Interferometer
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I. Introduction

In this experiment we will be using different set ups of an interferometer to split beams of light from a laser into several components in order to observe an interference pattern on a viewing screen. This interference pattern represents where the beam of light is experiencing constructive and destructive interference.

We will be using an interferometer base in two separate modes for different parts of the experiment, the Fabri-Perot and Michelson modes. These set ups will be used to measure the wavelength of an He-Ne laser by counting the number of fringes on the interference pattern and the distance that the micrometer moved. In the Fabri-Perot set up a reflective cavity is created by placing two parallel mirrors between the viewing screen and laser. In the Michelson set up a beam splitter is used to reflect half of the light to a fixed mirror with an adjustable dangle and the other half is transmitted to a moveable mirror and reflected back to the beam splitter. After our measurements for the wavelength in Michelson mode we will then attach an air pump with vacuum cell to the set up between the beam splitter and moveable mirror in order to measure the measure the index of refraction of air.

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II. Method

In the Fabry-Perot set up a reflective cavity was created by two parallel mirrors, the movable mirror, and the adjustable mirror. A He-Ne laser and viewing screen were set up on opposite sides of each other with the reflective cavity between them as displayed in Figure 1.

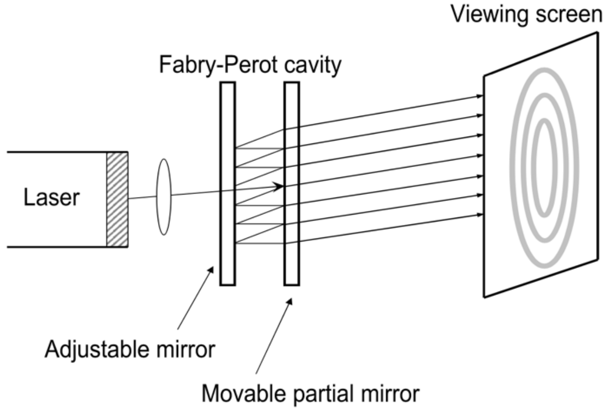

Figure 1: Fabry-Perot Inferometer basic apparatus

An 18 mm focusing lens was put in front of the laser and adjusted until there was a clear interference pattern displayed on the viewing screen. The interference pattern needed to both be clear and releatively centered on the viewing screen so that the fringes could be observed going in and out from its center as displayed in Figure 2.

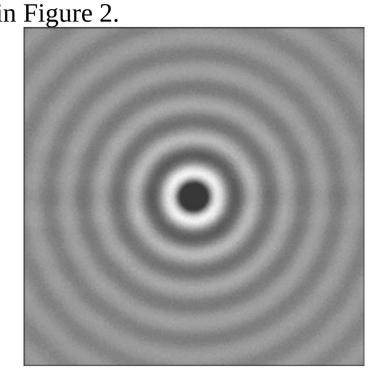

Figure 2: Interference pattern on viewing screen

The knob on the apparatus used to manipulate the interference pattern on the viewing screen was adjusted to a middle reading of 500 μm. We then slowly turned the knob counterclockwise to increase the d_m and watch the fringes on the interference pattern go inward towards the center. We counted 20 fringes passing through the center of the interference pattern then recorded the d_m on the knob that had passed at that point. This was repeated 10 times with each m number of fringes being 20 until we recorded the d_m.

We used the measured d_m and tracked m to calculate the wavelength of the laser at each collected data point by using Equation 1.

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

In the next part of the experiment we used the Michealson set up for the laser and mirror apparatus. The viewing screen was offset to the side to catch the oncoming laser light from the beam splitter with the movable mirror and fixed mirror on different sides of the beam splitter as shown in Figure 3. This was done so that the laser light would be half reflected and half transmitted. Two dots were intially shown on the viewing screen, so the adjustable mirror (shown in the apparatus as the fixed mirror with adjustable angle) was adjusted so that the two dots overlapped. Then the focusing lense was placed in front of the laser to create another interference pattern on the viewing screen similar to the one shown in Figure 2. The same process for recording the d_m with a certain number of passed fringes m, which was a constant 20, was repeated in this part of the experiment for 10 data points. Equation 1 was used to calculate the wavelengths.

