Determining the Index of Refraction of Air Using a Michelson Interferometer

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Introduction

Light:

- When light enters a new medium, it refracts and its speed changes.
- This phenomena is represented by: $n = \frac{c}{v}$ where n is the index of refraction, c is the speed of light in a vacuum, and v is the speed of light in the medium.

Michelson Interferometer:

- A Michelson Interferometer can be used to measure n.
- A Michelson splits a laser beam into two separate beams and then later recombines them after they reflect off of a mirror, so they can be viewed on a screen (see Figure 1).

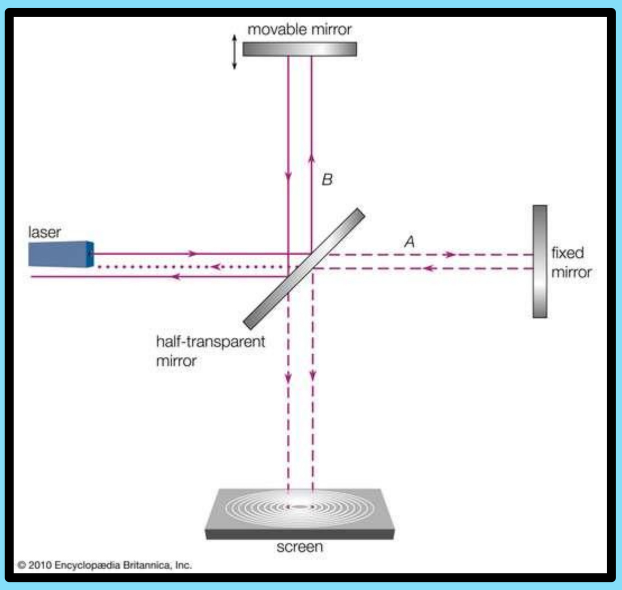

Figure 1: A Schematic of a Michelson Interferometer [2].

- The fringes viewed on the screen are the interference of the combined beams.
- Placing a vacuum chamber in the path of one of the arms of the interferometer affects the path length of one beam, and thus the fringes.
- The relationship between the index of refraction of a gas, n_{gas} and the length of the air volume in the chamber, L is shown by

$$n_{gas} = \left(\frac{N}{P}\right)\left(\frac{P_{atm}\lambda}{2L}\right) + n_{vacuum}$$

where N is the fringe count, P_{atm} is atmospheric pressure, λ is the wavelength of the laser beam, P is the pressure in the chamber, and n_{vacuum} is the vacuum index of refraction which is 1 [1]. $\frac{N}{P}$ is the slope of my graphs.

References

[1] Belmes, Kimberly B. and Stauffer, Carly E. (2018) "Using a Michelson Interferometer to Measure the Index of Refraction of Air," *Journal of Advanced Undergraduate Physics Laboratory Investigation*: Vol. 3

[2] Michelson interferometer. (n.d.). Retrieved from https://www.britannica.com/technology/Michelson-interferometer

Abstract

I calculated that the index of refraction of air is 1.00028 ± 1.1×10^{-5} (stat.) ± 1.2×10^{-5} (syst.) using a Michelson Interferometer and a calibrated hand pump. This value agrees with the established value of 1.00029.

Apparatus

- I built a Michelson Interferometer (see Figure 2).

