Properties of Interferometry

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Abstract

We utilized a technique of superimposing EM waves, called interferometry, to measure the property of wavelength of the wave itself and the relationship of changing air pressure and changing index of refraction. Our measured wavelength was $675nm \pm 8nm$, and it was discovered that the index of refraction of air decreased linearly with pressure.

INTRODUCTION

Waves are crucial in understanding more in physics, and one technique of understanding such properties is by combining them and understanding the properties of superimposed waves. One such technique is called *interferometry*, or the combination of electromagnetic waves that take different paths. By using a device called the Michelson Interferometer, we are able to study the properties of the interference of these EM waves. The Michelson Interferometer consists of many different materials that have the ability of manipulating light, such as a beam splitter, mirrors, and a 18mm convex lens.

This paper will discuss the different properties observed with said device and a Helium-Neon laser, such as verifying the laser's experimental wavelength value and its relationship with the index of refraction of air.

METHOD

This lab consisted of three different experiments that all used different setups for each one. However, the calibration for the interferometer itself involved the same steps and its own details. Moreover, each experiment had similarities and differences while recording measurements and performing the experiments.

Setup

Because of the many different pieces of equipment involved in the interferometer, it was crucial to perform a clean calibration. We began by turning on the laser, since it took about 30 minutes to completely warm up. Next, we placed the laser at a fixed height and aligned it with the movable mirror across from the laser so that the laser pointed and reflected right back into the laser aperture. Doing this allowed us the see that the laser and the movable mirror were both level with the table, and allowed us to continue setting up.

We added the beam-splitter (**FIG 1**) aligned at a 45° with respect to the laser beam. There were marks on the surface to guide the alignment to be as accurate as possible. To fully ensure that the beam-splitter's alignment was correct, the viewing screen adjacent from it had to display a pair of a set of red dots, each with only 1 bright dot in the middle and 2 or 3 dots on either side. We were then able to place the 18 mm focus-length lens in front of the laser.

We noticed that we were not seeing fringes on the viewing screen after setting up the lens. To fix this, we concluded that we could simply adjust the fixed mirror's position by moving two of the knobs meant for adjusting it on the back. After doing so, we observed a singular target-like shape on the viewing screen; a red circle of light with multiple fringes on it. Lastly, we adjusted the position of the viewing screen so that the fringes were centered around a common noticeable point on the screen. This setup was known as the *Michelson Mode Setup*, which is what we used throughout the entire lab.

Wavelength

The ability to experimentally measure the wavelength of the light source through interferometry exists, with this equation:

$$\lambda = \frac{2d_m}{\mathbf{N}} \tag{1}$$

where d_m is the change in the distance that the movable mirror moves and $\mathbf{N}$ is the number of fringes counted.

To do so, we used the Michelson Mode, and saw a fringe pattern. Then, we set the micrometer to a fixed reading of $500\mu m \pm 0.1$. This micrometer is used to adjust the movable mirror's position along the beam axis in small intervals. Then, as the micrometer rotated counterclockwise (causing the movable mirror to move), we counted the amount of fringes that passed through the common noticeable point on the viewing screen until we counted 20. This is our value of $\mathbf{N}$. Of course, the difference of the distance read in each measurement of the micrometer before and after the counting is the value d_m. Note that before each measurement of counting, we did one full clockwise rotation past 500 μm, then one full counterclockwise rotation to reach the starting point of 500 μm again. This was required to minimize a measurement mechanical error caused by the equipment called backlash, namely an error caused within the movable mirror. We repeated this process a total of 14 times, with 4 of them including a *compensator*.

The Index of Refraction of Air

The setup for this experiment requires a vacuum pump, a vacuum cell which the pump is attached to, and a rotational pointer. This is all alongside the normal Michelson Mode, except without the compensator. The rotational pointer is placed between the beam-splitter and the movable mirror, while the vacuum cell is attached to the magnetic backing that the pointer is placed on, and the vacuum pump's hose is attached to the air opening on the cell. Then, the rotational pointer is placed pointing at a "0" marking next to the fixed mirror to mark that the position of the cell is constant. To ensure that it is physically consistent, we taped down the pointer to the base of the table.

While the laser pointing at the beam-splitter, part of the beam takes a path directly into the vacuum chamber and is reflected back through into the viewing screen. We then slowly increase the vacuum pump manually until a certain number of fringes have passed through the reference mark on the screen. To find the relationship between the index of refraction of air and air pressure, we had to measure the pressure difference of 5 different fringe values, which we chose to be 7 to 11. The equation for the relationship is so:

$$Slope = m = \frac{2d}{\lambda}\frac{(n_i - n_f)}{(P_i - P_f)} \tag{2}$$

or, since $\frac{(n_i-n_f)}{(P_i-P_f)} = constant$,

$$m = \frac{2d\alpha}{\lambda}(P_i - P_f) \tag{3}$$

RESULTS

Wavelength

The theoretical confirmed value of the HeNe laser's wavelength is $\lambda = 632.8nm$. As shown in **TABLE 1**, there were 3 trials, each of which had an average calculated wavelength using the average of the distances for d_m in Equation (1). The first trial was shown to be 720nm $\pm 10nm$; the second one as 696nm $\pm 13nm$; and the third (with compensator) is 675nm $\pm 8nm$. Moreover, the corresponding percent errors from the confirmed value are: 13.87%, 9.987%, and 6.6689%.

Errors came from many sources, both from the equipment and external sources, such as ambient light and vibrations from the table. This was taken into account as seen in the results, since the error from the result including the compensator was lower than the two trials without ($\pm 13nm$ and $\pm 10nm$ versus $\pm 8nm$).

