To print higher-resolution math symbols, click the
Hi-Res Fonts for Printing button on the jsMath control panel.

PHY 124 Lab 6 - Interference and Diffraction

Important! You need to print out the 3 page worksheet you find by clicking on this link and bring it with you to your lab session. [http://www.ic.sunysb.edu/Class/phy122pk/labs/pdfs/Phy124Fall2011Lab6worksheet.pdf]

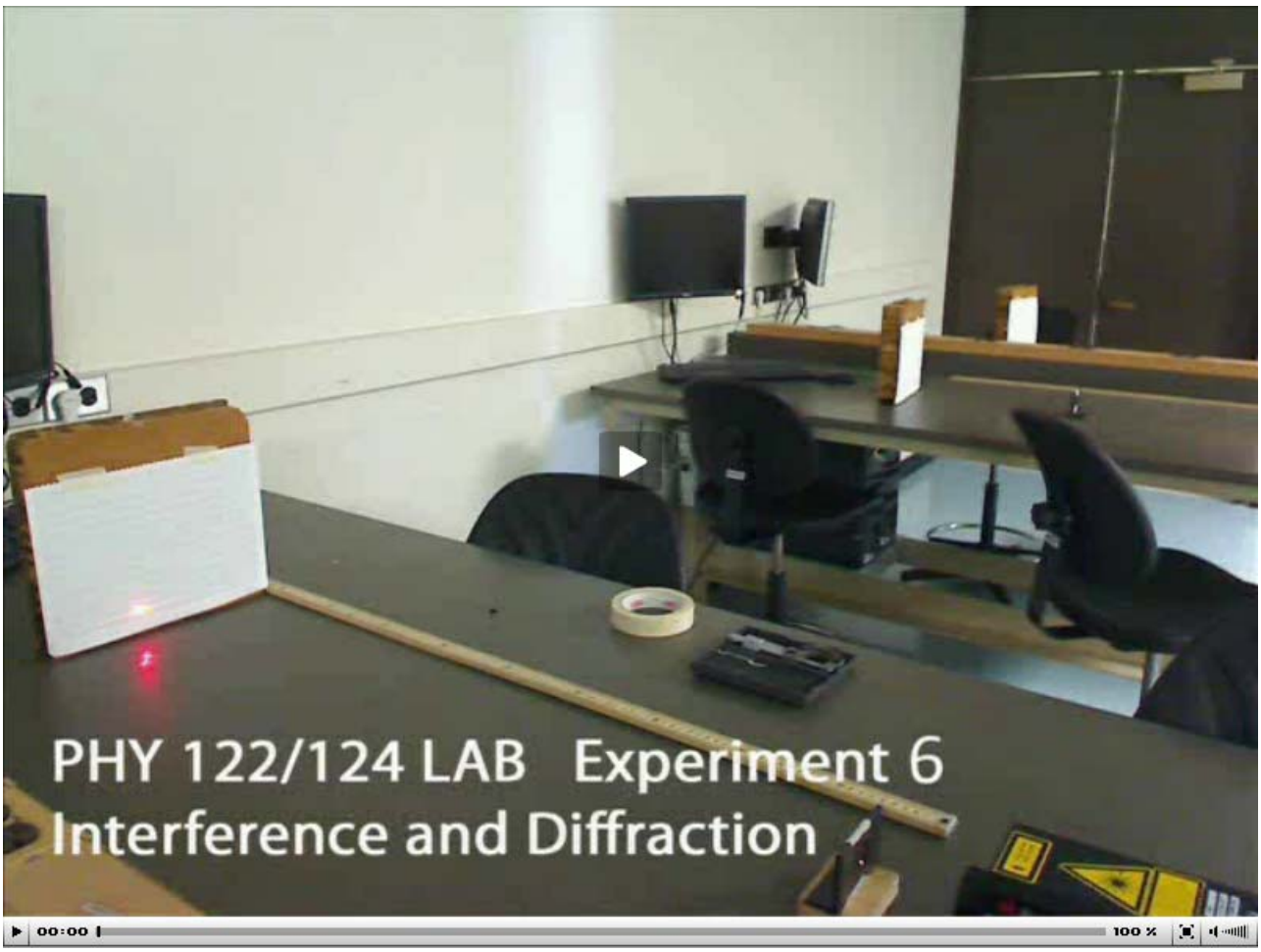
If you need the .pdf version of these instructions you can get them here [http://www.ic.sunysb.edu/Class/phy122pk/labs/pdfs/phy124s13intdifflab6.pdf].

Goals

The purpose of this laboratory is to study the phenomena of diffraction and interference. In Part I, you will observe the diffraction of light by a human hair (similar to the diffraction on a narrow slit), and in Part II, both interference and diffraction of light by various types of slit arrangements. You can do either Part I or Part II first.

