

# Calorimetry Lab - Specific Heat Capacity

## Introduction

Experience tells us that if a hot piece of metal is added to water, the temperature of the water will rise. If several different metals having the same mass are heated to the same temperature and added to the same amount of water at the same temperature, will the final temperature of the each mixture be the same?

## What is Specific Heat?

The ability of any material to retain heat energy is called that material's heat capacity. The measure of heat capacity, or the quantity of heat needed to raise the temperature of one gram of a substance by one degree Celsius, is termed specific heat and is represented by the symbol  $s$ ,  $C_p$ ,  $c$ . The SI units for specific heat are given in J/gC. Specific heat values are also commonly given in cal/gC, where 1 calorie=4.184 Joules. The specific heats for some common substances are provided in Table 1.

Table 1. Specific Heats of Some Common Substances

Substance	Specific Heat (in J/gC)
Water	4.184 (1.00 cal/gC)
Wood	1.76
Aluminum	0.902
Concrete	0.88
Glass	0.84
Iron	0.451
Nickel	0.444
Copper	0.385
Zinc	0.385
Tin	0.222
Lead	0.129

Compare the heat capacities of concrete and wood. Because the specific heat of wood is twice as great as that of concrete, it takes about twice as much heat to raise the temperature of wood than concrete. This can be verified by comparing the feel of walking on concrete versus walking on wood on a hot, sunny day with bare feet. The concrete feels hotter. The sun gives off energy which is absorbed

by the concrete and the wood equally. However, because the wood has a greater specific heat value, it is able to absorb more heat before its temperature rises, and therefore it does not feel as hot as the concrete feels to the bare feet.

*General Rule #1 - The greater the specific heat value, the less the temperature will rise when a given heat energy is absorbed.*

Not only does the specific heat value describe how much heat may be absorbed by a substance before its temperature rises, it also describes the ability of a substance to deliver heat to a cooler object.

*General Rule #2 - As the specific heat value decreases, the ability to deliver heat to a cooler object increases.*

For example, imagine holding two hot pieces of metal - X ( $C_p=2 \text{ J/gC}$ ) and Y ( $C_p=3 \text{ J/gC}$ ). If the hot piece of metal X was held in one hand and the hot piece of metal Y in the other hand, the hand holding the metal X would get hotter. Because metal X has a specific heat less than metal Y, the metal X sample transfers heat to a cooler object (your hand) more readily.

### **Why do different materials possess different specific heat values?**

One reason for the variation is that each substance is made up of atoms that have different masses. The mass of each copper atom is larger than the mass of each aluminum atom, for example. Therefore a given mass (such as 58 g of copper) has fewer atoms than the same mass of aluminum. When heat is added to 58 g of copper, fewer atoms need to be put in motion (remember temperature is related to kinetic energy). Thus, less heat is needed to increase the kinetic energy of the atoms in the sample, and raise the temperature by 1 C. As a result, the specific heat value for copper is lower than the specific heat of aluminum. Notice that copper and zinc have identical specific heat values. This is due to the similar mass of the atoms.

*General Rule #3 - The larger the metal atom, the lower is specific heat value.*

### **How is the specific heat of a material determined?**

Heat transfer 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 experiment, heat is transferred from a hot metal sample to a colder water sample. Because each metal has a different specific heat, each metal will cause the temperature of the water to increase to a different extent. The transfer of energy can be detected by measuring the resulting temperature change,  $\Delta T$ , calculated by taking the final temperature minus the initial temperature, according to Equation 1.

$$\Delta T = \text{final temperature} - \text{initial temperature} = T_f - T_i \quad (\text{Equation 1})$$

For the hotter object in this scenario (the metal), the amount of heat ( $q$ ) delivered by the metal ( $q_{\text{metal}}$ ) is equal to the mass of the metal ( $m_{\text{metal}}$ ) multiplied by the specific heat of the metal ( $C_{p\text{metal}}$ ) multiplied by the temperature change of the metal ( $\Delta T_{\text{metal}}$ ). This relationship is given by Equation 2.

$$q_{\text{metal}} = (m_{\text{metal}})(C_{p\text{metal}})(\Delta T_{\text{metal}}) \quad (\text{Equation 2})$$

For the cooler object in this scenario (the water), the amount of heat absorbed by the water ( $q_{\text{water}}$ ) is equal to the mass of the water ( $m_{\text{water}}$ ) multiplied by the specific heat of the water ( $C_{p\text{water}}$ ) multiplied by the temperature change of the water ( $\Delta T_{\text{water}}$ ). This relationship is given by Equation 3.

$$q_{\text{water}} = (m_{\text{water}})(C_{p\text{water}})(\Delta T_{\text{water}}) \quad (\text{Equation 3})$$

By convention, the sign of  $q$  is a signal showing the direction of heat transfer. When heat is transferred out of a material, the sign of  $q$  is negative. Conversely, when heat is absorbed by a material,  $q$  is positive. The signs of  $q$ , along with the necessary associated temperature changes, are summarized in Table 2.

