Modern Physics Lab

Michelson Interferometer

Introduction: The Michelson interferometer experiment is a historic achievement of human science. It demonstrated that the speed of light is invariant with respect to the frame of reference where it is measured. At the same time it disproved the existence of ether, which was a substance postulated to be the medium where electromagnetic waves travel. These results are the experimental support for the theory of special relativity, while other consequences were derived and confirmed later.

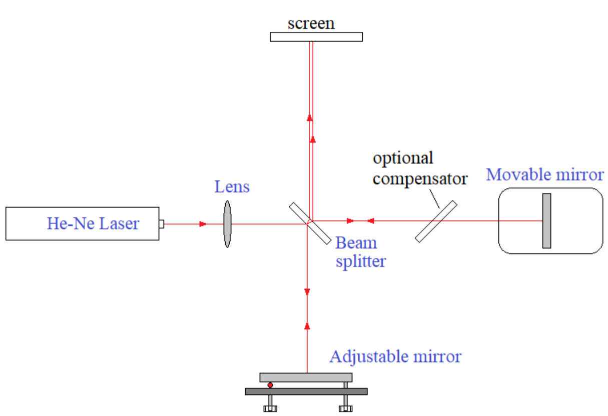
Goals: The experimenters will learn to assemble an interferometer configuration with a He-Ne laser and use it to:

Measure the wavelength of the laser light.
Measure the index of refraction of air at 1 atmosphere and room temperature.
Measure the index of refraction of a glass plate.

Equipment:

Five-kilogram aluminum base (optical table).
He-Ne laser.
One adjustable mirror with two degrees of freedom.
One fixed mirror to be mounted on a moveable holder.
A beam splitter to divide the laser beam.
A glass plate for compensation (optional).
Convergent lens with 18mm focal length.
Various component holders.
Rotating holder with pointer bar.
Vacuum cavity.
Air pump.

Experiment 1: *measuring the laser wavelength.*
Assemble the components according to the diagram below to obtain the bulls-eye interference pattern on the screen.

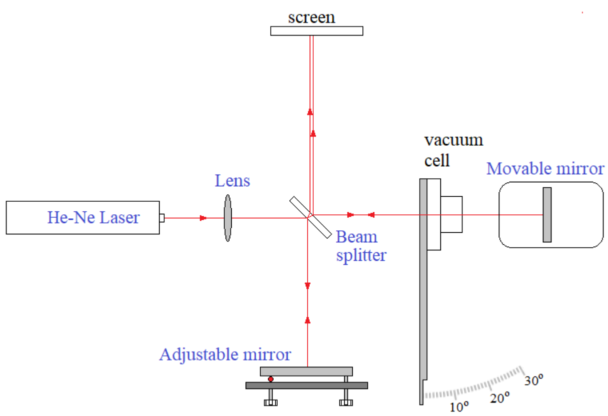


You can try different ways to get the interference pattern. For example, align one beam first without the adjustable mirror moving only the beam splitter and watching out for multiple reflections. Once you have that in place on the screen obstruct the beam with a business card and make the second beam fall on the same spot as the first with the help of the adjustable mirror. Only when you are satisfied that they are superimposed add the converging lens to get the bulls-eye pattern. Another idea: instead of the screen you can try projecting the pattern on the wall.

Once you have the desired pattern you can measure the wavelength by moving the movable mirror with the micrometer and counting the number of peaks that go through the interference pattern. Here it is important to have good statistics, so the larger the span the more accurate your measurement will be, but you also run the risk of miscounting peaks. Decide what the best way to do this is. For example, run the experiment with 100 microns 5 times and discard two outliers to get your best estimate. Remember that when the mirror moves 1 micron, the path becomes 2 microns longer or shorter because light goes back and forth to the mirror.

Once you have a good estimate you can calculate the error comparing the measured wavelength to the accepted value for a He-Ne laser.

Experiment 2: *measuring the index of refraction of air*.
The set-up is similar to the one for the measurement of wavelength, but we will insert the vacuum cell in place of the compensating plate. You can use the rotating holder to secure it in place as shown below.



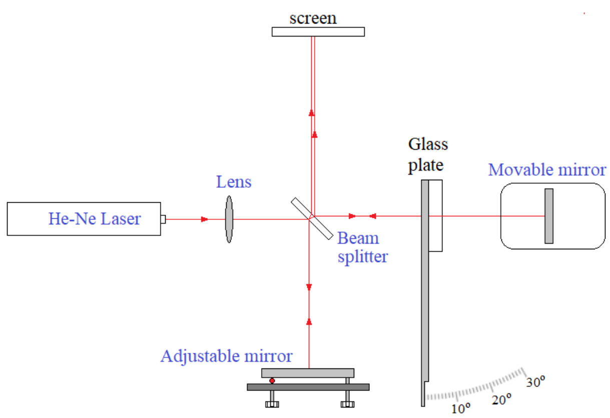
The idea is to get the number of peaks in the interference pattern as a function of gauge pressure. Once again, you should decide what the best way to do this is. Perhaps you can try with 5cm Hg, 10cm Hg and so on. It will not be possible to reach 1atm (76cm Hg) but we will extrapolate to that value once you have the data (let's call that extrapolated number of peaks n).

To get the index of refraction of air, notice that the beam goes back and forth inside the vacuum cell, so you will need to measure that length and multiply it by 2. Then you can find the number of wavelengths that that corresponds to (let's call it N). Finally, you can demonstrate to yourself that the index of refraction is (N + n) /N.

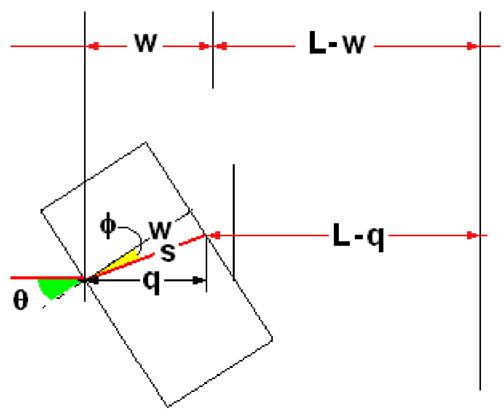
Once you have the best estimate, compare it to the accepted value for air.

Experiment 3: *measuring the index of refraction of plate of glass.*

The set-up is also similar to the one for the measurement of wavelength, but we will insert the glass plate in place of the compensating plate mounted on the rotating holder as shown below.



The diagram below represents the laser going through the glass plate with thickness w, then bouncing on a mirror and covering the same path again.



The experiment consists in turning the glass an angle θ and counting the number of fringes that change. The change is due to the longer time it takes for light to travel in glass as compared to air. The times in the two cases are:

$$t_1 = 2\left(n\frac{w}{c} + \frac{L-w}{c}\right) \qquad t_2 = 2\left(n\frac{s}{c} + \frac{L-q}{c}\right)$$

After some manipulation you can deduce the following approximation:

$$n = \frac{1}{1 - \frac{\# fringes}{w\theta^2}\lambda}$$

You can try measuring the number of fringes for angles of 5, 10, 15, 20 and 25 degrees. Perhaps adjust for a systematic error and compare with the expected value of index of refraction of glass.