To prepare for this lab you should review Ch 21.2 **Interference** and Ch 21.3 **Diffraction** in the online notes for the PHY 122 workshops. You will also profit from reading Chap. 17 , "Wave Optics", in Knight, Jones and Field, *College Physics: A Strategic Approach* (KJF2), the optional textbook for PHY 122 course. If you don't have a copy, you'll find one bolted to a table in the Help Room, A-131 physics building. A few copies are also available on closed reserve in the Math/Physics Library, level "C" of the physics building.

Video



Part I - Diffraction of monochromatic coherent laser light by a human hair.

In Part I you will observe the diffraction of light by a human hair (similar to the diffraction on a narrow slit), calculate the hair diameter from your observed diffraction pattern, and compare it to a measurement done with a screw micrometer.

Equipment for Part I

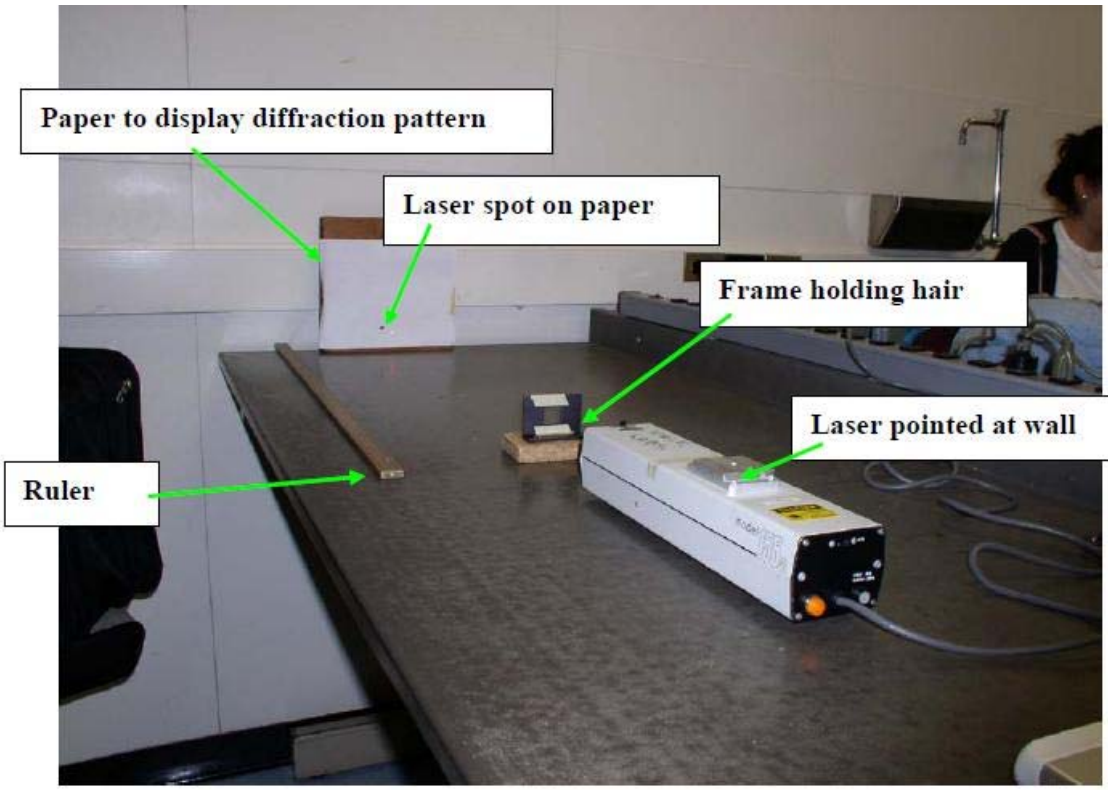
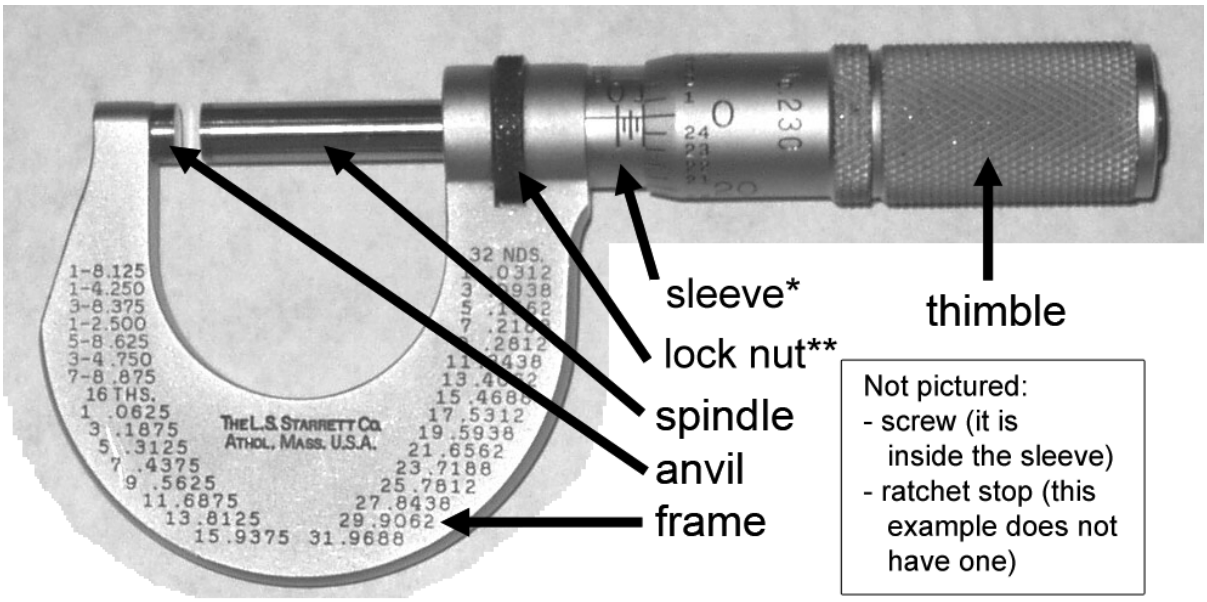


