

Experiment No. 2

Introduction to Interferometry

Experiment 2(a): Introduction to Interferometry.

I. OBJECTIVES

- To determine the wavelength of light using interferometry techniques
- To determine the role that polarization plays in producing an interference pattern

II. BACKGROUND

Interferometry is the process of combining waves and studying their interference patterns in order to gain information about the characteristic of the waves themselves or the materials that interact with the waves.

Interference, on the other hand, is defined as the combination of two waves in the same region of space in order to produce a resultant wave. For light waves, the interference is due to the oscillating electric and magnetic fields that constitute the individual waves. When two or more beams of light waves meet at a point in space, the electric and magnetic fields of the individual waves add up according to the principle of superposition. This simply means that the electric and magnetic fields at each point in space are determined by the vector sum of the fields of the separate beams.

The interference of two waves may be constructive or destructive. Constructive interference is when the amplitude of the resultant wave is greater than the amplitudes of the individual waves. Destructive interference, on the other hand, is when the amplitude of the resultant wave is less than the amplitudes of the individual waves.

If two light beams from different light sources meet in space, interference patterns are not really observed. This is because of the lack of a constant phase relationship between the individual light waves. This means that at one instant, there will be points in space where the light waves interfere constructively. At the next instant though, light at these points may interfere destructively. Such transition between constructive, destructive, or any intermediate state is not observable to the naked eye since they occur about once every 10^{-8} second.

In order to observe a sustained interference of light waves, the individual light waves must be monochromatic. The individual light waves must also maintain a constant phase relationship with respect to each other – that is, they should be coherent. This makes it possible for the light waves at one point in space to interfere constructively at all times thereby producing a bright spot that will be visible to an observer. At another point in space, the light

waves will interfere destructively at all times thereby producing a dark spot that will be noticeable to an observer.

The first to demonstrate the interference of light waves from two sources was Thomas Young. In 1801, Young demonstrated that when a narrow light beam hits two closely spaced narrow slits, the light emanating from the slits interfered and created a regular pattern of light and dark fringes on a viewing screen placed some distance away from the slits.

Young's double slit set-up is a simple interferometer. It gives an observer a way of determining the wavelength of light incident on the narrow slits if the spacing between the slits is known and if spacing between the minima and maxima in the interference pattern are known. Or, if the wavelength of light is known, the interference pattern may be used to determine the spacing between the slits.

Since Young demonstrated the interference of light, several interferometers have already been developed and among their applications are the measurement of very small thickness and distances, the study of spectrum lines, the determination of refractive indices of transparent materials, and the measurement of the distances between stars and the diameters of stars. [4]

In this experiment, The PASCO Precision Interferometer shown in Figure 3 will be used to explore the basics of Interferometry. In particular, the interferometer will be used to measure the wavelength of the light source. It will also be used to determine the role that polarization plays in producing an interference pattern.

The complete PASCO Precision Interferometer set is shown in Figure 4. The Three modes of interferometry that may be explored using the said set of equipment are the following: The Michelson Interferometer, the Twyman-Green Interferometer, and the Fabry-Perot Interferometer.

