

## Michelson Interferometer

Equipment- optical breadboard, line selectable He-Ne laser with scissors jack stand, beam splitter, fixed mirror, movable mirror, vacuum chamber with pump, screen, diverging lens, converging lens, cross hairs, Allen wrench

Reading Your text books, particularly regarding the Michelson-Morley experiment. “Fundamentals of Optics,” Jenkins and White (McGraw-Hill, 1937)

### WARNING: PROTECT YOUR EYES

IN THIS EXPERIMENT YOU WILL USE A LASER. THE LASER BEAM CAN INJURE YOUR EYES. DO NOT LOOK INTO THE LASER BEAM OR ITS REFLECTION. AVOID HAVING YOUR EYE AT THE SAME HEIGHT AS THE LASER BEAM. WEAR THE SAFETY GLASSES PROVIDED WHILE THE LASER IS ON.

DO NOT LOOK INTO ANY LASER EVEN IF YOU DO NOT SEE A BEAM! THE BEAM COULD BE IN THE NON-VISIBLE PART OF THE SPECTRUM.

## 1 Introduction

The Michelson interferometer divides a beam of light into two beams and then recombines the two beams into a single beam. If the travel time for the two beams is not the same, interference patterns or fringes can be observed. If the travel times of the two beams are changed relative to one another, the fringes will move. Some of the things that can be measured using this instrument are (1) the wavelength of a light source, (2) the index of refraction of a material, (3) the width of a spectral line, and (4) the Earth's motion through the “ether.” The last item refers to the Michelson-Morley experiment, which along with other experiments, showed that ether does not exist and that electromagnetic waves can propagate in a vacuum.

## 2 Apparatus

See Fig. 1. Light from a source S is directed onto a beam splitter (BS) which is oriented at 45 degrees with respect to the source. The light source can be diffuse, such as from a discharge lamp, or directed, as from a laser. The BS is a plate of glass which is coated on one side so that about 50% of the incident light is reflected and 50% is transmitted. The light that is transmitted by the BS, along with the light reflected from mirror  $M_1$ , form beams (1). The light that is reflected from the BS, along with the light reflected from mirror  $M_2$ , form beam (2). Beams (1) and (2) are then respectively reflected from and transmitted through the BS and form beam (3), which is observed. If the source is a modestly powered discharge lamp, beam (3) can be observed with the naked eye. If the source is a laser, BEAM (3) MUST BE OBSERVED BY LETTING IT FALL ON A SCREEN, and then looking at the screen.

The mirrors  $M_1$  and  $M_2$  are perpendicular to each other or nearly so. Their exact orientation determines the nature of the fringes observed. Two micrometer screws on each mirror

mount allow you to adjust the orientation of the mirrors. By examining the mirror mounts, can you see how this is accomplished? The adjustments are quite sensitive. Rotating the screws slightly will have a large effect on the fringe pattern.

Let  $t$  be the time that it takes a monochromatic light ray to travel from point A to point B along a specified path  $P_1$ . This path may include substances, such as glass, where the speed of light is different from  $c$ , the speed of light in vacuum. The optical path length (OPL) between A and B is defined as the distance in the time  $t$  that the light would have traveled in a vacuum. In this case  $\text{OPL} = ct = \int n ds$ , where  $n$  is the index of refraction and  $ds$  a differential of path length. The OPL may depend on the frequency of the light. If light also travels from A to B by a different path  $P_2$  and the OPL is the same for  $P_1$  and  $P_2$  the two beams will arrive in phase and constructively interfere. If the OPL's differ by  $(N)\lambda_0$  where  $N$  is an integer and  $\lambda_0$  is the vacuum wavelength, the two beams will also interfere constructively. If the OPL's differ by  $(N + 1/2)\lambda_0$  the two beams will interfere destructively.

Let the distance between the BS and  $M_1$  be  $d_1$ , and the distance between the BS and  $M_2$  be  $d_2$ . If  $d_1 = d_2$ , the optical path lengths of beams (1) and beams (2) will not be the same as beams (1) have traversed the BS three times, while beams (2) have done so only once. Sometimes a compensating plate (CP) is added as shown in the path of beams (2) to make the optical lengths identical if  $d_1 = d_2$ .

One of the mirrors, let's say  $M_1$ , can be moved parallel to beams 1 by a micrometer screw. This changes the optical path length for beams (1) and will cause the fringes to move and to change shape. It takes very little motion of the micrometer screw to have significant motion of the fringes. With care it is possible to rotate the micrometer screw and count the passing fringes. The wavelength of the light is measured in this way. For each complete fringe shift the mirror has moved  $\lambda/2$ .

## 2.1 Beam Expansion

The light beam emerging from the laser is fairly narrow. To widen the laser beam a diverging lens is placed in front of the laser and a converging lens is placed in front of the screen.

## 3 The Laser

The laser is a He-Ne laser with 5 selectable wavelengths, all in the visible. To turn the laser on rotate the key on the back panel of the laser housing clockwise a quarter of turn. A red light next to the key will light up. Also on the back panel of the laser housing are two micrometer screws, each of which has a white dot on the circumference of its knurled knob. The approximate rotational position of each knob is with the white dot lined up with the white line on the back panel, but do not rotate either knob to begin with. The knobs may have been left in positions for producing a laser beam. Within a few seconds of turning the laser on you may see a laser beam. If you do not, try rotating the color selector knob slowly one way or the other. When you see the laser beam, the intensity can be maximized by rotating the transverse adjustment knob. A modest rotation (less than half a turn) of the color selector knob will produce different laser beam colors.

