Thermal Expansion Experiment

This document introduces the *Thermal Expansion Experiment* from the Physics laboratory at the University of Toronto. It is intended to be used before you begin the experiment. The *Preparatory Questions* at the end of this document should be answered and turned in to your Demonstrator before you begin to work on the experiment.

Requirements

In order to effectively use this page, your browser needs to be capable of viewing *Flash* animations, also known as `swf` files. The Flash player is available free from http://www.macromedia.com/. Our animations are for Version 5 of the player or later.

You will also want to have either the RealMedia or QuickTime video player installed on your computer. The RealMedia player is available free from http://www.realnetworks.com/. The QuickTime player is available free from http://www.apple.com/quicktime/.

A document of the soundtrack of the video and a summary of this page are also available below. They are in *pdf* format. Accessing these documents will require that you have the *Acrobat Reader*, which is available free from http://www.adobe.com

Introduction

Most materials expand as they are heated and contract if they are cooled. Thus their length is a function of temperature. If the length of an object is **L** and the temperature changes by a differential amount **dT**, then the differential change in the length **dL** is given by:

$$\mathbf{dL} = \alpha \, \mathbf{L} \, \mathbf{dT} \tag{1}$$

where α is the *coefficient of linear expansion*.

The photograph to the right shows railroad tracks distorted because of thermal expansion on a very hot July day.

The photograph is from Halliday, Resnick and Walker, **Fundamentals of Physics**, 6th ed., Enhanced Problems Version, Figure 19-9 (Wiley, 2003), and is used by permission.

For small ranges of temperature, we can treat α
as a constant for a particular material; in the experiment this is a reasonable approximation. You will determine α for aluminum and copper.

In the figure to the right we show an aluminum rod. The length of the rod is defined in the figure, and is similar but not identical to the definition you will use in the experiment. The rod is at a temperature T_0 and has a length of L_0.
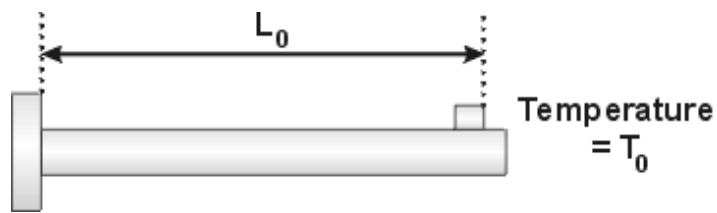
In the figure, you can see a *tab* on the right-hand side of the rod, and we measure the length of the rod to the right-hand side of the tab. In the actual experiment there is a line inscribed on the top of the tab, and you will measure the length of the rod from the left-hand side to the line inscribed on the tab. Thus the lengths and changes in length of the rod shown in the figures are only similar to the actual definitions you will use in the experiment.

We heat the rod up to a temperature $T > T_0$, and its length increases to L.
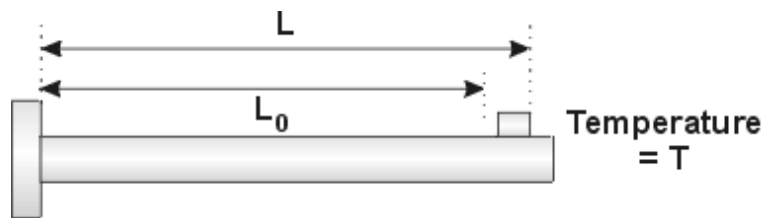
We shall call the change in temperature:

$$\Delta T = T - T_0$$

and the corresponding change in length:

$$\Delta L = L - L_0$$

Then if the product:

$$\alpha \times \Delta T$$

is small, Equation 1 becomes approximately:

$$\Delta L \simeq \alpha\, L_0\, \Delta T \tag{2}$$

You will use Equation 2 in the experiment.

You are supplied with two rods, made of aluminum and copper. Briefly, for each rod you will:

1. Determine the length L_0 of a rod at a reference temperature T_0. Room temperature is a good choice for the reference temperature.
2. Heat up the rod by pumping heated water through it. When the rod reaches a constant uniform temperature T measure its change in length ΔL.
3. Repeat Step 2 for a number of temperatures.
4. Use your data and Equation 2 to determine α.

Getting from Equation 1 to Equation 2 involves solving the differential Equation 1, expanding the result in a Taylor series, and dropping higher order terms from the expansion. This sort of mathematical manipulation, which is part of <u>theoretical</u> physics, is what you are learning in the lecture component of your course. The laboratory is teaching the "better half" of physics: <u>experimental</u> physics.

The Apparatus

In order to perform the experiment you will need to know how to read a *Micrometer*. An introduction to micrometers may be accessed by clicking on the blue button to the right. It will appear in a separate window and has a file size of 86k.

We have prepared a video in various formats to introduce you to the apparatus; the running time of the video is about 4:10 minutes. Links to the video appear below. You will wish to adjust the volume of the speakers on your computer so that you can easily hear the soundtrack. For the higher resolution **RealMedia** version, you may also wish to increase the size of the video using the controls provided by the player.

You may download a *pdf* version of the soundtrack of the video by clicking on the red button to the right. It will appear in a separate window, and has a file size of 59k.

The *Streaming* video will be played by the **RealMedia** player as it is delivered to your computer by the network. The *Download*
versions of the video will be downloaded to a temporary area on your local hard disc and then shown if your browser is configured to use the appropriate player. You may save these *Download* versions to a more permanent place that you specify on your computer's discs by right clicking on the link and then saving the `Target` (Internet Explorer) or `Link` (Netscape).

