Experiment 6: Interferometry

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Abstract

Using a 632.8nm He-Ne laser set up with a Michelson-Morley interferometer with a movable carriage and worm gear, the path difference was determined to be $d = \left(3.07 \times 10^{-5} \pm 1.8 \times 10^{-7}\right) m$*, which had a percent difference with the theoretical value of* $(2.97\% \pm 0.19\%)$*. Adding a cell that could be used as a vacuum chamber by removing the air, the index of refraction of air* μ *could be determined and was found to be* $\mu = \left(1.00067 \pm 2.1 \times 10^{-4}\right)$

1 Introduction

The Michelson-Morley interferometer is an apparatus which uses two mirrors M1 and M2 as well as two identical beam splitters A and C. A laser beam is sent into beam splitter A, which splits and sends the beam towards the mirrors. Mirror M1 has the identical beam splitter plate C in front of it, and M2 has nothing in front of it. Plate C in used to make the path length the same for each arm in glass. Beam splitter A has a partially silvered front mirror to reflect some light towards M1 passing through C and back towards A. Some light refracts and goes straight towards M2 and back. The two beams recombine to create the interference pattern observed on the screen. A worm gear used to move a carriage attached to M1 and C can be slowly moved using a graduated dial. This slowly changes the circular interference pattern on the screen producing an oscillation between the bright and dark fringes as there will be constructive and destructive interference occurring between the two arms of the laser. A full rotation of the dial and the rotation of the smallest division of the dial moves the mirror a certain distance as tabulated in 3. Introducing a cell in between beam splitter A and M1, it's possible to determine the index of refraction of air. This can be accomplished by using a vacuum pump to empty the cell of air until a vacuum is created. The laser will now travel through this chamber to M2 and back. The laser now partially travels through a vacuum, which will have a different path length compared to a medium like air. When air is let back into the cell slowly, there will again be constructive and destructive interference occurring. This will create oscillations of bright and dark fringes which can be counted to determine the index of refraction using equation 2.

1.1 Equations

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

$$n\lambda = 2l(\mu - 1) \tag{2}$$

2 Calculations

$$\begin{aligned} d &= \frac{n\lambda}{2} \\ &= \frac{(100)(632.8 \times 10^{-9}m)}{2} \\ &= 3.164 \times 10^{-5}m \end{aligned} \tag{3}$$

$$\begin{aligned} Average of part 1 trails &= (60 + 60 + 61)/3 \\ &= 60.3 \end{aligned} \tag{4}$$

$$\begin{aligned} (Average)(table travel for smallest division of dial) &= 60.3 * (5.09 \pm 0.03) \times 10^{-7})m \\ &= 3.07 \times 10^{-5}m \pm 1.8 \times 10^{-7}m \end{aligned} \tag{5}$$

$$\begin{aligned} error &= \frac{experimental - theoretical}{theoretical} x100 \\ &= \frac{(3.07 \times 10^{-5}m \pm 1.8 \times 10^{-7}m) - (3.164 \times 10^{-5}m)}{3.164 \times 10^{-5}m} x100 \\ &= 2.97\% \pm 0.19\% \end{aligned} \tag{6}$$

$$\begin{aligned} n\lambda &= 2l(\mu - 1) \\ \mu &= \frac{n\lambda}{2l} + 1 \\ &= \frac{(100)(632.8nm)}{2(47.47 \pm 0.01mm)} + 1 \\ &= 1.00067 \pm 2.1 \times 10^{-4} \end{aligned} \tag{7}$$

3 Experimental Procedure and Design

1. The first task was to setup the interferometer, which was almost already set up. The apparatus pointed a 632.8 nm laser at a beam splitter (A) at 45 degrees. Two mirrors (M1 and M2) were placed to reflect the light. M2 was perpendicular to the laser and M1 was perpendicular to it. Along with beam splitter A, an identical compensator plate (C) was placed between M1 and A. There is also a movable carriage that holds mirror M1 and plate C, which slowly moves with the turn of a graduated dial.

2. Using two knobs (x1 and x2) attached to M2 and observing the screen where an interference pattern was to be seen, the knobs were slowly adjusted until a circular interference pattern was observed.