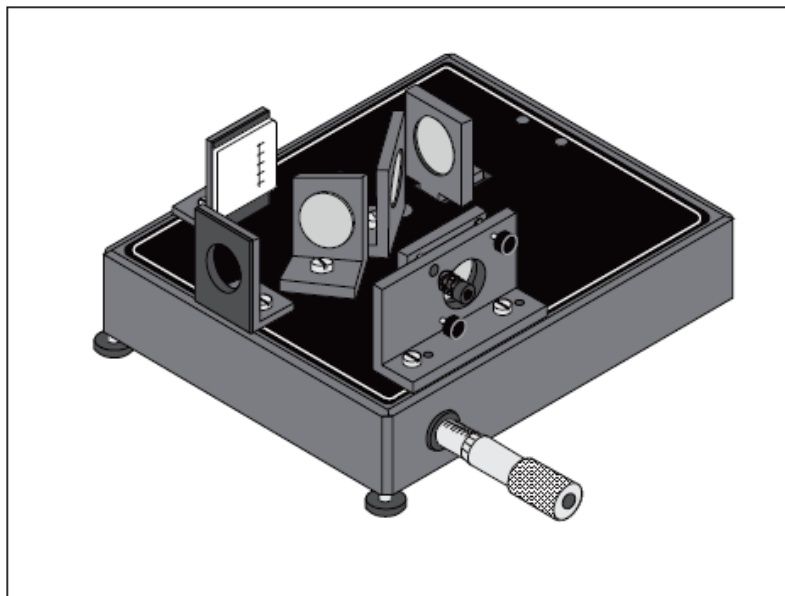


Figure 3. The PASCO Precision Interferometer

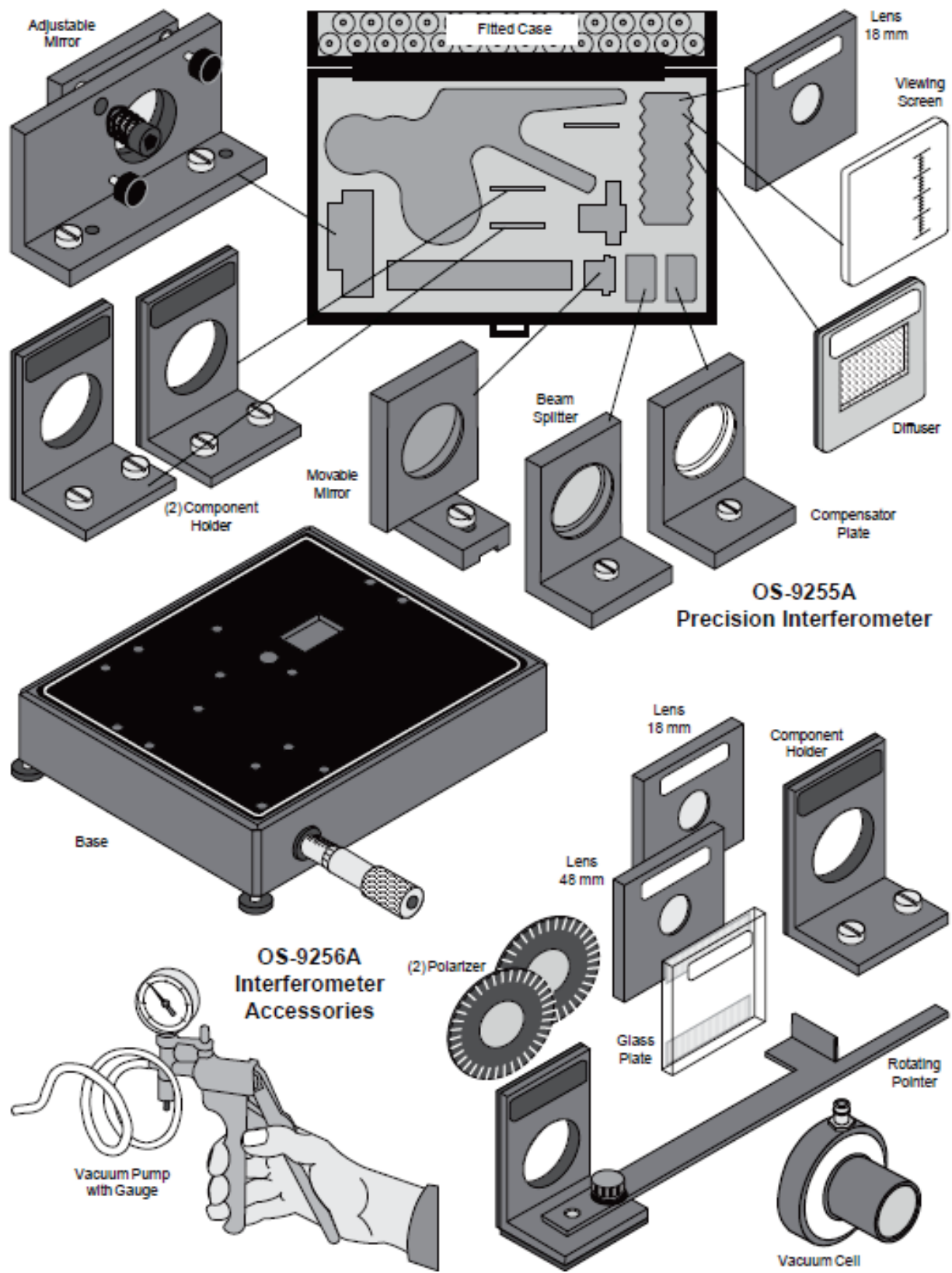


Figure 4. The complete PASCO Precision Interferometer Set

The Michelson Interferometer

In 1881, A. A. Michelson invented an interferometer based on the same principle as Young's simple interferometer. The said interferometer was used to test for the existence of the "ether", a hypothetical substance that was thought to be the medium through which light propagated. Due in part to Michelson's interferometry studies, this "ether" is no longer believed to be in existence.

Basically, a Michelson Interferometer splits a light beam into two parts and then recombines the parts to form an interference pattern. The set-up is shown in Figure 5.

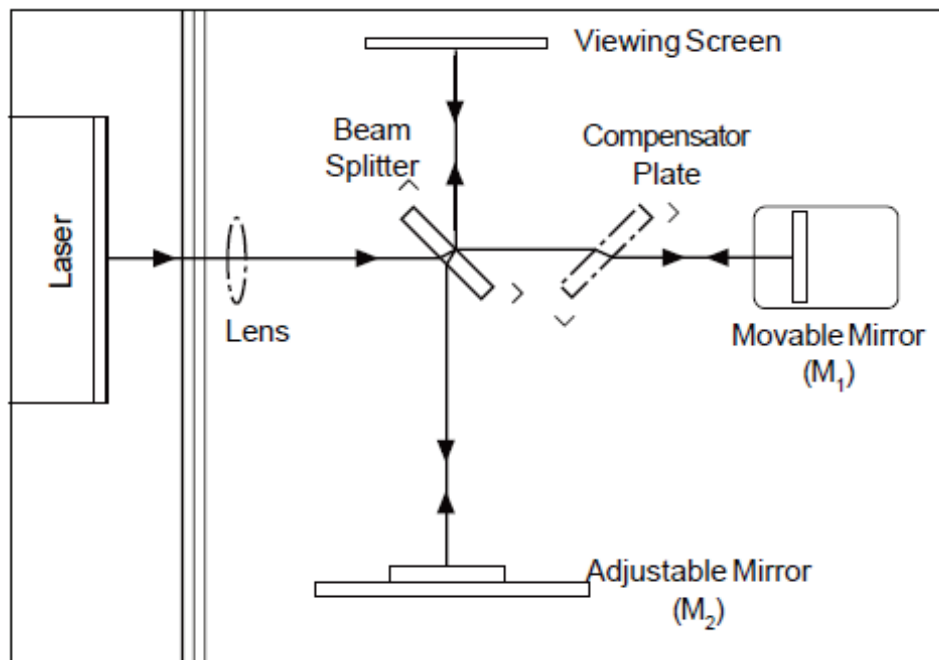


Figure 5. Michelson Interferometer

The beam of light from the laser strikes the beam splitter, an angled "half silvered" mirror, which splits the beam into two: half the beam is transmitted straight through the beam splitter and hits the Movable Mirror M_1 while the other half enters the beam splitter but is reflected by the silvered back surface of the beam splitter and thus goes out of the beam splitter and heads to the Adjustable Mirror M_2 .

The light that reaches both mirrors M_1 and M_2 are reflected back to the beam splitter. Half the intensity of the light beam coming from M_1 is reflected to the viewing screen while half the intensity of the light beam from M_2 is transmitted through the beam splitter to the viewing screen. In this way, we see that portions of the original beam from the Laser are brought back together in the viewing screen. An interference pattern like that in Figure 6 can then be observed on the viewing screen.

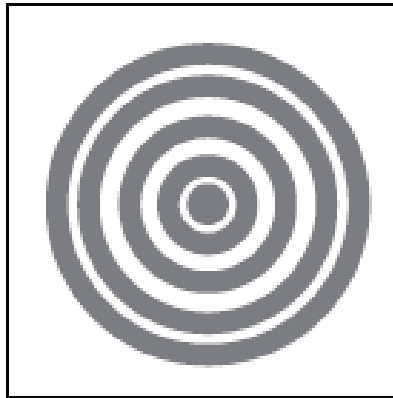


Figure 6. Fringes

Since the two interfering beams came from one source, they were initially in phase. When they meet at any point on the viewing screen, their relative phase will depend on the difference in their optical path lengths in reaching that point.

Note that in Figure 5, one of the interfering beams passes through the beam splitter thrice, while the other beam passes through the beam splitter only once. To compensate for this difference, a compensator plate is placed between the beam splitter and M_1 . The compensator plate is identical in size and shape to the beam splitter, and is made up of the same material as the beam splitter. It is, however, not “half-silvered”.

Moving the “movable” mirror M_1 varies the optical path length of one of the beams. Since the light beam traverses the path between M_1 and the beam splitter twice, moving M_1 a distance of one-fourth the wavelength closer to the beam splitter causes a reduction in the optical path length of the beam by one half the wavelength. The interference pattern will therefore change such that the radii of a maxima is reduced and will now occupy the position of a former minima in the interference pattern. If M_1 is moved again by an additional of one-fourth the wavelength closer to the beam splitter, the radii of the maxima is further reduced so that maxima and minima trade position, but this new arrangement will be indistinguishable from the original pattern.

By slowly moving the mirror a measured distance (d_m) and taking note of the number of times the fringe pattern is restored to its original state (N), the wavelength of light (λ) can be computed as $\lambda = \frac{2d_m}{N}$.

On the other hand, if the wavelength of light is known, the same procedure may be used to measure d_m .

The Twyman-Green Interferometer

A variant of the Michelson interferometer that is primarily used to test optical components is the Twyman-Green Interferometer. The set-up is shown in Figure 7.

