PHYS 7398
Modern Interferometry

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A Michelson interferometer utilizes a beam splitter and two mirrors arranged at right angles to produce interference patterns. Using a Michelson interferometer, we measured the wavelength of a He-Ne laser and the index of refraction of air. The average wavelength was found to be $\lambda = 646.44 \pm 5.71$ nm, which is within 0.88% of the accepted value. By inserting a gas cell into one arm and evacuating it from atmospheric pressure, we measured the index of refraction of air as $n = 1.0001145 \pm 4.22 \times 10^{-7}$. These results demonstrate the precision of modern optical interferometry and validate classical models of interference and gas dispersion.

I. INTRODUCTION

Interferometry is a technique that uses interference to make precise measurements. When two coherent light waves overlap, they create a pattern of bright and dark fringes. This happens because of constructive and destructive interference, depending on the phase difference between the waves [1].

Lasers are used in interferometry because they produce light that is both monochromatic and coherent [2]. This allows the fringe pattern to be sharp and easy to detect. Each fringe shift corresponds to a known change in the optical path length, which makes interferometry ideal for measuring small distances or changes in a medium.

A Michelson interferometer is an experimental configuration that splits a laser beam into two paths using a beam splitter [1]. Each beam travels to a their respective mirror, reflects, and returns to the beam splitter, where the beams then recombine and interfere. If one mirror moves by a distance d, the optical path changes by $2d$, causing N fringe shifts:

$$N\lambda = 2d, \tag{1}$$

This equation allows us to calculate the wavelength λ of the laser if we know N and d.

The Michelson setup can also measure the n, the index of refraction of air. If a gas cell of length L is placed in one arm of the interferometer, changing the pressure inside the gas cell changes the index of refraction. This alters the optical path length and shifts the fringes. The number of fringes N is given by:

$$N = \frac{2L(n-1)}{\lambda_{\text{vac}}} \tag{2}$$

Here, λ_{vac} denotes the vacuum wavelength of the laser light — the wavelength the light would have if it were propagating through a vacuum, unaffected by any medium. Solving for n gives:

$$n = \frac{N\lambda_{\text{vac}}}{2L} + 1 \tag{3}$$

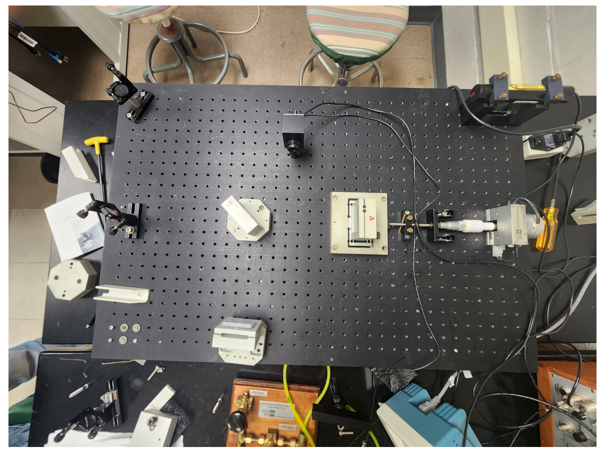

FIG. 1: Michelson Interferometer Setup

These equations are used to determine both the laser wavelength and the refractive index of air by counting fringe shifts in response to mirror movement or pressure changes.

II. PROCEDURE & METHODS

A. Wavelength of Light

The Michelson interferometer was set up on an optical breadboard using the TeachSpin Modern Interferometry system. A He-Ne laser with a known vacuum wavelength of approximately 633 nm was mounted and aligned to direct a collimated beam toward the beam splitter [1]. Two steering mirrors were used to adjust the beam path into the interferometer. Figure 1 shows a top-down visual of this setup.

