energy required to change the temperature of one gram of a substance one degree Celsius. In the SI system, heat energy, as well as other forms of energy, is expressed in joules (J). Specific heat may be determined experimentally by measuring the heat required to change the temperature of a given mass from temperature  $T_1$  to  $T_2$ :

$$\text{specific heat} = \frac{\text{joules}}{(\text{grams}) \cdot (T_2 - T_1)}$$

A convenient way to determine the specific heat of a solid sample is to heat it in boiling water, and then place the sample into a known amount of cool water. Heat energy flows from the sample to the water and its container (the calorimeter), causing the temperature of the water and container to rise and the sample's temperature to fall. In this experiment, assume that the heat lost by the sample is absorbed by both the water and the calorimeter. Expressed mathematically,

$$q_{\text{sample}} = q_{\text{water}} + q_{\text{calorimeter}}$$

where  $q$  represents a quantity of heat.

Efficient calorimeters are expensive.

You will use an inexpensive, plastic-foam, hot-drink cup instead of a conventional calorimeter. The error introduced, however, will not be large. Previous measurements show that this type of calorimeter (cup and thermometer) absorbs 42 joules of heat for each degree rise in temperature. You may use this value in your calculations.

To practice your technique, you will first measure the specific heat of lead. Then you will compare your results with the accepted value of  $0.13 \text{ J/g} \cdot ^\circ\text{C}$ . And

finally, you will determine the specific heat of an unknown metal.

Also, you can use the specific heat to approximate the molar mass of your unknown metal. This can be done with the “law” of Dulong and Petit. This “law” was developed in 1819 by French scientists Pierre Dulong and Alexis Petit, who suggested that a metal's specific heat was proportional to its molar mass. This relationship is only approximate, but it has become a useful rule of thumb. The so-called “law” of Dulong and Petit can be written as

$$\text{molar mass} \approx \frac{25 \text{ J/mol} \cdot ^\circ\text{C}}{\text{specific heat}}$$

You will use this “law” and your measured specific heat to discover the identity of the unknown metal.

- Heat Capacity of Cup, 42 J/°C
- Specific heat of Lead, 0.13 J/g·°C
- Specific Heat of Water, 4.184 J/g·°C

## PROCEDURE

### A. The specific heat of lead.

1. Obtain a sample of lead metal, and weigh it to the closest 0.1 g.

Place the lead in a 250-*mL* beaker containing approximately 150 *mL* of distilled water. Heat the water until it is boiling smoothly and a constant temperature is reached. While it is heating, go on to the next steps.

2. Weigh, to the nearest 0.1 g, a plastic-foam cup (the calorimeter).

3. Place about 50 *mL* of room-temperature water in the cup, weigh the cup and contents to 0.1 g.

4. Measure the temperature of the water to the nearest 0.1 °C.

5. Record the temperature of the boiling water (which is assumed to be the temperature of the lead sample also) to 0.1 °C.

6. Remove the thermometer from the boiling water. Cool it to room temperature by holding it momentarily under a cold-water faucet, and wipe it dry.

Grasp the lead sample firmly with tongs or forceps; remove it from the hot water; quickly tap it dry on a paper towel and place it in the foam-cup calorimeter.

Gently swirl the cup and watch closely the rise in temperature. Measure the maximum temperature to 0.1 °C.

7. Calculate the mass of the water in the cup.

8. Calculate the temperature change for the water.

9. Calculate the temperature change for the lead.

10. Calculate the heat gained by the water by multiplying its specific heat (4.184 J/g·°C) by its mass and by the water's change in temperature. Show your calculations in the space provided.

11. Calculate the heat gained by the calorimeter by multiplying the same change in temperature by 42 J/°C. Show your calculations.

12. All the heat used to raise the temperature of the water and the calorimeter came from the sample as it

cooled from its maximum temperature to the final temperature in the calorimeter. Thus, calculate the heat lost by the lead by summing the two heats calculated above.

13. Calculate the specific heat of lead by dividing lead's loss of heat by the mass of the sample and by the lead's temperature change. Show your calculations.

