SC560 Introduction to Photonics  
Lab 1: Optical Interference

Introduction

This experiment will familiarize your hands with some of the practical properties of laser light which have been discussed in class. At the same time, you will gain familiarity with some of the tools and tricks of modern optics, and learn basic skills which you will encounter time and time again as you continue with your careers in science.

In this experiment, you will first set up a laser and familiarize yourself with its output, and with some common optical components such as beamsplitters, lenses, and polarizers. Next you will build a Michelson interferometer, where light traveling along two paths of unequal length displays constructive and destructive interference when viewed on a screen. After this, you will “upgrade” your interferometer with one mirror mounted on a piezoelectric transducer driven by a function generator, and a photodiode instead of a screen. This setup allows you to observe the doppler shift of the light in in the interferometer. Finally, you will use the Michelson interferometer with polarization optics to rediscover the interference laws of Fresnel and Arago.

1.1 Introduction to Laser Light

All of the experiments conducted in the laboratory section of this course make use of Helium-Neon (HeNe for short) lasers as a source of coherent quasimonochromatic light. The HeNes used in the photonics lab radiate at one of two wavelengths: 632.8nm (red) or 543nm (green). The beam divergence of such lasers is typically on the order of 1mrad, and >95% of the optical power output is confined to the fundamental (TEM$_{00}$) mode. The light at the center of the beam may be taken to be a plane wave propagating along the z-axis. The light from the HeNe is unpolarized, which means that the two polarization modes do not possess a coherent phase relationship and the polarization state is random.

YOU MUST READ THE LASER SAFETY INFORMATION SHEET BEFORE PROCEEDING WITH THE LAB AND OPERATING ANY LASERS!

That said, here’s the procedure.

- Mount the laser on its carrier and place it on the optical rail. Use an iris to ensure that the beam is pointing straight along the path of the rail.

- Use a screen to observe the intensity distribution of the laser spot at different distances from the laser aperture.
• Place a lens in the beam and observe the spot size again. Is the focal length where it should be?

• Use two lenses, one with a short focal length and another with a long focal length, to focus, expand, and collimate the beam, as shown in the following figure.

![Diagram of laser beam with lenses]

• Remove the lenses, and place a beamsplitter cube (BS) into the laser beam as shown in the figure below. Verify that it splits light into a reflected beam and a transmitted beam of approximately equal intensities.

![Diagram of laser beam with beamsplitter]

• Place a sheet polarizer and a screen after the laser aperture. Rotate the polarizer 360° to verify that the laser light is not linearly polarized. Does this tell you whether the light is unpolarized?

• Remove the screen and rotate the polarizer again, letting the linearly polarized light pass through the beamsplitter. Does the BS favor one polarization mode?

1.2 The Michelson Interferometer

In 1887, Albert Michelson, the first American to win the Nobel prize in physics, demonstrated a revolutionary apparatus for measuring the the speed of light. Michelson and Morely’s use of this apparatus to demonstrate that light travels at the same speed in all inertial reference frames profoundly changed the face of nineteenth century physics, culminating in the formulation of special relativity by
Albert Einstein in 1905. After 115 years, the Michelson interferometer remains one of the most versatile and widely used tools in optical science.

Procedure:

- Set up a Michelson interferometer as shown in the following figure, using an iris aperture, a cube beamsplitter, two mirrors, and a screen.

- Set up and align the above system as follows:
  - Permit the laser light to pass through the iris aperture. Place the mirror M2 on a longitudinal translation stage with a micrometer, and adjust it so the reflection of the laser beam passes back into the aperture.
  - Insert the beamsplitter cube as shown in the above figure. There will be a weak (~4%) reflection of incident light off of the front surface. Align the beamsplitter so that this reflection passes back into the aperture as well.
  - Insert mirror M1 and the screen so that the distance from the BS to M1 is roughly the same as the distance from the BS to M2. Observe the two reflected spots on the screen. Adjust mirror M1 so that they overlap. If you've done it right the two beams should interfere.
  - Magnify the interfering beams by placing a lens between the beamsplitter and the screen. Slowly adjust mirror M1 so that the number of fringes is as small as possible. Can you get just one fringe on the screen?
• Turn the micrometer on the M2 stage, moving the mirror longitudinally. What happens to the fringes?

• Mark a point on the screen and observe how many fringes sweep past as you drive out the micrometer. If the path lengths in arms 1 and 2 are given by \( d_1 \) and \( d_2 \) respectively, then \( m = 2(d_1 - d_2)/\lambda \) fringes should be swept past a fixed point. Use this formula to measure the wavelength of the incident light. Is it the same that known to be produced by your HeNe?