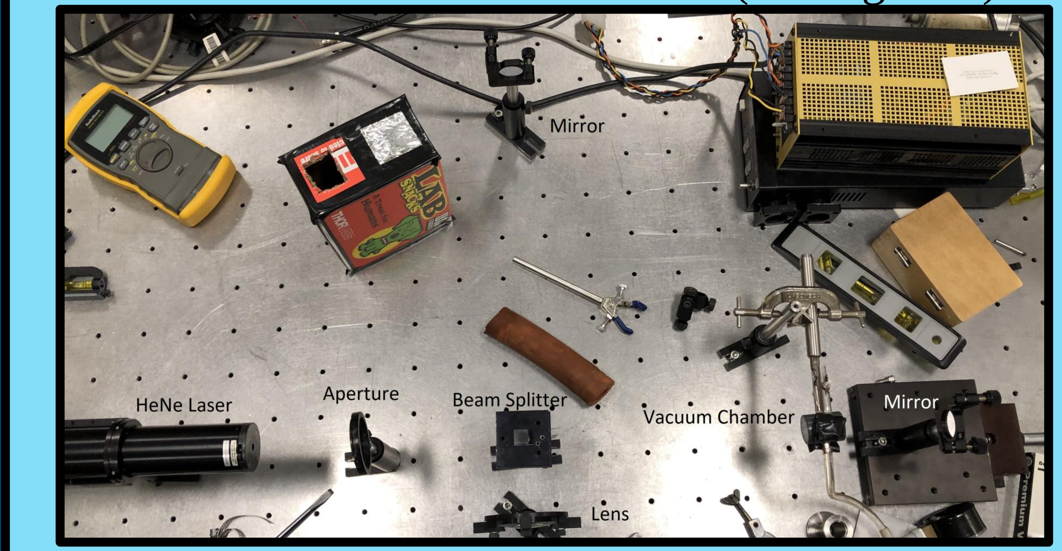

Figure 2: My Michelson Interferometer.

- My interferometer used a HeNe laser, so λ = 633nm.
- The vacuum chamber was 3.3cm ± .1cm in length
- The atmospheric pressure was 75.6 cmHg.
- The chamber attached to a hand pump that I squeezed to change the pressure.

First Trial and Results

- To find the index of refraction, I counted from the zeroth fringe to the 21st fringe four times.
- After fitting these measurements into a Fringe Count vs. Pressure plot, I found that the index of refraction is 1.00023 ± 1.9×10^{-6} (stat.) ± 1.6×10^{-5} (syst.), which is far off from the accepted value of 1.00029 (see Figure 3).

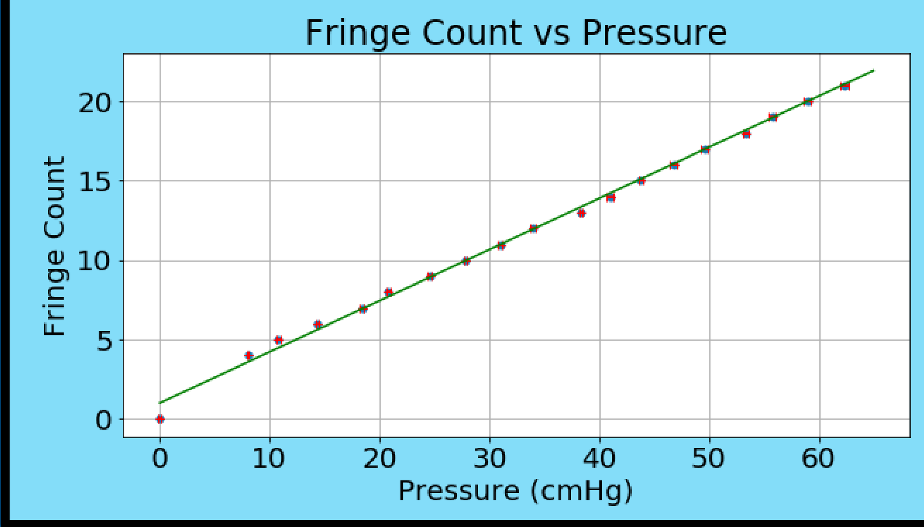

Figure 3: My first Fringe Count vs. Pressure Graph.

Acknowledgements

- I would like to thank Dr. Eric Jones, and Prof. Harold Metcalf for their help.

Welcome to the Laser Center

- This project was supported by the Laser Teaching Center.

Gauge Calibration and Results

- Since the refraction index was off, I calibrated the pressure gauge against an electronic gauge: $P_{hand\ pump} = (.98 \pm .012)P_{electronic} + 19 \pm 5.7$ cmHg.
- This gave me an index of 1.00024 ± 1.9×10^{-6} (stat.) ± 2.1×10^{-5} (syst.), which is still significantly off.

Removing the Intercept and Outlier

- Because the previous measurement was off I decided to remove the intercept of the graph because there should be no intercept and since the first measurement is an outlier I also removed it.
- Table 1 has all of the new indices using these changes and they were better.

	Include Intercept	No Intercept
Include N=0	$1.00024 \pm 1.9 \times10^{-6}$ (stat.) $\pm 2.1 \times10^{-5}$ (syst.)	$1.00027 \pm 1.1 \times10^{-6}$ (stat.) $\pm 1.0 \times10^{-5}$ (syst.)
Disregard N=0	$1.00023 \pm 2.1 \times10^{-6}$ (stat.) $\pm 2.9 \times10^{-5}$ (syst.)	$1.00027 \pm 1.1 \times10^{-6}$ (stat.) $\pm 1.1 \times10^{-5}$ (syst.)