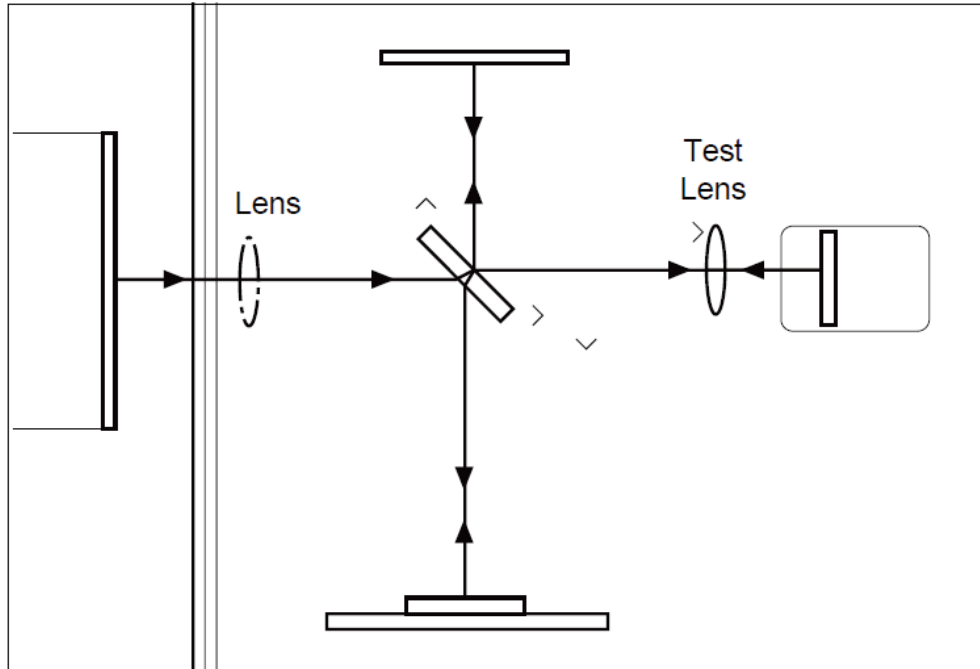


Figure 7. The Twyman-Green Interferometer

In the Twyman-Green Interferometer, a lens can be tested by placing it between the beam splitter and moving lens so that one of the interfering beams passes through the lens to be tested. Any irregularities in the lens can be detected in the resulting interference pattern. Spherical aberration, coma, and astigmatism show up as specific variations in the fringe pattern as shown in Figure 8.



Figure 8. Fringe patterns of aberrated lenses

The Fabry-Perot Interferometer

The Fabry-Perot interferometer represents significant improvement over the Michelson Interferometer. As such, it has become a valuable tool in high resolution spectrometry.

The basic set-up of a Fabry-Perot interferometer includes two mirrors that are aligned parallel to one another to form a reflective cavity. As is shown in Figure 9, two light rays entering such a cavity and being reflected back and forth inside. At each reflection, part of the beam is transmitted. Since the transmitted rays came from a single coherent light source, they maintain a constant phase relationship.

The phase relationship between the transmitted rays that interfere on the viewing screen depends on the angle at which the rays enter the cavity and the distance between the two mirrors. The expected result is a circular fringe pattern that are thinner, brighter, and more widely spaced compared to the interference pattern formed using a Michelson Interferometer.

Similar to the Michelson Interferometer, as the movable mirror is moved, the fringe pattern shifts. When the movable mirror is moved to a distance of $\frac{1}{2}$ the wavelength towards or away from the fixed mirror, the new fringe pattern is identical to the original fringe pattern.

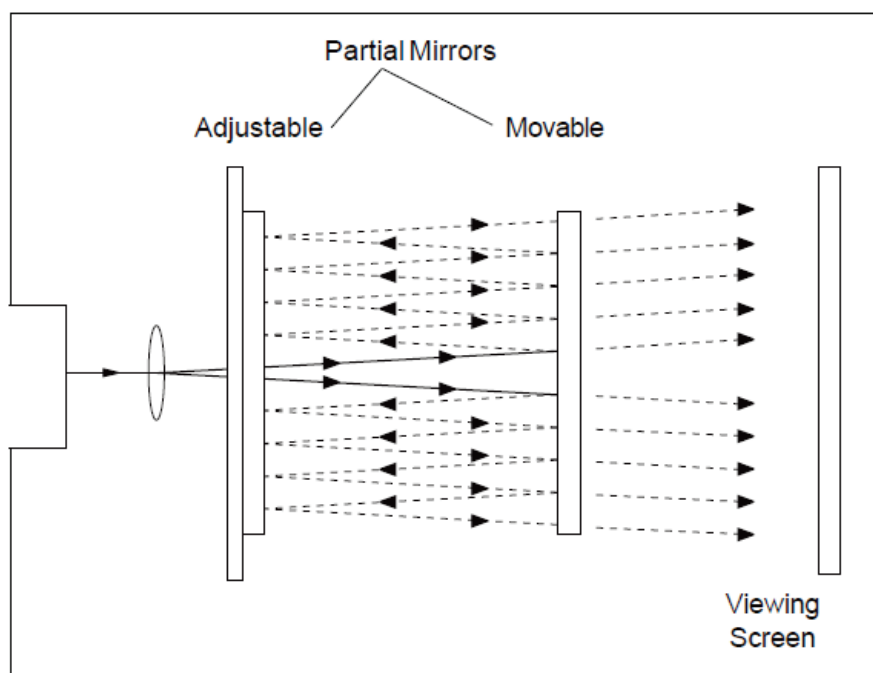


Figure 9. The Fabry-Perot Interferometer

III. PROCEDURES

A. Aligning the Laser

1. Set the interferometer base on a lab table with the micrometer knob pointing toward you.

2. Position the laser alignment bench to the left of the base approximately perpendicular to the interferometer base and place the laser on the bench.
3. Secure the movable mirror in the recessed hole in the interferometer base.
Note: Avoid touching all mirror surfaces. Minute scratches and dirt can impair the clarity of interference images.
4. Turn the laser on. Using the leveling screws on the laser bench, adjust its height until the laser beam is approximately parallel with the top of the interferometer base and strikes the movable mirror in the center. (To check that the beam is parallel with the base, place a piece of paper in the beam path, with the edge of the paper flush against the base. Mark the height of the beam on the paper. Using the piece of paper, check that the beam height is the same at both ends of the bench.)
5. Adjust the X-Y position of the laser until the beam is reflected from the movable mirror right back into the laser aperture. This is most easily done by gently sliding the rear end of the laser transverse to the axis of the alignment bench, as shown in Figure 10.

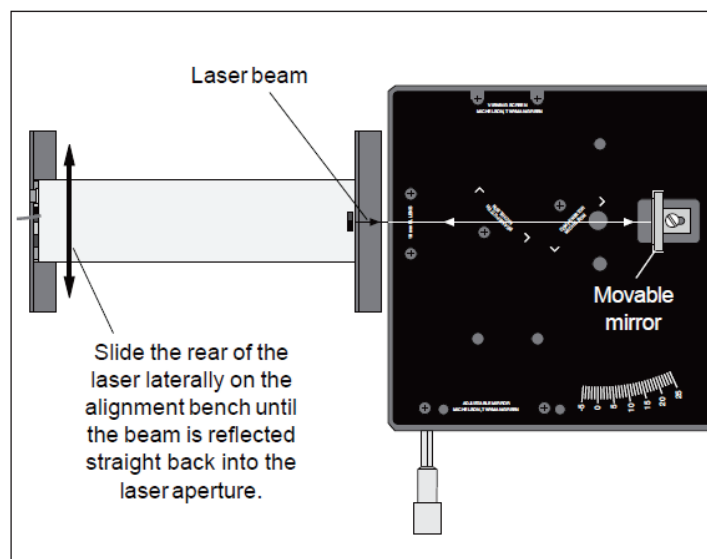


Figure 10. Aligning the Laser

B. Determining the Wavelength using the Michelson Interferometer Set-up

1. Align the laser and interferometer base as previously described. 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 directly back into the laser aperture.
2. Mount the adjustable mirror on the interferometer base. Position one component holder in front of the laser. Place the other component holder opposite the adjustable mirror and attach the viewing screen to its magnetic backing. See Figure 11.

