**Week IX: \nINTERFEROMETER EXPERIMENTS**

Notes on Adjusting the Michelson Interference

**Caution:** Do not touch the mirrors or beam splitters – they are front surface and difficult to clean without damaging them.

1. **Making the laser beam perpendicular to the movable mirror**
   Remove beam splitter and position the movable mirror so that the reflected beam from the movable mirror is collinear with the incident beam, and approximately parallel to the base of the interferometer.

2. **Aligning the stationary mirror**
   Replace beam splitter and position it so the reflected beam strikes the stationary mirror in its center. Position a screen at the output of the interferometer. You should see two sets of bright dots. (If you see more than two sets of spots, adjust the beam splitter so only two sets are seen.) Adjust the stationary mirror so that the spots coincide.

3. Now place a +18 mm f.l. lens in front of the laser, and position it so that the diverging beam is centered on the beam splitter.

4. You should now have circular fringes on the screen, but they are probably not centered. Adjust the stationary mirror so that the fringes appear as concentric circles.

**Note:** Adjusting and using an interferometer is somewhat an art, and if you have trouble at any point, feel free to ask.

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![Michelson Interferometer Diagram](image)

Fig. 1: Michelson Interferometer
Notes on Adjusting the Fabry-Perot Interference

1. Position the laser and adjust it so it strikes the first mirror in the center and the reflected and incident beam are collinear. You can insert a thin piece of paper between the mirrors to block the reflection from the second (movable) mirror. You may have to adjust the first mirror to get the laser beam perpendicular to it.

2. Remove the paper and place a screen at the output. You should see only one bright spot. If you see more, you should adjust the movable mirror so only one spot is seen. You may see fringes at this point.

3. Insert a +18 mm f.l. lens in front of the laser. Adjust it so the diverging beam fills the first mirror. You should see fringes now. Adjust the stationary mirror so that the fringes are concentric circles.

Fig. 2: Fabry-Perot Interferometer
Comments on the Fringe-Counters for Interferometer Experiments

The trigger circuit for these counters responds to difference in intensity over time. As the interferometer is never a perfect device, it will always allow some light through even when set for destructive interference. At various intensities, the destructive interference at one intensity may produce a brighter spot than constructive interference does at a lower average intensity. For example:

At high intensity, we want the on/off level to be between $I_1$ and $I_2$. At low intensity, this level should be between $I_2$ and $I_3$. Clearly, if the level is between $I_2$ an $I_3$ and we use high intensity, the fringe counter will not be able to recognize the difference between the destructive and constructive conditions.

It follows then that there is an optimum sensitivity level for every average intensity (or conversely). It is important that the intensity be properly adjusted to this level or miscounting will occur.

To adjust the intensity, the aperture size in front of the detector can be adjusted. The optimum intensity or sensitivity level is found by noting at what level the counter refuses to function because the intensity (or sensitivity) is too high, and also at what level the intensity (or sensitivity) is too low. A median is of course what is sought. Consult with the TA if you have trouble getting the fringe counters to work properly.

If the counter is skipping fringes, there will be a considerable inconsistency in the counts/displacement value. When properly adjusted, the counter is extremely consistent, and frequency measurements should be good to 1% (100 counts).
Experiments with Interferometers (report uncertainties and do error propagation)

There are 5 stations built up in the classroom. You may do these lab activities in any order. When you have taken your data, please move to an empty table to do any calculations so that other students can take data as well.

Experiment 1: Wavelength of Laser Light
Note: This activity can be performed on either the Michelson or the Fabry-Perot interferometer. You don’t have to do it on both.

To measure the wavelength of the laser light, position the photodetector (PSD) in a stable portion of the output interference pattern. Reset the counter to zero, and note the micrometer setting. Move the micrometer in one direction only, and count approximately 500. Now note the micrometer setting. Do not disturb the micrometer. The wavelength is given by

\[ \lambda = \frac{2d}{m} \]

Where \( d \) is the distance the mirror has moved (why the factor of 2?), and \( m \) is the number of fringes counted. Now reverse the direction of travel of the micrometer and count the same number of fringes as above. Note the final position of the micrometer. Is it in the same position as where you started? Calculate the % error in the wavelength as follows:

\[ \% \text{ error} = 100 \times \frac{\lambda_{\text{measured}} - \lambda_{\text{known}}}{\lambda_{\text{known}}} \]

Can you explain the error? (\( \lambda = 6328 \) Å for the HeNe laser)

Experiment 2: Index of Refraction of Air
Note: This activity can be performed only on the Michelson interferometer.