RealMedia Streaming	**STREAMING** Click Me	
RealMedia Download	Less Resolution (1.0M): Click here	
	More Resolution (2.4M): Click here	
Quicktime Download	Less Resolution (1.2M): Click here	
	More Resolution (2.9M): Click here	

A Flash animation of the apparatus with the rod undergoing temperature changes is available. It may be accessed by clicking on the yellow button to the right. It will appear in a separate window and has a file size of 19k. You should assume that the "Thermometer" in the animation is measuring the actual temperature of the rod in Celsius.

A Flash animation of what you will see when you look through the traveling microscope at the stationary tab on the rod as you move the microscope is available. The animation includes the line inscribed on the top of the tab, which we discussed above. The animation may be accessed by clicking on the orange button to the right. It will appear in a separate window and has a file size of 31k.

The figure to the right shows the part of the apparatus that heats the water and pumps it through the rod.

Note that the level of water must be above the hole that lets water into the pump. You are supplied a pitcher with which you can add water if needed.
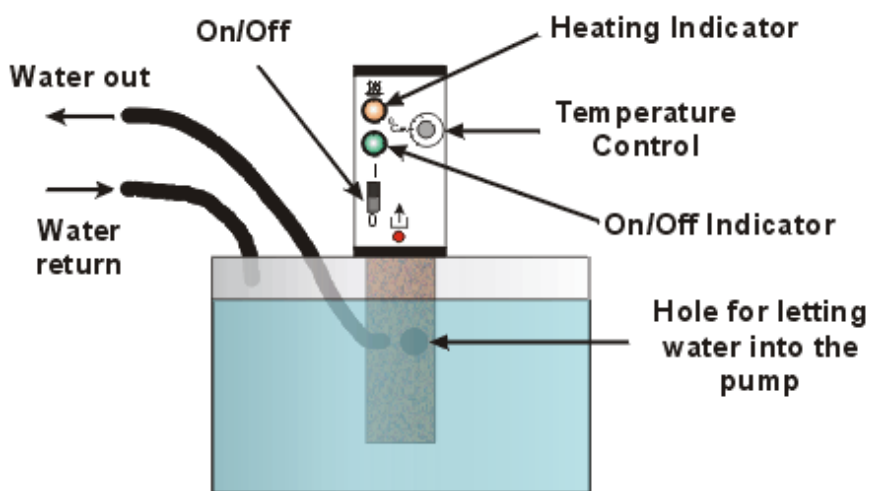
Data Collection and Analysis

You will determine the coefficient of thermal expansion α for the copper and the aluminum tube. For each:

- Determine the reference length L_0 at a reference temperature T_0. The length is from the fixed position of the tube to the line inscribed on the tab. Be sure you know which part of the tube is fixed.
- Flow water at various temperatures through the tube. Wait for the tube to achieve thermal equilibrium with the water.
- For each temperature, use the traveling microscope to determine the change in length from the reference length:
  $\Delta L = L - L_0$.
- To determine α either:
  - Fit ΔL versus ΔT to a straight line.
  - Fit ΔL versus $L_0 \Delta T$ to a straight line.
- Compare your values of α with the accepted values for different metals.

Summary

As promised, we have prepared a summary of the background information presented above. It does not attempt to provide a full discussion, but just reviews the "high points" from above.

You may access the summary by clicking on the green button to the right. The summary is in pdf format, will appear in separate window, and has a file size of 14k. You may wish to print this document.

Preparatory Questions

These questions should be answered and turned in to your Demonstrator *before* beginning the experiment. They *replace*
the questions in the Guide Sheet for the experiment: if you are using this web-document as the introduction to

the experiment you should answer these questions and not the ones in the Guide Sheet.

Note:

These questions are intended to guide you in your preparation for the experiment. They do not have any "tricks."

1. What are the units of α?
2. Usually when temperatures are written as **T** they refer to values in *Kelvin*; temperatures written as the lower case letter **t** usually refer to the value in *Celsius*. Above we have used **T** for temperature, while the thermometers you will use measure in Celsius. Does it make any difference? Why?
3. Values of α are typically on the order of 10^{-5} in SI units. Imagine a rod with exactly this value of α that has a length of exactly one meter when its temperature is 20°C.
    1. If its temperature changes from 20°C to 80°C what is its change in length?
    2. What is the *percentage* change in its length?
4. A rod made of the same material as in Question 3 has a length of exactly 100 meters when its temperature is 20°C.
    1. What is the percentage change in its length if its temperature changes from 20°C to 80°C?
    2. How does your answer compare to your answer to the second part of Question 3?
    3. Why did your answer to Question 4.2 come out as it did?
5. You will measure the temperature of the water when it enters the tube and again when it leaves the tube, using two thermometers. Particularly at temperatures much above room temperature, at equilibrium the two values may not be the same: the temperature of the water exiting the tube may be less than the water entering it.
    1. What is an explanation of why this is occurring?
    2. What is a reasonable value for the temperature of the rod in this case?
    3. If the difference in temperatures measured by the thermometers is greater than the reading errors of the thermometers, what is a reasonable value of the error in the measurement of the temperature of the rod?

Authors and Copyright

Earlier versions of the Guide Sheet for this experiment have been worked on by David Harrison (1983), Joe Vise (1988), Claude Plante (1993) and others.

This web version is by David M. Harrison, May 2003.

This is $Revision: 0.2 $, $Date: 2003/05/02 18:42:59 $ (y/m/d UTC).