NORTHERN ILLINOIS UNIVERSITY

PHYSICS DEPARTMENT

Physics 210 – Mechanics & Heat Fall 2022

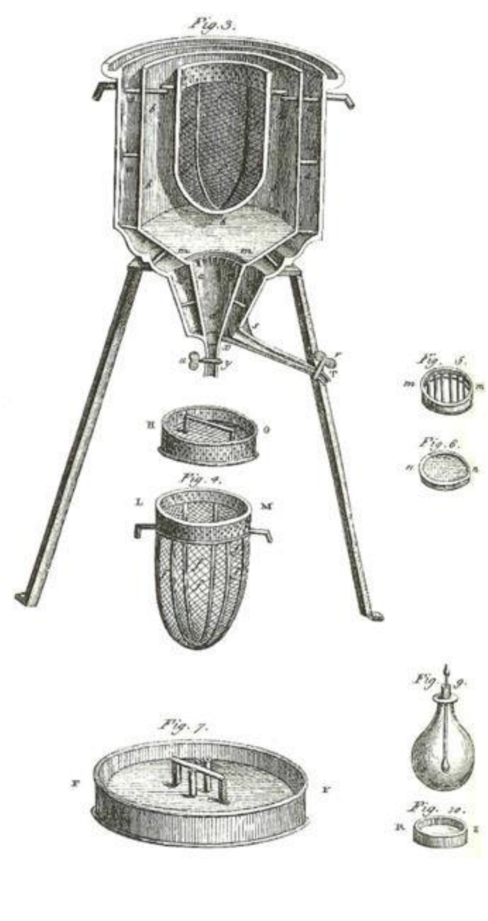
Lab #12

Lab Writeup Due: Tue/Wed/Thu, Nov. 29/30/Dec. 1, 2022
Read OpenStax: Chapter 14.1-14.3, Lecture Notes #11

Specific Heat

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. There is 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.

Water is heated externally via a heater to 50°C and is poured into the inner aluminum cup. A low temperature source consisting of an ice-water mixture in another cup is also used to cool objects to 0°C. The ice-water mixture 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 $(0°\text{C} = 273\,\text{K})$. For an ideal gas the internal energy $U = (3/2)NkT$, where N is the number of atoms, T is the temperature, and $k = 1.38 \times 10^{-23}$ 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—it could be measured in joules, but it is customarily measured in calories $(1\,\text{cal} = 4.186\,\text{J})$. The calorie is the amount of heat required to raise the temperature of 1 gram of water 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

$$Q = mc\Delta T \tag{1}$$

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

TABLE 1. Specific Heats

Material	***c***	**Specific Heat (cal/g°C)**
Water	c_w	1.00
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 substance. In our experiment, heat will be gained by an aluminum cup of mass m_{cup} and water m_w as they increase by a temperature ΔT_1. The heat will be lost by a metal slug of mass m as it decreases by a temperature ΔT_2. Eq. (2) below represents the balance of heat gained to heat lost:

$$m_w c_w \Delta T_1 + m_{cup} c_{Al} \Delta T_1 = mc\Delta T_2 \tag{2}$$

This equation can be solved for the unknown specific heat

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

Data Collection

1. Weigh and record the mass, m_{cup}, of the *inner* aluminum cup in the calorimeter.

2. Take an *external* aluminum cup and fill it with water. Place it on the hotplate (***do not place the calorimeter on the hotplate—it will melt!***) and heat the water to 50°C using the thermometer interfaced to the computer (do not let the thermometer touch the sides of the aluminum cup). Once the water reaches 50°C, *turn off the hotplate*, and fill the *inner* aluminum cup of the calorimeter about halfway with water. Weigh the *inner* aluminum filled with water, and record in your lab notebook this mass. From it you should be able to calculate the mass of the water in the cup, m_w.

3. Place the lid on the calorimeter and see that the thermometer is in the water and not touching the *inner* aluminum cup.

4. Fill another cup with water and ice, and make sure that unmelted ice always remains in the cup during the duration of the experiment—this ensures that the ice-water mixture stays at constant temperature of 0°C.

5. Weigh each of the three metal slugs (steel: m_{SS}, copper: m_{Cu}, tin: m_{Sn}) and place them in the ice water.

6. Record the temperature of the water in the calorimeter. Make certain at least 5 minutes has passed before adding any of the slugs so that you have a good idea of what the *thermal drift* is (the change of temperature with time before adding a slug).

7. Remove the lid from the calorimeter. Before placing one of the slugs into the calorimeter, quickly record its temperature by touching it with the thermometer—this is its initial temperature. Then put the lid back on the calorimeter, re-insert the thermometer, and make certain it is not touching the slug.

8. Record the temperature every 30 sec until the temperature reaches equilibrium. Stir the water occasionally to ensure the calorimeter has a uniform temperature distribution. **Save your data** recorded on the computer onto your USB flash drive—you will need it later! (make certain you record it as a ***text file!***). Also, save a screen capture of all plots on the computer for future use.

9. Remove the slug, pour the water into the other *external* aluminum cup, and reheat the water to 50°C. Once it reaches 50°C pour it back into the *inner* aluminum cup of the calorimeter (filled halfway again). Reweigh the *inner* aluminum cup again to find the mass of the water it holds. Record this information in your lab notebook.

10. Repeat Steps 6 through 9 for each of the other two slugs. **Remember to save your data (as a *text file*) before you start measuring the next slug!**

Data Analysis

11. Using Excel, make a table of data for each of the three slugs.

12. Find the temperature difference ΔT_1 (for each slug) by subtracting the final equilibrium temperature in Step 8 from the initial temperature in Step 6.

13. Find the temperature difference ΔT_2 (for each slug) by using the final equilibrium temperature in Step 8 relative to the ice water temperature of 0°C.

14. Carefully examine your *temperature vs. time* plots for the three slugs. Where do you believe thermal equilibrium was achieved?
15. Calculate the specific heat for each slug using Eq. (3), Table 1, and your *temperature vs. time* graphs.

16. Calculate the *percent error* for each of the measured specific heats:

$$\%Error = \left|\frac{Measured - Accepted}{Accepted}\right| \times 100$$

17. Show the specific heat, the *percent error*, and your calculations for each slug to your TA **<u>before</u>** you leave the lab.

18. Examine the *thermal drift* in your *temperature vs. time* curves. It should be quite apparent that the calorimeter system is continually loosing heat to the outside environment. Thus, during your measurement, some heat is being lost. Find a way to correct your measured temperature changes ΔT_1 and ΔT_2 by carefully analyzing the *thermal drift* in your *temperature vs. time* curves well before and well after you drop the slugs into the calorimeter. Recalculate the specific heat for the 3 slugs using your correction factors. How much has this improved your results?

19. Create a report that includes the raw data and calculated values in table form. Include the error of 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. Explain how good your data is and explain all possible sources of error. Explain how you can minimize these sources of error.

20. In your report, explain the direction of heat flow. Also calculate how much heat energy (in Joules) was required to cause the temperature change in each of the slugs.