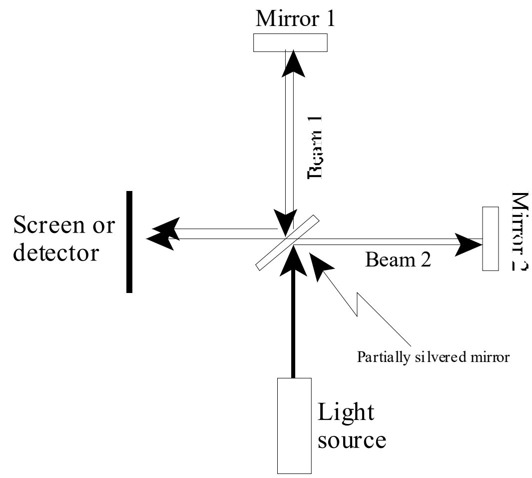
Using a Michelson Interferometer

I. Basics of the Michelson Interferometer

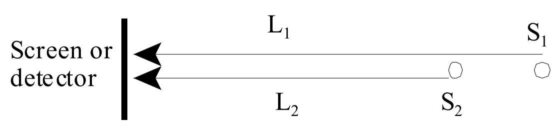
WARNING: Do NOT Touch the front surfaces of the mirrors!

You will use a Michelson interferometer to measure the dielectric constant of a gas. The Michelson interferometer is one of the more basic interferometers.

It consists of two full mirrors and a partially silvered mirror that lets about 50% of the light striking it through. This partially silvered mirror effectively splits the incoming beam into two beams. Beam 1 goes to mirror 1 and is reflected back to the partially silvered mirror where some of it is reflected to the screen or detector, the rest going back toward the light source. Beam 2 goes to mirror 2 and is reflected back to the partially silvered mirror, where half goes to the detector or screen and half back toward the source. The light arriving at the screen is a sum of the light from beams one and two.



When that light combines, it will add constructively or destructively (or somewhere in between) depending on the difference of the two path lengths, L_1 for beam 1 and L_2 for beam 2. If $L_2 - L_1 = m\lambda$, where m is an integer, the interference will be constructive and if $L_2 - L_1 = m\lambda + \lambda/2$ it will be destructive. (I'm ignoring the effect of the path through the partially silvered mirror.) From the point of view of the screen, the mirrors make the original source look like two different sources; one located a distance L_1 away and the other a distance L_2 away. As it is drawn, it makes it look like source 1 is right behind source 2. If $L_2 - L_1 = m\lambda$, then the spot where the two beams come together is bright, if $L_2 - L_1 = m\lambda + \lambda/2$ it will be dark.



Technically the L's above should be the optical path lengths, often abbreviated OPL. The optical path length is the physical length times the index of refraction of the material the light is traveling through. If the light travels a distance L_1 through medium one of index n_1 and a distance L_2 through medium 2 of index n_2 the total optical path length is $n_1L_1 + n_2L_2$.

II Measuring the Index of Refraction of Air

In this experiment you will have a cell containing a gas in one of the paths. When you pump the gas out, the optical path length through the cell changes and this changes the total optical path length of that beam. The spot where the two beams strike the screen will alternately turn bright to dark and back to bright again as the optical path length of the beam changes as you pump the gas out. If you change the optical path length by $m\lambda$, this bright to dark to bright transition will occur m times. The change in the optical path length is also given by the change in the index of refraction times the length of the cell $L_c \approx 5.0$cm, but the light goes through the cell twice so the total change is $2\Delta n \times L_c = m\lambda$, or

$$\Delta n = \frac{m\lambda}{2L_c} \qquad 1.$$

If you measure m = 12 and $\lambda = 600$nm, $\Delta n = 7.2\times10^{-5}$.