Fig 1.

- Helium-Neon Laser with a wavelength of 632.8 nm
- A hair from your (or some) human head (but see remark two paragraphs above Fig. 3!)
- Slide frame to mount the hair
- Paper to display the diffraction pattern on the wall
- Masking tape to record the pattern
- Ruler
- Metric screw micrometer

Using and reading the micrometer (upper fig. from Wikimedia Commons)



Sleeve is the most prevalent name. May also be called the *barrel* or *stock*.
**Aka *lock-ring*. Some mics have a *lock lever* instead.

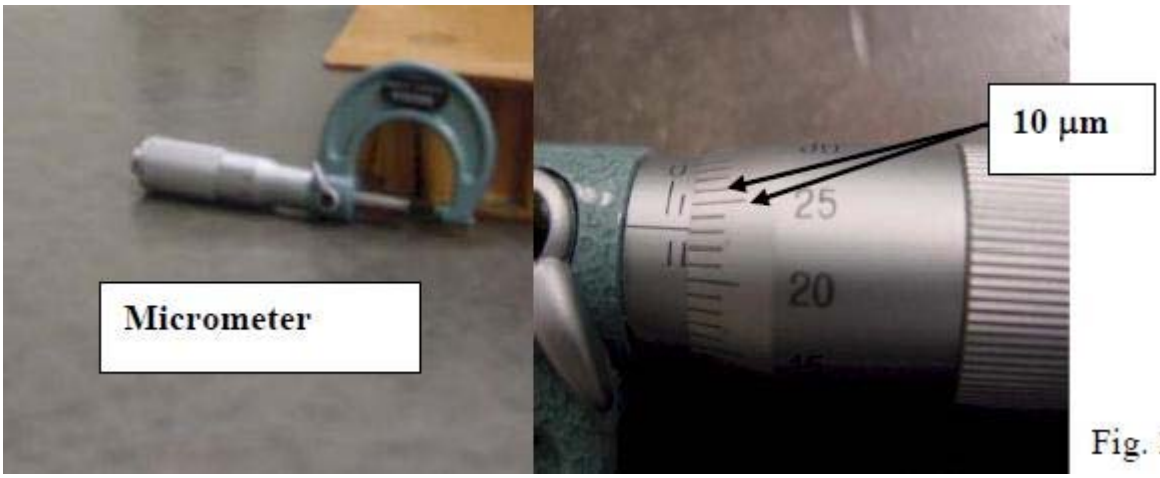


Fig. 2.

A screw micrometer allows you to use a carefully made, fine-pitch screw thread to measure dimensions (like the diameter of something) very carefully. The largest length it can measure is set by how big the open space, or gap, between the anvil and the end of the spindle can be. The upper panel of Fig. 2 shows an "American measure (inches)" 0 to 1 inch micrometer made by an American company. We use below the name labels in that panel to describe the micrometer and its operation. The lower panel of Fig. 2 shows a metric 0 to 25 mm micrometer made by a Chinese company. The two micrometers are similar, but a few details are different.

