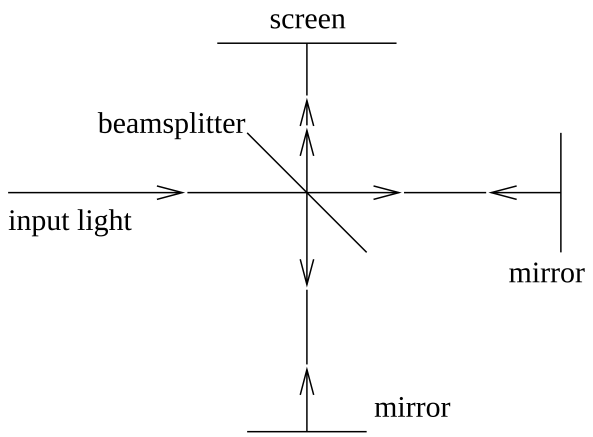
Experiment 4: Interferometers

1 Michelson interferometer

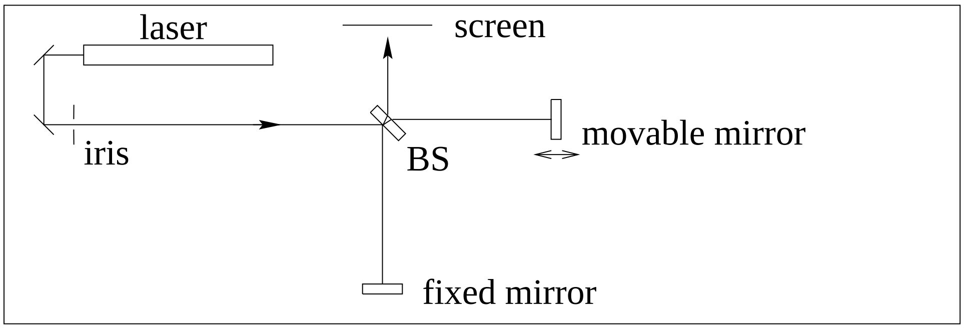
A schematic of the Michelson interferometer is shown in the figure. The input light is split at the beamsplitter and directed to two mirrors. These mirrors reflect the light back to the beamsplitter where the two waves combine. The phase difference between these waves depends on the optical path length difference between the two arms of the interferometer. The resulting interference can be observed on a screen placed at the output. When the optical path length of the two arms are exactly equal or differ by an integral multiple of the wavelength λ_0, the interfering waves have the same phase and the output is bright. When the path lengths differ from an integral multiple of λ_0 by $\lambda_0/2$, the output is dark.



The phase curvatures (wavefronts) of the two interfering waves may depend on the optical path length of the interferometer arms. For example when the input field is a diverging Gaussian beam, different path lengths result in different phase curvatures for the interfering waves. Hence, the interference pattern assumes a circular pattern. In other words, the phase difference becomes a function of the radial distance on the transverse plane.

Alignment The optics used in the interferometer have delicate dielectric coatings on them. Extreme care must be taken not to scratch the optical surfaces.

To set up a Michelson interferometer, first obtain a laser beam that is parallel to the optical bench. Mount the dielectric beamsplitter in a fixed optic mount and position it at 45° to the beam. Make sure that the beam splitting surface (coated surface) is facing the laser. Try to position the beam as close to the center of the beamsplitter as possible. The reflected beam may not be perfectly parallel to the bench in the vertical direction, but this does not cause any problems. Position an iris on the laser beam for alignment purposes, as shown in the figure.



Next, mount a dielectric mirror in a fixed height adjustable mirror mount, and position it near 0° incidence angle and as far from the beamsplitter as possible, as shown in the figure. You will be able to see the reflection on the iris. Adjust the mirror so that the reflected beam hits the iris close to the aperture. This will insure that the reflected beam does not get back to the laser and cause problems.

For the movable mirror, screw a post holder onto the translation stage and place a post in the post holder. Mount another dielectric mirror on an adjustable mirror mount. Mount this on the XZ translation stage using the right angle post clamp such that the beam height is approximately 3 inches. Position the translation stage on the bench such that the two arms of the interferometer have nearly the same length.

Place a piece of white paper as a screen and locate the beams coming from the two arms of the interferometer. There may be other stray reflections on the screen as well. Adjust the tilt angle of the movable mirror such that the two spots are on top of each other. Can you observe any interference? Translate the mirror back and forth with the micrometer to vary the path length difference.

Mount a negative lens ($f = -25$ mm) on a threaded optic mount. Position this lens near the beamsplitter at the input of the interferometer. Adjust the lateral position of the lens so that the beam goes through its center. Also, watch for the weak surface reflections from the lens on the iris to make the lens perpendicular to the beam. Realign the movable mirror to obtain a symmetric circular fringe pattern on the screen. Move the mirror with the micrometer and watch the fringes move.

Displacement measurement Calculate the mirror displacement from a count of the fringes as you turn the micrometer. Avoid leaing on the table to prevent random fluctuations. Compare the measured displacement with a direct reading off the micrometer.

Measurement of the index of refraction of air The interferometer can be used to measure any physical process that changes the phase of light. One such application is the measurement of the index of refraction of air. This is accomplished by using a vacuum cell in one arm to change the optical path length. For reasonably low pressures, the index of refraction of a gas varies linearly with pressure. Mount the vacuum cell on the plate holder. Using a post holder, place the vacuum cell in front of the movable mirror and connect the vacuum pump. Rotate the cell so that the windows are perpendicular to the beam. (Disregard the distortions in the fringe pattern.) The air in the cell is at atmospheric pressure (1 bar or 76 cm Hg) at this point. Count the movement of the fringes as you slowly pump out the air in the vacuum cell. Record the final pressure (atmospheric pressure minus the gauge reading). Make a plot of the refractive index as a function of pressure assuming linear dependence. (The vacuum cell is 3 cm long.) What is the refractive index at atmospheric pressure?

White light fringes It is possible to observe interference fringes even with white light. Even though white light from an incandescent light source is temporally incoherent, fringes will form if the interferometer path lengths are exactly equal. (Actually, equal within the very short coherence time.)

The laboratory assistant will demonstrate white light fringes with a separate Michelson interferometer. The interferometer will first be aligned with a laser. Then, you will turn the micrometer to make the path lengths exactly equal. When this is achieved, the phase curvatures will ideally be identical, and there will be only one fringe. At this point, the assistant will replace the laser with the incandescent light source and form the white light fringes. Move the micrometer to see how sensitive these fringes are to the absolute path difference. Find the coherence time of the incandescent light source from this measurement.

2 Fabry–Perot interferometer

A Fabry–Perot interferometer consists of two partially transmitting mirrors facing each other. The light wave bounces back and forth between the mirrors. At each pass, a portion of the light is transmitted out of the interferometer. Waves from these infinite number of passes interfere at the output. This is an example of multi-wave interference. The laboratory assistant will demonstrate a Fabry–Perot interferometer.