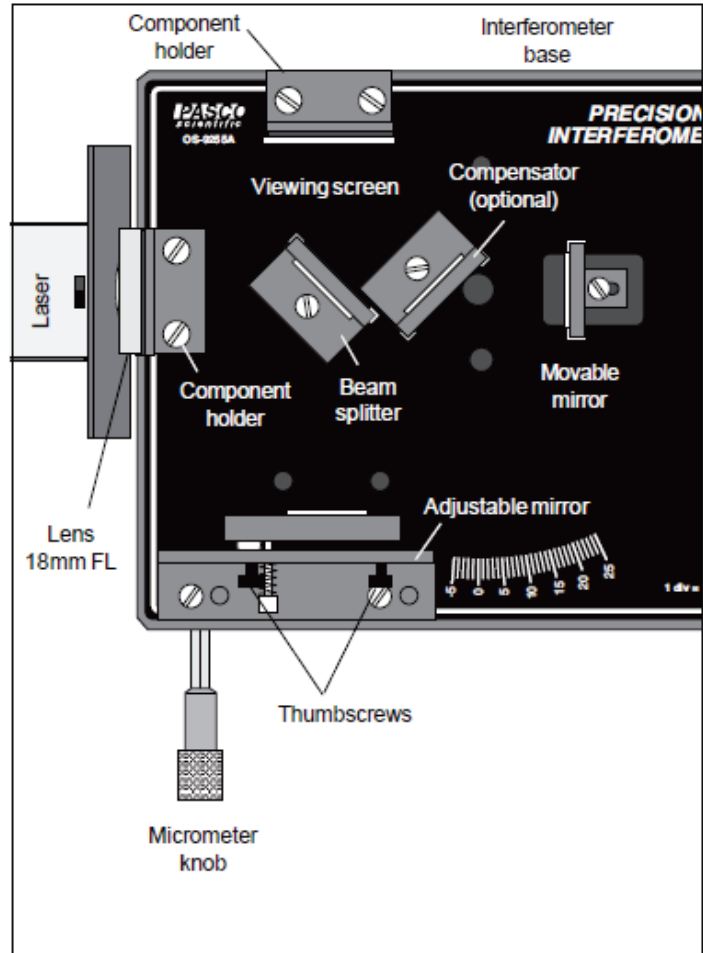


Figure 11. Michelson Mode Set-up using a PASCO Precision Interferometer

3. Position the beam-splitter at a 45 degree angle to the laser beam, within the crop marks, so that the beam is reflected to the fixed mirror. Adjust the angle of the beam-splitter as needed so that the reflected beam hits the fixed mirror near its center.
4. There should now be two sets of bright dots on the viewing screen; one set comes from the fixed mirror and the other comes from the movable mirror. Each set of dots should include a bright dot with two or more dots of lesser brightness (due to multiple reflections). Adjust the angle of the beam-splitter again until the two sets of dots are as close together as possible, then tighten the thumbscrew to secure the beam-splitter.
5. 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.

6. The compensator is not needed for producing interference fringes when using a laser light source. However, if you wish to use the compensator, it mounts perpendicular to the beam-splitter, as shown in Figure 11.
7. Attach the 18 mm FL lens to the magnetic backing of the component holder in front of the laser, as shown, and adjust its position until the diverging beam is centered on the beam-splitter. You should now see circular fringes on the viewing screen. If not, carefully adjust the tilt of the adjustable mirror until the fringes appear. The Michelson Interferometer Set-up is now ready.

NOTE: It's not necessary that your interference pattern be perfectly symmetrical or sharp. As long as you can clearly distinguish the maxima and minima, you can make accurate measurements.

8. Adjust the micrometer knob to a medium reading (approximately 50 μm). In this position, the relationship between the micrometer reading and the mirror movement is most nearly linear.
9. Turn the micrometer knob one full turn counterclockwise. Continue turning counterclockwise until the zero on the knob is aligned with the index mark. Record the micrometer reading.

NOTE: 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 involving reversals in direction of movement. By beginning with a full counterclockwise turn, and then turning only counterclockwise when counting fringes, you can eliminate errors due to backlash.

10. Adjust the position of the viewing screen so that one of the marks on the millimeter scale is aligned with one of the fringes in your interference pattern. You will find it easier to count the fringes if the reference mark is one or two fringes out from the center of the pattern.
11. Rotate the micrometer knob slowly counterclockwise. Count the fringes as they pass your reference mark. Continue until some predetermined number of fringes have passed your mark (count at least 20 fringes). As you finish your count, the fringes should be in the same position with respect to your reference mark as they were when you started to count. Record the final reading of the micrometer dial.
12. Record d_m , the distance that the movable mirror moved toward the beam-splitter according to your readings of the micrometer knob. Remember, each small division on the micrometer knob corresponds to one μm (10^{-6} meters) of mirror movement.
13. Record N , the number of fringe transitions that you counted.

14. Repeat steps 9 through 13 several times, recording your results each time in a well-constructed data table.
15. Calculate the wavelength of the light ($\lambda = 2d_m/N$) for each trial and average your results.

C. Polarization (using the Michelson Interferometer Set-up)

1. Place the Calibrated Polarizer (part of OS-9256A Interferometer Accessories) between the laser and the beam-splitter. Try several polarization angles. How does this affect the brightness and clarity of the fringe pattern? Can you determine the polarization characteristics of your light source? Does it vary with time?
2. Remove that polarizer and place a polarizer in front of the fixed or movable mirror. Try several polarization angles. How does this affect the fringe pattern?
3. Now try two polarizers, one in front of the fixed mirror, and one in front of the movable mirror. First rotate one polarizer, then the other. Again, note the effects. Do cross-polarized beams interfere?

D. Determining the wavelength using the Fabry-Perot Set-up

1. Align the laser and interferometer base as described in Laser Alignment at the beginning of this section. 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 directly back into the laser aperture.
2. Mount the adjustable mirror where indicated on the interferometer base and one component holder in front of the movable mirror. See Figure 12.

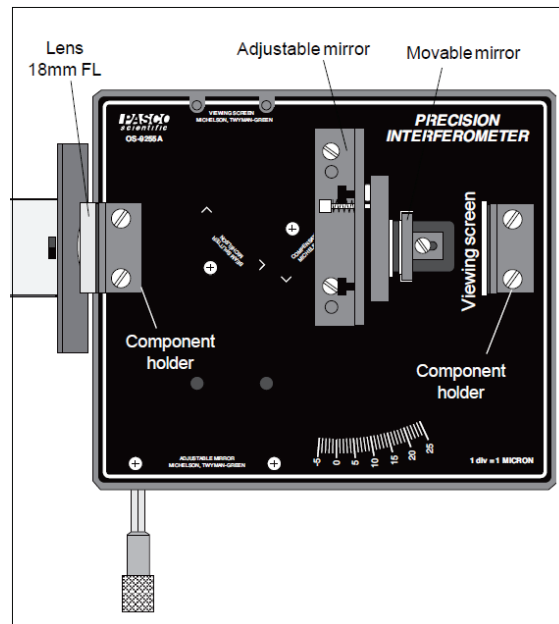


Figure 12. The Fabry Perot Set-up using a PASCO Precision Interferometer

3. Place the other component holder behind the movable mirror and attach the viewing screen to its magnetic backing. You should see several images of the laser beam on the viewing screen.
4. Using the thumbscrews, adjust the tilt of the adjustable mirror until there is only one bright dot on the screen.
5. Now mount the 18 mm FL lens on the front component holder. A clear sharp interference pattern should be visible on the viewing screen. If you use light with two component wavelengths, instead of a laser, two sets of fringes can be distinguished on the viewing screen. The Fabry-Perot Interferometer Set-up is now ready.
6. Adjust the micrometer knob to a medium reading (approximately 50 μm). In this position, the relationship between the micrometer reading and the mirror movement is most nearly linear.
7. Turn the micrometer knob one full turn counterclockwise. Continue turning counterclockwise until the zero on the knob is aligned with the index mark. Record the micrometer reading.