One difference you will probably notice is the "lock lever" on the metric micrometer in the lower panel. Your metric micrometer will likely have one, too. Rotating it CW supplies friction that prevents the thimble from being turned, i.e., it prevents you from changing the micrometer gap. The micrometer in the upper panel does not have a lock lever, but it does have a "lock nut" that serves the same purpose. Another difference is that your metric micrometer likely has a "ratchet stop", viz., a small, knurled knob that projects out from the larger thimble. Notice that when you apply a clockwise (CW) torque to the ratchet stop with your fingers, it "slips" and makes a "ratcheting sound" if the thimble is prevented from turning. This allows you to apply a reproducible, small torque when closing the micrometer gap onto an object being measured. Notice that the ratchet stop knob cannot be rotated counter-clockwise (CCW) with respect to the thimble; it only rotates one way, CW, if the thimble is kept from rotating.

On any screw micrometer, turning the thimble CW advances the spindle and closes the gap, while turning the knob CCW withdraws the spindle and opens the gap. Each division on the numbered end of the thimble represents (upper panel: 0.001 inch = one mil) (lower panel: 0.01 mm = 10 μm) of spindle motion and, therefore, that much change in the gap. Each division along the sleeve (between the numbered end of the thimble and and the C-shaped frame) represents (upper panel, where shorter and longer divisions alternate: 0.025 inch) (lower panel, where adjacent divisions are staggered: 0.50 mm). When measuring an object, open the gap (withdraw the spindle) by turning the thimble CCW until the object can just fit in the open gap. Then read the number of lines visible on the long part of the handle. They tell you number of integral (upper panel: 0.025 inch units) (lower panel: half-mm units) of distance that gap has. Next, find which marker on the thimble lines up with the long centerline parallel to the axis of the sleeve. Multiply this number by (upper panel: 0.001 inch = 1 mil) (lower panel: 0.01 mm) and add that to the number of (upper panel: 0.025 inch units) (lower panel: half-mm units) to get a final reading. You can consider the measurement error on the micrometer to be equal to one of the divisions on the numbered end of the thimble (upper panel: 1 mil) (lower panel: 10 μm).

From now on, we'll restrict ourselves to the metric micrometer because that is the kind you are using in this lab.

You should clean the jaws of the micrometer before you try to make any careful measurement. Reason: Even a speck of dirt on one of the shiny ends (of either the spindle or the anvil) will spoil your distance measurement: the micrometer is that sensitive. The simplest way to clean them is to close the gap on a piece of paper (such as one of the sheets of this Lab 7 manual) until the paper is almost, but not quite, prevented from moving, and then pull out the paper against the friction of the almost-closed micrometer. If the gap is too small, the paper won't move. If the gap is too large, the paper won't rub enough to clean the the shiny surfaces. Try it a few times and you'll get it right. You want "just enough" friction on the paper to clean the surfaces.

After doing this cleaning procedure, try a test measurement as an example: Measure the diameter of a "standard, yellow, wood" pencil (or some other pencil or pen if you don't have a yellow pencil handy). Suppose, after closing the gap on the pencil, you see that there are 12 lines visible to the right of the 0 line on the sleeve. That's 12 times one-half mm, or 6 mm. Then suppose that on the numbered end of the thimble you find the 45-mark lines up with the long centerline along the sleeve. Multiplying 45 by 0.01 gives 0.45 mm. Adding this to the first number gives you a diameter of 6.45 ± 0.01 mm for the pencil. Try it, but don't expect whatever you're measuing to have exactly this diameter. For your test measurement just get the number of half-mm units and add the number of 0.01 mm units to it to get the final result.

Interference and diffraction directly with the micrometer!

Now realize that 0.01 mm is only one order of magnitude greater than the wavelength of visible light. You may wonder if the gap can be made sufficiently small for you to observe diffraction phenomena when visible light passes through the gap. The answer is, yes; indeed, you can, but you have to know what you're looking for. The observation is complicated by the shiny faces of the anvil and spindle. When close together, they do not create a "slit" with sharp edges. Rather, they're like two plane mirrors, so what you observe when light passes through them when they're close together will be some combination of "direct transmission" and "reflected transmission" diffraction effects interfering with each other. How perfect you may say: the title of this lab is *Interference and Diffraction*.

