Michelson's Interferometer

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1 Summary

We used interferometry to determine the wavelength of a helium-neon laser, the distance between two emission lines in a sodium lamp, and the refractive index of air. This was accomplished by varying the path length in an interferometer and observing the interference fringes. To determine the wavelength of the laser and the width of the sodium doublet, we directly altered the position of one of the mirrors. To determine the index of refraction of air, we altered the effective path length by passing the beam through a closed chamber and adjusting the pressure.

2 Introduction

A Michelson interferometer operates by splitting light into two paths and allowing them to interfere, producing an interference pattern on a screen (figure 1). A small change in the length of one path will alter the phase of the beam and affect whether the beams interfere constructively or destructively at each point. For a coherent, monochromatic source, the shift in the interference fringes is related to the wavelength by

$$2d = n\lambda \tag{1}$$

where λ is the wavelength, d is the distance that the mirror moves and n is the number of fringes that move past a given point on the screen.

When the light source contains two wavelengths very close together, they create separate interference patterns, each of which will be affected differently by a change in path length. If the patterns line up, they will produce clear light and dark bands. If they do not, the resulting pattern will appear blurry (figure 2). As the mirror is moved, the pattern alternates between clear and fuzzy. Let d be the distance of 1 complete cycle. From equation 1, we have

$$2d = n\lambda_1 \tag{2}$$

$$2d = (n+1)\lambda_2 \tag{3}$$

Assuming that the the difference between λ_1 and λ_2 (denoted $\Delta\lambda$) is small relative to the average wavelength (denoted $\bar{\lambda}$), we can approximate from the above equations as

$$\Delta\lambda = \frac{\bar{\lambda}^2}{2d} \tag{4}$$

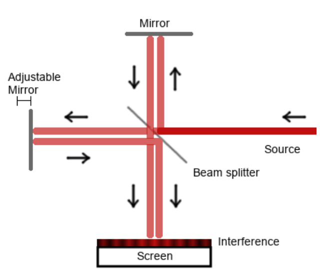


Figure 1

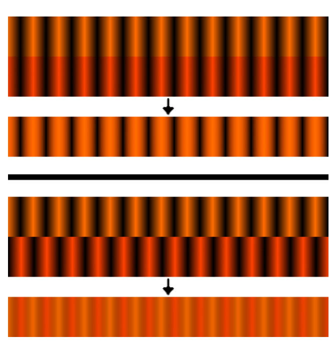


Figure 2

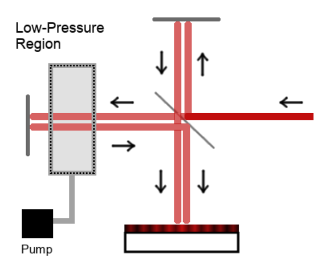


Figure 3

In addition to directly changing the mirror position, the effective path length can be varied by passing one of the beams through a region with an index of refraction different from the surrounding air (such as a vacuum). If the air pressure in the region is varied, the index of refraction (and therefore the path length) will change as well. This effect can be exploited to find the refractive index of air (figure 3). The number of fringes passing a given point is related to the change in refractive index by

$$2L\Delta n = m\lambda \tag{5}$$

Here, L is the chamber width, Δn is the change in refractive index, and m is the fringe shift (corresponding to n in equation 1). Assuming Δn is linearly related to the change in ΔP (the change in air pressure), we can use the previous to determine the index of refraction of air as:

$$n = 1 + \frac{m\lambda}{2L\Delta P}P \tag{6}$$

3 Procedure

3.1 Part 1

A helium-neon laser was shone through an interferometer, and the distance between one mirror and the beam splitter was varied until 100 fringes had passed a given point on the screen. The distance that the mirror moved was recorded, and this process was repeated 10 times. λ was then calculated via equation 1.

3.2 Part 2

The light from a sodium lamp was passed through an interferometer, and the distance between one mirror and the beam splitter was varied until the interference pattern changed from clear to fuzzy and back again. This process was repeated several times, and the wavelength difference was calculated from equation 4.

3.3 Part 3

A laser with a known wavelength was shone through an interferometer, and a vacuum cell was placed between the beam splitter and one mirror. The pressure in the room was recoreded, and the cell was gradually pumped down from atmospheric pressure. As the cell was pumped down, the number of fringes that passed a given point on the screen was recorded. Equation 6 was then used to calculate n.

4 Experimental Results

Raw data can be found in Appendix A.

4.1 Part 1

λ was calculated as (653 ± 9) nm. This is above the actual value of 633 nm by 2.2σ, suggesting some unaccounted-for source of error in the experiment.

4.2 Part 2

The difference between emission lines was calculated as (6.03 ± 0.05) Å, which agrees with the known value of 6.0 Å within 1σ.

4.3 Part 3

The mean value of n_{air} was found to be $1.000\,200 \pm 0.000\,013$. This does not agree with the known refractive index of air at STP, which is 1.000277 (difference of 5.9σ). However, as the measured pressure in the room was (625.80 ± 0.01) torr, we can expect the index of refraction to be lower than at STP. WolframAlpha gives 1.000221 as the refractive index at the recorded pressure, which agrees with the measured value within 2σ.

5 Discussion of Uncertainty

One potential source of systematic uncertainty was due to the difficulty of counting fringes in parts 1 and 3. The calculated value in part 1 was above the known value, suggesting that more fringes were counted than actually appeared. Though this source of error would also be present in part 3, it was less likely to affect the result as fewer fringes were counted.