NOTE: 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 involving reversals in direction of movement. By beginning with a full counterclockwise turn, and then turning only counterclockwise when counting fringes, you can eliminate errors due to backlash.

8. Adjust the position of the viewing screen so that one of the marks on the millimeter scale is aligned with one of the fringes in your interference pattern. You will find it easier to count the fringes if the reference mark is one or two fringes out from the center of the pattern.
9. Rotate the micrometer knob slowly counterclockwise. Count the fringes as they pass your reference mark. Continue until some predetermined number of fringes have passed your mark (count at least 20 fringes). As you finish your count, the fringes should be in the same position with respect to your reference mark as they were when you started to count. Record the final reading of the micrometer dial.
10. Record d_m , the distance that the movable mirror moved toward the beam-splitter according to your readings of the micrometer knob. Remember, each small division on the micrometer knob corresponds to one μm (10^{-6} meters) of mirror movement.
11. Record N , the number of fringe transitions that you counted.
12. Repeat steps 7 through 11 several times, recording your results each time in a well-constructed data table.

13. Calculate the wavelength of the light ($\lambda = 2d_m/N$) for each trial and average your results.

TIPS ON USING THE INTERFEROMETER

1. It's easy to lose track when counting fringes. The following technique can help. Center the interference pattern on the viewing screen using the thumbscrews on the back of the fixed mirror. Select a reference line on the millimeter scale and line it up with the boundary between a maxima and a minima (see Figure 13). 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 gone by.

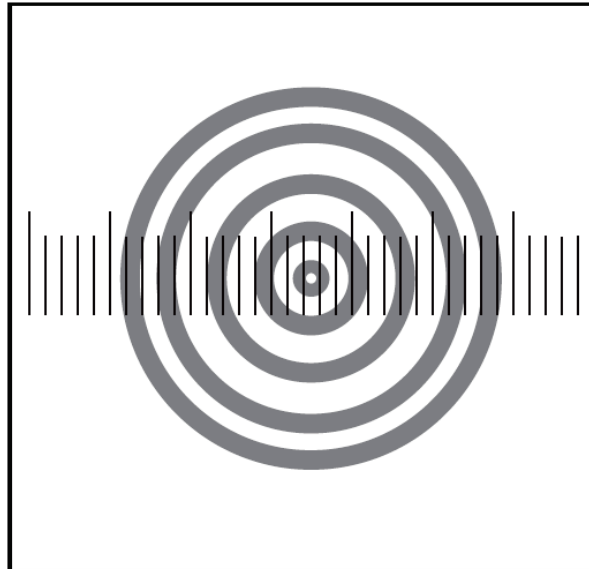


Figure 13. Counting Fringes

2. When turning the micrometer dial to count fringes, always turn it one complete revolution before you start counting, then continue turning it in the same direction while counting. This will almost entirely eliminate errors due to backlash in the micrometer movement. Backlash is a slight slippage that always occurs when you reverse the direction of motion in a mechanical instrument. Turning the micrometer dial clockwise moves the movable mirror toward the right. Turning the dial counter-clockwise moves the mirror toward the left.) The PASCO micrometer is designed to minimize backlash. However, by using the technique described above, you can practically eliminate all effects of backlash in your measurements.

3. Always take several readings and average them for greater accuracy.
4. The slip ring at the base of the micrometer knob adjusts the tension in the dial. Before making a measurement, be sure the tension is adjusted to give you the best possible control over the mirror movement.
5. Slight movements like a slight breeze can affect fringe patterns. Set up your experiment in a room that is free from perceptible air currents or other sources of vibrations that may cause problems in producing a clear set of interference fringes.

IV. EVALUATION

1. In the calculation to determine the value of λ based on the micrometer movement, why was d_m multiplied by two?
2. Why move the mirror through many fringe transitions instead of just one? Why take several measurements and average the results?
3. Was your measured λ the same for the Michelson Interferometer and the Fabry-Perot Interferometer? If not, can you speculate about possible reasons for the difference? Do you have more confidence in one value as opposed to the other?
4. If the wavelength of your light source is accurately known, compare your results with the known value by solving for the percent errors. If there is a difference, to what do you attribute it?
5. When measuring mirror movement using the micrometer dial on the interferometer, what factors limit the accuracy of your measurement?
6. When measuring mirror movement by counting fringes using a light source of known wavelength, what factors might limit the accuracy of your measurement?
7. What role does polarization play in producing an interference pattern?

The Index of Refraction of Air

Experiment 2(b): The Index of Refraction of Air.

I. OBJECTIVES

- To determine the index of refraction of air.

II. BACKGROUND

Basically, a Michelson interferometer splits into two a light beam that came from one source, then lets the two beams interfere after taking different optical path lengths. A schematic diagram of the Michelson interferometer is shown in Figure 14.

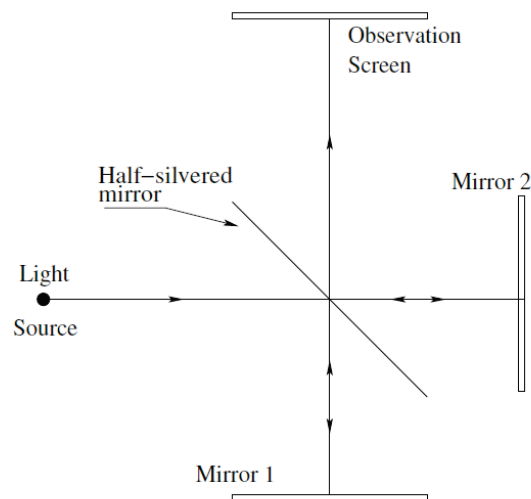


Figure 14. The Michelson Interferometer

From the figure, we see that light from a light source is allowed to hit a beam splitter (the half-silvered mirror). Half the light beam from the beam splitter is transmitted and hits Mirror 2 while the other half is reflected by the beam splitter and goes to Mirror 1. Half the light that reaches Mirror 1 is reflected back by the mirror and goes through the beam splitter to the viewing screen. Half the light that reaches Mirror 2 is reflected by the mirror, hits the silvered surface of the beam splitter, and then is reflected by the beam splitter to the viewing screen. So here we see that two light beams which have travelled different optical path lengths are to meet at the viewing screen.

The characteristic fringe patterns formed by the two interfering beams on the viewing depend on their phase relationships. To change the phase relationships between the interfering beams, one can change the distance traversed by one or two of the light beams. This is done by moving Mirror 2. There is, however, another way of changing the phase relationship between the two interfering beams and that is by changing the medium through which one or both beams pass.

In this experiment, the phase relationship of the interfering beams will be changed by manipulating the medium through which one of the beams is allowed to pass. This will be done by putting a vacuum cell between the beam splitter and the movable mirror (Mirror 2 in Figure 14) so that one of the beams passes through it twice before reaching the viewing screen.

Outside the vacuum cell, the light beams have the same wavelength throughout the experiment. However, inside the vacuum cell, the wavelength of light gets longer as the air pressure is reduced.

