Thermal Expansion

Objectives

- To measure the coefficient of thermal expansion of a rod.
- To determine the expected uncertainty in the measurements using propagation of errors.
- To compare the differences in the measurements to the expected uncertainty.

Background

When a material is heated its temperature increase is usually accompanied by an increase in size; it expands. For example, after shutting off the engine of a car, one can hear pinging or snapping sounds. These are the sounds of metal pieces shrinking while cooling. The initial rate of cooling is great, therefore it emits rapid pinging sounds at first; later the pinging dies away.

Some materials expand more than others for a given change of temperature. The expansion of materials over a wide range of temperature can be calculated if sufficient detail is known about the equation of state. Over restricted ranges of temperature, the expansion of many materials has a simple behavior. The expansion property of a particular material is called its *coefficient of expansion*. For many purposes it is simpler to measure the coefficient of expansion than to attempt to calculate it.

Each portion of an object expands equally. Thus, larger objects expand more than smaller objects. For common materials the expansion is proportional to its extent in each of the three dimensions. For a long thin rod, the expansion in the length may be the important property, while the expansion of the diameter may often be ignored. This is called linear expansion.

Linear expansion depends on the properties of the material and on both the length of the rod and the temperature change. Within a limited range, the expansion is linear in both of these properties. The equation which relates the parameters involved with expansion during heating is given as:

$\Delta L = \alpha L_0 \Delta T$ in which

ΔL = the expansion
L_o = the original length
ΔT = the temperature CHANGE
α = the coefficient of expansion (What are its units?)

Determination of the Coefficient of Linear Expansion, α

In this experiment you will determine the coefficient of linear expansion by heating a thin rod through a known temperature change and measuring its initial length and the change in length. You will measure only the expansion in length. The diameter also expands proportionately. Given the changes in temperature and length, you can derive α:

$$\alpha = \frac{\Delta L}{L_0 \Delta T} \qquad (1)$$

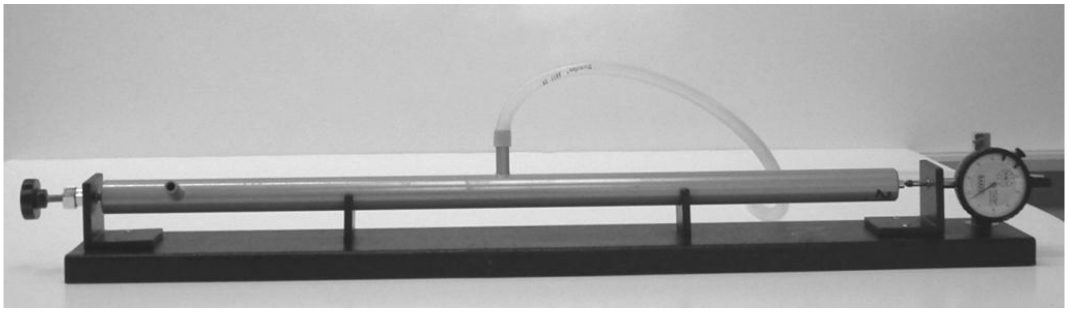


Figure 1 – The steam jacket in its base, without the steam generator.

Equipment

- A rod of a chosen material
- Steam generator and tubing
- Hot plate
- Steam jacket
- Dial gauge
- Meter stick
- Digital thermometer
- Beaker (for carrying water)
- Oven mitts
- Insulating pad to protect table top
- Large C clamp
- Tape

Procedure

The apparatus is shown in figure 1 (above). The actual apparatus may differ in detail. When you draw your diagram of the laboratory equipment, be sure to draw what you used! Do not copy the drawing above.

Allow the steam to enter at the center of the steam jacket. The steam generator itself should be located some distance away. A detailed illustration of the dial gauge is given in figure 2 (below). Make sure you understand how to read it!

1. Before doing anything else, make sure you understand how to read the dial gauge and know what are the sizes of each division on the scale of the dial gauge (see figure 2 below).

