PHY 252 Lab 1: The Michelson Interferometer

Fall 2008

To better understand the interferometer used by Michelson and Morley, we will use a simplified version of their instrument to calibrate the motion of a micrometer, and then to measure the refractive index of air.

The basic idea of the interferometer is shown in Fig. 1. The light from a (nearly) monochromatic source is split into two beams which recombine to form a visible pattern of areas of constructive and destructive interference; *i.e.*, bright and dark fringes. When the effective length of one of the optical paths is changed by some means, then any given point on the interference pattern shifts from light to dark or vice-versa for each half-wavelength of path length change.

As a general rule: treat the equipment with respect so that it remains in good shape for the students that follow you. Don't touch mirror surfaces, treat equipment gently, and so on. Also, *never* look directly into the beam or its reflection! There's a laser safety classification scheme; see for example

http://en.wikipedia.org/wiki/Laser_safety

If you consult this web page, you will learn that the lasers used for this lab will not cause permanent damage even if accidentally directed at someone's eye. However, it can be very uncomfortable, it can affect vision over a short period of time, and besides it's just poor practice in case you work with more powerful lasers later on. With more powerful lasers, you have to wear goggles that block out the narrow wavelength range that the laser operates in, and use other precautions. So, always use care when working with lasers, and also make it your own responsibility to understand safe procedures in addition to getting trained in the safe practices of the lab you work in.

To get fringes, you must make the two beams land on top of each other. Here's a suggested procedure to get there, based on the sketches of Figs. 1 and 2:

1. In the end you're going to want to see the fringes projected on a surface. A good way to set things up is to use a wall as the viewing screen; a sheet of white paper on a book will work fine too.

2. Adjust the micrometer knob so that the lever arm of mirror M2 is approximately parallel with the edge of the interferometer base.

3. Mirror M2 does not have a tilt adjustment. Therefore your first step is to rotate the beam splitter mirror out of the way, and orient the interferometer "table" so that the laser beam off of mirror M2 gets reflected back to its source. You may need to adjust the height and tilt of both the interferometer and the laser to make this happen.
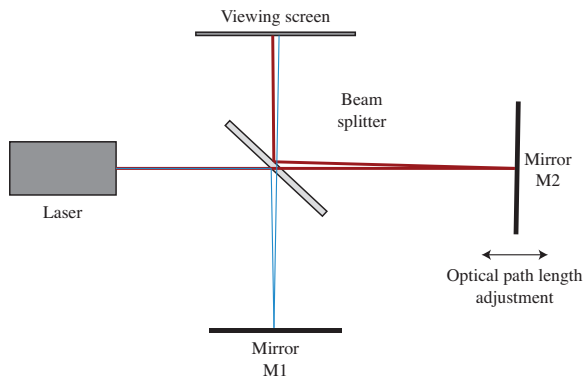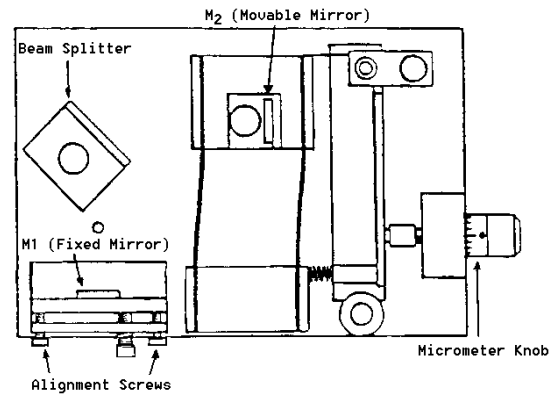
Figure 1: Basic idea of a Michelson interferometer

Figure 2: Crude sketch of the apparatus you'll use

4. You should now rotate the beam splitter into the path so that it is at about 45° to the laser beam as shown. Tweak the rotation of the beamsplitter until you see laser light pretty well centered on mirror M1. You can then tweak the tilt of mirror M1 by trying to steer beam back off of the beam splitter to the laser.

5. You should now see two light beams on the viewing screen: the light reflected off of mirror M2 and then the beam splitter, and the light reflected off the beam splitter and then mirror M1 (and then sailing through the beam splitter without reflection). You can always put a piece of paper in front of M1 temporarily to sort out which beam is which. What you want to do at this point is to get the two beams to approximately coincide with each other through further adjustment of the tilt of mirror M1.