Suppose that originally the cell length, d , was 10 wavelengths long (of course, it's much longer. For this set-up, the cell length is 3.0 centimeters). As you pump out the cell, the wavelength increases until, at some point, the cell is only 9-1/2 wavelengths long. Since the laser beam passes through the vacuum cell twice, the light now goes through one less oscillation within the cell. This has the same effect on the interference pattern as when the movable mirror is moved toward the beam-splitter by 1/2 wavelength. A single fringe transition will have occurred.

Originally there are $N_i = 2d/\lambda_i$ wavelengths of light within the vacuum cell (counting both passes of the laser beam). At the final pressure there are $N_f = 2d/\lambda_f$ wavelengths within the cell. The difference between these values, $N_i - N_f$, is just N , the number of fringes you counted as you evacuated the cell. Therefore:

$$N = \frac{2d}{\lambda_i} - \frac{2d}{\lambda_f} \quad (1)$$

For light of a specific frequency, the wavelength λ varies according to the formula:

$$\lambda = \lambda_0/n; \quad (2)$$

where λ_0 is the wavelength of the light in a vacuum, and n is the index of refraction for the material in which the light is propagating. The index of refraction for a gas varies linearly with the gas pressure (for reasonably low pressures) as shown in the graph of index of refraction (n) versus gas pressure (P) in Figure 15. (Note: index of refraction is 1 where pressure is zero, as in vacuum).

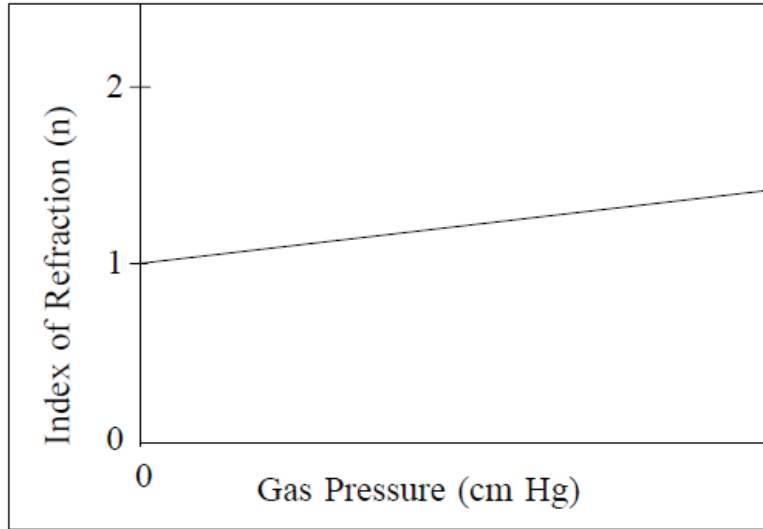


Figure 15. Index of Refraction vs. Gas Pressure

From equation (2) we see that , $\lambda_i = \lambda_0/n_i$ and $\lambda_f = \lambda_0/n_f$; where n_i and n_f are the initial and final values for the index of refraction of the air inside the cell. Therefore, equation (1) can be rearranged to get

$$N = \frac{2d}{\lambda_i} - \frac{2d}{\lambda_f} = 2d \left(\frac{1}{\frac{\lambda_0}{n_i}} - \frac{1}{\frac{\lambda_0}{n_f}} \right) = \frac{2d}{\lambda_0} (n_i - n_f) \quad (3)$$

Rearranging equation (3), we get

$$n_i - n_f = \frac{N\lambda_0}{2d} \quad (4)$$

From the linear graph in Figure 15, we see that the slope (change in y vs change in x) is given by:

$$\frac{\text{change in index of refraction}}{\text{change in gas pressure}} = \frac{\Delta n}{\Delta P} = \frac{n_i - n_f}{P_i - P_f} \quad (5)$$

where P_i is the initial pressure and P_f is the final air pressure.

Combining equations (4) and (5) we get

$$\frac{n_i - n_f}{P_i - P_f} = \frac{N\lambda_0}{2d(P_i - P_f)} \quad (6)$$

In this experiment, the slope of the graph index of refraction versus gas pressure (right hand side of equation (6)) will be determined and from there, the index of refraction of air will be determined for various pressures.

III. PROCEDURES

1. Set the interferometer base on a lab table with the micrometer knob pointing toward you.
2. Position the laser alignment bench to the left of the base approximately perpendicular to the interferometer base and place the laser on the bench.
3. Secure the movable mirror in the recessed hole in the interferometer base.
4. Turn the laser on. Using the leveling screws on the laser bench, adjust its height until the laser beam is approximately parallel with the top of the interferometer base and strikes the movable mirror in the center. (To check that the beam is parallel with the base, place a piece of paper in the beam path, with the edge of the paper flush against the base. Mark the height of the beam on the paper. Using the piece of paper, check that the beam height is the same at both ends of the bench.)
5. Adjust the X-Y position of the laser until the beam is reflected from the movable mirror right back into the laser aperture. This is most easily done by gently sliding the rear end of the laser transverse to the axis of the alignment bench, as shown in

Figure 16

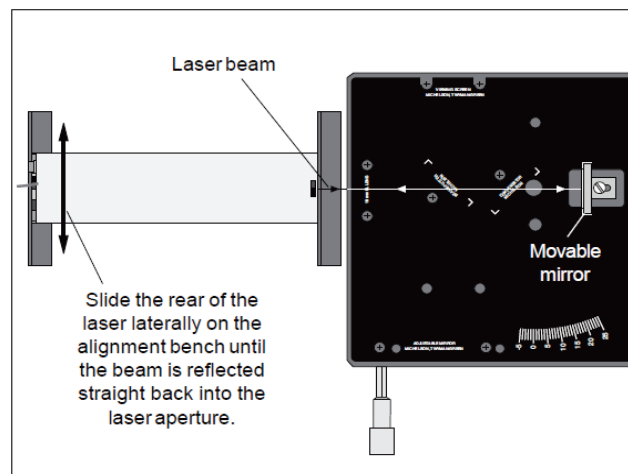


Figure 16. Aligning the Laser

6. Mount the adjustable mirror on the interferometer base. Position one component holder in front of the laser. Place the other component holder opposite the

adjustable mirror and attach the viewing screen to its magnetic backing. See Figure 17.