Table 2. Heat Transfer

<b>Direction of Heat Transfer</b>	<b>Sign of <math>q</math></b>	<b>Sign of <math>\Delta T</math></b>	<b>Change in Temperature of Material</b>
Heat is absorbed (transferred into a material)	+	+	Temperature increases
Heat is delivered (transferred out of a material)	-	-	Temperature decreases

According to the Law of Conservation of Energy, the heat delivered by the heated metal,  $q_{\text{metal}}$ , must be equal to the heat absorbed by the water,  $q_{\text{water}}$ , and its surroundings. Incorporating the sign convention given in Table 2 gives Equations 4 and 5.

$$q_{\text{metal}} = - q_{\text{water}} \quad (\text{Equation 4})$$

$$(m_{\text{metal}})(C_{p\text{metal}})(\Delta T_{\text{metal}}) = - (m_{\text{water}})(C_{p\text{water}})(\Delta T_{\text{water}}) \quad (\text{Equation 5})$$

In this laboratory activity, Equation 5 is used to calculate the specific heat of a heated metal added to a water sample. For calculation purposes, it is important to realize that when the metal is added to the water, the final temperature of both materials will be the same. The calculated specific heat value will then be compared to the known specific heat value given in Table 1.

To make accurate measurements of heat transfer and to prevent heat loss to the surroundings, an insulating device known as a calorimeter is used. A calorimeter is a device used to measure heat flow, where the heat given off by a material is absorbed by the calorimeter and its contents (often water or other material of known heat capacity). In this laboratory, a set of two Styrofoam cups will be used as the calorimeter.

### **Sample Calculation:**

If a 58 g sample of metal at 100 C is placed into a calorimeter containing 60 g of water at 18 C, the temperature of the water increases to 22 C.

- a. Calculate the amount of heat absorbed by the water in Joules.
- b. Determine the identity of the metal by calculating its specific heat.  
(Note: Assume no heat is lost to the surroundings.)

### **Materials**

Unknown metal	Stirring rod
Balance	Styrofoam cups (2)
Beaker	Test tube holder
Grad cylinder	Test tube, large
Hot plate	Thermometer
Paper towels	Tap water

### **Safety**

Handle the hot metal samples with care to avoid burns. Wear goggles!

### **Pre-Lab**

1. How much energy (in Joules) is needed to heat an iron nail with a mass of 7.0g from 25 C until it becomes red hot at 750 C? Show all work.
2. Calculate the amount of energy (in Calories) released during the combustion of a peanut that heats up 100 g of water from 20 C to 65 C. (Note: Food Calories are given in kilocalories where 1 Calorie = 1 kcal = 1000 cal) Show all work.

## Procedure

1. Fill a large beaker about half-full with tap water. Heat the water to a boil using a hot plate.
2. Weigh 40 - 50 g of the assigned metal shot and place it in a large test tube. Record the exact mass of the metal in the Data Table.
3. Put the test tube in the boiling water bath for approximately 10 - 15 minutes. Be sure the test tube is in the water so the metal is completely submerged.
4. Stack 2 styrofoam cups, one inside the other. This set of cups will be the calorimeter. Mass the empty calorimeter and record its mass in the Data Table.
5. Pour 25 mL of tap water into the calorimeter and mass the calorimeter again. Record this mass in the Data Table.
6. Measure the temperature of the water in degrees Celsius. Record this temperature in the Data Table.
7. Determine the temperature of the metal sample. To do this, measure the temperature of the boiling water bath. An assumption is made that the temperature of the metal is equal to the temperature of the water bath. Record this as  $T_{\text{metal}}$  in the Data Table.
8. Hold the thermometer in the calorimeter with the tap water. Caution: DO NOT LEAVE THE THERMOMETER SITTING IN THE CALORIMETER BECAUSE IT WILL LIKELY CAUSE THE CUP TO TIP OVER AND BREAK THE THERMOMETER.
9. Using a test tube holder, lift the test tube containing the heated metal shot from the boiling water bath and quickly, yet carefully, pour the metal shot into the calorimeter. Make sure no hot water from the outside of the test tube drips into the calorimeter.
10. Gently stir the water and metal shot in the calorimeter with a stirring rod. Measure and record the highest temperature the mixture reaches. Record this temperature in the Data Table as temperature of mixture ( $T_{\text{mixture}}$ ). Caution:

DO NOT STIR THE MIXTURE WITH THE THERMOMETER AS IT COULD BREAK.

11. Drain the water out of the calorimeter and pour the metal shot onto paper towels. Pat the metal dry thoroughly. Dry the calorimeter. Repeat steps 2-10 for 2 additional trials using the same type of metal shot.
12. Repeat steps 2-10 for the other type of metal shot.
13. Return the metal shot to the front counter.

NOTE: When you come in on Thursday or Friday, I will have a data table for you. You should have prepared all Pre-Lab activities for review. A hard copy of all procedures and Pre-Lab calculations is required before you may complete the lab and will count as your pre-lab quiz grade. You should thoroughly understand all calculations and procedures before you come to class.

One paper is required for each lab group of 2 students. Make sure both partners names appear on the paper.