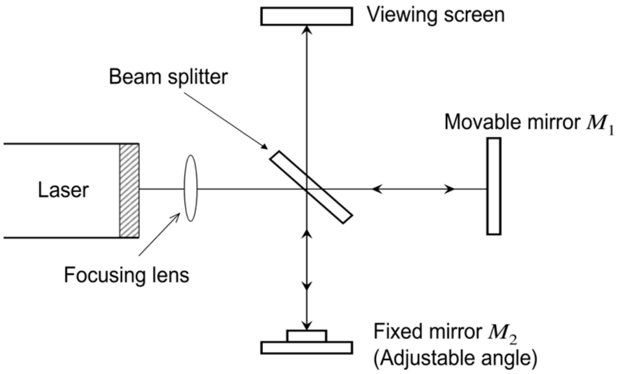

Figure 3: Michealson Interforemeter basic apparatus

For the part of the experiment where we measured the index of refraction of air we attached we attached an air pump with attached dial to the Michelson apparatus and pumped air out of an empty vaccum while measuring the changes in number of fringes, *m*, along with the change in pressure, ΔP.

Equation 2 describes the relationship between wavelength and index of refraction where λ_0 is the wavelength of the light in vacuum. As the index of refraction varies, so does the wavelength of the wave.

$$\lambda = \frac{\lambda_0}{n} \tag{2}$$

We used atmospheric pressure in the last part of the lab to alter the index of refraction since air has small particles and molecules in it that impact the index of refraction. The change in the index of refraction, and by extension the change in wavelength, for this part of the experiment is demonstrated visually in Figure 4.

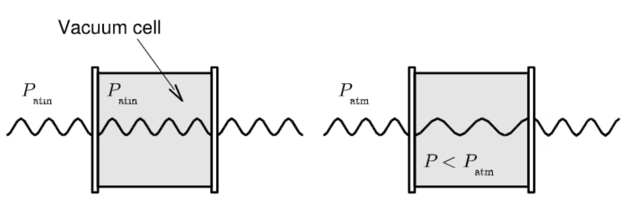

Figure 4: Change in light wavelength due to decrease in pressure

Because the light beam passes through the cell twice, once on the way through an once on the way back to the beam splitter, we can describe the change in the index of refraction with Equation 3 where *d* is distance moved.

$$n_f - n_i = \frac{m\lambda_0}{2d} \tag{3}$$

By dividing both sides of Equation 3 by the change in pressure, ΔP, we may derive Equation for that will provide us with our targeted data.

$$\frac{n_f - n_i}{P_f - P_i} = \frac{m\lambda_0}{2d}\frac{1}{P_f - P_i} \tag{4}$$

Since we want to observe the relationship between the change in pressure and the change in the index of refraction of the cell we may simplify the right hand side of the equation to a constant C that will be the slope of our relationship.

We set the attached dial on the around zero so that the interference pattern was clear and relatively centered on the viewing screen. We then pumped the air pump multiple times recording both the number fringes that passed and air pressure for 7 data points.

III. Results & Analysis

To measure the laser wavelengths in the first 2 parts of the experiment the we recorded data for the number of fringes, *m*, that passed on the interference pattern, the distance, d_m, that the moveable mirror passed. From here we used Equation 1 to find the wavelengths for each data point and found the average wavelength in nanometers for both parts, the Fabry-Perot set and the Michelson setup, as shown in Table 1. We also measured the standard deviation from the mean, or error.

Mode	$\bar{\lambda}$ **(nm)**	$\sigma_{\bar{\lambda}}$ **(nm)**
Fabry-Perot	1273	174.9796814
Michelson	1150	141.6411742

Table 1: The Wavelengths and Standard Error from Mean for the first two parts of the experiment

For the last part of the experiment, we recorded the pressure and number of fringes, *m*, that passed for 7 separate data points. We used the fringe raw data to calculate the change in the index of refraction using Equation 3. We then graphed the change in index of refraction vs change in pressure for each point and applied a linear fit.