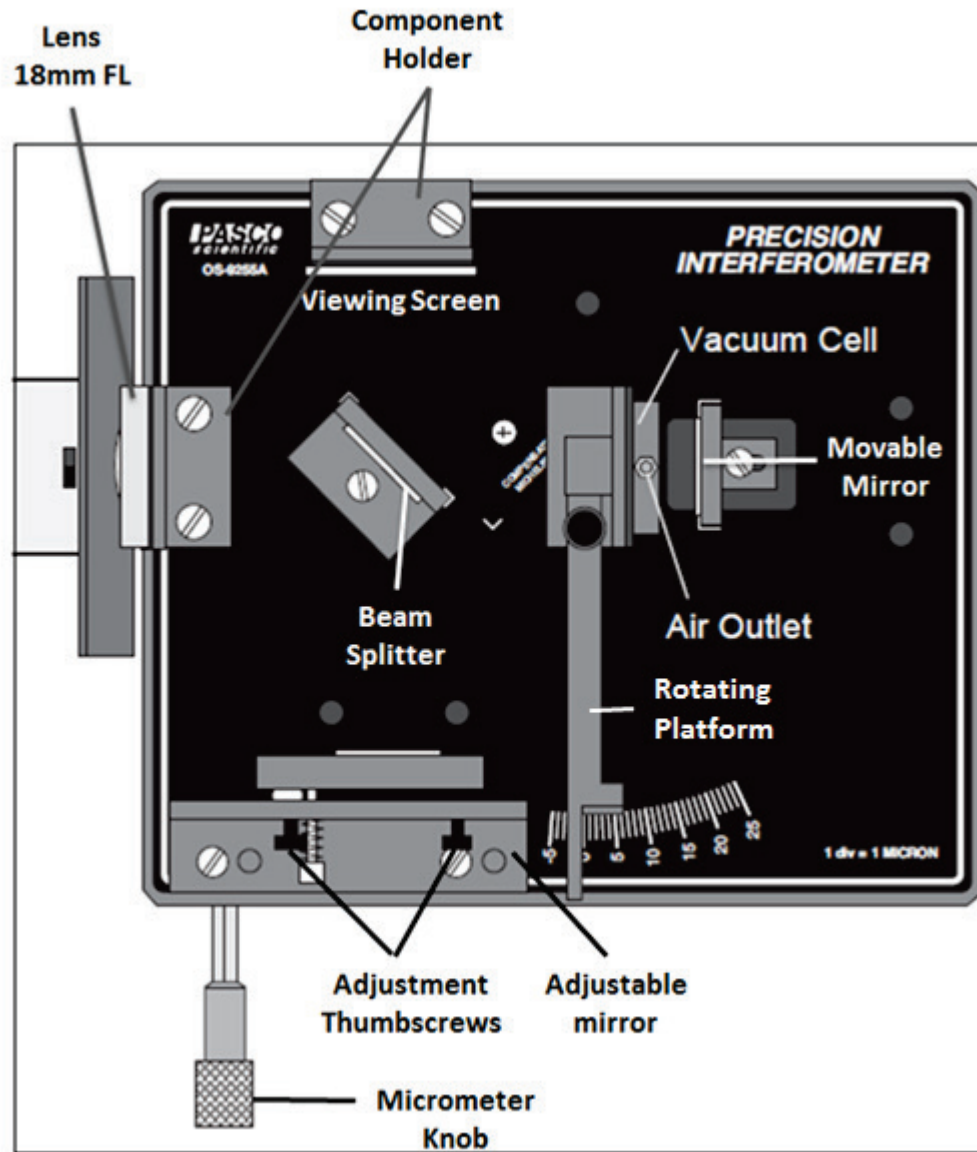


Figure 17. Michelson Mode Set-up using a PASCO Precision Interferometer

7. Position the beam-splitter at a 45 degree angle to the laser beam, within the crop marks, so that the beam is reflected to the fixed mirror. Adjust the angle of the beam-splitter as needed so that the reflected beam hits the fixed mirror near its center.
8. There should now be two sets of bright dots on the viewing screen; one set comes from the fixed mirror and the other comes from the movable mirror. Each set of dots should include a bright dot with two or more dots of lesser brightness (due to

multiple reflections). Adjust the angle of the beam-splitter again until the two sets of dots are as close together as possible, then tighten the thumbscrew to secure the beam-splitter.

9. 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.
10. Attach the 18 mm FL lens to the magnetic backing of the component holder in front of the laser, as shown, and adjust its position until the diverging beam is centered on the beam-splitter. You should now see circular fringes on the viewing screen. If not, carefully adjust the tilt of the adjustable mirror until the fringes appear. The Michelson Interferometer Set-up is now ready for this particular experiment.

NOTE: It's not necessary that your interference pattern be perfectly symmetrical or sharp. As long as you can clearly distinguish the maxima and minima, you can make accurate measurements.

11. Place the rotating pointer between the movable mirror and the beam-splitter (see Figure 17). Attach the vacuum cell to its magnetic backing and push the air hose of the vacuum pump over the air outlet hole of the cell. Adjust the alignment of the fixed mirror as needed so the center of the interference pattern is clearly visible on the viewing screen. (The fringe pattern will be somewhat distorted by irregularities in the glass end-plates of the vacuum cell. This is not a problem.)
12. For accurate measurements, the end-plates of the vacuum cell must be perpendicular to the laser beam. Rotate the cell and observe the fringes. Based on your observations, how can you be sure that the vacuum cell is properly aligned?
13. Be sure that the air in the vacuum cell is at atmospheric pressure. If you are using the OS-8502 Hand-Held Vacuum Pump, this is accomplished by flipping the vacuum release toggle switch.
14. Record P_i , the initial reading on the vacuum pump gauge. Slowly pump out the air in the vacuum cell. As you do this, count N , the number of fringe transitions that occur. When you're done, record N and also P_f , the final reading on the vacuum gauge. (Some people prefer to begin with the vacuum cell evacuated, then count fringes as they let the air slowly out. Use whichever method is easier for you.)

Note: Most vacuum gauges measure pressure with respect to atmospheric pressure (i.e., 34 cm Hg means that the pressure is 34 cm Hg below atmospheric pressure, which is ~ 76 cm Hg). The actual pressure inside the cell is

$$P_{\text{absolute}} = P_{\text{atmospheric}} - P_{\text{gauge}}$$

IV. EVALUATION

1. From your graph, what is n_{atm} , the index of refraction for air at a pressure of 1 atmosphere (76 cm Hg).
2. In this experiment, a linear relationship between pressure and index of refraction was assumed. How might you test that assumption?
3. The index of refraction for a gas depends on temperature as well as pressure. Describe an experiment that would determine the temperature dependence of the index of refraction for air.

The Index of Refraction of Glass

Experiment 2(C): The Index of Refraction of Glass.

I. OBJECTIVES

- To determine the index of refraction of Glass.

II. BACKGROUND

In a Michelson interferometer a beam of light is split into two and allowed to travel different optical path lengths. As shown in Figure 18 the light beam hits a beam splitter (half-silvered mirror) which splits the light beam into two. One beam reflects from the beam splitter, goes to Mirror 1, and reflects from Mirror 1 to pass through the beam splitter to hit the observation screen. The other beam passes through the beam splitter, hits Mirror 2, reflects from Mirror 2 to hit the beam splitter, reflects from the beam splitter, then goes to the viewing screen where it interferes with the other beam.

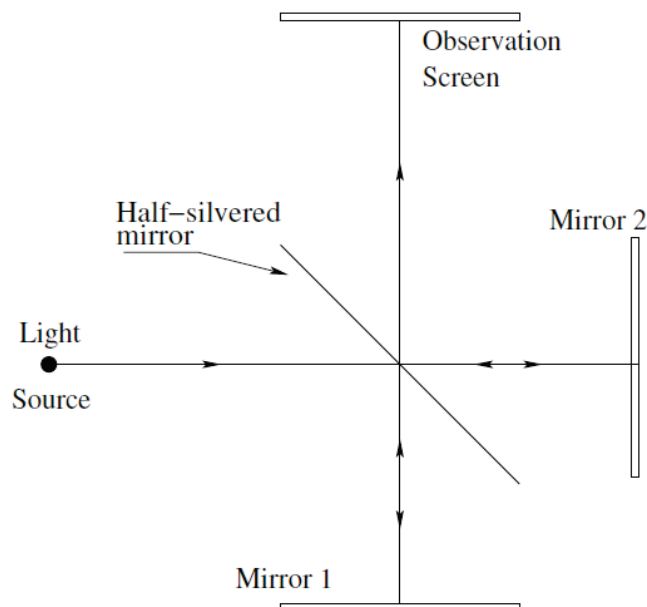


Figure 18. The Michelson Interferometer

The characteristic fringe patterns formed by the two interfering beams depend on their phase relationships. To change the phase relationships between the two beams, one can change the distance traversed by one or two of the light beams. This may be done by moving Mirror 2 or by changing the medium through which one or both beams pass.

