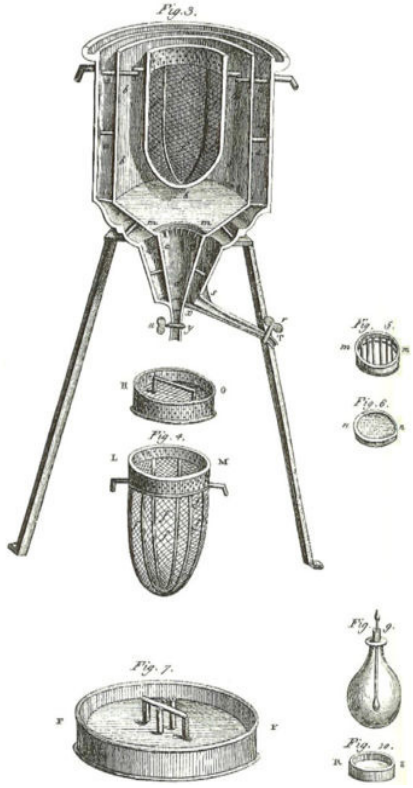
Calorimeter

Goals: Collect data based on observation of thermal equilibrium. Compare thermal properties of different metals.

APPARATUS

A calorimeter is a device designed to measure the exchange of heat between two bodies. It works by minimizing the loss of heat from inside the calorimeter to the outside. The first calorimeters were built in the late 1700's by the chemist Antoine Lavoisier, and they are still important in both chemistry and physics.



The calorimeter in this experiment consists of an inner aluminum cup surrounded by foam and an outer pot to insulate the contents. with a narrow opening at the top and a pressure relief nozzle at the side. The pot has a lid that provides some additional insulation and can hold a thermometer and an electric heating coil.

The water in the inner cup can be heated to boiling by supplying 2.5 A of current to the coil from a separate power supply. It is important to not provide too much current which can damage the supply. A low temperature source is made by putting ice in a cup of water. It will stay at 0 C as long as there is both ice and water in the cup.

THEORY

Mechanical energy includes the kinetic energy of motion and the potential energy of position. At the microscopic level, atoms and molecules are in constant motion and we can speak of the internal energy of and object. If the substance is an ideal gas, the internal energy is the average kinetic energy of the atoms times the number of atoms. Like kinetic and potential energy, internal energy must be considered for the correct conservation of energy.

Temperature is a measure of the internal energy of matter. It is measured in kelvin (K) or ^{o}C (0 ^{o}C = 273 K). For an ideal gas the internal energy $U = (3/2)\ NkT$, where N is the number of atoms, T is the temperature, and k is a constant equal to 1.38 x 10^{-23} J/K (Boltzmann's constant).

When two objects are at different temperatures, the hotter object will lose internal energy and cool off, while the cooler object will gain internal energy and heat up. The energy that is transferred from one object to another because they are at different temperatures is called *heat*. Like work, heat is a process that changes the energy of on object. Like work it could be measured in J, but is customarily measured calories (1 cal = 4.186 J). The calorie is the amount of heat required to raise the temperature of 1 g water by 1 ^{o}C.

The amount of heat needed to raise the temperature of other objects depends on the material. The specific heat (c) is the measure of how much heat it takes to raise the temperature. Mathematically, the heat (Q) is related to the mass (m) and change in temperature (ΔT) by EQ 1.

$$Q = mc\Delta T \qquad \textbf{(EQ 1)}$$

Based on the definition of the calorie, water has a specific heat c_w = 1.00 cal/g ^{o}C. Some other specific heats are in Table 1.

TABLE 1. Specific Heats

Material	Specific Heat, c (cal/g ^{o}C)
Water, c_w	1.000
Aluminum, c_{Al}	0.215
Steel (Iron), c_{SS}	0.111
Copper, c_{Cu}	0.093
Tin, c_{Sn}	0.054

Since energy is conserved, the heat gained by any substance equals the heat lost by another. In our experiment, heat will be lost by an aluminum cup of mass (m_{cup}) and water (m_w) as they decrease by a temperature ΔT_1. The heat will be gained by a metal slug of mass (m) as it increases by a temperature ΔT_2. EQ 2 represents the balance of heat lost to heat gained.

$$m_w c_w \Delta T_1 + m_{cup} c_{Al} \Delta T_1 = m c \Delta T_2 \qquad \textbf{(EQ 2)}$$

This equation can be solved for the unknown specific heat (c).

$$c = \frac{(m_w c_w + m_{cup} c_{Al}) \Delta T_1}{m \Delta T_2} \qquad \textbf{(EQ 3)}$$

DATA COLLECTION

1. Weigh and record the mass of the inner aluminum cup from the calorimeter (m_{cup}).
2. Fill the inner aluminum cup of the calorimeter about halfway full of water from the sink. Weigh the cup and water, and record the mass difference due to the water (m_w).
3. Place the lid on the calorimeter and see that the thermometer and heating coil are both in the water and not touching the aluminum cup.
4. Connect the power supply to the heating coil with banana plug cables. Turn on the power supply to read 2.5 A (about 4.5 to 5.0 V). Heat the water until it reaches 50 ^{o}C, then turn off the power supply.
5. Fill another cup with water and ice, make sure that unmelted ice remains in the cup during the experiment to keep the temperature at 0 ^{o}C.
6. Weigh each of the three metal slugs (steel: m_{SS}, copper: m_{Cu}, tin: m_{Sn}) and place them in the ice water.
7. Record the temperature of the water in the calorimeter.
8. Remove the lid from the calorimeter, place one of the slugs in the water in the calorimeter, then replace the lid. See that the thermometer is not touching the slug.
9. Record the temperature every 30 s until the temperature reaches equilibrium.
10. Remove the slug and turn on the power supply to reheat the water to 50 ^{o}C. Turn off the power supply.
11. Repeat steps 7 through 10 for each of the other two slugs.

DATA ANALYSIS

12. Make a table of data for each of the three slugs.

13. Find the temperature difference ΔT_1 by subtracting the final equilibrium temperature in step 9 from the initial temperature in step 7.

14. Find the temperature difference ΔT_2 by using the final equilibrium temperature in step 9, since it is compared to the ice water temperature 0 ^{o}C.

15. Find the specific heats with EQ 3. Use the masses measured in steps 2 and 3, the specific heats for water and the aluminum cup from Table 1, and the temperature differences calculated in steps 10 and 11.

16. Calculate the error on each of the measured specific heats.

17. Create a report that includes the raw data and calculated values in table form. Include the error on each of the values in the table. Remember to include captions that distinguish the tables and graphs from each other and enough text to help the reader follow the steps. Don't just submit the tables.

18. Your TA will assign an additional question or two to answer in the report. This work should be done by each group member individually.

19. Each student should assemble a single report from the group data report and the additional individual question. This report will be turned in for grading.