

Michelson Interferometry

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Michelson Morley's interferometer together with Einstein's theory of relativity helped in abandoning the concept of ether in the classical experiment performed in 1887. Since then, interferometers are used for many purposes, e.g., one of the most exciting and grand goals is measuring gravitational waves. The Laser Interferometer Gravitational-wave Observatory (LIGO), is a collaborative project of American universities aimed at detecting waves of gravitational origin.

The goal of the current experiment is to familiarize students with the Michelson Interferometer. It introduces optical components like beam splitters, translation and rotational stages, lenses and highlights important concepts in wave interference. Michelson interferometer is used for measuring the laser wavelength and finding the refractive index of glass. vspacelinch

KEYWORDS

Interferometer · Beam Splitters · Optical alignment · refractive index · constructive and destructive interference · optical path length ·

APPROXIMATE PERFORMANCE TIME 1 week.

1 List of Equipment

1. HeNe Laser with Mount, HR020, Thor Labs
2. Economy Beam Splitter, EBS1, Thor Labs
3. Protected Silver Mirror ME1-P01, Thor Labs
4. Post Holders PH3/M, PH3-ST, Thor Labs
5. Stainless Steel Posts, TR150/M, Thor Labs
6. Laser Mounting and Clamp C1501/M, Thor Labs
7. Laser Clamping Arm, PM2, Thor Labs
8. Cage Mount for lens, CP02, Thor Labs

9. Lens Mount, LMR1/M, Thor Labs
10. Kinematic Mirror Mounts KM100-E02, Thor Labs
11. Plano-Convex lens $f=25.4\text{mm}$, LA1027, Thor Labs
12. Plano-Convex lens $f=35\text{mm}$, LA1951, Thor Labs
13. Precision rotation platform, PR01/M, Thor Labs
14. DC Servo Motor Controller, Z825B, Thor Labs.

2 Experimental Objectives

The experimental objectives include:

1. working with optical components,
2. optical alignment of an interferometer,
3. understanding the concept of change in optical path length,
4. measuring the wavelength of the HeNe laser, and
5. finding the refractive index of thin glass sheet.

References

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- [2] Eugene Hecht, “Optics”, Chapter 9, pg 407-412, Pearson Education, 2002.
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- [4] “The index of refraction of glass”, Precision Interferometer, PASCO Scientific.
- [5] Jeremy Ong, “Investigations of Light with a Michelson Interferometer”, Cornell University, 2010.
- [6] J.J. Fendley, “Measurement of refractive index using a Michelson interferometer”, *Phys. Educ.* **17**, 209-211 (1982).

3 Introduction

An interferometer exploits the interference of light, a wave property. A fringe pattern results from optical path differences. The Michelson Interferometer is an amplitude-splitting interferometer. Figure 1 shows the schematic whereas Figure 2 is a photograph of a typical setup you will have to build in the lab. The working of the interferometer is described in detail [2, 3] and you are required to carefully read the background material.

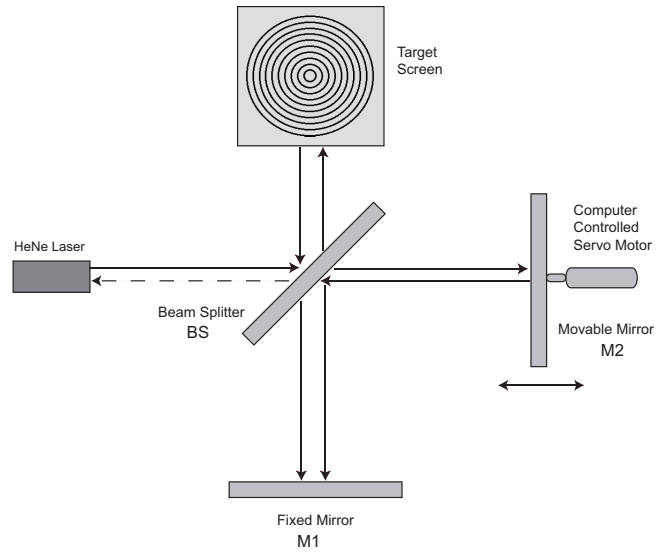


Figure 1: Working principle of the Michelson interferometer.

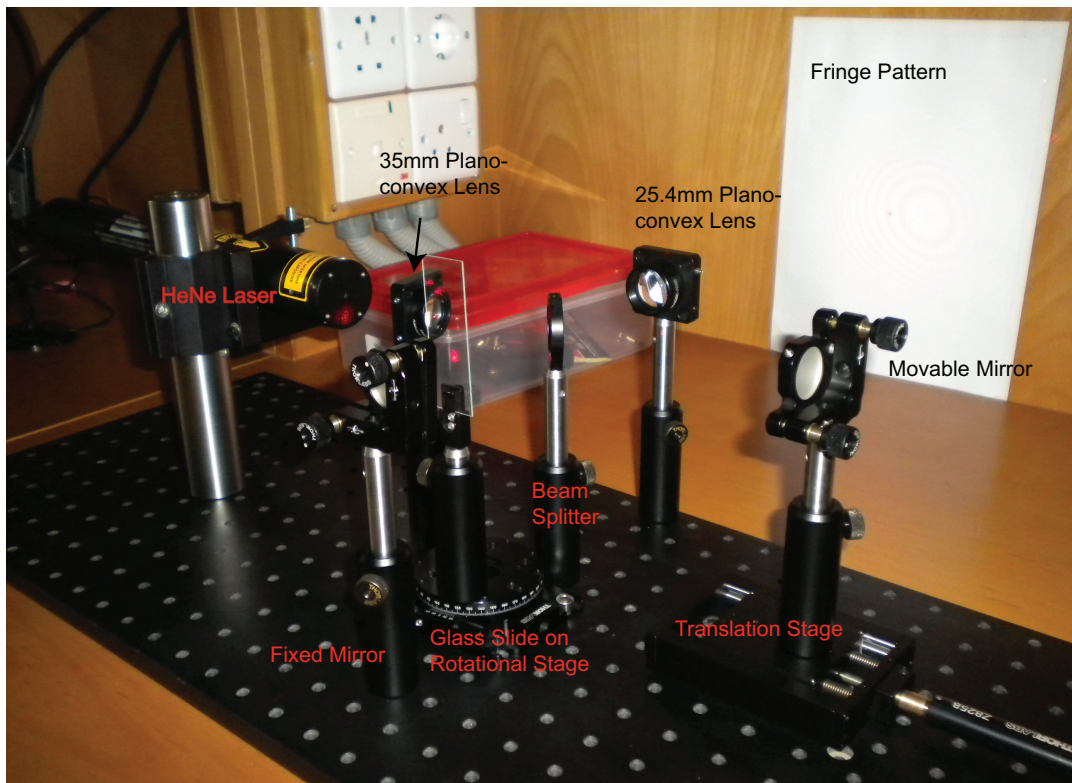


Figure 2: Laboratory setup of the Michelson interferometer.

4 Optical alignment

Q 1. Perform the following procedure to align the interferometer.

1. Place the HeNe laser into laser mount which is bolted on the optical breadboard. Align the laser parallel to the breadboard.
2. Now mount the beam splitter (BS) on the breadboard in front of laser.
3. Place a fixed mirror (M1) in the mirror mount assembly. Align the mirror such that the reflected beam from BS falls in the middle of it.
4. Now mount the other mirror (M2) on the translation stage which is being operated by the computer controlled servo motor. Align M2 such that the transmitted beam from BS falls in middle of it.
5. Turn ON the laser, you shall see the two small dot images. Using the screws of the mirrors, overlap all three dots. Now the two beams will be aligned.
6. Place the plano-convex lens of focal length 35 mm (L1) in between laser and BS.
7. On the opposite side of M1 place another plano-convex lens of focal length 25.4 mm before the target screen to enlarge the image.
8. Carefully adjust M1 and M2 using their screws so that the beams overlap on the target.
9. Perform alignment until you see concentric circular fringes.

5 Measuring the wavelength of a laser

If we move the movable mirror we see the fringes entering or exiting the center of the fringe pattern, depending upon the direction in which the mirror moves. The following equation relates the the distance moved by the mirror with the number of fringes passed by.

$$\lambda = \frac{2\Delta d}{N} \quad (1)$$

where, λ is the laser wavelength, N is number of fringes passed by and Δd is the distance moved by M2. You must understand the derivation of Equation (1).

Q 2. Perform the following procedure to measure the wavelength of the HeNe laser.

1. Use the computer software to move M2 using the servo controlled motor by a fixed distance of around 10 μm . The instructions and servo motor specifications are provided in Appendix A.
2. Count the number of fringes that passes by a fixed point.
3. Fringes shall be entering on exiting center depending on the direction in which you move M2.
4. Repeat the same procedure at least 5 times and takes the average to minimize the errors.
5. Use equation (1) to measure the laser wavelength. What is your uncertainty in the wavelength?

6 Measuring the refractive index of glass

Glass slide is mounted on the rotational stage and placed in between BS and M1. If we rotate the glass slide we see the fringes entering or exiting the center of the fringe pattern, depending upon the direction in which the rotation takes place. The refractive index is,

$$n_g = \frac{(2t - N\lambda)(1 - \cos\theta)}{2t(1 - \cos\theta) - N\lambda} \quad (2)$$

where, n_g is the refractive index of glass, λ is the laser wavelength, t is the thickness of glass slide, N is number of fringes passed by and θ is the angle rotated in radians.

Q 3. Draw a figure showing the path of the light beam as it passes through the glass slide at an arbitrary angle θ with respect to the light ray. What is the optical path length difference in this case?

Q 4. Derive Equation (2).

Q 5. Plot N versus θ as elicited by Equation (2).

Q 6. Perform the following procedure to find the refractive index of glass slide.