In this experiment, the phase relationship of the interfering beams will be changed by letting one of the beams pass through different lengths of glass. This will be done by putting a glass plate between the beam splitter and Mirror 2. The length of the glass through which the light beam passes will be varied by changing the orientation of the glass plate. The index of refraction of glass will then be determined.

Carrying out this analysis for the glass plate is rather complicated, so we'll leave you with the equation shown below for calculating the index of refraction based on your measurements. Nevertheless, we encourage you to attempt the analysis for yourself. It will greatly increase your understanding of the measurement and also of the complications inherent in the analysis.

$$n = \frac{(2t - N\lambda_0)(1 - \cos \theta)}{2t(1 - \cos \theta) - N\lambda_0}$$

III. PROCEDURES

1. Set the interferometer base on a lab table with the micrometer knob pointing toward you.
2. Position the laser alignment bench to the left of the base approximately perpendicular to the interferometer base and place the laser on the bench.
3. Secure the movable mirror in the recessed hole in the interferometer base.
4. Turn the laser on. Using the leveling screws on the laser bench, adjust its height until the laser beam is approximately parallel with the top of the interferometer base and strikes the movable mirror in the center. (To check that the beam is parallel with the base, place a piece of paper in the beam path, with the edge of the paper flush against the base. Mark the height of the beam on the paper. Using the piece of paper, check that the beam height is the same at both ends of the bench.)
5. Adjust the X-Y position of the laser until the beam is reflected from the movable mirror right back into the laser aperture. This is most easily done by gently sliding the rear end of the laser transverse to the axis of the alignment bench, as shown in Figure 19.

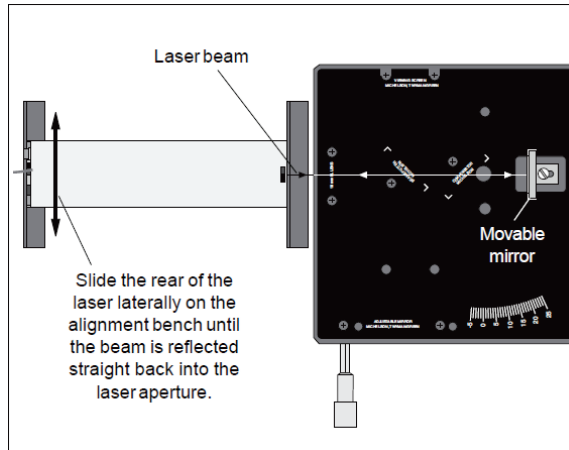


Figure 19. Aligning the Laser

6. Mount the adjustable mirror on the interferometer base. Position one component holder in front of the laser. Place the other component holder opposite the adjustable mirror and attach the viewing screen to its magnetic backing. See Figure 20.

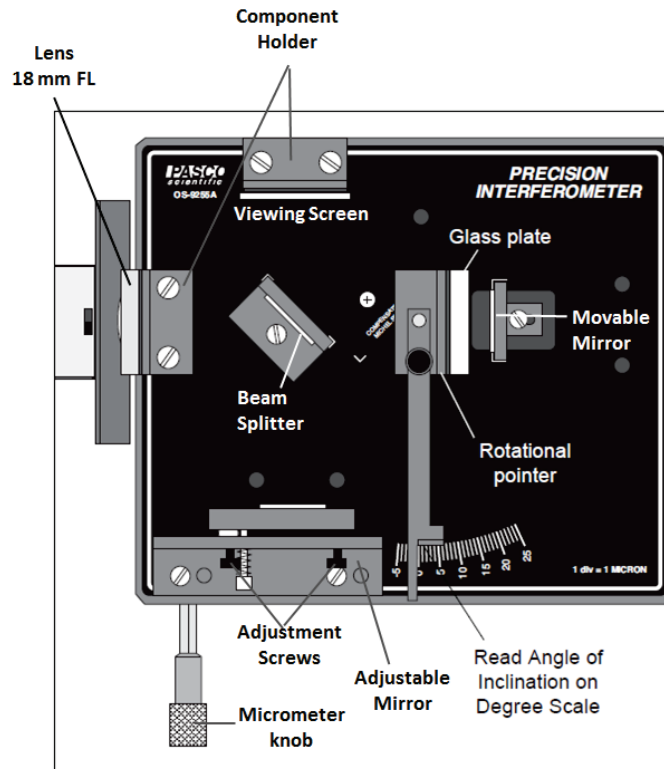


Figure 20. Michelson Mode Set-up using a PASCO Precision Interferometer

7. Position the beam-splitter at a 45 degree angle to the laser beam, within the crop marks, so that the beam is reflected to the fixed mirror. Adjust the angle of the beam-splitter as needed so that the reflected beam hits the fixed mirror near its center.
8. There should now be two sets of bright dots on the viewing screen; one set comes from the fixed mirror and the other comes from the movable mirror. Each set of dots should include a bright dot with two or more dots of lesser brightness (due to multiple reflections). Adjust the angle of the beam-splitter again until the two sets of dots are as close together as possible, then tighten the thumbscrew to secure the beam-splitter.
9. 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.
10. Attach the 18 mm FL lens to the magnetic backing of the component holder in front of the laser, as shown, and adjust its position until the diverging beam is centered on the beam-splitter. You should now see circular fringes on the viewing screen. If not, carefully adjust the tilt of the adjustable mirror until the fringes appear. The Michelson Interferometer Set-up is now ready for this particular experiment.

NOTE: It's not necessary that your interference pattern be perfectly symmetrical or sharp. As long as you can clearly distinguish the maxima and minima, you can make accurate measurements.

11. Place the rotating table between the beam-splitter and movable mirror, perpendicular to the optical path.

NOTE: if the movable mirror is too far forward, the rotating table won't fit. You may need to loosen the thumbscrew and slide the mirror farther back.

12. Mount the glass plate on the magnetic backing of the rotational pointer.
13. Position the pointer so that its "0" edge on the Vernier scale is lined up with the zero on the degree scale on the interferometer base.
14. Remove the lens from in front of the laser. Hold the viewing screen between the glass plate and the movable mirror. If there is one bright dot and some secondary dots on the viewing screen, adjust the angle of the rotating table until there is one bright dot. Then realign the pointer scale. The plate should now be perpendicular to the optical path.
15. Replace the viewing screen and the lens and make any minor adjustments that are necessary to get a clear set of fringes on the viewing screen.
16. Slowly rotate the table by moving the lever arm. Count the number of fringe transitions that occur as you rotate the table from 0 degrees to an angle θ (at least 10 degrees).

IV. EVALUATION

1. Determine the path length of the light beam as the glass plate is rotated. Determine how much of the change in path length is through glass, $d_g(\theta)$, and how much is through air, $d_a(\theta)$.
2. Relate the change in path length to your measured fringe transitions with the following equation:

$$\frac{2n_a d_a(\theta) + 2n_g d_g(\theta)}{\lambda_0}$$

where n_a is the index of refraction of air (see Experiment 3), n_g is the index of refraction of the glass plate (as yet unknown), λ_0 is the wavelength of your light source in vacuum, and N is the number of fringe transitions that you counted.