Laboratory 12: Three Thermodynamics Experiments

Experiment 1: Coefficient of Linear Expansion of Metals

The fact that most objects expand when heated is common knowledge. The change in the linear dimensions of a solid is very nearly proportional to the temperature change over a considerable range of temperature. The increase in length per unit of length per degree change in temperature at 0°C is called the *coefficient of linear expansion,* α .

If L_1 is the length of a rod at temperature T_1, L_2 is the length at temperature T_2, and α is the coefficient of linear expansion, then the amount of expansion is given by

$$\Delta L = \alpha \, L_o \, \Delta T \tag{1}$$

Why does one want to know the coefficient of expansion of a material?

Apparatus

The type of apparatus you will use in this experiment is illustrated in the Figure 1. A metal rod whose length you have measured is placed in the steam jacket and held in place by stoppers at each end. Steam for heating the rod is supplied by a boiler connected by a rubber hose to the jacket inlet. One end of the rod, protruding a little beyond the stopper, makes contact with a fixed end stop, while the other end makes contact with a micrometer stop designed to measure the change in length as the rod expands. The increase in length is determined by the difference in micrometer readings before and after heating. A battery and a light (not shown) are connected between the end stops and complete a light circuit when the micrometer screw makes contact with the rod. Also needed are a Bunsen burner and hose, meter stick, towel, two metal rods (different materials), metal thermometer, boiler and hose, and a boiler stand.

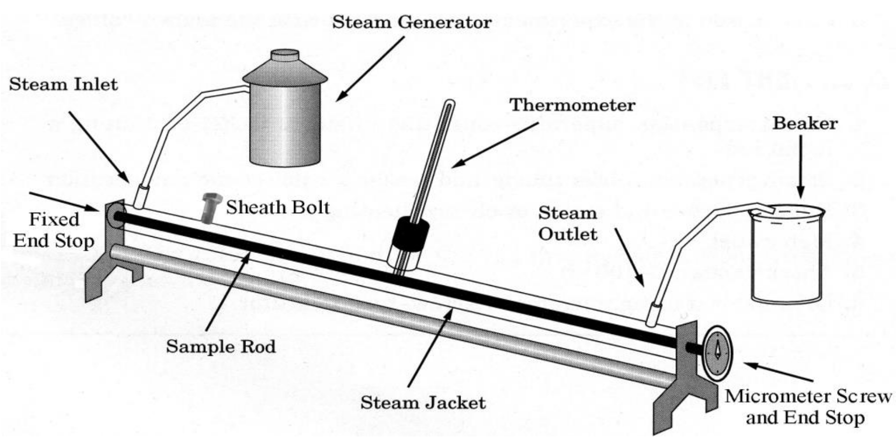

Figure 1 Experimental setup for measuring the coefficient of expansion.

Procedure

1. Fill the boiler about one-half full of water and start it heating while other adjustments are being made. Do not connect the hose to the steam jacket yet. Place the end of the hose in the sink. Record your initial guess for the kind of material of which each rod is made based on visual inspection.

2. Measure the length of each rod and record their lengths L_1 in table 1.
3. Insert one of the rods in the jacket and tighten the sheath bolt at the upper left end of the support jacket to hold it in place. Now adjust the left-hand fixed stop so that good contact is made. Carefully insert the thermometer through the stopper in the middle of the support jacket until you feel the thermometer barely touch the rod. Read and record the temperature .
4. Adjust the micrometer screw until you feel it barely touch the end of the rod. Do not force the screw. The screw will complete the light circuit and the light will indicate when the screw is touching. Obtain a reading of the vernier on both the linear scale and the circular scale on the screw head. **Make sure you remember what the scale and error are.**
5. After backing the micrometer screw off by at least 2 mm, connect the steam hose to the inlet of the support jacket. Route the hose from the steam outlet into the sink. After the temperature has reached equilibrium conditions (remained steady for 3 or 4 minutes), read the thermometer and record the temperature, T. Record the micrometer reading, D.
6. Disconnect the steam hose from the inlet pipe and place it in the sink. **Be careful! Steam burns, (melt the skin off of you burns).** As the rod cools record the temperature and micrometer settings every 10^oC or so until the rod reaches ~50^oC carefully remove tube from the steam generator and attach it to a spare steam generator filled with ice water. Slowly pour the water through the steam jacket and take a final low temperature reading of the micrometer. Disassemble the equipment and replace the rod just measured with a second and third of a different kind of material, and repeat the preceding steps.
7. From the readings which you have obtained, determine slope of the T vs D for each material measured and compute the coefficient of linear expansion. By comparing your values with the accepted values determine the makeup of the three rods you have chosen. Report the χ^2/ν and comment on any discrepancies.

