Physics 319 Laboratory: Optics

Michelson Interferometer

Objective: The objective of this lab is to familiarize yourself with the Michelson Interferometer and to use it to determine the wavelength of the Pasco laser.

Apparatus: You will need the interferometer kit, a Pasco laser and laser bench (the short optics bench), two bench couplers, and a viewing screen and component carrier from the Pasco optics kit.

Theory:

When two beams of light originate from two different sources, the fluctuations in the two beams are not in general correlated in any way. If the two beams are superposed on each other, the intensity distribution of the resulting beam is merely the sum of the intensities of the two original beams. However, if the two beams originate from the same source, the phase and intensity fluctuations are usually correlated to some degree. When two such "coherent" beams are superposed, the intensity distribution of the resulting beam displays a series of maxima and minima. This phenomenon is called interference. Wherever the two superposed beams are in phase, there corresponds constructive interference and hence a maximum in intensity. When the two beams are out of phase we have destructive interference and hence a minimum in intensity. If the light is monochromatic, the fluctuations in the beams are more highly correlated and hence the interference fringes are sharper.

Thomas Young was one of the first to discover the interference effect. He divided a beam of light by passing it through two closely-spaced slits. The resulting two beams when superposed form a series of maxima and minima. Young used these observations to establish the wave nature of light.

A light beam can also be divided by a partially reflecting surface such as the interface between glass and air. (This method is often called division of amplitude). A parallel plate of glass will divide a beam of light into a reflected beam and a transmitted beam. The transmitted beam may partially reflect off the bottom surface of the plate and then combine with the originally reflected beam to form an interference pattern. Similar patterns are formed by a film of liquid or even by a film of air.

The interferometer divides an incident beam into two beams via a partially reflecting mirror called a beam-splitter (see Figure 1). The two resulting beams are coherent and travel two separate, but nearly equal, perpendicular paths. Since the beam-splitter is usually a piece of glass partially mirrored on one side only, another plain piece of glass (compensator) is placed in one of the optical paths to insure that both beams pass through the same amount of glass.

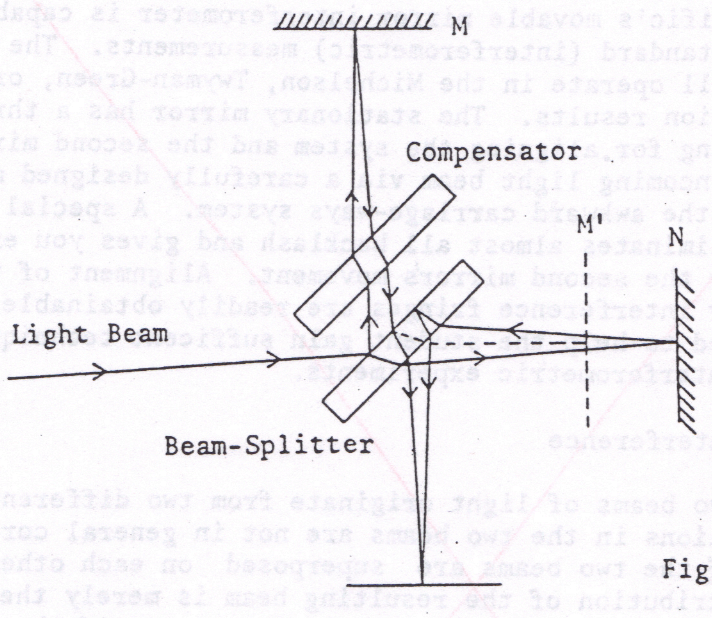

Fig. 1

Both beams are reflected by mirrors and consequently recombined. If both optical paths are not quite the same lengths, then circular fringes appear. In Fig. 1, the path to mirror M is slightly shorter than the path to mirror N. Consequently, there is a virtual image of M at M’. The film of air between M’ and N produces the interference pattern. If the mirrors are perfectly parallel, the pattern consists of circular fringes. Moving mirror N towards M’ causes the fringes to contract toward the center and decreases the number of fringes. When M’ and N are close together but inclined to form a wedge, the fringes are nearly straight lines parallel to the apex of the wedge. If M’ and N coincide, the mirrors are in optical contact and the pattern becomes a uniformly illuminated field. In practice, the interference pattern is often a combination of the above situations.

