23. Specific Heat Capacity of a Metal

Driving Questions

- ♦ If energy is added to a substance, but no work is done, where does that energy go?
- ♦ What happens to the temperature of one substance when it loses energy to another substance?
- ♦ How much energy is required to increase the temperature of different substances?
- ♦ Can we identify an unknown metal by experimentally determining how much energy was required to change the temperature of the metal?

Background

Doing work can add energy to systems or a substance. Examples include pushing a cart up an inclined track or using a wrench to tighten a bolt. However, this is not the only way to introduce energy to a system or substance. Energy can be added in the form of heat Q. Unlike work energy, energy added by heat has the ability to cause changes in the substance itself, such as changes in temperature and changes in phase.

One can experience an example of this heat (energy) exchange by dropping a cold metal spoon into a pot of hot water. After remaining in the water for a few minutes, the spoon feels hot when removed. When the spoon entered the hot water, the spoon began to absorb energy and convert that energy gain into a change in temperature.

One may have also noticed that after removing the spoon, the temperature of the water dropped slightly. This is a result of energy conservation within the system: as the cold spoon's energy (temperature) increases, the hot water's energy (temperature) must decrease.

The spoon in this example was made out of metal. How would the temperature changes be different if the spoon were plastic? One would expect a cold metal spoon to cause a greater drop in the water temperature than a plastic spoon. However, this is a property of the *specific heat* and mass of the object or substance. Specific heat is informally described as a substance's ability to resist changes in temperature due to the addition or subtraction of heat energy. Some substances require large amounts of energy to change just a slight amount in temperature, while others will change temperature with just a tiny bit of added energy.

The mathematical relationship between energy Q and temperature change ΔT for a substance of mass m is shown here:

$$Q = mc\Delta T \qquad \textbf{Eq.1}$$

where c is the specific heat capacity of the substance.

For positive temperature changes (T_{final} - T_{initial} > 0), energy is added to a substance. When ΔT is negative, Q is also negative, which indicates that energy is leaving a substance. Because of energy conservation, we can relate the changes in temperature from one part of the system to the other using this simple relationship:

$$-Q_{\text{lost}} = Q_{\text{gained}} \qquad \textbf{Eq.2}$$

$$-m_1 c_1 \Delta T_1 = m_2 c_2 \Delta T_2 \qquad \textbf{Eq.3}$$

In the spoon example, the right side of Eq.3 corresponds to the energy gained by the spoon; the left corresponds to the energy lost by the hot water; and each has a mass m_n and experiences a change in temperature ΔT_n that is governed by their specific heats c_n.

Materials and Equipment

For each student or group:

- Data collection system
- Temperature sensor, stainless steel
- Beaker, 600-mL
- Calorimetry cup (3)
- Metal sample (3)
- Balance (1 per classroom)
- Hot plate
- Tongs
- Water, 1 L
- String, 15-cm (3)

Safety

Add these important safety precautions to your normal laboratory procedures:

- When using the hot plate, be very careful not to burn your hands or fingers.
- Use a 600-mL beaker for boiling water that can withstand high heat, such as a Pyrex® beaker. Other beakers may shatter when exposed to high heat.
- Boiling water can cause severe burns. Be very careful when using boiling water, and do not carry the beaker without insulated gloves or tongs when it is hot.
- All glass beakers can break when dropped. Be very careful not to drop any of the glassware used in this lab. If an accident does occur, follow the proper cleaning and disposal procedure instituted by your teacher.
- Keep electronic and other sensitive equipment away from water.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

◯	◯	◯	◯	◯
Once the temperature reaches equilibrium (is constant), stop recording data.	Add equal amounts of water to the three calorimeter cups.	Start recording the temperature of the water in the calorimeter cup.	Use the final temperature of the water to calculate the amount of heat energy that was transferred.	Submerge the hot metal sample into the calorimeter water at room temperature.