6. Now you might want to blow up the beams so that they fill a larger area at the viewing screen. You can do this by putting a lens on the exit face of the laser. It can be a diverging lens to make the beam spread out, or it can be a converging lens to make the beam get focused down at a distance shorter than the distance it travels to the viewing screen, so that it can then diverge from the focus and again be a bit bigger at the viewing screen.

7. At this point you will hopefully see a sort of speckly appearance to the light at the viewing screen, and a beam spot that is half a centimeter in diameter or more (depending on what lens you used in the previous step). What you should now do is to try very gentle tilts of the mirror M1 to try to make some fringes appear. From there, see Fig. 3 for some further hints on how to improve the alignment.

Once the interferometer is aligned, you should play a little bit:

- Tap the table and see how the fringes change.

- Speak in a quiet or a loud voice next to the interferometer (without blowing on it) to see if pressure waves of acoustical noise affects the fringes.

Figure 3: Michelson interferometer fringe pattern. What you are likely to see at first is a band of almost straight fringes, such as are shown within the grey box. What you then want to do is to adjust the tilt of M1 to get closer to the center of the fringe pattern, until at the end you get fringes that look like concentric rings as shown at right. Note that the center fringe can be bright, or it could be dark (it changes every time the net optical path length changes by $\lambda/2$).

- Put a piece of glass in one "arm" of the interferomter (such as between the beamsplitter and M2) and see how the fringes change with tilt of the piece of glass.

But then enough of fun; it's time to make measurements! In our case, it makes sense to assume that the laser emits at a known wavelength of $\lambda = 632.8$ nm, and use that to calibrate the motion of the micrometer used to move mirror:

1. Turn the knob of the micrometer that moves mirror M2 in the "pressing in" or "getting tighter" direction until the zero on the knob is aligned with the index mark. (Why that direction? So that you're pushing on something with good contact at all times, instead of pulling away and relying on a spring force to keep you in good contact).

2. Make a reference mark on the paper between two of the fringes near the center of the interference pattern.

3. Rotate the micrometer knob slowly in the "getting tighter" direction. Count the fringes as they pass your reference mark. Continue until 25 to 40 fringes have passed your reference mark. As you finish your count, the fringes should be in the same position with respect to your reference mark as they were when your started the count.

4. Record d_m, the distance that the movable mirror M2 moved as you turned the micrometer knob, in units of micrometer divisions.

5. If the number of fringes that crossed your reference mark is m, the physical distance of one micrometer division d_m is given by

$$d_m = \frac{m}{2}\lambda \tag{1}$$

Explain this relationship and calculate d_m for your setup.

1   Measuring the index of refraction of air

Now that you have calibrated your interferometer, you will use it to measure the index of refraction n of air. To do so, put an air cell in one interferometer "arm" and readjust the interferometer as

required to get back to a nicely centered fringe pattern, and again use a mark on your viewing screen to count fringes. Now use the small hand-operated vacuum pump to slowly pump out the air cell. It's at *this* point, when the cell is pumped out as much as you can get it, that you should record the "vacuum pressure" (that is, the pressure in the cell is atmospheric pressure minus the vacuum pressure), and then slowly bleed air back in the cell while counting fringes. (Or it may in fact work out better to do it the other way around, and count fringes while slowly evacuating the air cell; in any case, it's really a two person experiment). In either case, you can construct a table of [pressure in air cell, number of fringes]. The relationship between the pressure change Δp and the number of fringe shifts $m_{\Delta p}$ is

$$m_{\Delta p} = \frac{2d(n-1)}{\lambda} \frac{\Delta p}{p_{\text{atm}}} \tag{2}$$

where λ is the light wavelength, n is the index of refraction of air at atmospheric pressure, d is the length of the air cell, p_{atm} is the current atmospheric pressure, and Δp is the pressure change. Explain this relationship. Plot $m_{\Delta p}$ versus Δp on a graph and draw the best straight line through your data points. From the slope of this line and a measurement of d, λ, and p_{atm}, determine n at atmospheric pressure. Estimate the experimental uncertainty on your measurements (by error propagation of various error sources) and compare to the literature value.