Measuring Thermal Expansion[1]

Purpose: Determine the coefficient of thermal expansion of a metal strip using single slit diffraction.

Discussion: The linear expansion of a solid is given by $\Delta L = \alpha L_0 \Delta T$ where ΔL is change in the length of a material of length, L_0, α is the coefficient of linear expansion and ΔT is the temperature change. Even for metals with fairly high coefficients of thermal expansion, α is only the order of 10^{-6} /^{0}C. For piece of metal that would be convenient to use in a lab, say around 10 cm, and for temperature changes that would be easy to handle in the lab (no more than 100^0C), estimate the expansion:

A meter stick would not give a very accurate measure of this. Why?

Instead of using a meter stick, we will use the same property of light that we used in the previous lab: interference of light waves. This time instead of a bunch of slits (diffraction grating), we will use one single slit that is connected to the metal that is expanding or contracting. When light travels through a slit, it spreads out. As it spreads out, light from different parts of the beam interferes constructively and destructively resulting in a pattern of bright and dark spots. Figure 1 below shows in a screen shot of the animation at http://micro.magnet.fsu.edu/primer/java/diffraction/basicdiffraction/.

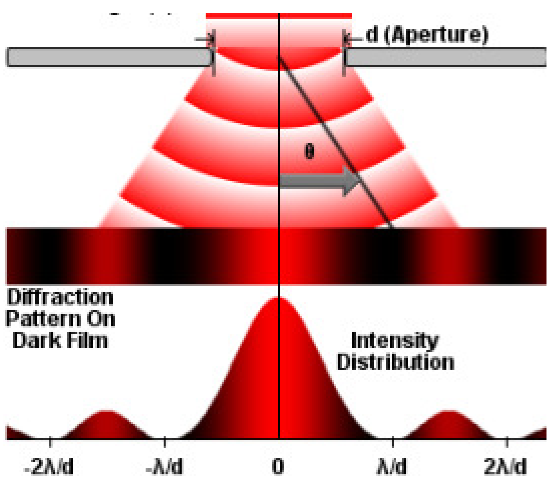


Figure 1: Screen shot of a single-slit diffraction animation http://micro.magnet.fsu.edu/primer/java/diffraction/basicdiffraction/

[1] Based on H. Fakhruddin, "Quantitative Investigation of Thermal Expansion Using Single-Slit Diffraction," *The Physics Teacher,* **44** (2006) 82-84.

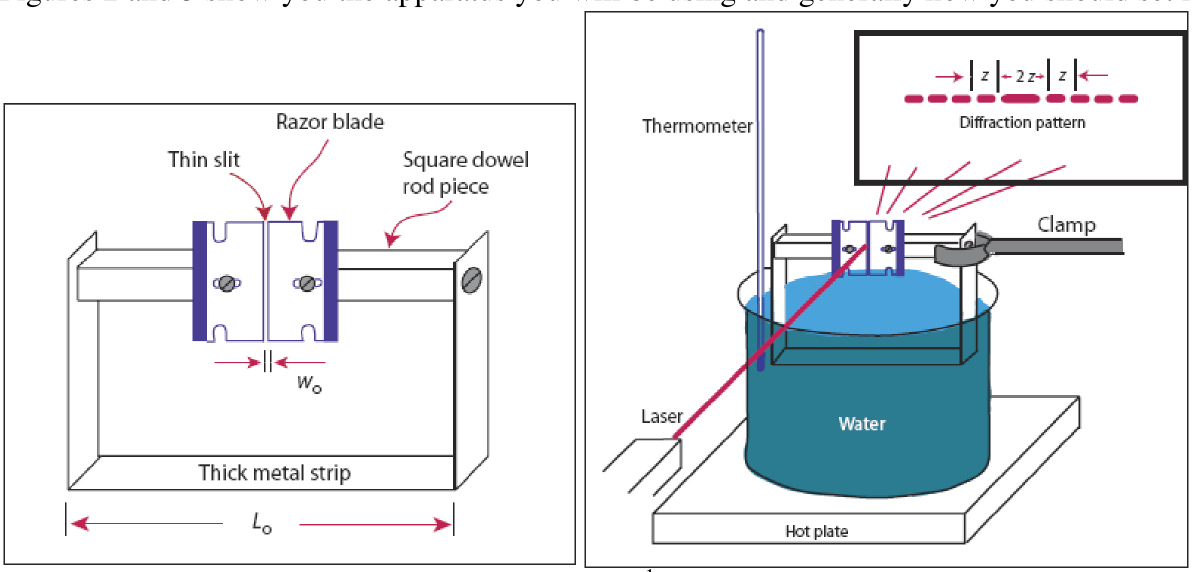
Go on-line to this animation. Describe what happens when you move the slider to change the aperture size, d.