Here is a procedure that will work. Go into the hallway outside the lab and look up at one of the lamp fixtures in the ceiling. Direct your attention to one of the (relatively) thin flurescent tubes, which you will use as a source of "white light". Hold the micrometer close to one of your eyes so that you're looking through a, say, 0.1 mm gap directly at a fluorescent tube "lengthwise". If you carefully orient the micrometer gap, you will both directly see the lamp and an image of it reflected off the shiny faces that delimit the gap. Adjust your "aim" so that the images coincide. Now, without moving the "aim" too much, turn the thimble CW to close the gap. At some closure you'll start to see whitish and blackish "bands", and their thickness and separation will vary with the width of the gap. This pattern is too complicated to understand without great care. However, if you keep closing the gap, at about 5 small units or so, which corresponds to about 0.05 mm, you should see colors of the rainbow. This is a clear sign that wavelength-dependent diffraction effects are occurring. See if you notice how the colors separate, and then try to figure out if this is what you would expect for "single-slit diffraction" (see Knight, Jones, and Field, *College Physics: A Strategic Approach*, 2nd. ed. (KJF2), Chap. 17.5). You are not looking through a single slit, though; you are looking through a "deep", reflective gap, but

maybe what you see is qualitatively similar to what you'd expect for the simpler case of a single slit. What happens to the colors as you close the gap further?

Treat your micrometer with care!

PLEASE: Throughout this lab (and later in life if you use a screw micrometer again), though it looks a lot like a small "C-clamp" used to hold pieces of wood or metal together, this device is NOT a C-clamp. It is a finely made, delicate instrument. If you close the gap too tightly on a trapped object, you'll damage the fine thread that is the heart of the device.

You are treating it carefully if you NEVER drop it and you NEVER try to close the gap too tightly on an object by rotating the thimble with too much torque. Use the thimble to go "most of the way", but then use the ratchet stop at the end of the thimble to go the final distance. The "slippage" built into the ratchet knob gives you a reproducible way to apply the small, final torque for your distance measurement, thereby preventing you from over-tightening the micrometer on whatever it is you're measuring. If for some reason your micrometer doesn't have a ratchet stop, you'll have to get used to applying the final torque – carefully – with your finger tips "by feel". Practice helps.

Measurement of the hair diameter with a micrometer

First, you must determine the "zero reading" of the micromenter so you have a clear reference point when measuring the diameter of the hair. After cleaning spindle-end and anvil, and without the hair between them, close the micrometer with the same, small "final torque" you will use later when measuring the hair. (Because neither the frame nor the internal, fine-thread screws are perfectly rigid, the micrometer will show different "zero" readings according to whether you close it gently, "just right", or "too much". What distance value do you read with micrometer when it's closed "just right"? This will be your "closed value". It would be nice if it were zero, but for any slight mis-adjustment, it won't be zero. That doesn't mean the micrometer is broken; it just means that you have to correct for the "zero shift". (This is a simple example of a "systematic error" that you correct for.) When measuring the diameter of the hair remember to start counting from your measured "zero shift" whatever it is. Record this "zero shift" on your worksheet.

Now insert a hair, which you can supply from your own head. But be careful which hair you choose. According to information on the internet, the diameter of human hair can vary a lot according to the person it's taken from and according to which part of the head or body it's taken from. Moreover, all human hair is not cylindrical. The hair making up a man's moustache is noticeably "flattened", like a belt. Since it's not circular in cross section, it doesn't have "a diameter", and, besides, it would be hard to know just how you mounted it on the frame used to hold it in the experimental setup. So make sure you choose a proper hair from your head or your partner's head.

Bring the jaws together with a CW rotation of the ratchet stop and record on your worksheet the reading you get with the final torque "just right". Subtract the zero reading from the reading with the hair to obtain the hair diameter. Include the dimensional unit and your estimate of the uncertainty in measuring the hair diameter.

