Coefficient of Linear Thermal Expansion (approx. 2.5 h) (3/2/11)

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)
- cardboard spacers
- beaker tongs
- hot plate
- eye protection & gloves
- brass boiler (half full)
- thermometer
- tubing (2)
- funnel
- meter stick

For the class as a whole: reg. screwdriver, channel lock pliers (if lid sticks), lubricant for thermometer

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 ΔT. If ΔT is sufficiently small, the change in length, ΔL, is proportional to L and to ΔT. Stated mathematically:

$$\Delta L = \alpha \cdot \mathrm{L} \cdot \Delta \mathrm{T} \,,$$

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

For an isotropic material, α will be the same in all directions, so we can measure α 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,** $\alpha\ (\times 10^{-6}\ /^{0}C)$
Aluminum	25.0
Brass	18.9
Copper	16.5
Steel	13.2

Procedure

In this lab you will measure α for rods made of different metals. These metals are isotropic so that α need only be measured along one dimension. Within the limits of this experiment, α 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, roll the rod on your desk top to make sure it is straight (i.e. not bowed or bent). Measure the length, L, of the rod using a meter stick and make an estimate of the *uncertainty* in your measurement and call this number σ_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 centered with, and firmly pressed against the screw protruding from the supporting apparatus. The other end must contact, and be precisely centered with, the tip of the micrometer probe. You may need to use a piece of cardboard or other shim in order to keep the rod precisely aligned. The dial micrometer will be used to measure ΔL. To zero the micrometer for your initial reading, simply turn the face of the dial until the needle points to zero.

Carefully insert a thermometer into the piece of tubing at the central opening in the aluminum jacket (using lubricant if needed) until it is barely touching the rod. (**Caution: Make sure the rod remains aligned after inserting thermometer.)** All time for the thermometer to reach equilibrium and record the initial temperature T_{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 pitcher (or sink). This opening allows steam and water (condensate) to escape the jacket. ***Check once again to be sure the ends of the rod have remained aligned and centered***. 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_{final}.

Read the micrometer to obtain ΔL. Note the units on your micrometer. If they are SI units, each minor tick on the 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 ΔL. 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 ΔL 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, turn off and unplug the hot plate.

Next, the rod must be cooled. First disconnect the tubing from the steam generator connection and fill a beaker with cool water. Then insert a funnel into the open end of the tubing and pour cool water into it. 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. **(Caution: Thermometers break easily.)** 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, ΔT, and ΔL to calculate $\alpha_{\exp erimental}$.

Calculate the uncertainty in your determination of α. The equation for α is given by $\Delta L = \alpha \cdot \mathrm{L} \cdot \Delta \mathrm{T}$. When multiplying or dividing uncertain numbers, the *fractional* uncertainties (σ_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 $\left|\frac{\alpha_{\exp eriemental} - \alpha}{\sigma_\alpha}\right|$. 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 of online lab manual for further discussion of uncertainty.

Description (color) of rod:

Length, L		T_{initial}		ΔT	
σ_L		T_{final}		$\sigma_{\Delta T}$	
Full turns		Additional			
ΔL		$\sigma_{\Delta L}$			

Calculations:

Coefficient, α ________________ Uncertainty, σ_α ________________

Probable rod material: ______________________________

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