Procedure

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: When you see the symbol "�" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

Set Up

1. ☐ Start a new experiment on your data collection system. �(1.2)

2. ☐ Connect the temperature sensor to the data collection system. �(2.1)

3. ☐ Display Temperature on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

4. ☐ Create a hot water bath by filling the beaker ¾ full with water and placing the beaker on the hot plate.

5. ☐ Set the hot plate temperature to boil the water in the beaker.

6. ☐ Why is it better to use boiling water to heat the metal sample and not room temperature water?

7. ☐ In this lab, we will use boiling water to heat the metal sample to ~100 °C. Could we have used ice water to cool the sample to ~0 °C so that the temperature of the calorimeter water would drop rather than increase? Explain.

8. ☐ Use the balance to measure the mass of the calorimetry cups, and then record the mass of the calorimeter cups in the Data Analysis section.

9. ☐ Add equal amounts of water to the calorimetry cups (approximately ¾ full), and record the mass of the calorimeter with water in the Data Analysis section for each cup.

Note: The calorimeter and beaker are only ¾ full so that the water level does not spill over the edge up the cup when you submerge the metal sample.

10. ☐ Why do we use a calorimetry cup when measuring the change in water temperature and not just another glass beaker?

11. ☐ Record the mass of each metal sample in the Data Analysis section.

12. ☐ Tie a 15-cm piece of string to each metal sample to make them easier to move from the hot water bath to the calorimeter cup.

Collect Data

13. ☐ Start data recording. �(6.2)

14. ☐ Check the temperature in each calorimeter to insure it is room temperature, and record this value in the Data Analysis section as the initial temperature of the water in the calorimeters.

15. ☐ Allow the hot water bath to come to a boil, and then use the temperature sensor to measure the temperature of the boiling water.

16. ☐ Why do you think it is important to measure the temperature of the boiling water if we "know" that water boils at 100 °C?

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17. ☐ Stop data recording. �(6.2)

18. ☐ Remove the temperature sensor from the hot water bath.

19. ☐ Place the first sample in the hot water bath, and allow it to equilibrate for 5 to 10 minutes.

20. ☐ Place the temperature sensor in the first calorimeter.

21. ☐ Start data recording. �(6.2)

22. ☐ Quickly but carefully transfer the first metal sample from the hot water bath to the calorimeter.

23. ☐ Place the second metal sample in the hot water bath.

24. ☐ Once the temperature in the calorimeter reaches equilibrium (remains constant), stop data recording. �(6.2)

25. ☐ Use the graph of Temperature versus Time on your data collection system to find the value of the equilibrium temperature. Record the temperature as the final temperature of both the water and the metal sample in the Data Analysis section. �(9.1)

26. ☐ Place the temperature sensor in the second calorimeter.

27. ☐ Start data recording. �(6.2)

28. ☐ Quickly but carefully transfer the second metal sample from the hot water bath to the calorimeter.

29. ☐ Place the third metal sample in the hot water bath.

30. ☐ Once the temperature in the calorimeter reaches equilibrium (remains constant), stop data recording. �(6.2)

31. ☐ Use the graph of Temperature versus Time on your data collection system to find the value of the equilibrium temperature. Record the temperature as the final temperature of both the water and the metal sample in the Data Analysis section. �(9.1)

32. ☐ Place the temperature sensor in the third calorimeter.

33. ☐ Start data recording. �(6.2)

34. ☐ Quickly but carefully transfer the third metal sample from the hot water bath to the calorimeter.

35. ☐ Once the temperature in the calorimeter reaches equilibrium, (remains constant) stop data recording. �(6.2)

36. ☐ Use the graph of Temperature versus Time on your data collection system to find the value of the equilibrium temperature. Record the temperature as the final temperature of both the water and the metal sample in the Data Analysis section. �(9.1)

37. ☐ Save your experiment as instructed by your teacher. �11.1)

38. ☐ Make sure your hot plate is turned off, and carefully clean-up as instructed by your teacher.

Data Analysis

1. ☐ After recording temperature data for all three of your samples, calculate the change in temperature ΔT for both the calorimeter water and the metal sample. Then, use those values to calculate the specific heat c of the sample.