• Insert a thin sheet of plastic or glass in one arm of the interferometer. What is the effect on the interference pattern? Explain why.

• According to the theory of wave optics studied in the classroom, two plane waves traveling with an angle \( \phi \) between them will display parallel interference fringes separated by a distance \( d = \lambda \csc \phi \). Why are the fringes curved in this case? Insert a lens with a long focal length between the laser and the beamsplitter and observe its effect on the fringes. Observe the behavior of the fringes as you move the mirror. Explain physically.

1.3 Laser Doppler Radar

The Doppler effect, first described by Christian Andreas Doppler in 1842, is the phenomenon wherein a moving source of waves is observed to have a frequency different from that observed in its rest frame.

![Diagram of Doppler effect](image)

The Doppler shift \( \Delta f = \frac{2vf}{c} \) is proportional to the velocity of the source, where \( f \) is the source frequency and \( c \) is the speed of light. This effect is particularly important in astronomy, where the magnitude of the Doppler shift can be used to measure the velocity of distant stars. Likewise, Doppler radar came into widespread use during World War II, where the Doppler shift was used to estimate the speed of enemy aircraft. Doppler radar is still widely used in weather forecasting. In the following experiment, we will construct a tabletop laser Doppler radar device which will allow us to compute the speed of a moving mirror in a Michelson interferometer.
Procedure:

- Replace the mirror M2 in the previous experiment with a mirror mounted on a piezoelectric transducer, whose longitudinal position is proportional to the applied voltage. Align both components using the technique learned in the previous experiment.

![Diagram of the experiment setup]

- Connect the transducer to a DC voltage supply.

- If the mirror displacement $\Delta d = aV$ where $V$ is the applied voltage, use the Michelson interferometer to measure the proportionality constant $a$ by slowly increasing the voltage from 0 to 25V and counting the number of fringes which sweep past a given point on the screen. Knowing the wavelength of the light, compute the distance $\Delta d$ traversed by the mirror and the proportionality constant $a$.

- Replace the screen with a photodiode and a pinhole. Be sure to keep the lens in the system. As the fringes sweep past the pinhole, the amount of light let through to the photodiode will vary. Connect the photodiode output to an oscilloscope. Vary the DC voltage as before, and watch the signal from the photodiode go up and down on the scope.
• Connect the transducer to the output a function generator. Also connect the output of the function generator to the other channel of the oscilloscope.

• Set the function generator to produce a low frequency (order of 10 Hz) sawtooth wave. The movement of the fringes should produce a sinusoidal signal from the photodiode.

• A mirror moving with speed $v$ reflects laser light with frequency $f$ Doppler shifted by an amount $\Delta f = \frac{2vf}{c}$. The frequency-shifted light from the transmission arm interferes with the unshifted light from the reflection arm, beating at the frequency $\Delta f'$. The optical intensity recorded by the photodiode should oscillate at the beat frequency, provided that the two beams are well aligned and the beat frequency is within the bandwidth of
your detector. Record the beat frequency and estimate the velocity of the mirror. Does your result agree with your previous estimate of the mirror velocity? Increase the frequency of your generated sawtooth wave. What is the highest frequency at which your system can perform satisfactorily? What is the reason for the failure? Return the frequency to its initial value. Gently misalign the wavefronts using mirror M1 and observe the diminution of the beat signal.

1.4 Interference of Polarized Light

Use a Michelson interferometer and four linear polarizers as shown in the following figure to verify the four laws of Fresnel and Arago, based on a series of experiments conducted in 1817.

- Observe the interference pattern with two parallel polarizers at B and C. Verify that two beams, linearly polarized in the same plane, can interfere.
- Observe the interference pattern with two orthogonal polarizers at B and C. Verify that two beams, linearly polarized in orthogonal directions, cannot interfere.
- Observe the interference pattern with polarizers at B, C, and D. Set B and C orthogonal, with D set 45 degrees to B. Verify that fringes disappear so that two beams, linearly polarized in orthogonal planes, if derived from unpolarized light and subsequently brought to the same plane, cannot interfere.
- Observe the interference pattern with polarizers at A, B, C, and D. Set B and C orthogonal, with D and A set parallel to each other and 45 degrees to B. Verify that fringes are seen, so that two beams, linearly polarized in
orthogonal planes, if derived from the same linearly polarized light and subsequently brought to the same plane, can interfere.

In 1817, Fresnel and Arago did not have an electromagnetic theory of light at their disposal. Why are these laws true? What general condition must be met for two beams of light to interfere?

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