Lab 3: Michelson Interferometer

(Based on Pasco's Precision Interferometer Instruction Manual and Experiment Guide)

Purpose: To study interference and experimentally determine the wavelengths of two lasers using a Michelson interferometer.

Equipment:

red semiconductor laser (λ = 650 nm)	Michelson Interferometer apparatus
green semiconductor laser (λ = 532 nm)	white screen
index cards (10)	small optical bench
small optical table	high sensitivity light detector

Theory: A beam of light can be modeled as a wave of oscillating electric and magnetic fields. When two or more beams of light meet in space, these fields add according to the principle of superposition. That is, at each point in space, the electric and magnetic fields are determined as the vector sum of the fields of the separate beams.

If each light beam originates from a separate source, there is generally no fixed relationship between the electromagnetic oscillations in the beams (they are said to be incoherent). At any instant in time there will be points in space where the fields add to produce maximum field strength. However, the oscillations of visible light are much faster than the human eye can detect. Since there is no fixed relationship between the oscillations, a point at which there is a maximum at one instant may have a minimum at the next. The human eye averages these results and perceives a uniform intensity of light.

For light beams that originate from the same source, there is generally some degree of correlation between their frequency and phase (they are coherent). At one point in space the light may be continually in phase. Then, the combined field will always be maximum and a bright spot will be seen. At another point the light may be continually out of phase and a minimum, or dark spot, will be seen.

Thomas Young was one of the first to design a method for producing such an interference pattern. He allowed a single, narrow beam of light to fall on two narrow, closely spaced slits. Opposite the slits he placed a viewing screen. Where the light from the two slits struck the screen, a regular pattern of dark and bright bands appeared. When first performed, Young's experiment offered important evidence for the wave nature of light. Young's slits can be used as a simple interferometer. If the spacing between the slits is known, the spacing of the maxima and minima can be used to determine the wavelength of the light. Conversely, if the wavelength of the light is known, the spacing of the slits could be determined from the interference patterns.

The Michelson Interferometer

In 1881, 78 years after Young introduced his two-slit experiment, Albert Michelson designed and built an interferometer using a similar principle. Michelson originally designed his interferometer to test for the existence of the ether, a hypothesized medium in which light propagated. Due in part to his efforts, the ether is no longer considered a viable hypothesis.

Beyond this, Michelson's interferometer has become a widely used instrument for measuring the wavelength of light, for using the wavelength of a known light source to measure extremely small distances and for investigating optical media.

Fig. 1 shows a diagram of a Michelson interferometer. The beam of light from the laser strikes the beamsplitter, which reflects 50% of the incident light and transmits the other 50%. The incident beam is therefore split into two beams; one beam is transmitted toward the movable mirror (M1) and the other is reflected toward the adjustable (fixed) mirror (M2). Both mirrors reflect the light directly back toward the beamsplitter. Half the light from M1 is reflected from the beamsplitter to the viewing screen and half the light from M2 is transmitted through the beamsplitter to the viewing screen. This way the original beam of light is split and portions of the resulting beams are brought back together. Since the beams are from the same source, their phases are highly correlated. When a lens is placed between the laser source and the beamsplitter, the light ray spreads out and an interference pattern of dark and bright rings is seen on the viewing screen.

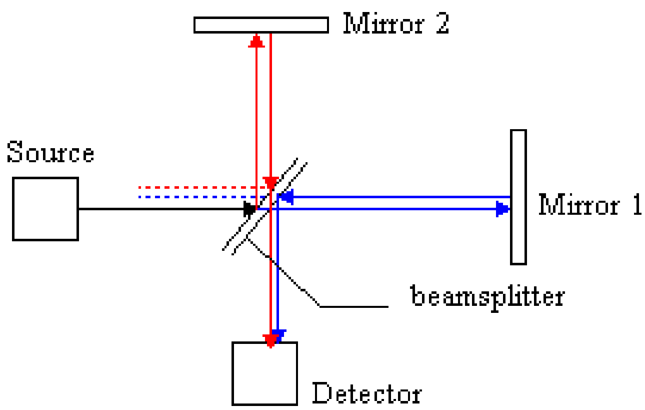

Figure 1

Since the two interfering beams of light were split from the same initial beam, they were initially in phase. Their relative phase when they meet at any point on the viewing screen, therefore, depends on the difference in the length of their optical paths in reaching that point. By moving M1, the path length of one of the beams can be varied. Since the beam traverses the path between M1 and the beamsplitter twice, moving M1 1/4 wavelength toward the beamsplitter will reduce the optical path of that beam by 1/2 wavelength. The interference pattern will change; the radii of the maxima will be reduced so they now occupy the position of the former minima. If M1 is moved an additional 1/4 wavelength closer to the beamsplitter, the radii of the maxima will again be reduced so maxima and minima trade positions, but this new arrangement will be indistinguishable from the original pattern. By slowly moving the mirror a measured distance d, and counting N, the number of times the fringe pattern is restored to its original state, the wavelength of the light, λ can be calculated as:

$$\lambda = \frac{2d}{N}$$

If the wavelength of the light is known, the same procedure can be used to determine d.

Procedure

Never stare directly into the laser opening or point the laser at somebody's face. Please do not touch the surfaces of mirrors and lenses - grab by their holders instead.

1. Position all the pieces of the equipment in the order they are given in the instructions. Carefully align each piece before moving onto the next. Otherwise, you may not obtain an interference pattern and will have to dismantle the whole setup and start over.

2. Install the movable mirror on the interferometer base, aligning it carefully with the crop marks on the interferometer base. Also mount the adjustable mirror on the base. Do not turn the thumbscrews on the back of the adjustable mirror!

3. Position a component holder in front of the laser. <u>Do not mount the lens yet.</u> Leave enough space (at least 6 mm) between the laser opening and the component holder, to allow the lens to fit in later. Align the red laser and the base. The laser beam should be approximately parallel with the top of the base, should strike the center of the movable mirror and should be reflected <u>directly back into the laser aperture</u> (Fig. 2). If not, place several index cards under the laser stand to tilt it appropriately.

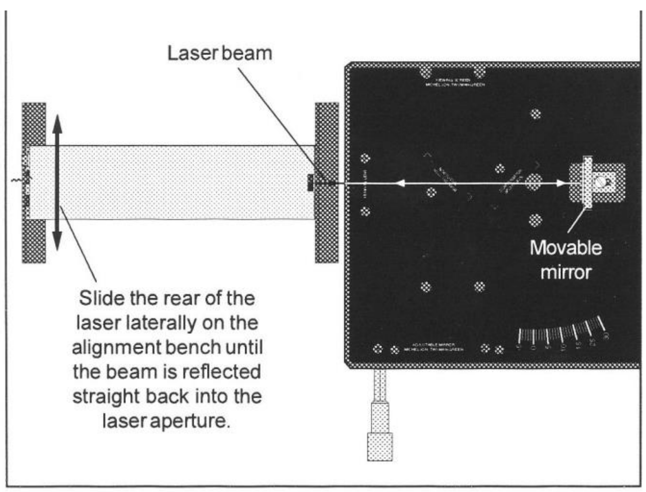

Figure 2

4. Position the beamsplitter at 45^{o} to the laser beam, within the crop marks, so that the beam is reflected to the adjustable mirror (Fig 3). Adjust the angle of the beamsplitter as needed so that the reflected beam hits the adjustable mirror near its center.

5. Place a viewing screen on the optical table farther away than indicated in Fig. 3. It is best not to use the small viewing screen that comes with the apparatus (and is shown in Fig. 3). Instead, you may use the provided white screen that screws in the optical table.