The Specific heat of water is c_{water} = 4,186 J/(kg·°C).

Mass of the calorimeter cup: ____________
Mass of the calorimeter cup plus water: ____________

Table 1: Mass and temperature data

Sample 1	T_{final} (°C)	$T_{initial}$ (°C)	ΔT (°C)	m (kg)	Q (J)
Calorimeter Water					
Aluminum					

Mass of the calorimeter cup: ____________
Mass of the calorimeter cup plus water: ___________

Table 2: Mass and temperature data

Sample 2	T_{final} (°C)	$T_{initial}$ (°C)	ΔT (°C)	m (kg)	Q (J)
Calorimeter Water					
Copper					

Mass of the calorimeter cup: ____________
Mass of the calorimeter cup plus water: __________

Table 3: Mass and temperature data

Unknown Sample	T_{final} **(°C)**	$T_{initial}$ **(°C)**	ΔT **(°C)**	m **(kg)**	Q **(J)**
Calorimeter Water					
Metal Sample					

Analysis Questions

1. **What were your calculated values for the specific heat of your first two sample metals? How did they correspond to the theoretical values shown in the table below? What was your percent error for each?**

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Table 3: Specific heat of different metals

Substance	**Specific Heat J/(kg·°C)**
Aluminum	900
Beryllium	1,830
Cadmium	230
Copper	387
Germanium	322
Gold	129
Iron	448
Lead	128
Silver	234
Brass	380

2. Using the table above, what kind of metal is your unknown sample?

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3. Explain some of the factors that may have caused your calculated values for specific heat c to be inaccurate and how these factors may have been avoided.

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Synthesis Questions

Use available resources to help you answer the following questions.

1. If one places a 100 g hot piece of copper in a calorimeter containing 200 g of room temperature (25 °C) water, and the final equilibrium temperature of the water + copper was 75 °C, what was the initial temperature of the copper before it was placed in the calorimeter? Show your work.

2. If a piece of iron and a piece of gold (same mass) were both exposed to the same amount of heat (Assume 100 g samples with the addition of 1,200 J of energy), which one would be hotter? Explain.

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3. Explain in terms of energy why wood is used to insulate homes rather than metal, considering that the specific heat of wood is ~1,800 J/(kg·°C).

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Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Which of the following metals requires the most energy to experience a temperature change of 20 °C?

A. Copper

B. Gold.

C. Lead

D. Silver

2. If 300 g of room temperature water (25 °C) is heated and experiences a temperature increase of 40 °C, how much energy has the water absorbed?

- **A.** 75.2 kJ
- **B.** 50.2 J
- **C.** 80.7 J
- **D.** 50.2 kJ

3. If the same water from the previous question was then heated again such that it experiences another temperature increase of 40 °C, how much more energy has the water absorbed?

- **A.** 50.2 kJ
- **B.** 75.2 kJ
- **C.** 725.0 kJ
- **D.** Cannot solve this with just Eq.1; water turns to steam at 100 °C.

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. When energy is added to a substance in the form of heat, that substance experience a change in ____________. However, not all substances experience the same change in temperature from the same addition of ____________. The magnitude of temperature change depends on that substance's ____________. A substance with a large specific heat has a tendency to ____________ temperature changes with the addition or subtraction of heat energy, while a substance with a ____________ specific heat will easily ____________ in temperature with the addition of heat energy.

2. Energy is a ____________ quantity, thus indicating that the total energy in a closed system is ____________ capacity. If a closed system consisted of a hot piece of copper submerged in a pool of cold mercury, the ____________ lost by the piece of copper must equal the amount of energy gained by the mercury. The mercury's ____________ would increase while the copper's temperature would decrease relative to the specific heat and ____________ of each substance.

Key Term Challenge Word Bank

Paragraph 1	Paragraph 2
Temperature	Mass
Large	Temperature
Latent heat	Conserved
Increase	Energy
Energy	Specific heat
Resist	Constant
Specific heat	Dissipative
Small	Transferred
Conduct	Lost
	Volume