OPTICS AND LASER PHYSICS LABORATORY #4
MICHELSON INTERFEROMETER

What is an interferometer?

An optical interferometer is an instrument designed to utilize the interference of light in order to measure optical properties such as wavelength, coherence lengths of light sources, and indices of refraction of materials placed in one arm of the interferometer. In 1881, Albert Michelson developed the particular optical arrangement that we now know as the Michelson interferometer. A schematic of it is pictured below in Figure 1.

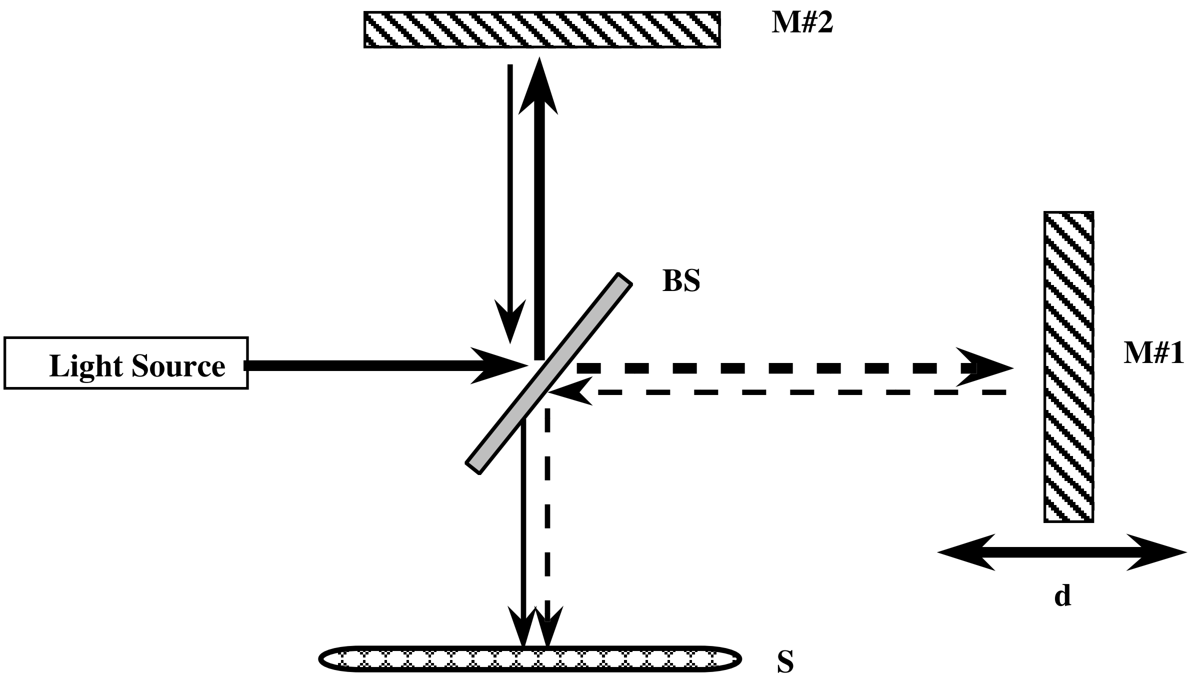

Figure 1: Schematic of a Michelson interferometer where BS ≡ beam splitter, M ≡ mirror, and S ≡ screen.

Light from a laser or other coherent source strikes the beam splitter and is divided into two beams -- one of which is transmitted through the beam splitter to a movable mirror (#1) and the other of which is reflected to a mirror (#2). The beams' reflections recombine at the beam splitter on their return trip and the resultant interference of the two electro-magnetic fields is viewed on the screen. The field at the screen is a superposition of the two beams that have traveled the two separate paths. By turning the micrometer screw adjustment on the movable mirror, the first mirror translates forward or backward and the interference pattern shifts as different portions of the combined beam undergo constructive or destructive interference. Note that when mirror #1 moves forward a distance, d, that the path length traversed by the beam is reduced by 2d.

1) What type of interference pattern would you expect to observe if the two beams were perfectly overlapped and parallel upon exiting the beam splitter?

2) What type of pattern is formed when the two beams are nearly collinear?

3) What interference results from highly divergent beams?

