

Introduction to Interferometry

In this lab, we will construct and use a Michelson interferometer to measure the wavelength of light from a helium-neon laser.

Introduction

A beam of light can be modeled as a wave of oscillating electric and magnetic fields. When two or more beams of light meet in space, these fields add according to the principle of superposition. That is, at each point in space, the electric and magnetic fields are determined as the vector sum of the fields of the separate beams.

If each beam of light originates from a separate source, there is generally no fixed relationship between the electromagnetic oscillations in the beams. At any instant in time, there will be points in space where the fields add to produce maximum field strength. However, the oscillations of visible light are far faster than the human eye can apprehend. Since there is no fixed relationship between the oscillations, a point at which there is a maximum at one instant may have a minimum at the next instant. The human eye averages these results and perceives a uniform intensity of light.

If two beams of light originate from the same source, there is generally some degree of correlation between the frequency and phase of the oscillations. At one point in space the light from the beams may be continually in phase. In this case, the combined field will always be a maximum and a bright spot will be seen. At another point the light from the beams may be continually out of phase and a minima, or dark spot, will be seen.

Thomas Young was one of the first to design a method for producing such an interference pattern. He allowed a single, narrow beam of light to fall on two narrow, closely spaced slits. Opposite the slits he placed a viewing screen. Where the light from the two slits struck the screen, a regular pattern of dark and bright bands appeared. When first performed, Young's experiment offered important evidence for the wave nature of light.

In 1881, 78 years after Young introduced his two-slit experiment, A.A. Michelson designed and built an interferometer using a similar principle. Originally built to test for the existence of the ether, Michelson's interferometer has become a widely used instrument for measuring the wavelength of light, for using the wavelength of a known light source to measure extremely small distances, and for investigating optical media.

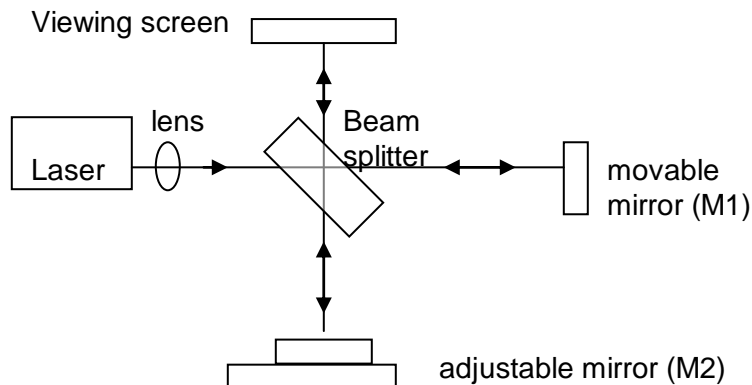


Figure 1

Michelson
Interferometer

Figure 1 above shows a diagram of a Michelson interferometer. The beam of light from the laser strikes the beam splitter, which reflects 50% of the incident light and transmits the other 50%. The incident beam is therefore split into two beams; one is transmitted toward the movable mirror (M1), and the other is reflected toward the fixed adjustable mirror (M2). Both mirrors reflect the light directly back toward the beam splitter. Half of the light from M1 is reflected from the beam splitter to the viewing screen and half the light from M2 is transmitted through the beam splitter to the viewing screen. In this way the original beam of light is split, and portions of the resulting beams are brought back together. Since the beams are from the same source, their phases are highly correlated. When a lens is placed between the laser source and the beam splitter, the light ray spreads out, and an interference pattern of dark and bright rings, or fringes, is seen on the viewing screen (figure 2).

Since the two interfering beams of light were split from the same initial beam, they were initially in phase. Their relative phase when they meet at any point on the viewing screen, therefore, depends on the difference in the length of their optical paths in reaching that point.

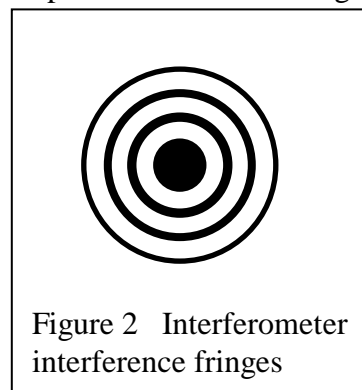


Figure 2 Interferometer interference fringes

Experiment I: Measuring the Laser Wavelength

By moving M1, the path length of one of the beams can be varied. Since the beam traverses the path between M1 and the beam splitter twice, moving M1 $1/4$ wavelength nearer the beam splitter will reduce the optical path of that beam by $1/2$ wavelength. The interference pattern will change; the radii of the maxima will be reduced so they now occupy the position of the former minima. If M1 is moved an additional $1/4$ wavelength closer to the beam splitter, the radii of the maxima will again be reduced so maxima and minima trade positions, but this new arrangement will be indistinguishable from the original pattern.

By slowly moving the mirror a measured distance d_m , and counting m , the number of times the fringe pattern is restored to its original state, the wavelength of light (λ) can be calculated as:

$$\lambda = 2d_m/m$$

Procedure

Moving Mirror Calibration

1. To make an accurate measurement of the laser wavelength, we need to know how far the moving mirror moves. Turn the micrometer knob clockwise one full rotation past the zero mark on the shaft, then turn the knob counter-clockwise one full rotation until the zero on the knob is aligned with the index mark, at zero on the shaft.