14. The accepted value for the specific heat of lead is 0.13 J/g·°C. Calculate the percent error on your specific heat calculation as follows:

$$\% \text{ Error} = \frac{\text{your result} - 0.13}{0.13} \times 100\%$$

Repeat Steps 1-14 on the same sample of lead for Trial #2. Although some of the data (like the temperature changes) will be different on this second trial, the final result (lead's specific heat) should agree closely with that of the first trial.

### B. The specific heat of an unknown metal.

15. Obtain a sample of unknown metal, which you can assume is a pure, elemental metal, not an alloy. Record its number.

16. to 28. Follow steps 1 through 13 using the unknown metal instead of lead. Do these measurements a second time (on the same sample of unknown metal) for precision.

### C. The identity of the unknown metal

29. Use the "law" of Dulong and Petit to approximate the molar mass of the unknown metal.

30. Remembering that the "law" of Dulong and Petit is only accurate to within 10% or so (high or low), locate a region of the periodic table that likely contains your unknown element. Also recall that many elements are not reasonable laboratory samples (i.e., sodium and magnesium are too reactive in water, neon is a gas, and silver is too expensive to use). With this

information, identify several metals that your unknown sample may be.

31. Suggest another physical property of the metal that you could measure with the equipment in this laboratory to characterize the unknown further. Plan how you would make such

a measurement. Then make the measurement.

32. Consult your textbook, the *Handbook of Chemistry and Physics*, or any other reference in the library for tables of the physical property you measured. Give your best estimate of the unknown's identity.

# 2 Specific Heat

Name \_\_\_\_\_  
Partner \_\_\_\_\_  
Section \_\_\_\_\_ Locker \_\_\_\_  
Instructor \_\_\_\_\_

Enter the data or answer the questions *according to the corresponding step in the procedure*

## A. The Specific Heat of Lead

	<b>Trial #1</b>	<b>Trial #2</b>
1. Mass of lead		
2. Mass of plastic-foam cup		
3. Mass of cup and water		
4. Initial temperature of water		
5. Temperature of hot lead		
6. Final temperature of contents		
7. Mass of water in cup		
8. Temperature change of water		
9. Temperature change of lead		
10. Heat gained by water		
11. Heat gained by calorimeter		
12. Heat lost by lead		
13. Specific heat of lead		
14. Percent error		

## CALCULATIONS

**B. The Specific Heat of an Unknown Metal**

	<b>Trial #1</b>	<b>Trial #2</b>
15. Number of unknown metal		
16. Mass of metal sample		
17. Mass of plastic-foam cup		
18. Mass of cup and water		
19. Initial temperature of water		
20. Temperature of hot metal		
21. Final temperature of contents		
22. Mass of water in cup		
23. Temperature change of water		
24. Temperature change of metal		
25. Heat gained by water		
26. Heat gained by calorimeter		
27. Heat lost by metal		
28. Specific heat of metal		

**CALCULATIONS****The Identity of the Unknown Metal**

29. Molar mass by “law” of Dulong and Petit	
30. Metals consistent with your measurements	
31. Measurement of another physical property	
32. Best estimate of identity of unknown	

**Reference used:**

**APPLICATION OF PRINCIPLES**

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1. A sample of unknown metal has a mass of 36.7 *g*. This metal was placed in boiling water at 96.0°C until the metal had reached the temperature of the water. The metal was then placed in a foam cup with 50.0 *mL* of water in it at 20.0°C. The cup absorbs 42.0 *J/°C*, and the temperature of the water went up to 24.0°C. What is the specific heat of the metal?

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2. A 60.0 *g* sample of chromium at 82.0°C (sp. ht. for Cr is 0.45 *J/g°C*) was placed in 80.0 *g* of water. Assume there is no loss of heat to the environment. What is the final temperature of the water and the chromium? The initial water temperature was 24.0°C.

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3. What mass of chromium metal at 92.0°C would be required to raise the temperature of 250 *g* of water from 22.0°C to 27.5°C? Assume there is no loss of heat to the environment.