Assemblage and Alignment of Michelson Interferometer

Begin by directing the output of a HeNe laser into the beam splitter. Adjust the beam splitter until the reflected portion of the beam is at a 90^o angle to the input, additionally insuring that the reflected beam strikes near the center of mirror #2 and the transmitted beam strikes near the center of mirror #1. Adjust the path lengths of the two arms until they are within 0.5 cm of each other. Be sure to leave sufficient room for the rotating stage in one leg. Tie down the various components of the interferometer and the HeNe while maintaining the above-discussed alignment. Then using the mirror mount adjustments on the fixed mirror direct the reflection off the mirror back onto the beam spot on the beam splitter. This should produce a spot on the screen which has flat mm rulings on it. Follow a similar procedure for the movable mirror. Here you have the additional concern of maintaining alignment as the mirror translates! Once the two beams are directed back through the beam splitter you should observe fringes on the viewing screen.

1) What type of fringes do you see? Move mirror #1 back forth with the micrometer screw. What happens to the fringes?

2) Can you adjust the interferometer to see a perfectly aligned spot? How close do you get? (measure the distance between fringes and compute the crossing angle). The fringe spacing d and total crossing angle ø are related as follows.

$$d = \lambda/\sin\{ø/2\} \qquad \text{Eq. 1}$$

3) Place a diverging lens into the input beam's path. What happens to the fringe pattern now? If you cannot see one, adjust the mirrors. Move mirror #1 forward and back and record observations.

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CHOOSE ONE OF THE FOLLOWING 3 MEASUREMENTS TO ACCOMPLISH.

Use of the Michelson to Determine Wavelength of Source

Once a clearly visible interference pattern is formed (with a diverging lens) on the viewing screen. You will note that motion of the movable mirror shifts the interference pattern.

1) Why?

By moving the movable mirror in a single direction, your partner can count how many times the fringes become dark (or bright) during the change in path length of one beam. From this information, you can calculate the wavelength of the light source. Remember, the path length difference between the two beams is twice the distance you moved your mirror and this path difference must be equal to an integral number of wavelengths for totally destructive (or constructive) interference to make one cycle.

2) What equation would you use to determine the wavelength from the above information?

The best results come from observing the distance the mirror #1 moves as approximately 100 fringes fade in and out of focus on the screen. Measure the wavelength of the HeNe. Take four measurements. Each person on the team should take a turn as the fringe counter/observer or the micrometer reader/turner. Compare your calculate result to the known wavelength of the HeNe (632.8 nm).

3) What are possible sources of error in this experiment?

4) Furnish suitable error bars for these measurements.

5) Why would one want to count 100 fringes or more on the screen instead of just watching a single cycle?

Use of Michelson Interferometer to Determine the Index of Refraction of a Translucent Material

An interferometer can easily determine the thickness of an object with a known index of refraction or can be used to determine the index of refraction of an object if one knows the thickness. The expression from which the count of net fringe shift is translated into an index of refraction or sample length is

$$n = \left(\frac{\lambda}{2L}\right) m + 1 \qquad \text{Eq. 2}$$

where L is the thickness of the sample, and n is the index of refraction of the sample. The medium in which the remainder of the interferometer lies is assumed to be air with an index of n = 1.

1) Derive Eq.2.

Hold a butane lighter or lighted match under one leg of the interferometer.

2) What happens? Record observations.

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One of the classic examples of such a measurement is to slowly evacuate a glass cell which is initially filled with a gas. One could also measure the thickness of a thin film with a Michelson. In this lab, we will measure the index of refraction of a glass etalon.

3) How would you suggest this measurement be made?

Set-up the apparatus so that you can make this measurement and see what value for the index you find.

4) How might you check your result using a method unrelated to the Michelson? Try it.

Use of the Michelson to Determine the Coherence Length of a Laser

With your intereferometer set at equal path lengths, you begin with perfectly aligned, coherent beams. You can extend the length of the one leg a few centimeters at a time watching the fringes.

1) As the laser's coherence decreases, what do you expect to see?
2) How do you know when you have reached the coherence of the laser?

Measure the coherence of the laser provided. Note: You must carefully realign the moving mirror with each extension of leg length.

3) What are the coherence time and bandwidth of the laser?
4) If you were to measure the linewidth of the emission spectra of a sodium vapor, what would you need to be concerned about in terms of the information you have just gathered?