III Measuring the Wavelength of a laser (Optional)

In this experiment you will be able to move mirror 1 and change L_1. As L_1 changes, the spot where the two beams strike the screen will alternately turn bright to dark and back to bright again. If you gradually change L_1 by $n\lambda$, this bright to dark to bright transition will occur n times. If it occurs n times and you changed L_1 by 5mm, then $n\lambda = 5mm$, or $\lambda = 5mm/n$. To determine λ you only need to know the change in L_1 and measure n. The change in L_1 is known because you will use a micrometer to move mirror 1. However, the change in the micrometer reading is not ΔL_1 but rather $\Delta L_1 = \frac{2}{5}(\text{change in micrometer reading})$. *This is because the micrometer is connected to the mirror by a lever which reduces the distance the mirror moves to 1/5 the distance the micrometer moves. The 2 comes from the fact that the beam goes to the mirror and back, so if the mirror moves 1mm, the beam path changes by 2mm. So if the micrometer changes by 10mm, $\Delta L_1 = 4mm$. If this corresponds to 10,000 transitions, or n = 10,000, then the wavelength is 400nm.*

ALIGNMENT PROCEDURE

The most difficult part of the experiment is to align the mirrors and the light source. You will use a laser as the light source. Put it in one of the laser mounts and put it on an optics bench. You want to line it up so that the reflection from mirror 1 that passes back through the partially silvered mirror goes right back into the laser, i.e. back through the "hole" that the original beam comes out. (This is easiest to do if you block the beam from the beam splitter (the partially silvered mirror) that goes to mirror 2. ***DO NOT TOUCH THE FRONT SURFACE OF EITHER MIRROR!***.) Do this either **by moving the interferometer, adjusting the position of the laser using the micrometers on the laser mount, or both.** Note that there may appear to be multiple reflected beams. However, one reflected beam is stronger than the others. The weaker ones come from multiple reflections in the beam splitter. Ignore the weaker ones. When this is aligned, block the beam that goes to mirror 1 and unblock the beam to mirror 2. **Then use the adjustments on the back of mirror 2** to make the beam it reflects back to the laser via the splitter go directly back into the "hole" the original beam comes out.

At this point the mirrors are almost aligned. Now unblock both mirrors and look at the spots they both produce on the screen. There should be two intense spots that hopefully overlap and some weaker ones from multiple reflections in the splitter. Again, ignore the weaker ones. Because the spots are small, it can be hard to make the final adjustment at this point. I usually insert a beam spreader or a weak lens in front of the laser between it and the interferometer. A weak lens makes the beam diverge and produce a bull's eye pattern on the screen when the final adjustments are made to mirror 2. If you use a lens, you make the final adjustment by trying to make the light and dark fringes as large as possible until the center of the pattern is a bull's eye.

COUNTING THE FIRNGE SHIFTS

The movement of the light to dark to light transitions are called fringe shifts. You need to count these as the optical path length changes. They can occur so rapidly that it is difficult to do so with your eye. **If you can make them go slow enough, you can count them manually. Otherwise put a photodiode in the center of the interference pattern in front of the screen.** The photodiode produces a current proportional to the light intensity. Therefore, connect the photodiode's output to a current to voltage converter, i.e. either a resistor or an op amp in a current to voltage configuration. This signal may have to be amplified before you send it to the counter, e.g. a HP Agilent 53131 Universal Counter. Connect your input to channel 1.

Put the Counter in the **TOTALIZE** mode by pressing the **OTHER MEASUREMENTS** button until **TOTALIZE 1** is displayed. (See p 2-14 of the manual.) Adjust the gain of your amplifier so that the voltage change is about 3V when you go from dark to light. (Lower the room lighting before doing this. You don't have to turn all the lights off, just reduce the level.) Set the **TRIGGER LEVEL** for cannel 1 so that it is half way between the two voltage output levels, i.e. the dark and light levels. Do this by pressing the channel 1 **TRIGGER SENSITIVITY KEY**. **AUTO TRG: ON** should be displayed. Then press an **ARROW KEY** to turn **AUTO TRG** to **OFF**. Press the **TRIGGER SENSITIVITY KEY** again and it should show LEVEL: _________V. (See pp. 2-48 to 2-50 in the manual.) The number may vary. Then adjust the trigger level by using the arrow keys so that it is half way between the light and dark voltages. **PRESS THE ENTER KEY TO COMPLETE THE ENTRY**. Press the **TRIGGER**

