	Sample #1	Sample #2	Sample #3
mass of dipper			
mass of shot+dipper			
mass of shot (m_s)			
mass of stirrer			
mass of cup			
mass of cup+stirrer (m_c)			
mass of water+cup			
mass of water (m_w)			
initial shot temperature (T_1)			
initial calorimeter temperature (T_2)			
final temperature (T_3)			
measured heat capacity of sample (c_s)			

5. While the metal is heating, add some cold water to the inner cup of the calorimeter and measure the mass. Do not fill the inner cup so full that it will overflow when the sample of metal is added to the water. Assemble the calorimeter and place one thermometer into the cold water.

6. When the metal is at or above 95°C, record the temperature T_1 of the metal shot and the temperature T_2 of the calorimeter (= water + cup + stirrer combination). Remove the dipper from the boiler and quickly pour the shot quickly into the cold water. Put the lid on. Stir occasionally, and record the highest temperature reached by the calorimeter/shot combination (T_3). It will take several minutes for equilibrium to be reached.

7. Pour out the water from the inner cup, but save the shot. Pout the shot onto a paper towel to dry. Carefully dry the dipper: the fact that it was very warm means that most of the water on the outside will evaporate very quickly.

8. Repeat steps **4–7** for the other two unknown samples.

9. For each sample, compute the heat capacity from your data, with the help of Eq. (2). SHOW YOUR WORK! Based on the values tabulated below, what might the material in each sample be?

Substance	Specific Heat	Substance	Specific Heat
Aluminum	0.220 cal/g·°C	Lead	0.031 cal/g·°C
Antimony	0.049 cal/g·°C	Nickel	0.109 cal/g·°C
Arsenic	0.079 cal/g·°C	Platinum	0.032 cal/g·°C
Bismuth	0.030 cal/g·°C	Silver	0.057 cal/g·°C
Brass	0.090 cal/g·°C	Steel	0.118 cal/g·°C
Cobalt	0.109 cal/g·°C	Tin	0.055 cal/g·°C
Copper	0.093 cal/g·°C	Uranium	0.028 cal/g·°C
Gold	0.031 cal/g·°C	Water	1.000 cal/g·°C
Iron	0.110 cal/g·°C	Zinc	0.092 cal/g·°C

In Eq. (1), m is the mass of the object and c is the *specific heat* of the object. The specific heat depends only on the type of material which the object is made of, and so a measurement of c can give some information on the nature of an unknown sample. When people started measuring thermal properties of matter, they didn't know that heat was a form of energy. Thus, it is traditional to use a different set of units for heat than for other forms of energy. The *calorie* is the standard heat unit, and 1 cal is the amount of heat needed to raise the temperature of 1 gram of water by 1 degree Celsius.* The convention implicit in Eq. (1) is such that when the final temperature T_f is larger than the initial temperature T_i, Q is positive (heat absorbed by the object). Likewise, when T_f is lower than T_i, Q is negative (heat given off by the object). Because Eq. (1) depends on a difference of two temperatures, we may use either the Celsius or Kelvin scales to specify the temperature.

In this experiment, hot metal shot is added to the cold calorimeter. The metal shot gives up heat since it cools, while the calorimeter absorbs heat as it gets warmer. The heat given off by the metal shot plus the heat absorbed by the calorimeter must equal zero. If the metal shot starts at temperature T_1, the calorimeter starts at temperature T_2, and everything ends up at temperature T_3, repeated application of Eq. (1) tells us that

$$m_s c_s (T_3 - T_1) + m_w c_w (T_3 - T_2) + m_c c_c (T_3 - T_2) = 0. \tag{2}$$

In Eq. (2), the subscript s stands for "sample" (the metal shot), w stands for "water", and c stands for cup (plus the stirrer). If you measure all three temperatures and the appropriate masses, then the only unknown in Eq. (2) is the specific heat of the metal shot, c_s.

Procedure

1. Fill the boiler $\frac{1}{3}$ to $\frac{1}{2}$ full of water, and start heating it on the hot plate.

2. Measure and record the mass of the dipper to the nearest 0.05 gram (use the table on page 4). Although the dipper is really a part of the boiler, we need to know its mass since we need a container to hold the metal shot while we measure its mass.

3. Separately measure and record (on page 4) the masses of the inner cup and the stirrer from the calorimeter. Be sure to measure these masses while these objects are dry!

4. Measure out some **dry** metal shot, put it into the dipper, and measure the mass of the combination. Place the dipper plus the shot into the boiler (do **not** pour the metal shot into the hot water, put the dipper containing the shot into the water). Wait for the metal to heat, stirring occasionally.

NEVER USE THE GLASS THERMOMETERS TO STIR THE METAL SHOT! This will result in a broken thermometer and unwanted experience in filling out the paperwork required to report a mercury spill to the proper authorities.

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* The *Calorie*, used to measure the energy content of food, is actually 1000 calories. Correct usage requires that the food Calorie always be written with a capital "C", to indicate that it is a larger unit.

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Experiment 11 – Specific Heat of Solids

Objective

To measure the specific heat capacity of several different samples of metal.

Equipment

- Calorimeter (inner and outer cups, stirrer, insulating ring, and lid).
- Boiler.
- Hot plate.
- Balance.
- 2 thermometers.
- Various unknown samples of metal shot.

Introduction

Heat and temperature are actually different quantities. Heat is a quantity of thermal energy, while temperature determines the direction and rate of heat transfer between two objects or an object and its surroundings. It is possible for an object to have a very high temperature but contain very little heat and vice versa. The purpose of this experiment is to understand the difference between heat and temperature, and make some quantitative measurements concerning both.

We'll be using a technique called *calorimetry* to measure the specific heat. Calorimetry is literally "the measurement of heat content." For our purposes, we'll use a simple calorimeter consisting of an aluminum cup filled with cold water (plus an aluminum stirrer). The cup and water are isolated from the surroundings as much as possible, through the use of a non-heat-conducting ring, a layer of air, and a non-heat-conducting lid. You measure the temperature of the calorimeter (= water + cup + stirrer) and the temperature of the sample of material. You next add the sample to the water and stir. The highest temperature reached after adding the sample allows you to determine the specific heat of the solid.

Calorimetry is a standard laboratory technique, and is used in many sciences from chemistry to particle physics (although the calorimeters used differ in form and sophistication).

Theory

The amount of heat Q needed to change the temperature of an object from some initial value T_i to some final value T_f depends on (at least) two things: the mass of the object and the difference in temperature. A more massive object naturally needs more thermal energy to change temperature. Likewise, a larger change in temperature also requires more heat. It turns out that these are the only factors which matter, and that the amount of heat required is given by

$$\begin{aligned} Q &= mc(T_f - T_i) \\ &= mc\Delta T. \end{aligned} \tag{1}$$