Procedure:

I. Set Up

Set the interferometer base on a lab table with the micrometer head pointing towards you. There are two angle brackets with mirrors mounted in them The larger bracket and mirror is the beam-splitter and the smaller on is the movable mirror. **Do Not Touch the surface of the mirrors!**

Select the movable mirror and mount it in the slot on the interferometer base with the front surface of the mirror facing the left. Tighten the thumb screw to secure the mirror. Mount the beam-splitter in the hole near the left edge of the base. Do not tighten the thumb screw. Finally mount the stationary mirror assembly on the edge next to the micrometer head. The stationary mirror should be facing the beam-splitter. Tighten the two thumb screws to secure the assembly.

II. Laser Alignment

You will be using Pasco’s laser and optical bench. Use the bench couplers to secure the optical bench to the left side of the interferometer base. When the Pasco laser sits on the bench it will be at the proper level.

Swing the beam-splitter out of the way of the laser beam. Adjust the X-Y position of the laser until the beam reflected from the movable mirror re-enters the laser. Now position the viewing screen (white screen with millimeter scale) on a component carrier and set the assembly to the right of the movable mirror. Observe the image of the laser beam. There will probably be one main dot and several secondary dots. Carefully adjust the laser position until there is only one image dot. The laser's beam should now be perpendicular to the movable mirror