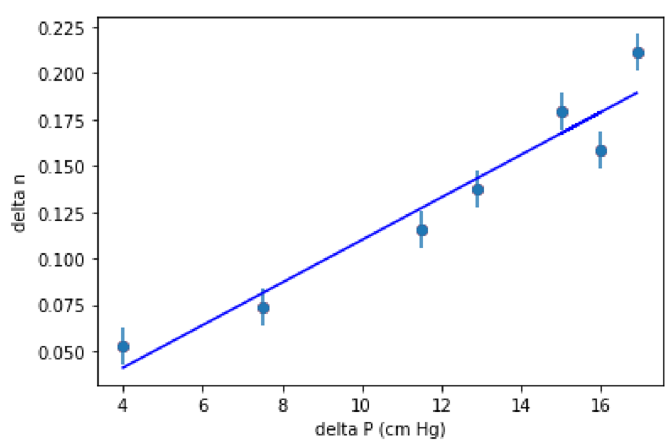

Figure 5: Plot of change in index of refraction vs change in Pressure

The slope of the curve for the linear fit when we plotted the change in the index of refraction $n_f - n_i$ vs P_f - P_i, or the C constant is 1.267 cm/Hg. Using this C constant, we can use Equation 4, where the whole right-hand side is C, to solve for the index of refraction in the atmosphere which was calculated to be 1.93 which is almost double the real index of refraction of the atmosphere. This is potentially due to the inconsistent number of fringes that passed on the interference pattern as the air pump was pumped causing it go very fast at certain points increasing the likelihood for observer error when counting the fringes.

The wavelength measurements for the Fabry-Perot apparatus and Michelson apparatus were 1273 nm and 115 nm respectively, and they were within statistical error of each other although the statistical error was large for both set ups due to the large variation in data measurements of wavelength.

As the knob was adjusted slowly the number of fringes that crossed through the center was highly inconsistent sometimes going by steadily and sometimes going by in large numbers over a short distance. This made it difficult for the human eye to observe the number of fringes that passed at certain points making the experiment open to human error which could have offset the wavelength data values and made the statistical error larger. In order to reduce human error there were two experimenters observing the fringes pass through the center, but a slightly offset *m* could have a large effect on the resulting wavelength. The sudden very fast movements of the fringes on the interference pattern are likely due to slippages in the mechanical parts of the micrometer system.

The Michelson and Fabri-Perot interferometers are capable of measuring extremely small distances on the order of 1 micrometer making the uncertainty 10^{-6} m. The Fabri-Perot interferometer though has sharper interference lines compared to the Michelson interferometer meaning that the Fabri-Perot interferometer will have more precise fringe counts.

In order to make the data collection more accurate experimenters could use a device with smaller divisions than 1 micrometer allowing for more precise distance data. Another way to make the data more accurate would be to remove human error in counting the fringes by having a computerized device count the fringes. This would help remove human errors where the slippage of the equipment causes the interference pattern to change quickly and inconsistently since the computer would be able to keep up with the changes better than the human eye. If the same equipment used in this experiment were used then having one experimenter with good eye sight measure all the fringe counts so as to make the data more accurate and consistent.

IV. Conclusion

In this experiment a commercial interferometer base was used in two different modes, Fabri-Perot and Michelson to measure the wavelength of an He-Ne laser. After the measurements from the Michelson interferometer, we attached a vacuum cell with air pump to the set up to measure the index of refraction of air. The wavelengths we got for the first two parts were 1273 nm and 1150 nm respectively which is significantly off from the actual wavelength even though they did agree within uncertainties of each other which is likely due to the slippage in the mechanical system of the micrometer causing inaccurate readings of the fringes. The index of refraction for air that we got was also pretty off from the actual index of refraction for air likely caused by similar issues we had in measuring the wavelength. In future iterations of the experiment a computerized measuring device and set up could be used to more accurately record the number of fringes, *m*, that cross the interference pattern which would help remove human error.

References

[1] Department of Physics, “Experiments in Physics,” Columbia University. New York, pp. 1 5 -22.