

# Coefficient of Linear Thermal Expansion

## Introduction

In this experiment, you will study the thermal expansion properties of various materials. With few exceptions materials expand somewhat when heated through a temperature range that does not produce a change in phase (i.e. melting, freezing, boiling etc.). The added heat increases the average amplitude of vibration of the atoms in the material, which increases the average separation between the atoms. Although this effect is small, it is very important in any application that involves using different materials in an environment where they are heated and cooled. For example, if a rivet of one metal is used inside a hole in a different material, it can become too tight or too loose if the thermal expansion of the materials is very different.

## Equipment

- linear expansion apparatus
- rods of different metals
- beaker of cooling water (~500ml)
- pitcher (to catch condensate)
- beaker tongs
- hot plate
- eye protection & gloves
- brass boiler (half full)
- thermometer
- tubing (2)
- funnel
- meter stick

For the class as a whole: paper towels, channel lock pliers (in case boiler lid gets stuck)

**Note: Heating is time consuming -- set hot plate on high and begin heating boiler right away!**

## Theory

For solids that are isotropic (i.e. uniform in all directions), the material undergoes thermal expansion as a whole: that is its volume expands. For materials that are not isotropic such as an asymmetric crystal for example, the thermal expansion can have different values in different directions. Thermal expansion can also vary somewhat with temperature so that the degree of expansion depends not only on the magnitude of the temperature change, but on the absolute temperature as well.

Suppose an object of length  $L$  undergoes a temperature change of magnitude  $\Delta T$ . If  $\Delta T$  is sufficiently small, the change in length,  $\Delta L$ , is proportional to  $L$  and to  $\Delta T$ . Stated mathematically:

$$\Delta L = \alpha \cdot L \cdot \Delta T,$$

where  $\alpha$  (lower case Greek letter "alpha") is called the *coefficient of linear thermal expansion* for the material.

For an isotropic material,  $\alpha$  will be the same in all directions, so we can measure  $\alpha$  simply by measuring the change in length of a rod of the material. The values obtained for the coefficient of linear thermal expansion will be compared with commonly accepted values to determine the composition of each rod.

Substance	Coefficient of linear thermal expansion, $\alpha (\times 10^{-6} / ^\circ C)$	Substance	Coefficient of linear thermal expansion, $\alpha (\times 10^{-6} / ^\circ C)$
Aluminum	25.0	Nickel	12.8
Brass	18.9	Silver	18.8
Copper	16.5	Steel	13.2
Glass (common)	8.5	Tin	20
Iron	11.7	Zinc	39.7
Lead	29.3	Ice	51

## Procedure

In this lab you will measure  $\alpha$  for rods made of different metals. These metals are isotropic so that  $\alpha$  need only be measured along one dimension. Within the limits of this experiment,  $\alpha$  does not vary significantly with temperature.

To make this measurement the metal rod is measured and placed in the apparatus. The reading on the built-in dial micrometer is recorded at room temperature, then, steam is passed around it. The expansion of the metal is measured using the dial micrometer.

**BEWARE: THE ROD AND JACKET WILL BECOME VERY HOT.  
BE EXTREMELY CAREFUL! USE GLOVES.**

Fill the boiler about one-half full of water, cap it loosely, and connect the rubber hose to its spout. Heat it on the hot plate. While waiting for the water to boil, the rest of the apparatus can be assembled.

First, measure the length,  $L$ , of the rod using a meter stick and make an estimate of the *uncertainty* in the length and call this number  $\sigma_L$ .

Next, insert the rod into the aluminum jacket and put it in place on the supporting apparatus. It is very important that the rod is properly placed. One end must be firmly pressed against the screw protruding from the supporting apparatus, while the other must be in contact with the micrometer probe. The rod must not be bowed however. The micrometer will be used to measure  $\Delta L$ . To zero the reading initially, simply turn the face of the meter until the needle points to zero.

Insert the thermometer in the central opening in the aluminum jacket until it is barely touching the rod. (**Caution: Thermometers break easily.**) Record the initial temperature  $T_{\text{initial}}$ . Make note of the *uncertainty* in your temperature measurements.