Table 1

Kind of material						
Original length (cm)	L_1 =		L_1 =		L_1 =	
	T (°C)	D (mm)	T (°C)	D (mm)	T (°C)	D (mm)
Slope from graph						
Coefficient of linear expansion, α						
Accepted value of α						
X^2/υ						

Accepted values

	α
Al	24.0×10^{-6}/°C
Brass	18.9×10^{-6}/°C
Cu	16.8×10^{-6}/°C
Steel	10.8×10^{-6}/°C
Zn	26.3×10^{-6}/°C

Answer the following questions:

1. To which measurement or reading do you attribute most of your error? Explain.
2. Give a practical example where consideration of linear expansion is critically important. The picture illustrates a common problem caused by temperature expansion.

Figure 2 A heat damaged railroad track.

Experiment 2: Thermocouple Voltages

Figure 3 illustrates the use of a thermocouple to read an unknown temperature. Thermocouples work in the following way; when two dissimilar metals are joined, differences in the electronic structure cause a net flow of electrons from one metal to the other. At equilibrium, this results in a potential difference between the metals. The effect is temperature dependent. Thus, if two different metal wires are joined at their two ends to form a complete circuit and the two junctions are maintained at different temperatures, then there is a net EMF in the circuit and a current flows. If the circuit is broken at some point, no current flows but a potential difference equal to the EMF is generated at the break point. This EMF depends on the temperature difference between the two junctions. At room temperature, the EMF on the order of millivolts and is relatively linear with temperature difference.

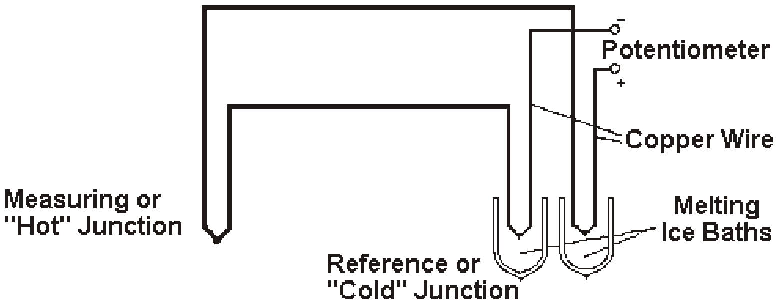

Figure 3 Thermocouple layout.

In general, a thermocouple is calibrated by keeping one junction at a reference temperature. As shown in Figure 3, the reference temperature is 0°C created by an ice-water bath. Thermocouple effects may also appear in the measuring instrument if temperature gradients occur in the instrument. To reduce these effects, all external circuitry should be copper. Thus, the actual reference junction is formed by joining the reference ends of the thermocouple to two copper wires.

Procedure

1. Place the reference junctions in ice water and the measuring junction in water at room temperature. Connect the two copper leads to a voltmeter. Remember to stir both solutions often.
2. Measure the EMF. If the reading is negative, interchange the leads of the thermocouple at the voltmeter.
3. Using the hot-plate take readings at 5°C intervals up to the boiling point.
4. Plot and fit your results and compare fit values with those from the Handbook of Chemistry and Physics. (This is a type K thermocouple with chromel-alumel junctions).

Experiment 3: Specific Heat

To raise the temperature of a body from a given initial temperature T_1 to a final temperature T_2 requires a total quantity of heat which depends on the mass of the body, the heat absorbing properties of the body, and the temperature difference, ΔT. Thus, the amount of heat needed to raise the temperature of a body is given by

$$Q = C\,\Delta T \tag{2}$$

where C is called the *heat capacity* of the particular body. Heat capacity depends on the amount of material in the body or the mass of the body, m. This equation can be rewritten to separate out the intrinsic property of the particular element involved, i.e.

$$Q = mc\,\Delta T \tag{3}$$

where c is the *specific heat* of the material and is equal to the number of calories required to raise the temperature of one gram of the substance one degree Centigrade. For reference purposes you should know that the specific heat of water at 0^{o}C is 1 calorie per gram. In fact, the definition of the calorie unit comes from this measurement. Water has interesting properties. Among them is the fact that its specific heat is much higher than many other elements or compounds. Thus, it takes much *less* heat to raise the temperature of the same mass of aluminum than it does for water.