SENSITIVITY KEY again until you see **SENSITIVITY: HI** displayed. By pressing the arrow keys you can adjust the sensitivity. You should try it on **HI** first, and if you seem to be getting too many false counts, go to **MED** or **LO**. Make measurements for two of the settings. The **GATE** setting should be on AUTO. By pressing the **START/STOP** button you can start or stop a run.

It will be beneficial to reduce the overall lighting in the room. This will decrease the noise. Vibration of the table will also cause fringe shifts, so do not bump the table. Talking loud can also cause vibration of the apparatus and produce "noise".

Jarring the apparatus is likely to produce extra counts. Will that make your measured Δn too large or too small? Can you think of any reason you might not count all the fringe shifts? If you missed some, would that make your measured Δn too large or too small?

It may be helpful to construct a comparator with hysteresis to convert the signal from the photodiode into a square wave before sending it to the counter. By adjusting the hysteresis you can get rid of more noise while still being able to detect the signal. You probably want the hysteresis to be about one half the amplitude of the minimum signal amplitude. If the signal varies between ± 2V, you would want the trip points for the hysteresis to be at ± 1V or so.

DATA

You should take data for two lasers, the red and green He-Ne lasers. If you pump all the air out, your Δn should be $n_{air} - 1$. At 20°C and 1atm of pressure, $n_{air} - 1 = 2.71\times10^{-4}$ at λ=600nm.. Call this Δn_{atm}. If you could do this, you could average your Δn_{atm}'s to see if they are within ± one standard deviation of the accepted value for air. (n_{air} varies slightly with wavelength in the visible, but not too much. You can check this in the Handbook of Chemistry and Physics or try the calculator at *http://emtoolbox.nist.gov/Wavelength/Ciddor.asp*)

A problem is getting a pressure change of 1 atm. If the pressure and temperature were at the "standard" temperature and pressure and the final pressure was zero, adding the change in index to 1 would give the index of refraction for the gas that is normally given in textbooks. You will not be able to get the pressure to zero with the hand pump we have. If it goes from 100kPa to 10kPa, it only goes 90% of the way to zero. Instead of trying to get a 1 atm change in pressure, I recommend you measure the change in n for several pressure changes between 30kPa and 90kPa and plot those. You can use the slope and intercept to extrapolate to what Δn would be for a change in pressure of 1atm. Alternatively, you can plot the m's for the different ΔP's and extrapolate to find the m for a change of 1 atmosphere of pressure (101kPa) and use that to calculate a Δn_{atm} for 1 atm. of pressure. This Δn_{atm} +1 is your estimate n for air at atmospheric pressure. **When you compare your value to the "book" value for air at 1 atm. of pressure, you should compare your Δn_{atm} to $n_{book} - 1$.** Are these within one standard deviation of each other? I want to see how you calculate the standard deviation or uncertainty for your Δn. **This second approach is probably the best way to do it**.

Note that $n_{air} - 1$ is sensitive to the actual temperature, so you should **measure the temperature in the room**.

To complete the lab you will need to align the interferometer. See me when you are ready to do this.

If you use the photodiode, there is a "touch" you need to make accurate measurements in this experiment. You need to watch the hysteresis levels and make sure they match the signal amplitudes. If the hysteresis trip points are ± 1.0V, you want the signal amplitude to be about 4V peak to peak, or ± 2 V. If the signal amplitude is too small you may not count all the fringe shifts and if the amplitude is too large, noise (from sound and other vibrations) may produce extra counts.