NOTE: When you reverse the direction in which you turn the micrometer knob, there is a small amount of give before the mirror begins to move. This is called mechanical backlash, and is present in all mechanical systems involving reversals in direction of movement. By beginning with a full counterclockwise turn, and then turning only counterclockwise when counting fringes, you can eliminate errors due to backlash.

2. Place a ruler on the interferometer, and measure the number of counter-clockwise rotations of the knob that are needed to move the mirror back one millimeter. according to the ruler. (It's OK to round your answer to the nearest integer, as the micrometer is calibrated so that each tick mark on the knob is some integer number of microns ($1 \mu\text{m} = 10^{-6} \text{m}$).)
3. Using your measurement, determine how many microns the mirror moves for each tick mark on the knob.

Laser alignment

1. Set the interferometer base on a lab table with movable mirror on the right.
2. Position the laser alignment bench to the left of the base approximately perpendicular to the base and place the laser on the bench.
3. Turn the laser on. Using the leveling screws on the laser bench, adjust its height until the laser beam is approximately parallel with the top of the interferometer base and strikes the movable mirror in the center. To check that the beam is parallel, place a piece of paper in the beam path, with the edge of the paper flush against the base. Mark the height of the beam on the paper. Using the piece of paper, check that the beam height is the same at both ends of the bench.
4. Adjust the x-y position of the laser until the beam is reflected from the movable mirror right back into the laser aperture. This is most easily done by gently sliding the rear end of the laser transverse to the axis of the alignment bench.

Interferometer construction and alignment

1. Place the beam splitter into the interferometer base (NOTE: For the square interferometer base, position the beam splitter at a 45 degree angle to the laser beam, within the crop marks, so that the beam is reflected into the fixed adjustable mirror M2. Adjust the angle of the beam splitter as needed so that the reflected beam hits the fixed mirror near its center.)
2. There should now be two sets of bright dots on the viewing screen; one set comes from the fixed adjustable mirror M2 and the other comes from the movable mirror M1. Each set of dots should include a bright dot with two or more dots of lesser brightness (due to multiple reflections). Adjust the angle of the beam splitter again (square base only) or the tilt of the fixed adjustable mirror M2 until the two sets of dots coincide.
3. Attach the 18 mm lens to the magnetic backing of the component holder (square base) or directly to the laser itself. Adjust its position until the diverging beam is centered on the beam splitter. You should now see circular fringes on the viewing screen. If not, carefully adjust the tilt of the fixed adjustable mirror until the fringes appear. Adjust the tilt of the fixed adjustable mirror to obtain the clearest, sharpest interference pattern you can.

Using the interferometer

1. Slowly move the micrometer dial, and watch the interference pattern on the screen. You will see the concentric rings move in and out very rapidly as you turn the micrometer knob.
2. Carefully position the input end of the Pasco Light Sensor at the center of your interference pattern. Try to avoid leaning on the table, or touching any part of the apparatus, as very small shifts in position will throw things off.

3. Open the Data Studio program, and create a new experiment that will display the light intensity as a function of time. The fringes will change very rapidly, so you will want to increase the sampling rate of the light sensor detector to at least 1000 Hz.
4. Adjust the micrometer knob to a middle reading. In this position, the relationship between the micrometer reading and the mirror movement is most nearly linear.
5. Turn the micrometer knob one full turn counterclockwise. Continue turning counterclockwise until the zero on the knob is aligned with the index mark. Record the micrometer reading.

NOTE: When you reverse the direction in which you turn the micrometer knob, there is a small amount of give before the mirror begins to move. This is called mechanical backlash, and is present in all mechanical systems involving reversals in direction of movement. By beginning with a full counterclockwise turn, and then turning only counterclockwise when counting fringes, you can eliminate errors due to backlash.

6. Start Data Studio recording data, then smoothly turn the micrometer knob over at least ten small tick marks on the dial. Stop recording with Data Studio. Carefully note the start and stop positions of the micrometer dial, and determine the distance that you moved the mirror (d_m).
7. Your graph should show a large number (>50) of rapid oscillations in the intensity recorded by the detector. These are the interference fringes going past. Zoom in on the graph, and count the number of fringes (m) that went by as you moved the mirror (recall that a change from a maximum to a minimum in intensity is $\frac{1}{2}$ of a fringe).
8. Repeat steps 4-7 twice for each lab partner (so that each lab partner contributes three data points), recording your results each time.
9. Calculate the wavelength of your laser light from your data, and compare your result to the wavelength stated on the laser housing.

Polarization

1. Place a polarizer between the laser and the beam splitter. Try several polarization angles. How does this affect the brightness and clarity of the fringe pattern? What does this tell you about the polarization characteristics of your light source?
2. Remove that polarizer and place a polarizer in front of the fixed or movable mirror. Try several polarization angles. How does this affect the fringe pattern? Does this observation give you any more information about the polarization of your source?
3. Now try two polarizers, one in front of the fixed mirror, and one in front of the movable mirror. First rotate one polarizer, then the other. Again, note the effects. Do cross-polarized beams interfere?