Specific Heat

Introduction

Three different metals of equal mass are heated to the same temperature in a boiling water bath. The metals are then added to three insulated foam cups, each containing the same amount of water initially at room temperature. The temperature of the water changes by different amounts for the three metals. Why?

Concepts

- Heat
- Heat capacity
- Specific heat
- Calorimetry

Materials

Metal shot, Al, Pb, and Zn, 40–60 g each*

Balance, centigram (0.01-g precision)

Beaker, 600-mL

Beakers, 400-mL, 3

Boiling stones

Digital thermometers, 3

Graduated cylinder, 100-mL

Hot plate or Bunsen burner setup

Insulated foam cups, 6

Stirring rods, 3

Test tubes, large (25 × 150 mm), 3

Test tube holder or tongs

Water

*The "Specific Heat Set" (AP9220) is ideal for this activity. See the *Tips* section.

Safety Precautions

Handle hot metal samples with care to avoid burns. Wear chemical splash goggles whenever working with chemicals, heat, or glassware in the lab.

Procedure

Recruit student volunteers to measure and record data.

1. Prepare a boiling water bath: Fill a large, 600-mL beaker half-full with water, add a couple of boiling stones, and heat the water to boiling using a hot plate or Bunsen burner setup.
2. Prepare equal-mass (±0.2 g) samples, 40–60 g each, of the three metals. Record the mass and identity of each metal.
3. Label three large test tubes and carefully add one metal sample to each tube. Place all test tubes in the boiling water bath for at least 10 minutes to heat the metals to 100 °C.
4. Prepare three calorimeters: Nest two insulated foam (coffee) cups together and set them in a 400-mL beaker for extra stability. Label the calorimeters. Using a graduated cylinder, add 50.0 mL of water to each calorimeter. Measure and record the initial temperature of water in each.
5. Using a test tube holder, lift each test tube from the boiling water bath and quickly, yet carefully, pour the metal sample into the appropriately labeled calorimeter.
6. Stir the water in each calorimeter with a stirring rod. Measure and record the highest (final) temperature the water reaches.
7. Compare the final temperature of the water in the three calorimeters. Are they the same? Why or why not? Discuss which variables have been controlled in each calorimeter experiment and which variables are different. *[The following variables were controlled in this experiment: the volume (mass) and initial temperature of the water, the initial temperature of the metals, the mass of the metals, the type of reaction vessel. The variable that is different is the identity and nature of the metal. In order for the final temperature of the water to be different in the three calorimeters, different amounts of heat must have been*

added. Students should conclude that different substances—in this case metals—store different amounts of heat at the same temperature. The ability of a substance to store heat is one way of defining the heat capacity or specific heat of a substance.]

8. *(Optional)* Use the heat equation: $q = m \times s \times \Delta T$, to calculate the amount of heat gained by the water in each calorimeter. *Note:* Use the mass and specific heat of *water* (4.18 J/g·C) in this calculation.
9. *(Optional)* According to the law of conservation of energy, the energy gained by the water in each calorimeter is equal to the amount of heat lost by the metal sample as it cooled. Calculate the amount of heat lost by each metal sample.
10. *(Optional)* Use the heat equation to calculate the specific heat of each metal. *Note:* Use the mass of the metal and the temperature change of the metal in this calculation. Assume that the initial temperature of the metal is 100 °C and the final temperature of the metal is the same as the final temperature of the water in the calorimeter.
11. *(Optional)* Discuss the findings. If the metal samples were not identified at the beginning of the activity, hand out a reference table listing the specific heats of different metals and ask students to identify the metals.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. The water may be rinsed down the drain. The metal samples should be collected, dried, and stored for repeat use.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Constancy, change, and measurement
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter, transfer of energy
Content Standard G: History and Nature of Science, nature of science
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter, conservation of energy and increase in disorder, interactions of energy and matter
Content Standard G: History and Nature of Science, nature of scientific knowledge

Tips

- Aluminum, zinc, and lead are good choices for this demonstration. Their specific heat values (in units of J/g·°C) are high (0.899), medium (0.385), and low (0.129), respectively. Copper and tin shot are also suitable.
- The "Specific Heat Set" available from Flinn Scientific, Inc. (Catalog No. AP9220) contains five different metal cylinders (aluminum, copper, lead, tin, and zinc) of equal mass (58.2 ±0.1 g). The pre-massed metal cylinders are convenient, easy-to-use, and give a wide range of temperature changes in this experiment.
- Prepare the boiling water bath and calorimeters and pre-measure the metal samples before class begins. It is important that students see, however, that the metals have the same mass and that the amount of water in each calorimeter is the same.
- This demonstration may be used on a qualitative level (steps 1–7) to illustrate the definition of specific heat, or it may be used to introduce a quantitative in-class activity (steps 8–11). If specific heat and heat equation calculations are included in your curriculum, this demonstration will make them more real and less contrived than sample problems from a book.
- Discuss the specific heats of different metals in terms of their use in cookware (pots and pans). Is a low or high specific heat desired in cookware? What other properties of the metals are important in this application?
- Because the density of aluminum is much lower than that of lead and zinc, an equal mass of Al occupies a much larger volume than Pb or Zn. Choose a mass such that the aluminum shot in the test tube will be submerged in the boiling

water bath.