Do not rotate the knobs more than half a turn in either direction. If you do, the white dot may line up with the white line but the laser will not work as the knob is one or more full

rotations from the correct position. If you believe this has happened, consult your instructor. There is a procedure for resetting the knobs.

## 4 Coherence

To observe interference between two light beams, or for that matter, any type of wave, it is necessary for there to be a constant phase difference between the two waves. Two such beams are said to be coherent. The light from two different discharge or incandescent light sources is not coherent, and will not produce interference, or the same thing, fringes. (The light from two different laser sources can be coherent.)

Coherence is not a yes or no property. The degree of coherence is usually described by a coherence length or a coherence time. As you might expect, the coherence length is the distance beyond which the phase relationships in a beam become fuzzy. A similar statement applies to the coherence time. The longer the coherence length or the coherence time, the more coherent the source is. A He-Ne laser might have a coherence time of a millisecond and a coherence length of a thousand kilometers. A sodium light source might have a coherence time of  $10^{-8}/s$  and a coherence length of a fraction of a meter. To see interference fringes with a classical light source it is necessary to create the two beams from the same source, either by sampling the source from a very small region (e.g. Young's double slit experiment) or splitting a single beam up into two beams (e.g. Michelson interferometer). You can actually see white light fringes with a Michelson (its hard) if the optical lengths of the two arms are almost exactly the same.

## 5 Fringe Shapes

The exact form the fringes take depends on whether mirrors  $M_1$  and  $M_2$  are exactly perpendicular to each other and whether the optical lengths of the two arms is the same or not. Assume that  $M_1$  is the movable mirror.

### 5.1 Circular fringes

If the two mirrors are exactly perpendicular to one another, circular fringes are observed. Assume the optical length of beams (1) is greater than that of beams (2). As the difference in optical lengths is made smaller by turning the micrometer screw, the fringe radii will decrease and the difference between adjacent ring radii will increase. When the optical lengths are the same, the central fringe will cover the entire field of view. As  $M_1$  is moved further in the same direction so that the optical length of beams (1) becomes smaller than that of beam (2), the radii of the fringes becomes bigger and the differences between adjacent radii becomes smaller.

### 5.2 Non-Circular Fringes

If the two mirrors are not quite perpendicular, the fringes will appear as straight parallel lines if the optical length difference between the two arms is small. As the optical length difference between the two arms increases, the fringes become curved, as shown in Fig. 2.

## 6 Laser Alignment

REMINDER: PROTECT YOUR EYES!

1. Measure the distances from the reflecting surface of the BS to the two mirrors. Adjust the position of  $M_1$  so that these two distances are the same to within about 1mm.
2. Turn on the laser. Adjust its height and angle so that the beam goes through the center of the BS and goes through to  $M_1$ .
3. Place the screen so that beams (3) fall on it. You will probably see a number of laser spots, but two will be brighter than the others and can be moved by adjusting the mirror angles. Adjust the mirrors so that these two spots converge. What are the other spots due to?
4. Put the concave lens between the laser and the beam splitter to expand the laser beam. Be sure the laser beam passes through the center of the lens. You should now see interference fringes.
5. Experiment with the angular adjustment of the mirrors and the position of mirror  $M_1$ . Can you get circular fringes, straight fringes, and curved fringes? Sketch what you are able to get.

## 7 Laser Wavelengths

Make a mark on the screen, and record the micrometer setting. Use the shortest laser wavelength at your disposal (green). Very slowly rotate the micrometer screw and count 50 to 100 fringes that pass the mark. Let  $N$  be the number of fringes that cross the mark and  $D$  the distance that the mirror was moved. Use the equation  $2D = N\lambda$  to determine the wavelength  $\lambda$  of the laser light. Justify this equation.

Now measure the wavelength of the longest laser wavelength at your disposal (red). Finally measure the wavelength of one of the remaining three laser lines.

## 8 Index of Refraction of Air

1. Measure the length of the vacuum chamber,  $L$ .
2. Place the vacuum chamber in the path of beams (1) and pump all the air out. Use the shortest laser wavelength available to you (green).
3. Slowly let the air back into the chamber and count the number of fringes  $N$  that pass your mark. Use the equation  $2(n - 1)L = N\lambda$ , where  $n$  is the index of refraction, to calculate  $n$ . Justify this equation.
4. Repeat for the longest wavelength available to you (red).

## 9 Questions

1. Were you able to discern any dispersion for air?
2. To observe white light fringes, you must use a compensating plate. Why?
3. Could you devise a way to measure the index of refraction of a transparent solid?

## 10 Acknowledgments

Michael Salvati, 2nd floor staff, built the interferometer. David Toner, an undergraduate, supplied much of this write-up.

## 11 Finishing Up

Please leave the bench as you found it. Thank you.

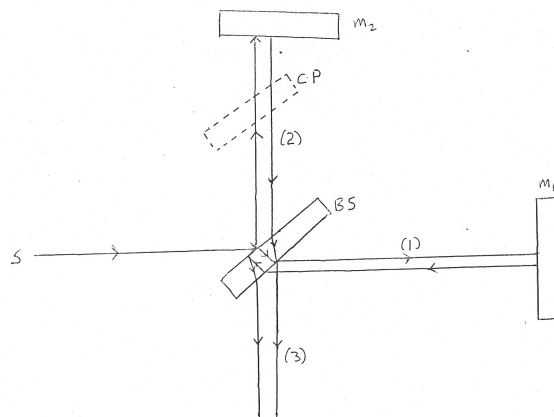


Figure 1

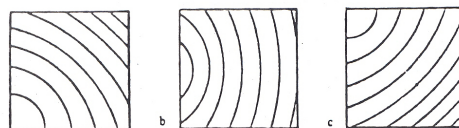


Figure 2