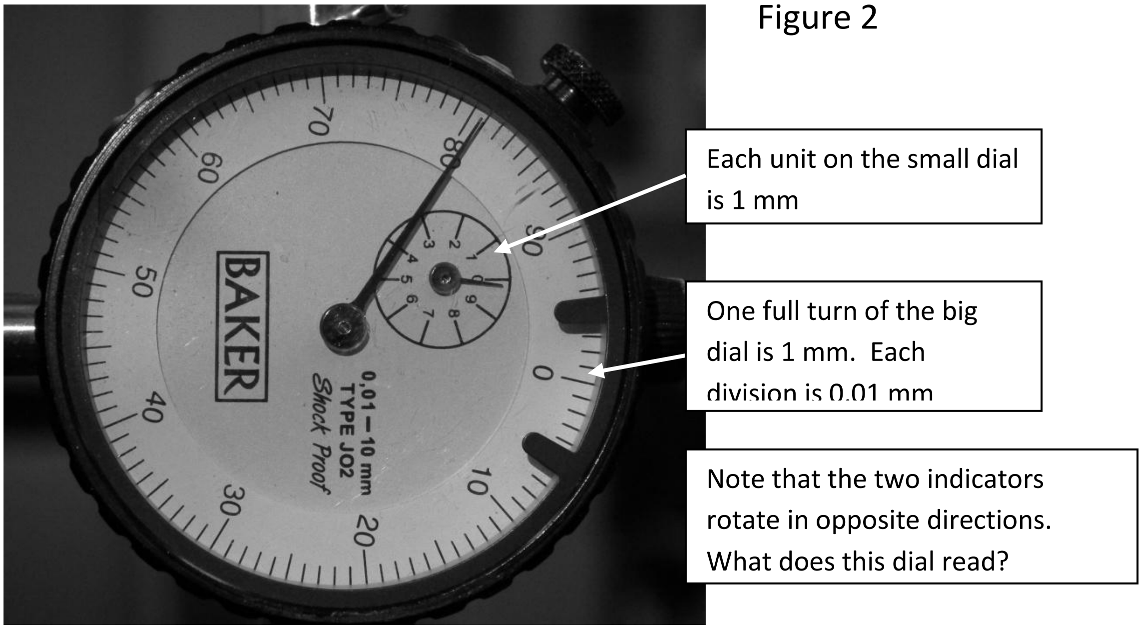
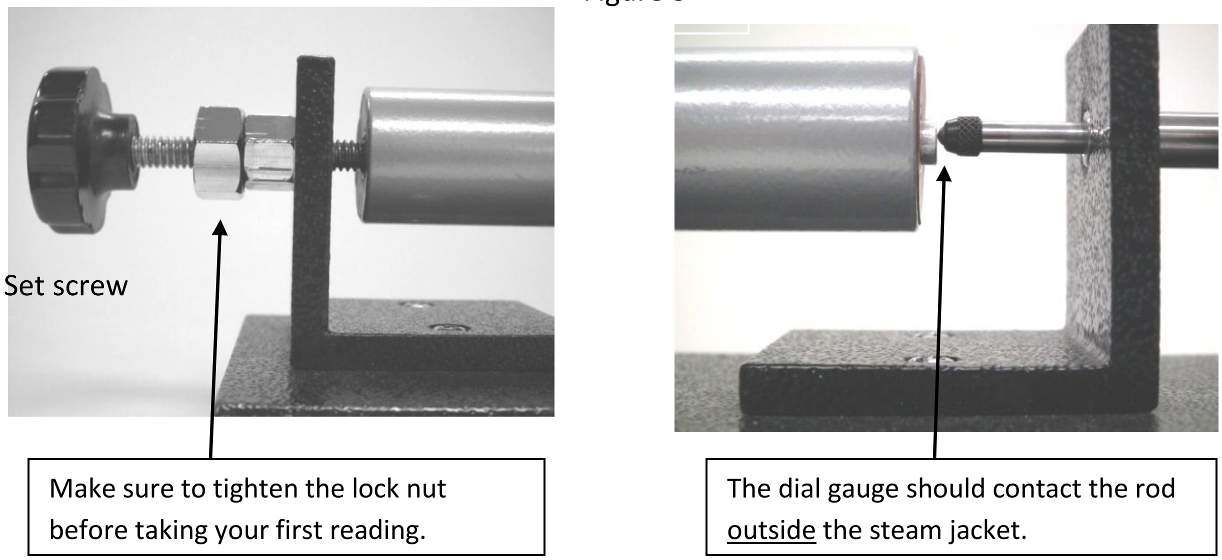


Figure 2

2. Obtain a sample metal rod and record its length L_o on the data sheet. Record an estimate of the uncertainty, σ_L. **The uncertainty of L should probably be related to the size of the rulings on the ruler.**
3. Mount this rod through the center of the steam jacket as shown in figure 1. The flat end of the rod should be at the dial gauge. The pointed end should be at the set screw at the location shown as A in figure 1.
4. It will probably be helpful to tape the steam jacket to its base and gently clamp the base for the steam jacket to the table.
5. Fill the steam generator about half full. Connect a tube between the inlet at the center of the steam jacket and the outlet on the steam generator. Do not allow it to hang below the table or water will condense in it.
6. The set-screw at location shown as A in figure 1 should now be screwed in until the rod begins to compress the dial gauge. Make sure that contact between the rod and dial gauge is <u>outside</u> the steam jacket. Tighten the lock nut against the steam jacket mounting to prevent the set screw from being turned accidentally. Do not touch the steam jacket after this to avoid changing the reading on the dial gauge. See figure 3 (below) for details.