When d is bigger, what happens to the position of the first dark spot?

a) gets further from the center
b) gets closer to the center
c) stays in the same position

In the animation, how does the slit size compare to the wavelength of light? Is this a distance that is easily measured using a ruler? Explain.

Figures 2 and 3 show you the apparatus you will be using and generally how you should set it up.



Figures 2 & 3: Experimental apparatus and set-up.[1]

In this experiment, you will take advantage of the sensitivity of the diffraction pattern to changes in the slit size. As the thick metal strip (in Figure 2) expands, the slit width will increase. This increase will not be easy to measure accurately with a ruler, but measure the changes in the diffraction pattern can give an accurate measure of the change and, thus, the thermal expansion.

Procedure:

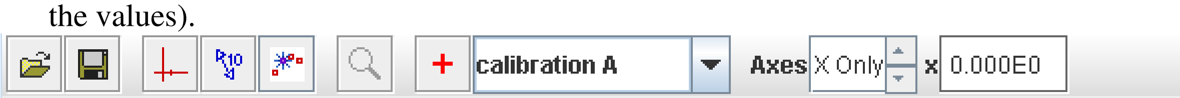
We would love to have you do this lab but it is seems to be very sensitive to vibrations from the surrounding environment so we did the experiment and recorded it on video for you to analyze. We will use *Tracker*, a program most of you have used in PH241:

Using *Tracker* for Thermal Expansion Lab:

1. Double-click on the tracker_thermal_expansion.jar file.
2. Double-click on the green node: 

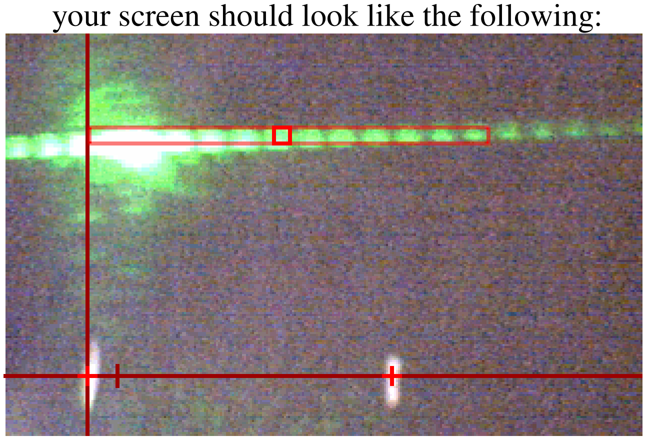
to start Tracker and load the movie.
3. Tracker has a tool that measures the bright and dark spots on the screen and it is this tool we will use to analyze the diffraction pattern on the screen.
4. First, we must calibrate the screen (so Tracker knows what size things are). You will use two calibration points (the white chalk marks on the screen). So, in the menu, choose "Track" and then "New" and then "Calibration Points."

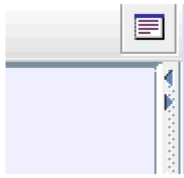
5. The instructions on the screen tell you to Shift-click to mark calibration point. For "Axes" choose "X Only" (because we only care about the x-distance between the chalk marks). Put the first one on the left-hand chalk mark and in the x-boxes on the menu bar replace the number there and type in the values 0 (make sure you push "Enter" to record the values).