Measurement of the hair diameter from the diffraction pattern

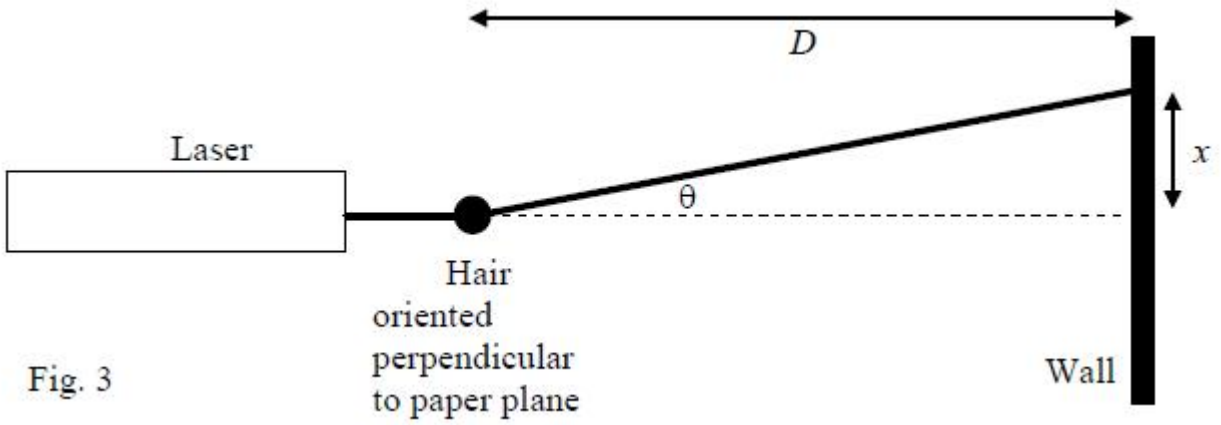


Fig. 3

Tape the hair in a vertical position onto the slide frame. Put the laser ~ 1.2 m from the wall and align its beam axis perpendicular to the wall. Place the slide frame ~ 10 cm from the laser. Note that these are not the exact values you will use for this lab because you will need to make slight adjustments to your individual setup. When recording distances in your worksheet remember to make accurate measurements of the distances for your setup along with a good estimate of the uncertainty for each of these distances.

Move the slide sideways until the laser beam is hitting the hair fully. When this occurs you should see the hair light up from the laser hitting it, and a diffraction pattern should appears on the wall. The central, very bright, roughly circular spot is due to the laser beam being much wider than the hair. This is the light that is not being diffracted and is hitting the wall directly. Ignore this spot and concentrate on the wider and less intense central diffraction maximum that is spread out horizontally.

Qualitative observations

You will see that diffraction on a hair is very similar to diffraction by a narrow slit; see KJF2, Chap. 17.5, especially Figs. 17.24 on p. 560 and STOP TO THINK 17.6 on p. 564. (The equivalence of the two diffraction patterns is the subject of Babinet's Principle. Though not discussed here, you could look it up in Wikipedia if you're interested. Engineers who deal with antennas and other electromagnetic devices often make effective use of this principle.)

1. - Record on your worksheet the direction of the spread of the diffraction pattern when the hair is positioned vertically. Turn the frame by 90 degrees so that the hair is horizontal. Move the frame vertically until the laser beam is obstructed by the hair and you observe the diffraction pattern. Record the direction of the pattern you see wjem the hair is positioned horizontally.

– Put the hair back in the original, vertical position. Shift the position of the frame by making the distance, D, between it and the wall about ~ 0.5 m smaller than before. Observe and record on your worksheet what happens to the pattern, specifically what happens to the positions x of the intensity maxima. How are D and x and related? (Use your observations from the cases where the hair is ~ 10 cm from the laser and from where the hair is ~ 0.5 m from the laser.)

Quantitative measurements

In this part of the lab you will use the diffraction pattern and the geometry of your experimental setup to obtain a value for the diameter of the hair.

Record the wavelength of the laser light on your worksheet.

Again, position the frame with the hair close to the laser, viz., about 10 cm away. Carefully measure the distance D between the frame and the wall and estimate its uncertainty ΔD. Record these values on your worksheet. Place a long piece of masking tape (obtained from your TA) so that the diffraction pattern appears

on the tape. Mark the center positions of the diffraction minima (dark lines, where there is very little laser light) to the left and the right of the central maximum. Place the tape on your worksheet.

For the first 5 orders of diffraction (m = 1,2,3,4,5) measure the distance between the corresponding minima on either side of the beam. Measure from center of the "left" diffraction minimum labeled by "m" to the center of the "right" diffraction minimum labeled by the same value of "m" but with opposite sign. Why is it correct to call these the m-dependent values of (2x)? Write these values into the table on your worksheet. Estimate for m ~3 the uncertainty in (2x). This will be the uncertainty you use for values of (2x) obtained for other values of m.

BE CAREFUL! When making your experimental measurements you are measuring the distance from the center of a minimum on one side of the central maximum to the center of the same order minimum on the other side of the central maximum. This value is (2x) ± Δ(2x). When doing your calculation you will only use the distance from the center of a minimum to the center of the central maximum; this is x ± Δx. Make sure you understand why the value you need is half of what you actually measure.

You now need to use the tool below to plot your data and find the diameter of the hair.