The beam splitter divided the laser into two perpendicular arms. Each beam was reflected off a mirror and returned to the beam splitter. The recombined beams were directed toward a photodetector connected to the TeachSpin fringe counter. In order for the photodetector to register when a fringe occured, the diffraction pattern was maximized by making slight adjustments to the

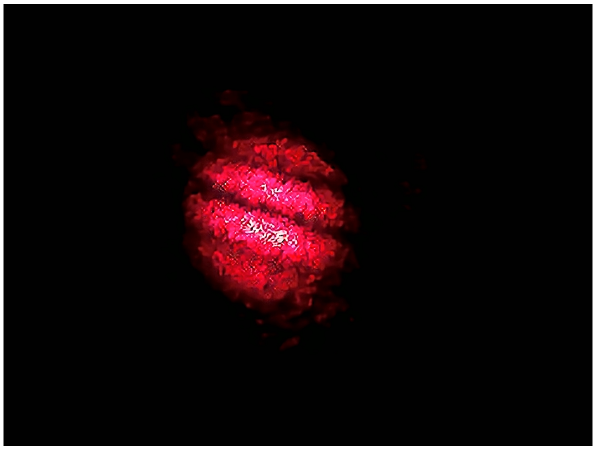

FIG. 2: Image of diffraction and interference pattern.

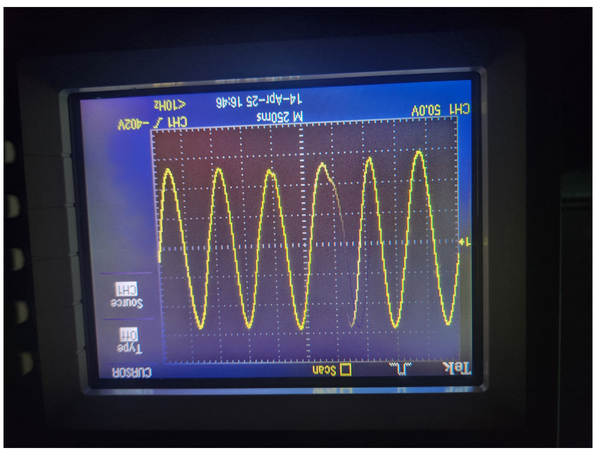

FIG. 3: Image of oscilloscope signal during trials.

steering mirrors. An image of that diffraction pattern is shown in Figure 2.

A differential micrometer controlled by a motor was attached behind one of the mirrors. This micrometer slowly moved the mirror to change the path length in one arm. Each time the mirror moved by $\lambda/2$, a fringe shift occurred.

In order to protect the photodetector and reduce oversaturation, a small aperture was placed before the photodetector. The fringe counts were verified against the oscilloscope output, which displayed a sinusoidal signal corresponding to the interference pattern. This output can be seen in Figure 3.

For each trial, the motorized micrometer was run through until the counts slowed down. The total displacement of the mirror was recorded, along with the number of fringe shifts. The wavelength was calculated using Equation 1 and solving for λ.

B. Index of Refraction

The same interferometer setup was used, but a gas cell was inserted into one arm between the beam splitter and the top mirror. The cell was connected to a vacuum pump and pressure gauge. Its length was $L = 100.0 \pm 0.1$ mm.

To begin each trial, the gas cell was initially at atmospheric pressure and then evacuated to near vacuum. As the pressure decreased, the optical path length through the gas cell decreased, causing a shift in the interference fringes. The total number of fringe shifts N corresponds to the optical path difference introduced by removing air from the cell.

Fringe counts were again collected using the TeachSpin control unit . The photodetector signal was monitored to ensure clean, consistent counts.

The number of fringe shifts N was used to calculate the index of refraction n using Equation 3.

III. ANALYSIS AND RESULTS

A. Wavelength of Light

Table I shows the measured displacements and fringe counts for five trials. The average wavelength of the He-Ne laser measured over five selected trials was:

$$\lambda = 646.44 \pm 5.71 \text{ nm}$$

TABLE I: Fringe Counts and Displacements for Wavelength Trials

Trial	Counts	Displacement (mm)	Wavelength (nm)
1	1095	0.3538	646.21
2	426	0.1551	728.17
3	1584	0.5064	639.39
4	1100	0.3622	658.55
5	1250	0.3932	629.12

The uncertainty represents the 95% confidence interval in the mean value. The standard deviation of the individual measurements was 12.77 nm, indicating the spread across the trials. Compared to the accepted vacuum wavelength of 632.8 nm [1], the percent error in our result is approximately 0.88%.

B. Index of Refraction

Ten trials were performed to measure the index of refraction of air using fringe shift data collected as the gas cell was evacuated from atmospheric pressure to near vacuum. The number of fringes observed per trial ranged between 36 and 37. Table II shows the index of refraction and fringe counts for ten trials.