Place the gas cell between the beam splitter and the movable mirror. Be sure you get a good fringe pattern. Attach hand pump or a motorized pump to the gas cell. Pump air out of cell. Then use the relief valve to slowly let the air back into the cell. Stop and note the number of fringes counted at several pressures. The index of refraction varies directly with its density (assuming constant temperature and vapor pressure), and the value in vacuum is 1. When the pressure in the gas cell changes by \( \Delta P \), the index of refraction changes by \( \Delta n \), and a shift of \( \Delta m \) fringes occurs, with

\[ \Delta n = \frac{\Delta m \lambda}{2l} \]

(\( l = \) path length of gas cell, excluding windows, \( \sim 4 \) cm). Verify this relation. Plot the number of fringes observed versus the pressure. Using the slope of this line, \( \Delta m / \Delta P \), calculate the index of refraction \( n \), for each pressure measured, and for atmospheric pressure. Plot \( n \) as a function of \( P \). Show through mathematical derivation that

\[ n = 1 + \frac{\Delta m \lambda}{2l P} \]
Experiment 3: Index of Refraction of Glass Plate

Note: This activity can be performed only on the Michelson interferometer.

The index of refraction of the glass plate can be measured by rotating it slowly (thus changing the optical path length), while counting fringes. Place the glass plate on the rotating table so it is perpendicular to the optical beam. Be sure you have a nice set of fringes. While counting fringes (use fringe counter if available) slowly rotate the table and glass plate through an angle $\Theta$ (10° is good). The index of refraction of the glass plate is given by

$$n = \frac{(2t - ml)(1 - \cos\Theta)}{2t(1 - \cos\Theta) - ml}$$

where $t =$ thickness of plate, $m =$ number of fringes counted, and $\Theta =$ angle plate turned through.

Can you think of another way of measuring $n$ for the glass plate?

Experiment 4: Separation of Sodium Doublet

Note: This activity is performed on a Fabry-Perot interferometer.

You can adjust the Fabry-Perot interferometer used in this experiment by replacing the lens with a small aperture. The small aperture produces a single dot when looking through a perfectly adjusted interferometer (mirrors parallel). When mirrors are not parallel, a set of aligned dots is seen. By adjusting the mirror screws the separation of the dots can be decreased until they all overlap and a single dot is seen. You can then replace the aperture with the lens again and do fine adjustment of the mirror screws to see and optimize the ring pattern. A diffuser can be placed between the sodium lamp and the lens to produce a “more even” light source. The yellow sodium light consists of a “doublet” of two emission lines of slightly different wavelengths. Each of these two emission lines will create its own fringe pattern and, as the movable mirror is translated; the two fringe patterns will slowly move “in-phase” and “out-of-phase”. As a consequence, you will see (besides the quick motion of the fringes) that the whole fringe pattern changes in a periodic way from clear and distinct (in-phase) relatively widely separated fringe pattern to an either washed-out uniform illumination (out-of-phase) or, if you have a well enough adjusted mirror system, you may even see the double-pattern of very narrowly spaced fringes (out-of-phase).

☛ Determine the average wavelength $\lambda$ of the sodium doublet by measuring the number of fringes over a given distance of mirror translation, as in experiment 1. Since the slow double-line change of the pattern confuses the fringe counter, you must count the fringes by eye. You must be careful to not double count due to the double line. It is best to first adjust the mirror position such that the doublet is “in-phase” and you see the widely spaced fringe pattern. If you then count over a not-too-large range, so that the fringe patterns do not get out-of-phase, you may avoid double-counting.

☛ Measure as accurately as possible the distance $(d_1 - d_2)$ between adjoining mirror positions, for which the pattern is “out-of-phase” (either washed out or you seeing equally and narrowly spaced double fringe patterns). Determine the wavelength difference $\lambda_1 - \lambda_2$ of the two lines from

$$\lambda_1 - \lambda_2 = \frac{\lambda^2}{2(d_1 - d_2)}$$