3. There are two parts to this experiment. For the first part, it should be known that the circular interference pattern changes as the carriage carrying M1 and C are moved using the graduated dial. The pattern slowly moves from bright fringes to dark fringes as the carriage moves closer or away from the laser.

4. From equation 1, the path difference 2d (or more specifically, d) was calculated rotating the graduated dial until n=100 fringes were observed. The carriage moves using a 100 to 1 worm gear which moves the carriage (5.09 $\pm$0.03)$x10^{-7}$m per the smallest division on the dial. The number of dial graduations for 100 fringes were recorded for 5 trials, so the results could be averaged.

5. The second part of the experiment involved measured the index of refraction of air using a cell placed between beam splitter A and M2. The cell was placed perpendicular to the laser such that the laser could travel through the chamber to mirror M2 and back. Minor adjustments were made so that the circular pattern could still be properly observed.

6. The cell was connected to a vacuum pump which evacuated the air from the cell, so that the light now travels through a vacuum. The fringes slowly oscillate as the air is being removed since there is a difference in travel path of the laser in a vacuum and in any given medium like air.

7. Once the air was evacuated from the cell, it was time to conduct the experiment by slowly letting the air back into the cell and as it does, the circular fringes will oscillate between bright and dark. The air was slowly let back into the cell, and the number of fringes were counted until the pattern settled into a steady-state (at atmospheric pressure). This part of the experiment was repeated twice to average the results.

4 Data Tables

Table 1: Experimental data for Part 1 of the experiment: Number of dial graduations for 100 observed fringes

Trail	number of dial graduations for 100 fringes
1	$86(Excluded)$
2	$60(Included)$
3	$85(Excluded)$
4	$60(Included)$
5	$61(Included)$

Table 2: Experimental data for Part 2 of the experiment: Number of fringes observed as air enters the cell

Trail	number of fringes observed as air fills up the cell
1	40
2	40

Table 3: Table of Other quantities used throughout the experiment

For	Quantity
He-Ne laser (λ)	632.8nm
Friction pin drive diameter	$(1.62 \pm 0.01) \times 10^{-3}m$
table travel per turn (100 to 1 gear)	$(5.09 \pm 0.03) \times 10^{-5}m$
table travel per smallest division on dial	$(5.09 \pm 0.03) \times 10^{-7}m$
Length of the cell (l)	$47.47mm \pm 0.01mm$

5 Results

The final results for the first part of the experiment yielded an experiment result of $d = (3.07 \times 10^{-5} \pm 1.8 \times 10^{-7})\, m$ and a theoretical result $d = (3.164 \times 10^{-5})\, m$ as shown in the calculations above. The percent difference between these results was $(2.97\% \pm 0.19\%)$. The second part of the experiment was to determine the index of refraction of air μ. The final result for $\mu = (1.00067 \pm 2.1 \times 10^{-4})$, as shown in the above calculations, and the theoretical value is 1.00029 at STP.

6 Discussion

From the results shown above, both parts of the experiment produced accurate results in comparison with their theoretical values. From table 1, there are five trials conducted in the first part of the experiment, but only three of those trails were used in the final analysis. Trials one and three were ignored since in the fringe observation phase of the experiment as the dial was slowly turned, the fringes for the first several dial graduations remained constant, instead of the oscillations that were supposed to occur. This produced the inaccurate results shown in table 1 for trials one and three. As you move the dial, it might take a small amount of rotation for the dial to lock with the gear to move the carriage, which was the cause of the unused results of trials one and three. However, the results for both parts of the experiment were close to their theoretical values and there isn't a lot of improvements that can be made to increase the accuracy of the results besides having conducted more trials for both parts. It should be noted that the coherence path length/temporal coherence of the He-Ne laser was $6 \times 10^7 m$, which is far exceeds the difference in path length, so the fringes will not disappear even with many rotations of the dial.

7 Conclusion

Experimentally, $d = (3.07 \times 10^{-5} \pm 1.8 \times 10^{-7})\, m$, which had a $(2.97\% \pm 0.19\%)$ percent error and the index of refraction for air was determined to be $\mu = (1.00067 \pm 2.1 \times 10^{-4})$. Both results were accurate to their theoretical values from this experiment. Other experiments using a different source or a different length of cell may be used to further confirm these findings.

References

[1] D. Rosa. Physics 325, Laboratory Manual. University of Victoria, 2021.