Figure 3



7. Record the initial measurement of the dial gauge and an estimate of the uncertainty, $\sigma_{\Delta L}$. If your initial measurement is zero, record that fact!
8. Record the room temperature and an estimate of the uncertainty, $\sigma_{\Delta T}$.
9. Turn on the hot plate to "high." While the rod is heating, the needle on the dial gauge will move.
10. Record the dial gauge reading when the hot rod has stopped expanding. Also, record the final temperature of the rod inside the steam jacket. **Remember, record both the start and end scale and temperature readings; subtract later!**
11. Turn off the hot plate and let the apparatus cool. Disconnect the tubing from the steam jacket. Use the oven mitts! If you remove the steam generator from the hot plate, place it on the insulating pad.
12. You must allow enough time for the steam jacket to return to room temperature. You may wish to rinse the steam jacket off in room temperature water.
13. Repeat the experiment with the same rod. The rod and equipment should begin as close to room temperature as possible. When reconnecting the tubing to the steam jacket, make sure no hot water or steam drips out to "pre-heat" the rod.
14. Turn on the hot plate only after recording the initial reading on the dial gauge and the initial temperature. The water will not take nearly so long to heat as it did the first time, if you are fast enough that it does not cool off too much.
15. Repeat as many times as possible in one lab period.
16. When cleaning up, dry all equipment before putting it away.

Data Analysis.

Compute α for each attempt using equation (1). Also compute an uncertainty σ_α. The method for doing so is described below. Finally, compute an average value of α.

Error Analysis

You will have to use appropriate propagation of errors to calculate σ_α. Use your estimates of the uncertainty of L, ΔL, and ΔT.

Last semester you used an approximate method to calculate the uncertainty in a derived result based on one or more uncertainties in the measurements. In this lab we have uncertainties in more than one quantity. The uncertainties are of different sizes, but so are the measured quantities. We will use the correct formalism to derive the uncertainty in α. See the Introduction to Measurements, Laboratory Experiments and Lab Reports or another reference for an explanation.

For this lab use equation (2) to calculate the uncertainty in α.

$$\sigma_\alpha = \alpha \times \sqrt{\frac{\sigma_L^2}{L^2} + \frac{\sigma_{\Delta L}^2}{\Delta L^2} + \frac{\sigma_{\Delta T}^2}{\Delta T^2}} \qquad (2)$$

Note: this particular version of the error propagation formula is specific to the functional relationship of the variables in this problem. Different equations will have different error propagation formulae.

Conclusions

For this lab, no explanation of physical principles is required. In your discussion, compare the coefficients of linear expansion (α) you determined to a reference value you look up. Are your individual measured values within the range of uncertainty from the reference value (are the errors less than the uncertainty)? How does the average value of α compare to the reference value? How do the different measurements of α compare to each other? Are they within the uncertainty from each other, even if they are not within the uncertainty from the reference value? If they are close to each other but outside the range of uncertainty from the correct value, what might that mean?

Discuss the sources of error. **Be sure to discuss:** What were the estimated uncertainties for the measured quantities, L, ΔL, and ΔT? How did you decide what they should be? Which makes a greater contribution to the uncertainty in α, the uncertainty in L, the uncertainty in ΔL, or the uncertainty in ΔT? Explain! (Hint: look at the ratios of these values to L, ΔL, and ΔT respectively.) What additional sources of error might reasonably contribute that you do not have numerical estimates for?

Summary Table

Record your final results in a summary table following the format given in the lab as closely as possible. This is the summary table for this lab.

Material	ΔT	$\sigma_{\Delta T}$	L	σ_L	ΔL	$\sigma_{\Delta L}$	α_{calc} $\times 10^{-6}$	σ_α $\times 10^{-6}$	$\alpha_{reference}$ $\times 10^{-6}$	$\lvert \alpha_{calc} - \alpha_{ref} \rvert$ $\times 10^{-6}$	Source of reference value
Trial 1											
Trial 2											
Trial 3											
Average	X	X	X	X	X	X		X			

In this and all other labs, the source of the reference value may be given below the table if it does not fit in the table.

When recording your numbers, you should use the correct number of significant digits. In general, there is no reason to keep more than one significant digit (or at most two) in your uncertainty. The uncertainty tells you the range within which your answer may be expected to fall; to say that your uncertainty is ±0.00012345 is no more informative than it is to say that your uncertainty is ±0.0001 or ±0.00012, and it's a lot messier. That also determines how many digits you should keep in your result. Uncertainties are added or subtracted to your result, so the addition/subtraction rule for significant digits applies. For addition or subtraction of two numbers, you keep the least significant digit common to both numbers. Thus, 1.234567 ± 0.00321 should be given as 1.234 ± 0.003

All results and their uncertainties should be quoted with the same exponent, for ease of comparison, as should all related numbers. **In this lab, give all the results for α_{calc}, σ_α, $\alpha_{reference}$, and $\lvert \alpha_{calc} - \alpha_{ref} \rvert$ as multiples of 10^{-6} for ease of comparison, even if that is not standard scientific notation.**