Now, it is time to heat the rod. Connect the free end of the rubber hose from the boiler to the opening in the jacket that is sticking upwards. Make sure that the tube slopes downward everywhere so condensate doesn't lay in it and block the steam. Align the whole apparatus so the remaining opening (directed downwards) is situated over the sink (or pitcher). This opening allows steam and water (condensate) to escape the jacket. The temperature of the rod should remain essentially unchanged until the water begins to boil. At this point, steam will enter the jacket through the rubber tube and heat the rod.

While the rod is heating, observe the micrometer and make a note of how many full revolutions it makes.

Wait until the rod has reached thermal equilibrium with the steam. In other words, wait until the temperature of the rod is no longer increasing and has remained constant for a couple of minutes. At this point, record the final temperature  $T_{\text{final}}$ .

Read the micrometer to obtain  $\Delta L$ . Note that each minor tick on the micrometer scale represents 0.01 mm and a full revolution by the needle represents a length change of 1.00 mm. Be sure you observe each time that the micrometer completes a full revolution, since you must then add 1.00 mm to the final reading for  $\Delta L$ . (Note: If your micrometer is graduated in .001 inches instead of millimeters, you should convert your readings to millimeters.)

Make an estimate of the *uncertainty* in the change of length and call this number  $\sigma_{\Delta L}$ .

Calculate the change in temperature. Estimate the uncertainty in change of temperature by adding the uncertainty in the initial and final temperatures. Call the total uncertainty in temperature  $\sigma_{\Delta T}$ .

After obtaining the necessary measurements, unplug the hot plate.

Next, the rod just measured must be cooled. This is done by removing the thermometer (and tubing, if necessary) from the opening. Then, a funnel is inserted into the opening and cool water is poured into it from a beaker. This water will exit through the hole situated over the sink/pitcher. Tilting this end upwards temporarily will allow the water to flow throughout the length of the jacket and cool all portions of the rod. Once the rod is cool, remove it and insert another rod.

Repeat the experiment for the three remaining rods.

### **CALCULATIONS**

Use the measured values of  $L$ ,  $\Delta T$ , and  $\Delta L$  to calculate  $\alpha_{\text{experimental}}$ .

Calculate the uncertainty in your determination of  $\alpha$ . The equation for  $\alpha$  is given by  $\Delta L = \alpha \cdot L \cdot \Delta T$ . When multiplying or dividing uncertain numbers, the *fractional* uncertainties ( $\sigma_L/L$  for example) are squared and summed to give the square of

the net uncertainty, thus.,  $\sigma_\alpha = \alpha \sqrt{\left(\frac{\sigma_L}{L}\right)^2 + \left(\frac{\sigma_{\Delta L}}{\Delta L}\right)^2 + \left(\frac{\sigma_{\Delta T}}{\Delta T}\right)^2}$ . Which

measurement has the greatest effect on the final uncertainty?

Compare the experimental values for the coefficient of linear expansion with those found in the table. Use these numbers (and any other observations that you can make) to determine the composition of each rod. Take into account the uncertainty in your measurements to see if your result is conclusive.

Calculate the quantity  $\left| \frac{\alpha_{\text{experimental}} - \alpha}{\sigma_\alpha} \right|$ . This is a measure of how accurate your

experiment is. If this is less than one you are doing pretty well, if less than 2 you are doing okay, if greater, then hmmmmm.....

If the final results seem outside the experimental uncertainties, discuss any random or systematic errors.

See Appendix for further discussion of uncertainty.
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**Description (color/weight) of rod:**

Length, $L$		$T_{\text{initial}}$		$\Delta T$	
$\sigma_L$		$T_{\text{final}}$		$\sigma_{\Delta T}$	
Full turns		Additional			
$\Delta L$		$\sigma_{\Delta L}$			

Calculations:

Coefficient,  $\alpha$  \_\_\_\_\_ Uncertainty,  $\sigma_\alpha$  \_\_\_\_\_

Probable rod material: \_\_\_\_\_

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Probable rod material: \_\_\_\_\_