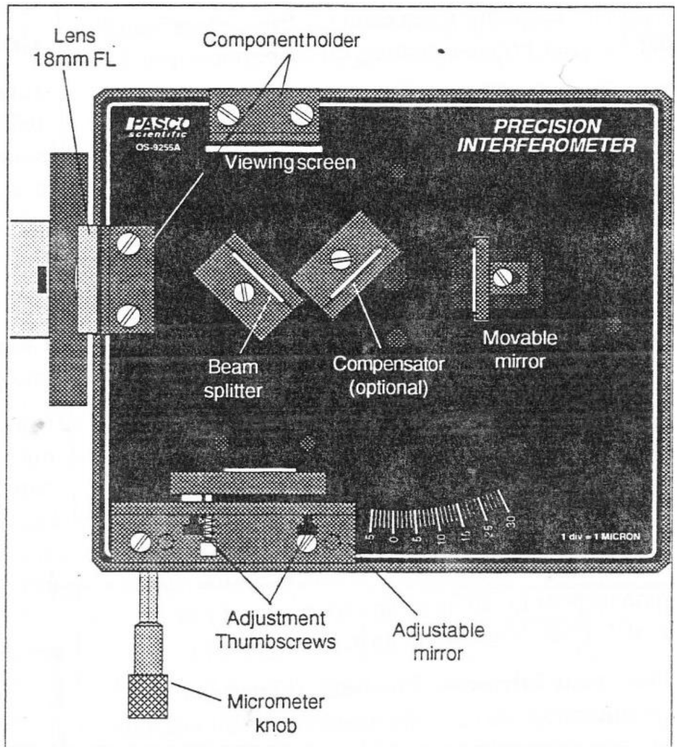

Figure 3

6. If you adjusted everything correctly in the previous steps, there should now be two sets of bright dots (one from each mirror) on the screen. Each set of dots should include a bright dot with two or more dots of lesser brightness (due to multiple reflections). Finely adjust the angle of the beamsplitter until the two sets of dots are as close together as possible and then tighten the thumbscrew to secure the beamsplitter.

7. Using the thumbscrews on the back of the adjustable mirror, adjust the mirror's tilt until the two sets of dots on the viewing screen coincide.

8. Attach the 18-mm-focal-length lens to the magnetic backing of the component holder in front of the laser, as shown in Fig. 3, and adjust its position until the diverging beam is centered on the beamsplitter. You should now see circular fringes (maxima) on the viewing screen. If not, carefully adjust the tilt of the adjustable mirror until the fringes appear.

9. The micrometer knob (Fig. 3) controls the motion of the movable mirror (even though it is placed behind the adjustable mirror). Adjust the knob to a medium reading (approximately

50 µm) by rotating it CCW 2 full turns. In this position, the relationship between the micrometer reading and the mirror movement is nearly linear. Each small division on the micrometer knob corresponds to 1 µm of the mirror movement. So, one full turn of the knob corresponds to 25 µm of the mirror movement.

VERY IMPORTANT NOTE: *Failure to consider backlash can result in large errors!* *When you reverse the direction in which you turn the micrometer knob, there is a small amount of give before the mirror begins to move. This is called* ***mechanical backlash*** *and is present in all mechanical systems with direction reversals. By beginning with a full counterclockwise (CCW) turn, and then turning* ***only*** *CCW when counting fringes, you can eliminate errors due to backlash.*

10. Slowly turn the micrometer knob one full turn CCW, until the zero on the knob is aligned with the index mark. **NOTE: If you overshoot the index mark, do not reverse the direction of the knob (remember the backlash)! Instead, repeat this step carefully.**

11. Record the micrometer reading as x_{ini} in Table 1.

12. Using a pencil (not a pen!) or a piece of tape, mark the position of a fringe on the viewing screen. Rotate the micrometer knob slowly CCW and count the fringes that pass by the marked position. Continue until you have counted 60 fringes (N = 60). Make sure you stop rotating the knob if you need to rest your eyes. In Table 1, record the final micrometer reading as x_{fin}.

13. Calculate and record distance d the micrometer knob moved the movable mirror.

14. Calculate the wavelength of the incident light in nanometers ($\lambda = 2d/N$).

15. Repeat the measurements two times and record your results each time in Table 1.

16. Calculate the average wavelength. Calculate the standard deviation, σ, associated with λ_{avg}.

17. Repeat the measurements using a green semiconductor laser as the light source. Record in Table 2. Calculate the average wavelength and associated uncertainty.

Results (you may include this page in your Lab Notebook)

Red light laser (N = 60)

Table 1

Meas. #	x_{init} (μm)	x_{fin} (μm)	d (μm)	λ (nm)
1				
2				
3				

λ_{avg} = ______________________________ (nm)

$\sigma = \sqrt{\frac{\sum_{i=1}^{4}(\lambda_{avg}-\lambda_i)^2}{2}} =$ ________________ (nm)

Does your result agree with the given λ value for the red laser? ________________

Green light laser (N = 60)

Table 2

Meas. #	x_{init} (μm)	x_{fin} (μm)	d (μm)	λ (nm)
1				
2				
3				

λ_{avg} = _______________________ (nm)

$\sigma = \sqrt{\frac{\sum_{i=1}^{4}(\lambda_{avg}-\lambda_i)^2}{2}} =$ ________________ (nm)

Does your result agree with the given λ value for the green laser, within the experimental error?

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