PH 481/581 **Physical Optics** **Winter 2014**

Laboratory #4 **Week of February 3**

Read: pp. 363-372 of "Optics" by Hecht

Do: 1. Experiment IV.1: Fabry-Perot Interferometer: find Finesse using $\Delta\lambda$ of Na_D

2. Experiment IV.2: Fabry-Perot Interferometer: Mercury doublet

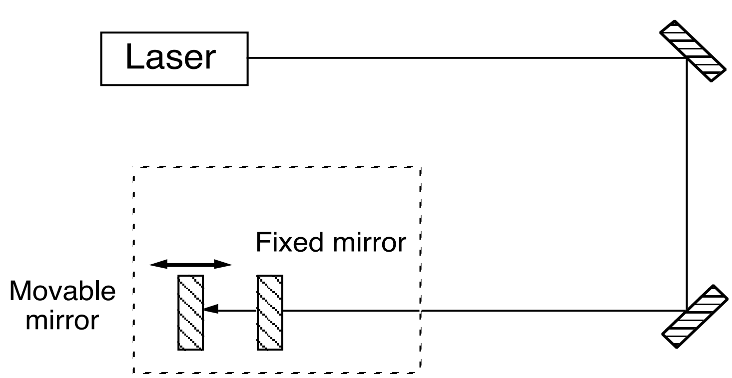
Experiment IV.1: Fabry-Perot Interferometer: find Finesse using $\Delta\lambda$ of Na_D

The goal of this lab is to familiarize yourself with the Fabry-Perot Interferometer, to align it properly, and to measure the finesse using the sodium doublet. The figure below shows a schematic of the Fabry-Perot Interferometer you will use. As with the Michelson Interferometer, you will use both a laser and a lamp source and a platform for stability. Be sure to use a target when using the Helium-Neon laser. **Do not under any circumstances look into the interferometer output when using the laser** (even though you will when using the lamps).

To align the interferometer, first adjust the two turning mirrors so the laser beam is parallel to the table top (at an approximate height of 13.5 cm) and parallel to but in between the two sets of holes that lead toward the interferometer. This should place the laser beam approximately in the middle of the mirrors. These mirrors are dielectric coated mirrors, designed for the HeNe wavelength, with a reflectivity of 95%. Adjust the fixed mirror so that the reflection returns nearly directly back to the laser. There should now be a streak of reflected spots on the target. Adjust the movable mirror so that the streak collapses to a single spot. At this point you may already noticed some interference fringes. To make things more clear, convert the parallel laser input beam into a diverging beam (i.e., a point source) by inserting a diverging lens (-25 mm works well) in front of the interferometer. You should then see a set of concentric circles (a bull's eye pattern). These are the fringes formed by the interference of the multiple beams that are reflected back and forth between the two mirrors of the interferometer. Slight adjustments of the interferometer mirrors will allow you to center this pattern.

The Fabry-Perot interference pattern obeys the same equation as the pattern in the Michelson Interferometer:

$$2d\cos\theta_m = m\lambda,$$



where d is the spacing of the two mirrors. The new aspect of this interferometer is that multiple beams produce the interference pattern rather just two as was the case for the Michelson Interferometer. This results in sharper fringes. The Michelson fringes were sinusoidal, whereas the Fabry-Perot transmission fringes obey the Airy function equation:

$$I(\delta) = \frac{I_0}{1 + \left(\frac{2F}{\pi}\right)^2 \sin^2 \frac{\delta}{2}} \ ,$$

where F is the finesse (not to be confused with the coefficient of finesse) and δ is the phase shift which is given by $\delta = 2kd\cos\theta$. The sharp fringes mean that if a doublet is present, you will clearly see two sets of rings except when they are almost exactly overlapping. The finesse is the ratio of the fringe spacing to the fringe width. You can quote the spacing and width in many different ways, e.g., in terms of frequency, wavelength, phase shift, or fringe number. If we call the fringe width ε in terms of the fringe number (i.e., the fringe spacing is 1), then the finesse is simply $F = 1/\varepsilon$.

If the fringes from two different wavelengths (e.g., the sodium doublet) overlap at the center (θ=0) exactly, then

$$2d = N_1\lambda_1 = N_2\lambda_2 .$$

If we now change the mirror spacing until we can just resolve the two fringes, then the fringes will be separated by the resolution of the instrument. For a Fabry-Perot, the resolution is approximately the fringe width. Thus if we go from a spacing d' where the fringes are just resolved, through the overlap position d to the next spacing d'' where the fringes are just resolved, then we can write:

$$\begin{aligned} 2d' &= N_1'\lambda_1 = (N_2' - \varepsilon)\lambda_2 \\ 2d'' &= (N_1' + N)\lambda_1 = (N_2' + N + \varepsilon)\lambda_2 \ , \end{aligned}$$