From values in the table on your worksheet find the distance x for each m value and enter it in the table below. Include values for the error in x. Clicking on submit should produce a plot of your distances x versus the order m of the diffraction minimum for the 5 measured values of x. Record the slope of the graph and its uncertainty on your worksheet because you will use this to find the hair diameter.

x axis label (include units):
y axis label (include units):

m= 1	x=	+/-	
m= 2	x=	+/-	
m= 3	x=	+/-	
m= 4	x=	+/-	
m= 5	x=	+/-	

submit

The equation for diffraction minima is Eq. (17.18) on p. 562 of KJF2. [NOTE: KJF2 uses *a* (not *b*)for the width of a single slit, uses *L* (not *D*) for the distance from the slit to the observation screen, and uses *p* (not *m*) for the integer that counts minima. Please don't be confused by this simple difference in notation.] Using this equation, the small angle approximation, and the geometry in Fig. 3, the diffraction minima can be expressed in the following way:

$$m\lambda = b\sin\theta \approx b\tan\theta \approx \frac{bx}{D}, m = 1, 2, ..$$

(6.1)

where b is the hair diameter, λ is the wavelength of the laser light, D is the distance from the hair to the wall, θ is the angle between forward (undeflected laser beam) direction and a line pointing to the diffraction minimum of order m, and x is the distance on the screen between θ = 0 and the location of the m-th diffraction minimum. Use the equation given above to write x = slope * m and express b in terms of the measured slope, λ, and D. Propagate your uncertainties for D and the slope to obtain an uncertainty for b. (Use expression E.7 in *Uncertainty, Errors and Graphs*.) Record the value you obtain for the hair diameter on your worksheet and compare it to the one you measured with the micrometer.

Are the two values of the hair diameter consistent within their combined uncertainty?

Part II

In Part II you will observe both interference and diffraction of light by various types of slit arrangements and explain the patterns observed.

Equipment for Part II

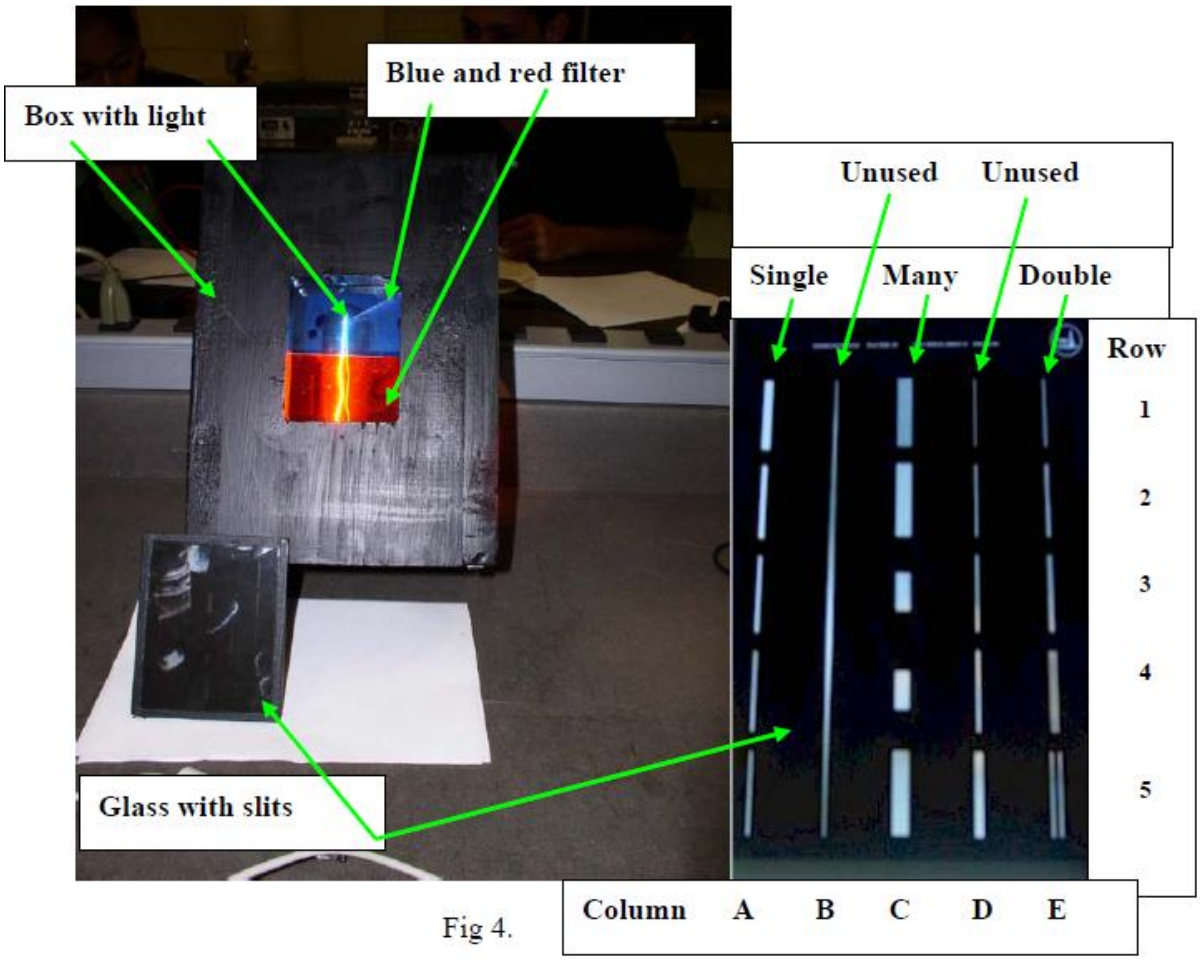


Fig 4.