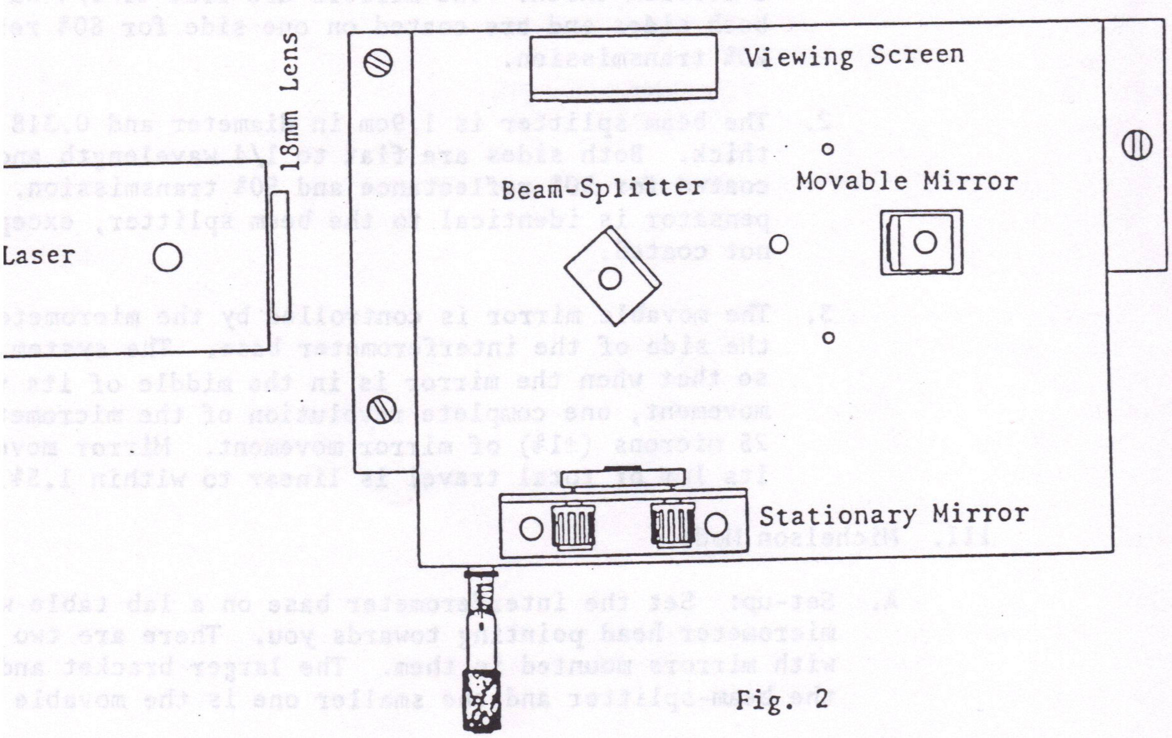

Fig. 2

III. Final Alignment

Swing the beam-splitter into the laser's beam so that part of the beam is reflected to the stationary mirror. Adjust the position until the reflected beam hits the stationary mirror near its center. Now set the viewing screen assembly on the rear edge of the interferometer base as shown above in Fig. 2. There should be two sets of bright dots on the screen. Adjust the beam-splitter again until the two sets of dots are as close together as possible. Secure the beam-splitter via the thumb screw. Using the two adjusting knobs on the back of the stationary mirror, adjust the mirror’s tilt until the two sets of dots coincide.

The compensator is not necessary for producing fringes from laser light. However, to use the compensator, first determine which side of the beam-splitter has the reflective coating. It should be the side furthest from the thumb screw holding the beam-splitter bracket. Mount the compensator on this side of the beam-splitter.

Now place the 18 mm lens in front of the laser (or on the face of the laser), and adjust its position until the diverging beam centers on the beam-splitter. The set-up should now resemble Fig. 2. You should see circular fringes on the viewing screen. If not, carefully adjust the tilt of the stationary mirror until fringes do appear.

IV. Counting Fringes

Once the fringes appear, center them with fine adjustments of the stationary mirror. You can view the fringes either through the diffuser or as reflected from the viewing screen. Move the micrometer dial and watch the fines pass by.

Utilize the millimeter scale on the viewing screen to help count fringes. Line up the boundary between one of the maxima and one of the minima with the millimeter scale (see Fig. 3). Move the micrometer dial until the boundary between the next maximum and minimum reaches the same position as the original boundary. (The fringe pattern should look the same as in the original position.) One fringe has now passed by.

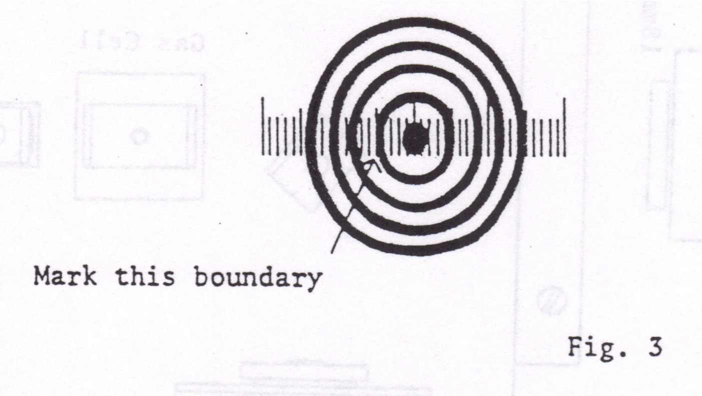

Fig. 3

Turning the micrometer dial clockwise moves the movable mirror toward the right. When turning the dial to count fringes, turn it one complete revolution in the direction you wish before counting fringes. This eliminates almost all possibility of backlash. Always take several readings and average them for greater accuracy.

V. Wavelength of Light

To calculate the wavelength of the laser light, count off ten fringes and record the distance the micrometer dial moved. One division of the movement on the micrometer dial represents one micron of mirror movement (i.e., one revolution of the dial represents 25 microns of mirror movement). If the mirror moves a distance d, the optical path has changed by 2d since the light travels to the mirror and back. Hence, divide 2d by the number of fringes to get the wavelength of the laser light.

You should use the following procedure when counting fringes: record the distance the micrometer dial moved for ten fringes from zero to the 190th fringe. Record your data so that you may obtain the difference in reading between the 0th and the 100th, the 10th and the 110th , and the 20th and the 120th , etc. Determine the mean difference per 100 fringes and the deviation, and the mean deviation.