Discussion

Transfer of heat or heat flow always occurs in one direction—from a region of higher temperature to a region of lower temperature—until some final equilibrium temperature is reached. In this demonstration, heat is transferred from a hot metal sample to colder water sample. Each metal causes the temperature of the water to increase to a different extent. This means that each metal has a different ability to absorb and store heat energy.

The ability of a substance to contain or absorb heat energy is called its heat capacity. Heat capacity is an extensive property—it depends on the amount or mass of the sample. Specific heat is a measure of the heat capacity of a substance. Specific heat is defined as the amount of heat required to increase the temperature of one gram of a substance by one degree Celsius. It is an intensive property, a characteristic physical property of a substance. Specific heat is usually represented by the symbol s and is given in SI units of J/g·°C. Table 1 lists the specific heats of six metals that may be used in this demonstration. Notice a general trend—the larger the atomic mass of a metal, the lower its specific heat. Copper and zinc have very similar atomic masses, and identical specific heat values.

Table 1.

Metal	**Aluminum**	**Copper**	**Lead**	**Silver**	**Tin**	**Zinc**
Specific Heat (J/gz°C)	0.899	0.385	0.129	0.234	0.222	0.385

Water is a very unusual substance in many ways. The specific heat of water is very high, 4.18 J/g·°C. The high specific heat value of water means that water is able to absorb and store large amounts of heat.

The amount of heat (q) transferred to an object or substance depends on three factors: the amount of the substance (its mass, m), the ability of the substance to absorb heat (its specific heat, s), and the resulting temperature change (ΔT), according to Equation 1. The SI unit of heat (and energy) is the joule (abbreviated J).

$$q = m \times s \times \Delta T \qquad \textit{Equation 1}$$

Equation 1 may be used to calculate the specific heats of the metals used in this demonstration (see Steps 8–11). The heat gained by the water in the calorimeter should be equal in magnitude but opposite in sign to the heat lost by the metal sample in each case:

$$q(\text{gained by water}) = -q(\text{lost by metal}) \qquad \textit{Equation 2}$$

The amount of heat gained by the water is calculated using the mass of water, its specific heat, and the difference between the final and initial temperature of the water in the cup:

$$q(\text{gained by water}) = \text{mass (water)} \times s\,\text{(water)} \times \Delta T\,\text{(water)} \qquad \textit{Equation 3}$$

The amount of heat lost by the metal is calculated using the mass of the metal, its specific heat, and the difference between its final temperature (assumed to be the same as the final temperature of the water in the cup) and its initial temperature (assumed to be equal to the temperature of the boiling water bath in Step 3):

$$q(\text{lost by metal}) = \text{mass (metal)} \times s\,\text{(metal)} \times \Delta T\,\text{(metal)} \qquad \textit{Equation 4}$$

Combining Equations 2–4 makes it possible to calculate the specific heats of the metals using the data obtained in this demonstration. Sample data and results are reported in Table 2 for zinc and aluminum.

Table 2.

	Zinc	Aluminum
Mass of Metal	46.19 g	46.31 g
Mass of Water	49.9 g	49.9 g
Initial Temperature (Calorimeter)	20.0 °C	20.0 °C
Final Temperature (Calorimeter)	26.2 °C	32.9 °C
Initial Temperature (Metal)	100 °C	100 °C
ΔT (Water)	6.2 °C	12.9 °C
ΔT (Metal)	73.8 °C	67.1 °C
Specific Heat (Metal), calculated	0.38 J/g·°C	0.866 J/g·°C
Specific Heat (Metal), literature	0.385	0.899
Percent Error	1%	4%

Materials for Specific Heat are available from Flinn Scientific, Inc.

Catalog No.	Description
AP9220	Specific Heat Set
AP6049	Flinn Digital Pocket Thermometer, Economy Choice
AP7234	Hot Plate, Flinn, 7″ × 7″
A0262	Aluminum Shot, 100 g
Z0021	Zinc Shot, 100 g

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.