Incandescent Light Bulb with vertical filament sitting in a box covered with red (bottom) and blue (top) filters.

3" x 5" Glass Slide with various slit arrangements.

Diffraction and Interference of red and blue light through various slit arrangements

Orient the slide so the double slit is located at its bottom right corner, as shown in Fig 4. Identify the 5 columns of slit arrangements with column A,B,C,D,E, and the rows with 1,2,3,4,5 (as in a spreadsheet) as shown in Fig 4.

You will not use columns B and D. Since there is only one light box for this part of the lab, you will be sharing this setup with the other classmates in your lab section. However, since there are several sets of slides with slits, many students can use and view the box simultaneously or in quick succession. You should record your observations in a timely manner so that everyone can complete this part of the lab successfully.

You will be observing the red and blue filaments of the light bulb. Hold the slide close to your eyes and observe the red-filtered and blue-filtered filament through the various slit arrangements as follows.

Single Slit Diffraction

Column A has 5 rows of single slits with the slit width b decreasing by a factor of 2 as you step through each row from top to bottom.

Start at A5. You should see a single slit diffraction pattern with a broad central intensity maximum and maxima on either side that become weaker as you go away from the center. As you saw in Part 1, intensity maxima alternate with intensity minima.

What you are looking at is the intensity distribution as sketched in KJF2, Chap. 17.5, especially Figs. 17.24 on p. 560 and 17.27 on p. 563.

Starting from A5 go up the rows on the slide and observe how the central diffraction maximum and the distances of the minima from this center maxium vary. Refer back to the part of your Lab 6 Pretest where you looked at the behavior of the formula $b \sin\theta = m\lambda$. Does what you see match with what the formula predicts?

Pay attention to the following points:

- Is the blue pattern, wider or narrower than the red one? Why?
- How do the central maximum and the minima vary with slit width b?
- Why does the pattern eventually disappear when b becomes very large (b » λ)?

(Hint: what happens to θ when b » λ, do the minima spread apart or crowd together?)

Double Slit Interference

NOTE! For what follows, it is helpful to know that when studying two- or multi-slit interference, you're seeing the combined effect of single-slit diffraction and multiple-beam interference. The single-slit diffraction is always present due to the finite width of the slits, and its intensity distribution controls the intensity distribution of the interference pattern; see, e.g., the figures made with orange/red laser light near the beginning of http://en.wikipedia.org/wiki/Double-slit_experiment [http://en.wikipedia.org/wiki/Double-slit_experiment].

E1 has the same single slit as A5 and thus produces the same pattern. Positions E2 to E5 have 2 slits with the slit width b kept constant and the same as E1 and the slit distance d increasing by a factor of 2 for each step down through the rows.

Observe the light from farther back. As you go from E1 to E2, you should notice how the central broad diffraction maximum (one bright band in E1) is now divided into 3 narrower bright lines in E2. This is the same for red and blue light. Starting from E2 go down the rows on the slide and observe how the number of maxima (or minima) inside the central diffraction maximum changes. Note also when the two slit interference maxima/minima become difficult to observe.

Recall your Lab Prep exercise which looked at the behavior of the equation $m\lambda = d \sin\theta$. Does what you see match with what the formula predicts?

As you go from E2 to E5 how does the number of two slit interference maxima (or minima) inside the central diffraction maximum change?

The slit widths are the same for all slits in column E of your slide. What does this mean for the width of the central diffraction maximum?

Many Slits, going toward the Diffraction Grating (KJF2, Chap. 17.3)

Column C has from 15 to 80 slits in the various rows. The slits are distributed over the same size area for each row on the slide, so the separation between slits changes according to the number of slits in each row.

The slit width varies as well, so ignore the width of the central diffraction maximum and concentrate on how much the many-slit interference maxima are spread apart as you go from row to row.

You should notice that the spread changes as you go from C1 to C5, but the spread does not change uniformly.

Explain your observations about the change in the spread of the maxima from slide to slide in terms of the equation $m\lambda = d\sin\theta$ (KJF2, Eq. [17.12] on p. 563) using the fact that different numbers of slits are etched into the same size area on the different slides.