The Index of Refraction of Air

By using a vacuum pump altering the pressure of air directly in the path of the beam, we were able to find a linear relationship between the pressure and the index of refraction of air using interferometry. As shown in **TABLE II**, absolute pressure decreased as we pumped more air out of the chamber, meaning that the final index of refraction (n_f) increased in the chamber. Absolute Pressure is defined by

$$P_{absolute} = P_{atm} - P_{final}$$

where P_{atm} is defined as 76 cmHg. So, the more pressure added to the chamber means that absolute pressure decreased. In this experiment, we observed that more pressure was needed to increase the fringes passing the reference point on the viewing screen, so this checks out. The resulting relationship resulted in a linear trend, as expected.

CONCLUSION

Interferometry is a technique used by superimposing waves to observe properties of said wave. In this lab, we investigated the properties of both its wavelength and the relationship of air pressure with the index of refraction of air with this technique. The wavelength experimentally found was $675nm \pm 8nm$, which is 6.7% from the confirmed value of $\lambda = 632.8nm$. We were also able to observe a linear relationship between the pressure difference and the index of refraction of air, just by observing the amount of fringes that passed the reference point as we increased the pressure in the vacuum chamber.

Future Improvements

This lab contained several errors that could have been mitigated, mostly from equipment issues. In the wavelength portion of the lab, it was not clear how to read the micrometer, since there was no reference for each tick mark. Not only could we have avoided time loss on such a trivial process, but we could have been more certain about both the starting and ending point of each measurement, as the starting point on the micrometer was easily the most crucial measurement of the experiment. This would have minimized the measurement error, as each trial observed a wavelength some percent larger than the confirmed value.

Another error that could have been avoided with a change in equipment involved the vacuum pump and chamber in the second experiment. Because the pump was mechanical, there were a lot of counting and human errors, giving large measurement outliers with the smallest mistake. As an improvement, replacing it with an electronic pump would give a more consistent measurement, compared to a hand pump.

Some other minor errors came from table vibrations and ambient lights, as both environmental influences affected the fringe-counting process, but could not be avoided. Having the interferometry lab on its own table in its own room would be the only possible solution, as other labs would not be able to hit the table nor be affected if the room light was off.

FIGURES

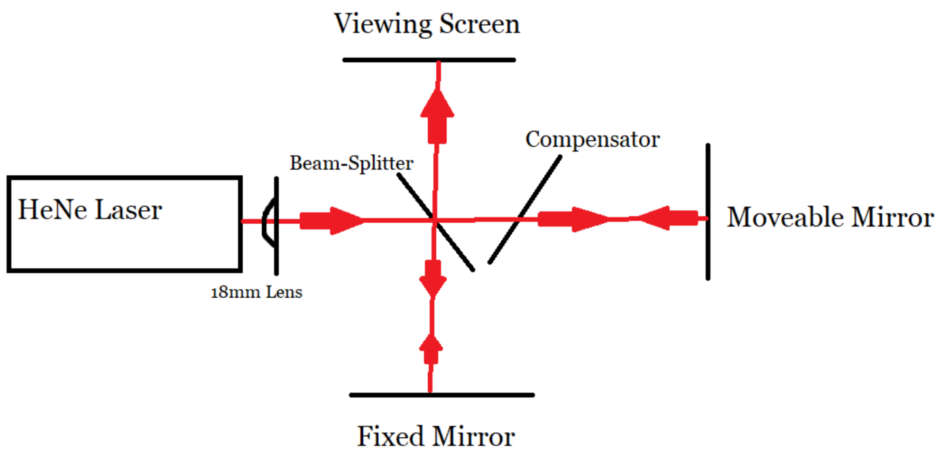

FIG. 1. A diagram of the setup for the first experiment.

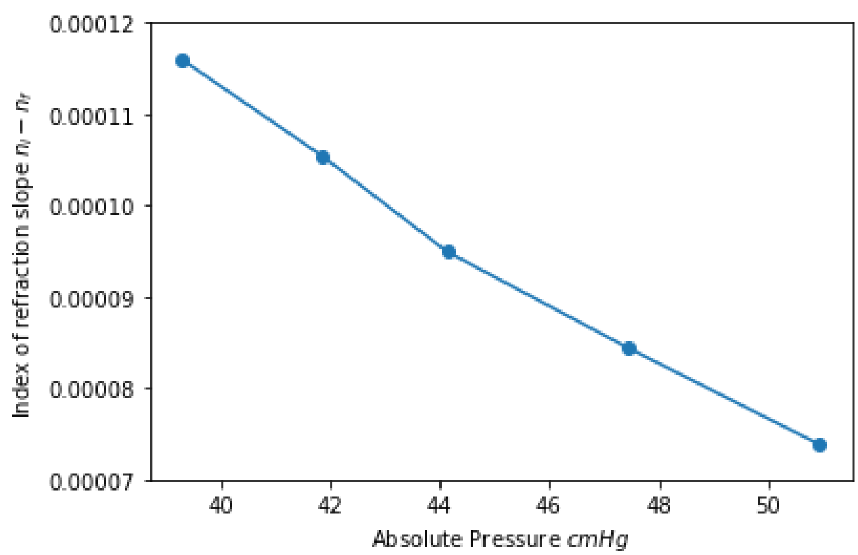

FIG. 2. A diagram of the setup.

TABLES

TABLE I. Table depicting experimentally calculated wavelength using inferterometry.

Trial Number	Average Wavelength (nm)	% Deviation from Actual Value
1	720	13.78
2	696	9.987
3 (Compensator)	675	6.6689

TABLE II. Table of values from the second experiment.

Fringe Count (N)	Absolute Pressure (cmHg)	Slope of Index of Refraction (e-5)
7	50.94	7.38267
8	47.45	8.4373
9	44.14	9.492
10	41.84	10.5467
11	39.28	11.6013