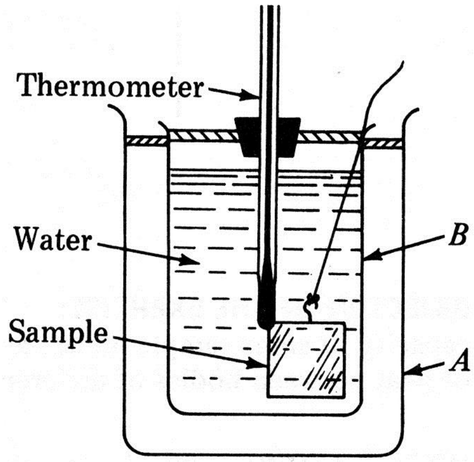

Figure 4 Calorimiter

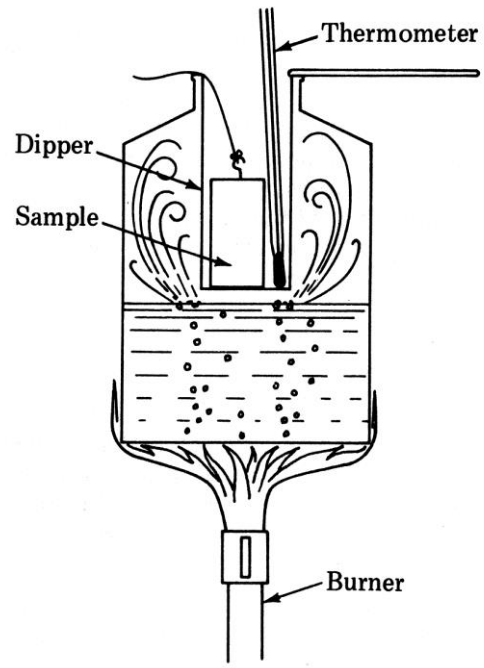

Figure 5 Steam generator (boiler) with dipper.

The process of measuring quantities of heat is called *calorimetry*. The particular calorimetric technique we will use is known as the *method of mixtures*. This makes use of the principle that when a heat interchange takes place between two bodies initially at different temperatures, the quantity of heat lost by the warmer body is equal to that gained by the cooler body, and some intermediate equilibrium temperature is finally reached. This is true provided no heat is gained from or lost to the surroundings. The vessel in which the interchange takes place is called the calorimeter and is shown in Figure 4. Container B is an aluminum can which is part of the calorimeter. Container A is an external jacket providing an insulating air barrier between the laboratory and the calorimeter.

The experimental determination of the specific heat of a metal by the method of mixtures consists in dropping a known mass of the metal, M, at a known high temperature, T_H, into a known mass of water, m_w, at a known low temperature, T_L. The equilibrium temperature, T, is then measured. The heat absorbed by the water and calorimeter is equal to the heat lost by the metal. The unknown specific heat is computed.

Note: The heat capacity of the calorimeter system should also account for the heat absorbed include the effect of the thermometer, but its mass is small and we will ignore the effects.

The initial temperature of the cold water should be as much below room temperature as the equilibrium temperature will be above it, so as to balance out errors due to losses of heat by radiation. For this experiment tap water will suffice.

Apparatus

We have

- an aluminum calorimeter and stirrer
- 0 - 100°C thermometer
- Boiler, dipper, and tripod stand
- Sample thermometer either
  - a 0 - 50°C thermometer or
  - the thermocouple from Experiment 2.
- Bunsen burner
- Samples: aluminum cylinder, lead cylinder, and unknown cylinder
- triple beam arm balance.

Procedure

Record all data in Table 2 below.

1. Fill the boiler about half way with water. Light the Bunsen burner and get the water to just lightly boil.
2. Weigh the empty calorimeter and stirrer together.
3. Weigh the aluminum sample and then lower it into dipper in the boiler by means of a thread. You should allow a few minutes for the cylinder to reach a temperature near 100^{o}C.
4. Pour cold water from the tap (about 3 degrees below room temperature) into the calorimeter until it is half filled. Then weigh the water filled calorimeter with the stirrer.
5. Place the calorimeter in the outer calorimeter jacket and record the temperature of the water.
6. Record the aluminum sample's temperature, it should be at or near 100^{o}C, and then quickly transfer the sample into the calorimeter without splashing any water.
7. Stir the water and record the equilibrium temperature. Calculate the specific heat of the aluminum sample.
8. Repeat the procedure for the lead cylinder and determine the specific heat of lead. (Hint you might find it useful to make use of more than one lead cylinder).
9. Repeat the procedure for the unknown cylinder and determine the nature of the material based on its specific heat.

Mass of calorimeter + stirrer = ___________________

Specific heat of calorimeter + stirrer = 0.215 cal/g^{o}C

Table 2

	Aluminum Cylinder	Lead Cylinder(s)	Unknown
Mass of Cylinder			
Mass of Calorimeter with Stirrer and Cold Water			
Mass of Cold Water			
Initial Temperature of Cold Water			
Temperature of Boiling Water			
Equilibrium Temperature			
Calculated Specific Heat			
Specific Heat from Tables	0.215 cal/g^o C	0.0305 cal/g^o C	
X^2/υ			

Questions

1. What is the purpose of starting with the temperature of the water lower than room temperature and ending about the same amount above room temperature?
2. How would the computed value of the specific heat be affected if some boiling water were carried over with the metal? Determine the size of this effect and, along with your percent error from above, estimate your overall uncertainty. If your values for lead and/or aluminum are not within your uncertainty of the accepted value, offer plausible explanations for what might account for the difference.