Table 1: A summary of all of the index of refraction values.

- However, the residuals, graphs that show how far each point is from the fit, were still not ideal because their slope was not close to zero (see Figure 4).

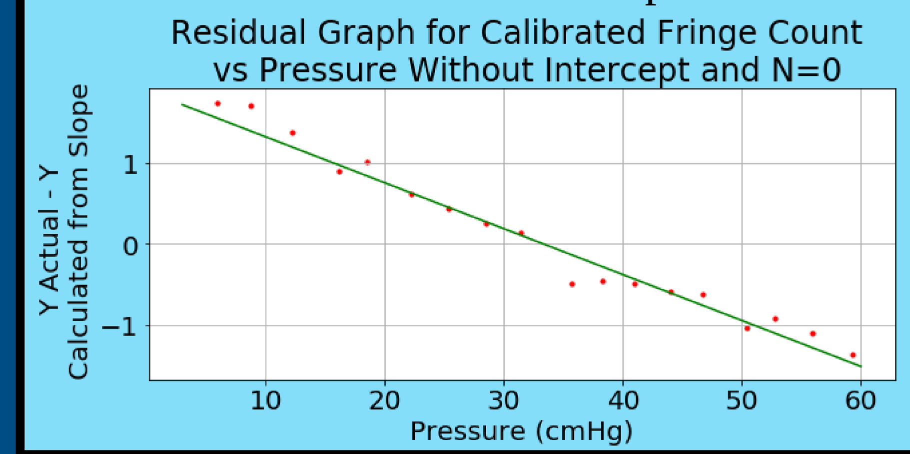

Figure 4: Residual graph for the plot without the intercept and N=0 data point.

Changing Linear Fit Formula

- Since the residual was inadequate, I used a different fitting formula that didn't weigh each point by its error, improving the residual, but it left me with an inaccurate index: 1.00023 ± 9.8×10^{-6} (stat.) ± 1.0×10^{-5} (syst.) (see Figure 5).

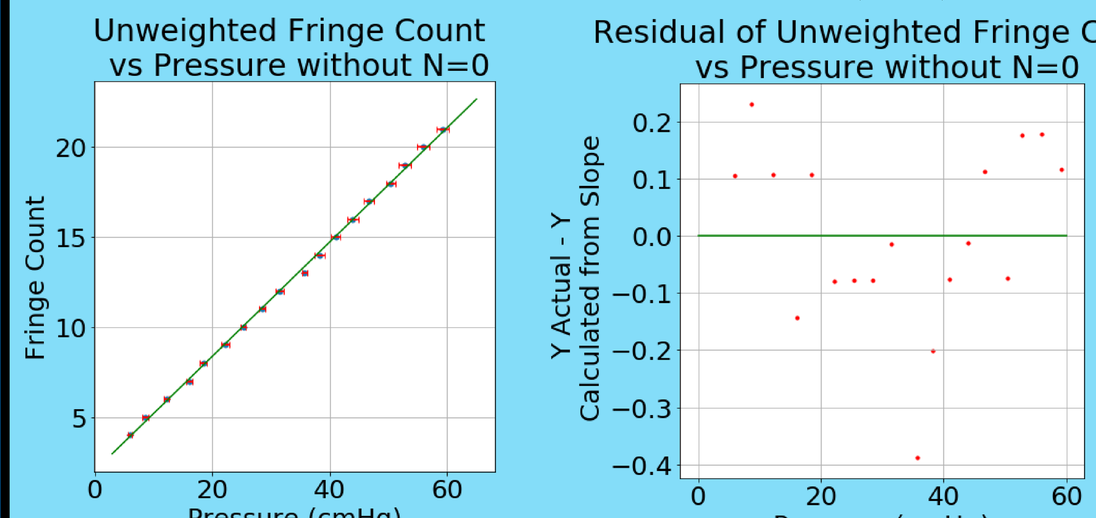

Figure 5: Fringe Count vs. Pressure Graph and its residual using the new linear fit formula.

- If I reduce the length of the vacuum chamber by ¼ in. to account for the glass ends, I get 1.00028 ± 1.1× 10^{-5} (stat.) ± 1.2×10^{-5} (syst.), which is a good value.
- Currently, I am preparing to find the exact thickness of the glass ends.