where N is the number of fringes we count between d' and d''. If we keep going in the same direction until the fringes just start to become unresolvable again (i.e., fringes look just like d' case), then we can write

$$2d''' = (N_1' + N_m)\lambda_1 = (N_2' + N_m + 1 - \varepsilon)\lambda_2 ,$$

where d''' is the new spacing and N_m is the number of fringes between adjacent overlaps of the two fringe patterns. The extra 1 is on the right side because one set goes one more fringe than the other. From taking differences of these equations we can derive an equation for the finesse:

$$F = \frac{1}{\varepsilon} = 2\frac{N_m}{N} = 2\frac{d''' - d'}{d'' - d'} .$$

Thus we only need to count fringes or measure the distances that the stage moves to find the finesse.

To measure the finesse, use the sodium lamp in place of the laser. A piece of frosted or ground glass in front of the lamp will help to reduce the intensity and will also provide a uniform background against which to view the fringes. A small value of d will provide a larger pattern, which makes the experiment simpler. However, be very careful not to get close enough for the mirrors to touch. These mirrors are quite expensive. You can use the stepper motors without calibration since your result depends on the ratio of two distances or fringe number. You may want to try out different filters to see if you can reduce the background light intensity. You may also want to use the CCD camera to observe the fringes (although they must be very well defined for this to work - make sure you can observe them by eye beforehand). Estimate the error of your measurement.

<u>Experiment IV.2: Fabry-Perot Interferometer: Mercury doublet</u>

In this experiment you will measure the separation of a pair of lines in the mercury spectrum. The mercury lamp emits many different spectral lines, but you will mostly see the yellow lines since they fall within the range of wavelengths that these mirrors reflect (they are designed for Helium-Neon lasers at 633 nm). We also have some filters to select out the yellow lines; their use will make life easier. The mean wavelength of this doublet is 578 nm.The mercury lamp also emits ultraviolet light, so be careful to keep the glass on the front of the lamp (the glass absorbs the UV light) to avoid giving your eyes a sunburn (quite painful) and do not allow any stray light from the lamp out.

The two wavelengths present in the light from the mercury lamp will produce a pair of interference patterns. There will be two sets of concentric circles corresponding to λ_1 and λ_2. These wavelengths are only slightly different, which means that patterns will be nearly identical, with only a slight difference in the angular separation between two adjacent fringes. If the two patterns each have a bright fringe at $\theta = 0$, then we cannot distinguish one from the other there. As θ increases, one set of circles will start to move away from the other until the bright fringes from one wavelength fall exactly half way between the bright fringes of the other wavelength. As θ increases further, we will eventually come to another place where the bright fringes overlap. If there are N fringes of the λ_1 pattern between the center and the next location of maximum overlap, then there will be $N + 1$ fringes of the λ_2 pattern (or $N - 1$ if $\lambda_1 < \lambda_2$). To actually count these numbers we will move the mirror and watch at θ=0. In that case, one finds that displacement of the mirror Δd can be written as

$$\Delta d = N\lambda_1 = (N+1)\lambda_2 .$$

Since $\lambda_1 = \lambda_2 + \Delta\lambda$, we can derive an equation for the splitting:

$$\Delta\lambda = \frac{\lambda_2}{N} .$$

Place the vapor lamp close to the input of the interferometer. A piece of frosted or ground glass in front of the lamp will help to reduce the intensity and will also provide a uniform background against which to view the fringes. Look into the output port of the interferometer. You should see a set of concentric fringes as before.

To measure λ (which will be the average of λ_1 and λ_2) you should count 100 fringes. To measure $\Delta\lambda$, you should count fringes between overlaps since they are easier to determine than the half way points. It will be difficult to actually count all the fringes, but you can infer N, since you know λ and Δd. You should go through several overlaps to improve your precision. If each overlap is hard to determine within 10 fringes and they are separated by 100 fringes, then your error is about 10% (10/100). But if you go through ten overlaps, then your error is only 1% (10/1000). Estimate the error for your experiment.

Equipment needed:

Item	Qty	Source (part #)
Helium-Neon Laser	1	Melles Griot 05 LHP 121
Al mirror	2	Newport 10D10ER.1
Polarizer	2	Edmund A38,396
-25 mm lens	1	Newport KPX043
Sodium vapor lamp	1	
Mercury vapor lamp	1	
Mercury line filter	1	Oriel
3 finger clamp	1	Chem stores
Magnetic base	1	Thor Labs MB175
Fabry-Perot hardware		
Platform for stability	1	Thor Labs (special)
Mounting posts	4	Thor Labs P3
Translation stage	1	Thor Labs MT1-Z8
Mirror mount	2	Thor Labs KM1
Riser block	1	Thor Labs RB2
Base plate	1	Newport BP2
He-Ne mirrors	2	CVI