VI. Gas Cell

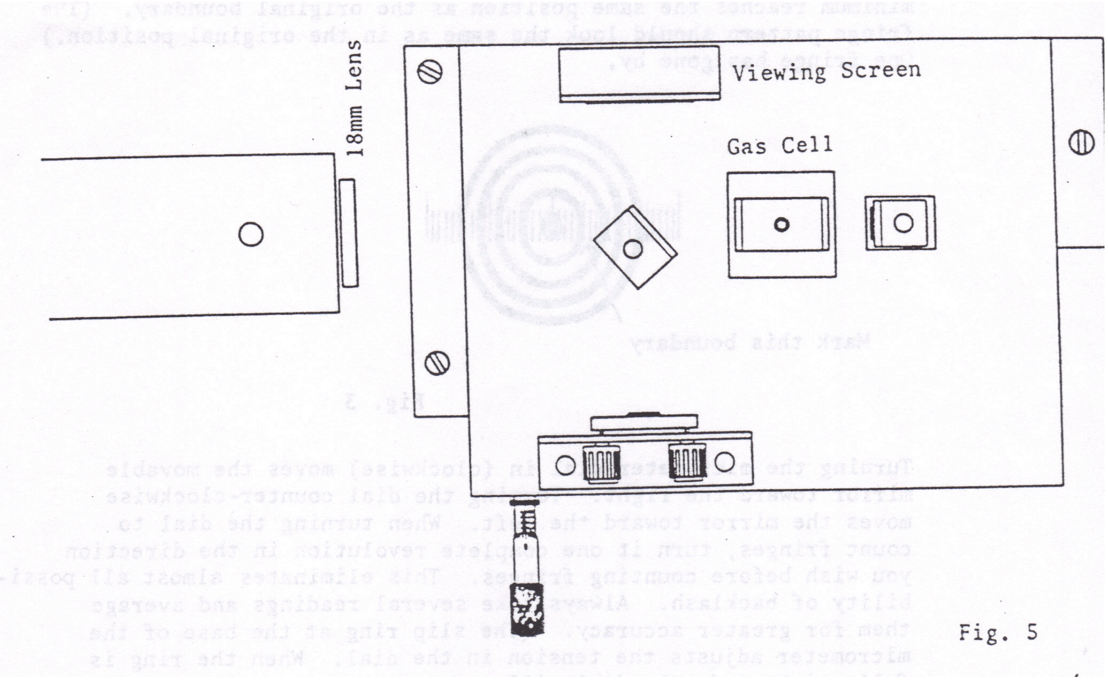

Fig. 5

Position the gas cell between the beam-splitter and movable mirror (see Fig 5). The light beam should pass through the cell. Make any minor adjustments to obtain a clear set of fringes. Now **slowly** pump air out of the cell. Watch the fringes pass by. Not the vacuum gauge reading and then pump out the cell to a convenient pressure while counting the fringes. Not the final gauge reading. Now the refractive index of a gas varies directly with its density and the index of a vacuum is 1. Thus, a graph of pressure (x-axis) versus refractive index (y-axis) is a straight line going through the point (0,1). Determine the slope of the line by calculating the change in refractive index. If n is the refractive index at the starting pressure and n' is the refractive index at the final lower pressure, $n - n'' = m\lambda/2d$, where m is the number of fringes counted, d is the length of the gas cell excluding the end windows. For accurate results, your calculated value for the index of refraction of air must be corrected for vapor pressure and temperature.

Questions:

1. Give a brief explanation, with words and a diagram, of the setup of the Michelson Interferometer. Also, why is this device so important from an historical physics point of view?

2. In the calculation to determine the value of λ based on the micrometer movement why was d_m multiplied by two?

3. Why move the mirror through many fringe transitions instead of one? Why take many measurements and average the results?

4. When the movable mirror is translated by 0.073 mm a shift of 300 fringes is observed. What is the wavelength of the light? What displacement (in m) of the fringe system takes place when a piece of glass of index 1.51 and 0.005 mm thickness is placed in one arm of the interferometer? Assume the glass.