A potential source of statistical uncertainty was the wobbling of the vacuum cell in part 3. It frequently caused fringes to wobble back and forth across the screen. The difficulty of determining the "sharpest" and "fuzziest" points in part 2 also acted as a source of statistical uncertainty. However, neither of these appear to have affected the result.

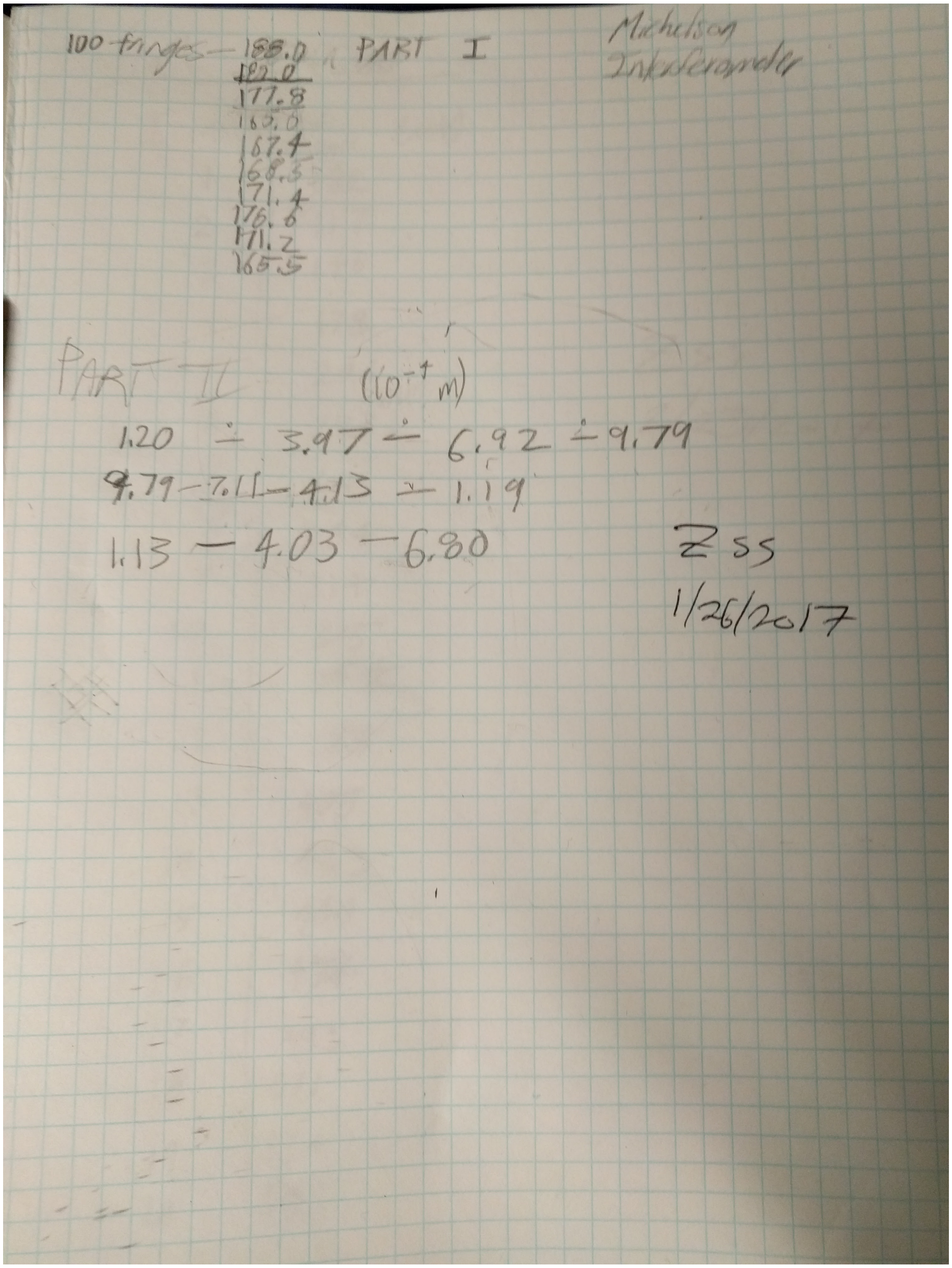
6 Conclusion

The procedure in part 1 was found to be unsuccessful in determining the wavelength of the helium-neon laser (with a value of $(653 \pm 9)\,\mathrm{nm}$ instead of $633\,\mathrm{nm}$). This was likely caused by errors in counting the number of fringes.

The interferometry procedure the was successful in determining the width of the sodium doublet, which was calculated as $(6.03 \pm 0.05)\,\text{Å}$. The approximation of $\Delta\lambda$ as small relative to $\bar{\lambda}$ was found to be accurate in this case.

The refractive index of air (at the pressure and temperature in the lab) was accurately determined by varying pressure in a vacuum cell. All trials agreed on the value for the refractive index, with an average of $1.000\,200 \pm 0.000\,013$. Neither the wobbly vacuum cell nor difficulty measuring the fringes appeared to affect the results.

Appendix A Raw Data



Part III

P (in Hg, ±0.5)	# fringes
21.5	17
21.5	17
21.0	16
21.5	15
21.5	17