Interferometer

Physics 150/126L   Spring 2025

See course web page for information about due dates

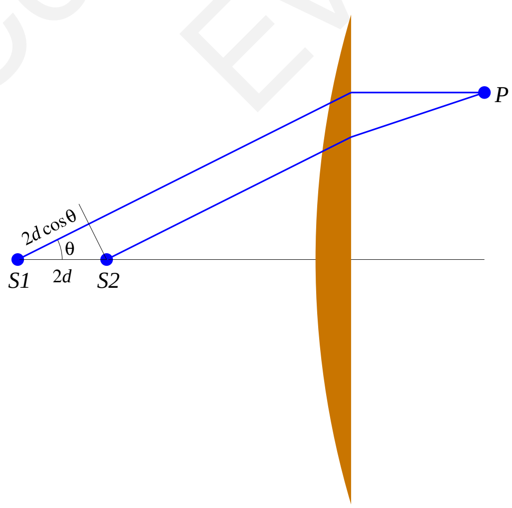
Introduction

In this lab we will learn to assemble, align, and use a Michelson interferometer, one of the most versatile and sensitive instruments in all of experimental physics. From the Michelson-Morley experiment in 1887, to the redefinition of the meter from the length of a particular metal bar to a specific multiple of a krypton line wavelength in 1960, to the first direct detection of gravitational waves by LIGO in 2015, this device has continued to produce revolutionary physics for more than 130 years.

In our interferometer, light from a diode laser or an LED is split into two beams of roughly equal amplitude. Each beam travels down an “arm” of the interferometer, reflects off of a plane mirror, and travels back to the beamsplitter, where the two beams are recombined. The resulting interference pattern is projected on a screen or detector.

The interference pattern is typically a circular fringe surrounded by a series of concentric rings. This pattern will be altered if there is stress in the interferometer components, or some other reason why the path length varies in an irregular way across the fringes.

Only part of the pattern appears on the screen, but by making small changes in the alignment of the mirrors, one can shift the pattern around to see different regions. To understand how this pattern arises, examine the diagram below:



Imagine looking into the interferometer from the position of the screen. We will not actually do this if we are using a laser, since it is dangerous to look into the beam. However, it can be done if the interferometer is configured with an LED instead of the laser.

The view from the screen position looking back into the instrument would be two virtual images, $S1$ and $S2$, of the source, each created by one of the mirror reflections. If the difference in the lengths of the two arms is d, then the sources would appear to be separated along the optical axis by a distance $2d$, just as your virtual image in a normal mirror appears at twice the distance from you to the mirror.

Light from the two sources that travels along the optical axis (not shown in the diagram) will arrive at the screen with a phase difference of $2kd$, where $k = 2\pi/\lambda$ is the wavenumber, and $2d$ is the on-axis optical path length difference.[1]

For light departing the sources at an angle θ, the optical path length difference will be $2d\cos\theta$, as shown in the diagram, and the two rays will arrive at point P on the screen with a phase difference of $2kd\cos\theta$. Note that the lens directs all rays arriving at a particular angle to a single corresponding point on the screen. As θ varies, so will the phase difference, and the result is a series of maxima and minima moving radially outward from the center of the pattern.

If the path lengths of the two arms are exactly matched, as is necessary to see fringes with an LED source, the pattern ideally has only one central fringe across the entire field. In practice, distortions will make the pattern unpredictable in that situation.

In typical usage, one arm is fixed, and the length of the second arm is varied, causing a shift of one full fringe at the center of the pattern for every $\lambda/2$ change in arm length. The beam traverses the arm twice, once on the way to the mirror and once on the way back. So a $\lambda/2$ change in arm length causes a full one-λ change in the optical path difference.

A typical Michelson interferometer is built on a very rigid platform with high-quality mounts having the ability to make very smooth and precise changes in the angles and positions of the optical components. Since we have a limited budget, is not possible to purchase a two foot thick optical table and \$2000 worth of mirror mounts for each pair of students. We are fortunate that a working interferometer can be assembled using our breadboards and a small number of precision components, with the rest being 3D-printed.

Assembling the interferometer

Assemble your interferometer according to the instructions given by the instructors.

Aligning the interferometer

You will need to work on a stable surface.

Get two index cards and use one in the appropriate pedestal holder to make a screen. The other will be helpful for alignment.

Make sure not to stare into the laser beam! A 1 mW laser would deliver into your eye about the same amount of energy per unit time as you'd get staring directly into the

[1] Depending on the type of beamsplitter, there can be an additional constant 180° phase difference caused by reflections. This only has the effect of inverting the entire fringe pattern, and can be ignored except when $2d$ is comparable to λ.

sun.

Follow directions from the instructors to align your interferometer.

Measurements

1. Align the interferometer to obtain fringes with the laser. Typical laser diode coherence lengths are greater than 10 m, so this is relatively easy.

2. Measure the calibration of the differential micrometer that adjusts mirror position along the axis of the interferometer arm. In other words, by counting fringes, determine how far the micrometer moves the stage for each tick mark on the barrel.

3. Approximately equalize the lengths of the two arms as best you can using calipers and the flexure stage with differential micrometers. Make sure you have a good centered fringe pattern, then replace the laser with a red LED. Carefully adjust the stage to equalize the path lengths. You should obtain fringes from the red LED.

4. Adjust the path length difference to maximize contrast of the red LED fringes. Then replace the red LED with a warm white LED. Readjust if necessary to obtain white light fringes. At this point, your path lengths are equal to within a few microns.

5. By measuring the range of path length differences over which you can observe fringes, estimate the coherence lengths and corresponding spectral widths, in nanometers of wavelength, of the red LED and warm white LED.

6. **Extra credit:** Measure the coherence length and corresponding spectral width of an incandescent bulb.

7. Using the laser interferometer and rotation stage, measure the index of refraction of each of the two transparent windows. You will need to know each window's thickness, and you will need to calculate the optical path length as a function of angle.