TABLE II: Fringe Counts and Calculated Index of Refraction

Trial	Counts	Index of Refraction
1	36	1.000113904
2	36	1.000113904
3	36	1.000113904
4	37	1.000117068
5	36	1.000113904
6	36	1.000113904
7	36	1.000113904
8	36	1.000113904
9	36	1.000113904
10	37	1.000117068

The index of refraction was calculated for each trial using Equation 3. The average index of refraction across the ten trials was:

$$n = 1.0001145 \pm 4.22 \times 10^{-7}$$

The uncertainty represents the 95% confidence interval in the mean. The standard deviation of the values was 1.33×10^{-6}, showing good consistency across the measurements. The percent error relative to a typical accepted value of $n_{\text{air}} = 1.000271$ [1] was 0.0000422%.

This result is within expected bounds, though slightly low, which could be due to local atmospheric conditions such as humidity or temperature not matching standard assumptions.

IV. ERROR CALCULATION AND UNCERTAINTIES

A. Wavelength of Light

Uncertainties in measuring the wavelength of the He-Ne laser arise from both displacement measurements and fringe count accuracy. The displacement d was measured with a differential micrometer with a precision of approximately ± 0.001 mm. Fringe counts were registered automatically but were susceptible to vibration or optical misalignment.

The standard deviation of the five measured wavelengths was found to be:

$$\sigma = 12.77 \text{ nm}$$

The uncertainty in the mean value (95% confidence interval) was:

$$\Delta\lambda = \frac{\sigma}{\sqrt{n}} = 5.71 \text{ nm}$$

Thus, the final reported value is:

$$\lambda = 646.44 \pm 5.71 \text{ nm}$$

The percent error relative to the accepted value of 632.8 nm is:

$$\text{Percent Error} = \frac{|\lambda - \lambda_{\text{accepted}}|}{\lambda_{\text{accepted}}} \times 100 = 0.88\%$$

B. Index of Refraction of Air

Uncertainty in n depends primarily on the consistency of the fringe count N, since the laser wavelength and cell length were known to high precision. The fringe count varied slightly between 36 and 37, producing minimal spread in calculated n values.

The standard deviation of the index values was:

$$\sigma_n = 1.33 \times 10^{-6}$$

The confidence in the mean value (95%) was:

$$\Delta n = 4.22 \times 10^{-7}$$

The final result is reported as:

$$n = 1.0001145 \pm 4.22 \times 10^{-7}$$

The percent error compared to the typical value for standard air ($n = 1.000271$) is:

$$\text{Percent Error} = 0.0000422\%$$

V. DISCUSSION AND CONCLUSION

The measured average wavelength of the He-Ne laser was $\lambda = 646.44 \pm 5.71$ nm, which is close to the accepted value of 632.8 nm. The percent error was 0.88%, indicating good agreement. The main sources of error likely came from imperfect alignment of the interferometer and possible overcounting or undercounting of fringes due to mechanical vibrations or intensity fluctuations at the photodetector. Despite these, the relatively low standard deviation of 12.77 nm across five trials suggests the setup was consistent. The use of confidence in the mean further reduced uncertainty, resulting in a precise measurement.

The average index of refraction of air was $n = (1.0001145 \pm 4.22) \times 10^{-7}$, which is slightly lower than the accepted value of 1.000271. The percent error was

$4.22 \times 10^{-5}\%$, which is very small but still shows a consistent offset. This could be due to environmental factors such as humidity and temperature, which were not monitored or controlled during the experiment. Additionally, small inaccuracies in pressure changes or delays in fringe detection during evacuation may have contributed to the result.

Both measurements confirm the utility of the Michelson interferometer in making precise optical measurements. The data followed expected theoretical trends, and the results were repeatable. Improvements such as environmental monitoring and better mechanical isolation could further reduce uncertainty and increase agreement with reference values.

VI. ACKNOWLEDGMENTS

I would like to thank my lab partner, Anthony Grant, for his assistance in this experiment. I would also like to thanks the Louisiana State University Department of Physics and Astronomy for use of their equipment and space.

[1] Department of Physics, *Interferometry Lab Manual, Chapters 0–11*, Rutgers University, 2024.

[2] TeachSpin, Inc., *Modern Interferometry Instruction Manual*, Rev. 1.0, 2006.