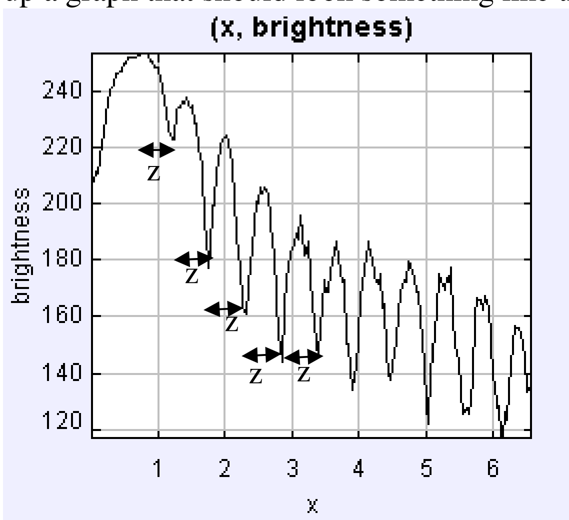


6. Now Shift-click on the right-hand chalk mark (at about the same vertical spot) and for this one, enter 5 for the x-value (again remember to hit enter!).
7. Now, under the "Track" menu, choose "New" and "Line Profile." In the boxes near the menu bar, change the spread to a value of 5 or so (you want it wide enough to get a good reading on the peaks). These marks are 5 centimeters apart.
8. Play the entire video. Do the dark spots (minima) generally compress towards the center or expand away from the center as the temperature rises?

9. Now you are ready to analyze the video. Initially you will not observe the profile tool until you press Shift-drag the mouse around the diffraction pattern. When you are done your screen should look like the following:



10. On the right hand side of the Tracker window is a small set of arrows that will hide or show graphs:  Click on this bar below the triangle pointing right to open up a graph that should look something like the following:



11. You will make your measurements from this graph. First record the position of the central bright spot (center of the biggest peak) and then record the position of the first five minima. To get better statistics do this again about a second later in the film at the same temperature (make sure you do not take data when the diffraction pattern is in a transition).

Now record your video analysis data below (4 temperatures, two sets of five points each for each temperature). Be careful, though, as the temperature raises, your corresponding z values should be getting smaller and it may be that the first minimum is buried too close to your central peak to show up on the graph. If this is the case, look for the well-defined minima and measure the distances between them, getting 5 data points for each time (10 data points total for each temperature) and don't worry about getting the distance between the central peak and any other peak.

Raw Data: z (cm)

Temperature 1	Temperature 2	Temperature 3	Temperature 4

12. Find the average value for z at each temperature by using these 10 points.

T (K)	*Average z* (cm)

In the equation $\omega_0 = \frac{\lambda D}{z_0}$ for wave diffraction, , ω_0 is the initial slit width, λ is the wavelength of the light, *D* is the distance between the slit (razor blade) and the screen, and z_0 is the initial distance between two maxima .

The series of bright spots that make up the diffraction pattern should get closer together as the temperature increases. Why?

The wavelength of the light is given on the side of the laser (532 nm for a green laser).

D=185 cm., Measure L_0 from the demonstration apparatus:

At what temperature should L_0 be measured (or does it matter)? Explain:

The change in the width of the slit is equal to the change in the length of horizontal metal strip:

$$\Delta L = \omega - \omega_0 = \frac{\lambda D}{z} - \frac{\lambda D}{z_0},$$

The increase in length is given by $\Delta L = \alpha L_0 (T - T_0)$ where T_0 is the initial temperature, T is the final temperature, and α is the linear coefficient of thermal expansion. Using the two equations for the increase in length show that (this means do the necessary algebra and show your work):

$$\alpha = \frac{\lambda D}{L_0} \frac{\left(\frac{1}{z} - \frac{1}{z_0}\right)}{(T - T_0)}$$

Again, do the necessary algebra to rearrange the above equation into the from below:

$$\frac{1}{z} = \frac{\alpha L_0}{\lambda D} T + \left(\frac{1}{z_0} - \frac{\alpha L_0 T_0}{\lambda D}\right)$$

The graph of $\frac{1}{z}$ vs. T will be a straight line with a slope of $\frac{\alpha L_0}{\lambda D}$. Why (explain clearly—it may help to identify the constants in the equation above)?

Plot a graph of $\frac{1}{z}$ vs. T and find the slope of the line (please hand in your graph)

slope of the line: ________________

From this calculate your value of α:

α = _________________

The accepted value for α is $23.1 \times 10^{-6}\ {}^\circ C^{-1}$. Calculate your percent error and comment on the possible sources of error: