Lab 5: Michelson Interferometer

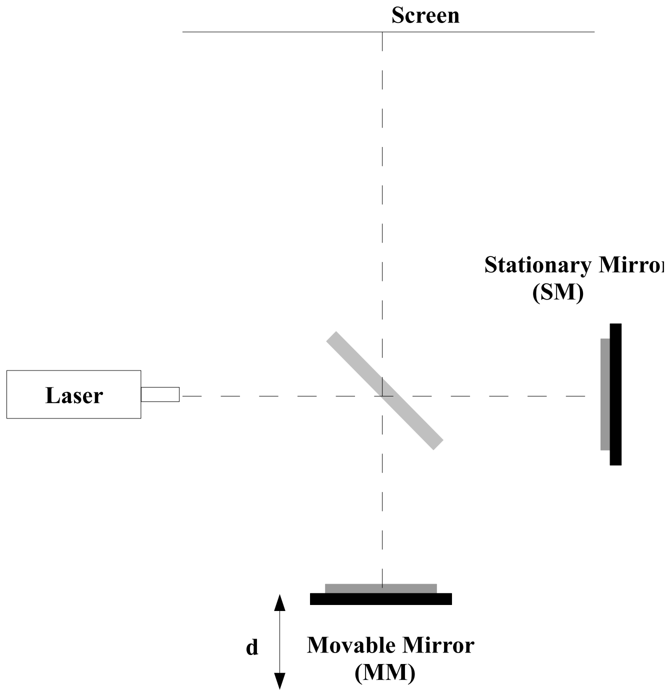

Figure 1: A schematic diagram of a Michelson interferometer.

1 Introduction

Refer to Appendix D for photos of the apparatus

In 1802, Thomas Young demonstrated his experiments on the interference of light. These experiments established the wave theory of light on a sound footing. In 1881, Albert A. Michelson designed an interferometer, which is a device based on the phenomenon of interference of light waves. This simple instrument is, among other things, used for measuring the wavelength of light, the thickness of thin films, the flatness of surfaces, and for standardization of the meter. Michelson himself used it to disprove the existence of "ether", and thus provide experimental evidence for Einstein's theory of relativity. One of the most recent applications that have been proposed for the Michelson interferometer is to use it for a measurement of gravitational waves.

In this lab you will build an optical Michelson interferometer and use it to measure the wavelength of a monochromatic light source (a Helium-Neon laser).

EXERCISES 1-4 PERTAIN TO THE EXPERIMENTAL SECTIONS.

2 Background

The primary beam, produced by the laser, encounters a beam splitter. The beam splitter, also called a half-silvered mirror, reflects a part of the beam and transmits the other part. Actually, an ideal beam splitter reflects 50% of the incident light and transmits the other 50%. The reflected part of the beam proceeds towards the moveable mirror MM and is then reflected backwards along the same path towards the beam-splitter. The same happens to the transmitted beam, that is, it gets reflected back along its own path by the stationary mirror SM. When the beams return to the beam splitter, an equal part of each beam gets both transmitted and reflected. Out of the four resulting beams, the transmitted part of the reflected beam and the reflected part of transmitted beam both proceed towards the viewing screen. Since these beams are derived from the same source, they will interfere on the screen, producing a stationary pattern of light and dark areas (fringes).

The lens L is introduced into this setup to make the laser beam diverge, thus making the interference pattern a series of concentric circles (fringes), which can be easily discerned on the viewing screen. A particular area of the screen will be bright or dark depending on the path difference ΔL in the distances that the two interfering light waves (beams 1 and 2) have traveled. The condition to obtain constructive interference (bright areas on the screen) is $\Delta = n\lambda$, where n is an integer. This means that the two waves will be exactly in phase and will add to produce an intensity maximum. If $\Delta L = (n + 0.5)\lambda$, destructive interference will occur.

The wavelength of the laser light can be found by changing the distance one of the beams has to travel, and counting the number of the fringes that moved across the field of view. As can be seen from the above discussion, the fringe pattern will repeat itself every time one of the mirrors is translated (moved) exactly one half of the wavelength of light. Note that a $0.5\Delta L$ displacement of the mirror will cause a change ΔL in the path length. Thus, by moving the mirror through a distance d, we will observe a number N of fringes move through a point on the screen,

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

After measuring d and the corresponding N, the wavelength can be found as follows,

$$\lambda = \frac{2d}{N} \tag{2}$$

In this experiment, one of the mirrors is mounted on a micrometer translation stage, which allows you to move the mirror and record the distance through which it has traveled.

3 Suggested Reading

Refer to the chapters on Interference,

D. Halliday, R. Resnick and K. S. Krane, **Physics** (Volume 2, 5th Edition, John Wiley, 2002)

4 Apparatus

- A He-Ne laser with a mount and a power supply
- A diode laser (wavelength 650 nm)
- Three mirrors, a beam splitter and a lens, all in post-mounted holders
- Five postholders and bases
- A micrometer translation stage
- A viewing screen
- 3/16" Allen key
- Optical breadboard

WARNING!!: KEEP TRACK OF YOUR LASER BEAM AT ALL TIMES. NEVER POINT THE BEAM AT PEOPLE, OR LOOK IN THE APERTURE OF THE LASER OR BE AT EYELEVEL WITH THE BEAM.

KEEP EYES AWAY FROM DIRECT OR REFLECTED LASER BEAMS. OTHERWISE SERIOUS EYE DAMAGE WILL OCCUR.

YOU SHOULD BE AWARE OF WHERE THE LASER BEAMS STRIKE OPTICAL COMPONENTS. REFLECTIONS FROM OPTICAL COMPONENTS SHOULD BE BLOCKED BY USING PIECES OF CARDBOARD THAT ARE PROVIDED. BE PARTICULARLY CAREFUL WHEN YOU INSERT OR REMOVE LENSES INTO A LASER BEAM.

DO NOT TOUCH THE OPTICAL SURFACES OF LENSES AND MIRRORS. IF THE SURFACES ARE UNCLEAN, PLEASE BRING IT TO THE ATTENTION OF THE TA IMMEDIATELY.

USE THE TRANSPARENT LENS TISSUES TO DETECT THE BEAMS.

MAKE SURE ALL MOUNTS ARE SECURELY FASTENED ON THE OPTICAL TABLE.

The optical components you will be using are all mounted on stainless steel posts. This allows you to position them on the optical table using the postholders and screws. The grid of holes on the optical table provides a good spatial reference, and simplifies the alignment of the experiment.

In this experiment a micrometer screw gauge will be used. The measuring scales on a gauge consist of a sleeve and a thimble. The thimble rotates around the sleeve when turned. The sleeve carries a millimeter scale graduated to 0.5 mm. The rotating thimble is subdivided into 50 equal divisions, where each division is 0.01 mm. This is called the least count (LC). Therefore, the thimble must be rotated through two revolutions to move the jaws by 1 mm. To make a measurement, first note the main scale reading (MSR) from the sleeve. Next, the thimble reading has to be recorded. The final measurement M is given by,

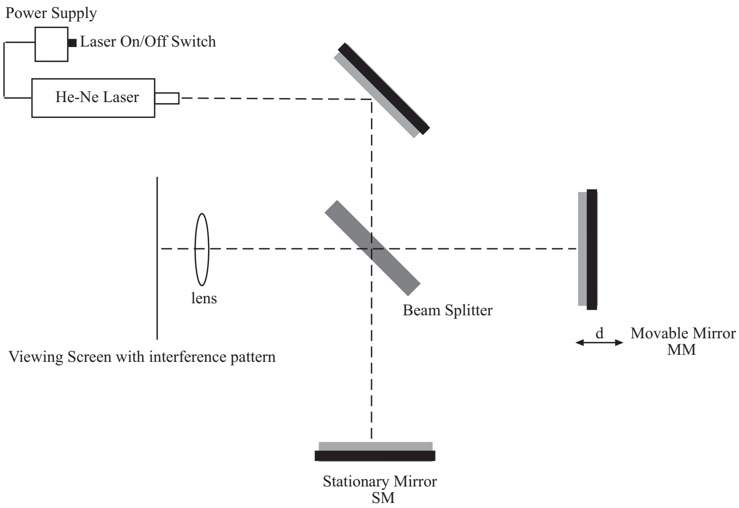

Figure 2: Experimental setup.

$$M = MSR + (ThimbleReading)(LC) \qquad (3)$$

5 Experiment

Setting up the laser: On the optical table, mount the He-Ne laser directly above a row of holes on the table. Place a cardboard screen in the path of the beam, and turn the laser on using the switch on the power supply. In this experiment, all the beams need to be in the same plane, parallel to the table. To verify that the beam is horizontal, make a pencil mark on a cardboard screen at the location of the red dot produced by the beam. Now move the screen to various distances from the laser, and make sure the beam strikes the screen at the same height. If it does not, adjust the leveling of the laser and repeat the test until the beam strikes the same mark on the screen at all distances. Also make sure the beam propagates directly above a row of holes in the table, since this will simplify further alignment.

Setting up the stationary mirror (SM): Take a postholder, and mount it on the table using two screws, so that the laser beam path is above the center of the postholder. Insert mirror SM, which has a longer post than mirror MM, into the postholder, perpendicular to the beam, facing the laser. Remove the blocking screen, and adjust the mirror position so that the beam strikes the center of the mirror and reflects directly into the laser cavity. You can adjust the position of the mirror by moving the postholder. Use the thumbscrews located on the mirror mounts to adjust the angle of the mirror. Ideally, the laser beam should be normal (perpendicular) to the mirror. Use one of the cardboard screens to locate the reflection from the mirror in case you lose track of it.

Setting up the beam-splitter: Place another postholder approximately halfway between the laser and mirror SM. Insert the beam splitter into the postholder, so that it makes approximately a 45^o angle with the laser beam. You can use the holes in the optical table as a reference.

BLOCK THE RESULTING REFLECTED BEAMS USING CARDBOARD SCREENS.

Setting up the moveable mirror (MM): Take a postholder and attach it to the top of the translation stage using two screws. Mount the translation stage on the table in the position suggested by Figure 2. The translation stage consists of two parts, which are not separable, but are spring-loaded. In order to mount the stage on the optical table, you have to slide open the top and use two short black screws to attach the bottom part to the table. The distance from the mirror SM to the beam splitter should be about the same as from the mirror MM to the beam splitter. Align the mirror to reflect the beam back onto the beam splitter.

Final alignment: At this point, you should be able to observe two bright dots on the viewing screen, corresponding to reflections off the two mirrors. Use the angle screws on the two mirrors and the beam splitter to merge the two spots into one. Mark this spot with a light pencil mark. Now attach a postholder to the table at a short distance from the beam splitter in the path of the beam. Insert the lens L into this postholder, and move it around to center the now large red spot on your pencil mark. Once you fixed the lens in place, you should be able to observe a circular interference pattern or some part of it. By fine adjusting the mirrors' and beam splitter positions, you should bring the center of the circular pattern into the middle of the field of view.

Once you see an interference pattern, rotate the micrometer screw that controls the translation stage back and forth to get a feel for how its movement impacts the fringes that you observe on the screen. It might seem to you that the pattern disappears when you touch the screw. Remember that a micrometer displacement of the mirror will produce a shift in the fringes. Be careful and systematic.

Exercise 1: Your task now is to obtain the numbers N and d that will allow you to calculate the wavelength of the laser light. There exist many ways to do this, here are two examples,

- By slowly turning the screw, count off a fixed number of fringes, say 30. Note the initial and the final readings of the Vernier scale. Repeat 3-4 times and record your measurements.

- Set the micrometer screw to a reference point of your choice. Slowly rotate the screw through one or more complete turns. Count the number of fringes that disappear in the center of the pattern. Repeat the measurement 3-4 times.

In either case, you will have to figure out by how much the moveable mirror is displaced when you adjust the micrometer screw. Round off errors due to the second method are smaller. Therefore, setting a reference point on the micrometer and rotating the thimble through two revolutions, while simultaneously counting the number of fringes is more reliable.

Exercise 2: Once you have completed these measurements, convert them to SI units and tabulate the results.

Exercise 3: Estimate the errors for each measurement and include them in the table. In the last column, include the wavelength obtained using the equation 2 with the estimated error. Average your results, and compare them with the actual value (632.8 nm).

Exercise 4: Is your result consistent with the actual value? If not, explain why this could have happened.

Exercise 5: Replace the He-Ne laser with the diode laser and align the optics so that you once again have an interference pattern. Repeat exercises 1 - 4 using the diode laser.

Exercise 6: Comment on any systematic differences between the two measurements. Where you able to measure the difference in wavelength between the two lasers using this method?.

Note: Once you have completed the experiment, please remove all optical elements from their mounts and place them on the optical table.

Your lab report should include:

Answers to exercises 1-6 with relevant data tables, graphs, figures and qualitative comments.

Refer to Appendix C for Maple worksheets.