1. Find the thickness of the glass slide with the provided micrometer.
2. Place the glass slide on the rotational stage in between M1 and BS such that it is exactly parallel to M1.
3. Rotate the glass slide by certain number of degrees and count the number of fringes that passes by a fixed point.
4. Fringes will enter on exiting center depending on the direction in which you rotate the glass slide.
5. Use equation (2) to compute the refractive index of glass.
6. Repeat the same procedure at least 5 times and take the average result to minimize the error. Remember that the relationship (2) between N and θ is nonlinear.
7. Calculate the uncertainty in n_g arising from the uncertainties in N and θ .

7 Appendix A

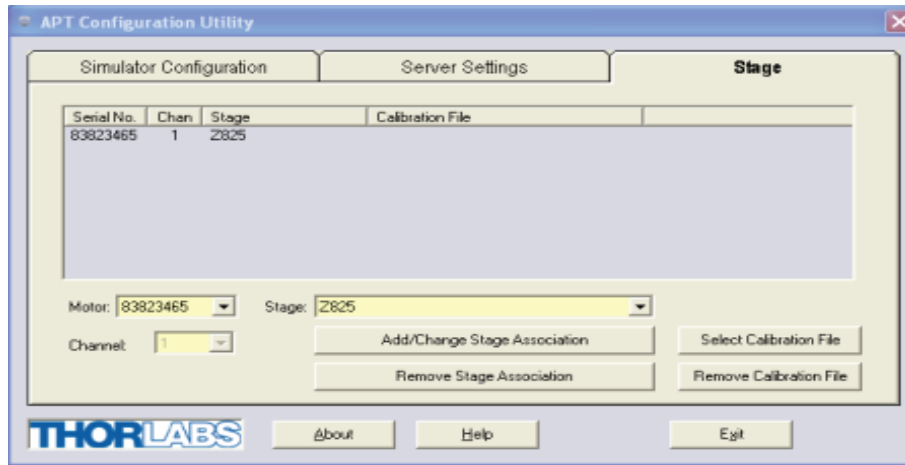
7.1 Software Instructions

1. Open **APT Configuration Utility**, and select the following Motor and Stage options as shown in Figure (3a).

Motor **83843713**,

Channel **1**,

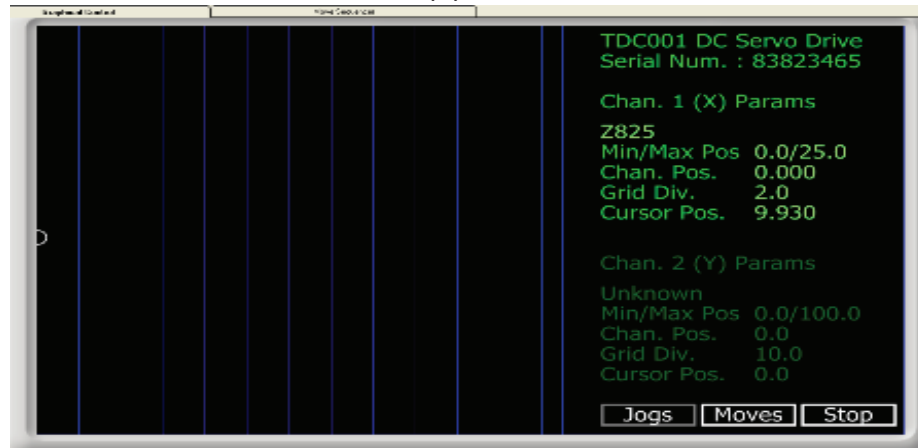
Stage **Z825**.



(a)



(b)



(c)

Figure 3: (a) APT configuration utility, (b) panel view of APT user utility, and (c) graph view of APT user utility.

2. After configuration, close this window and run **APT User Utility**.
3. Select the **Motor driver Settings** tab and enter the following parameters,
 - (a) In **Moves-Velocity Profile**,
Max. Vel. = 0.0003 mm/sec,

Acc./Dev. = 0.03 mm/sec/sec,

- (b) Step distance = 0.001 mm. We must advance the mirror M_2 through some distance and simultaneously count the number of fringes that pass through a reference point. The procedure to translate M_2 is given below. Remember to count the fringes *during* translation.
4. After completing the settings, click **Enable** then right click on the **Panel window** and select **Graph view**. The snapshots are given in Figure (3b, c). There are 12 vertical lines showing grid division as the maximum travel range is 25 mm. On right side of the screen you can see the Channel position (current position) and cursor position (desired position).

Select **Moves** and bring the cursor position to any vertical line. Simple clicking on the screen will initiate motion. You will see that the distance value (mm) is increasing. Click **Stop** after the position has advanced by approximately $\Delta \cong 0.01$ mm. Note down the initial and final positions. This is your Δd .

7.2 DC Servo Motor Specifications

Travel range = 25 mm

Lead Screw Pitch = 1 mm

Resolution = 29 nm