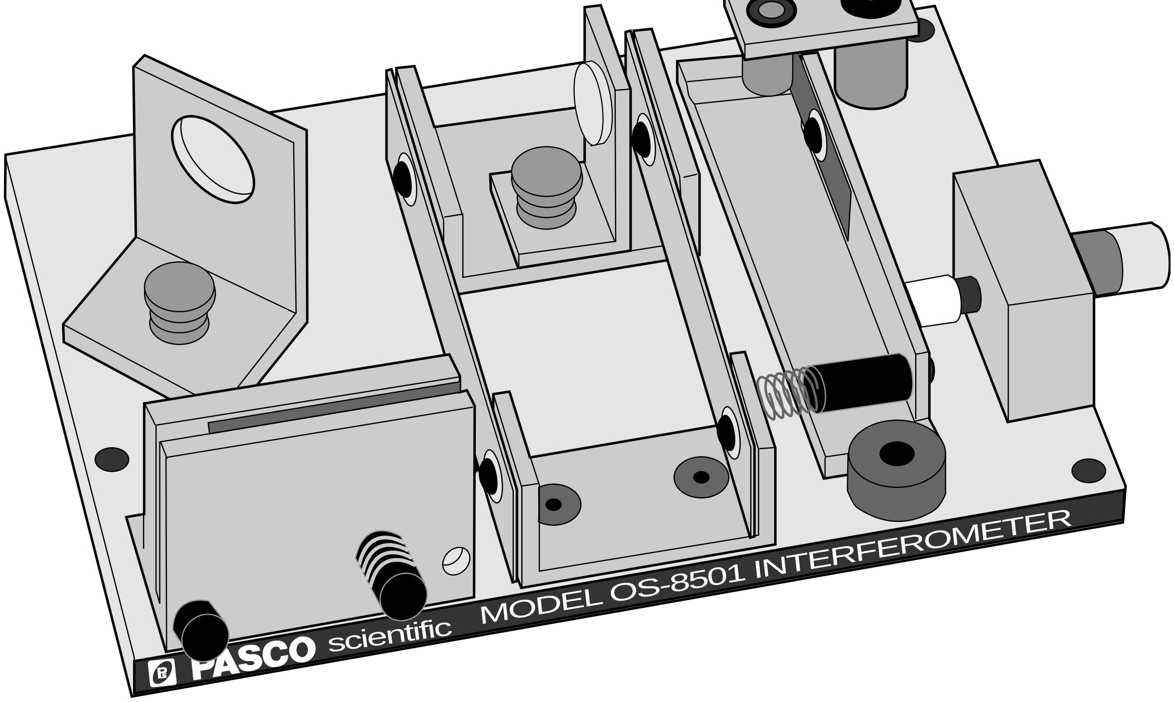
Instruction Manual and Experiment Guide for the PASCO scientific Model OS-8501

012-02675
10/91
Revision B

Interferometer



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PASCO scientific
10101 Foothills Blvd. • Roseville, CA 95747-7100
Phone (916) 786-3800 • FAX (916) 786-8905 • www.pasco.com

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When returning equipment for repair, the units must be packed properly. Carriers will not accept responsibility for damage caused by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

① The packing carton must be strong enough for the item shipped.

② Make certain there are at least two inches of packing material between any point on the apparatus and the inside walls of the carton.

③ Make certain that the packing material cannot shift in the box or become compressed, allowing the instrument come in contact with the packing carton.

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10101 Foothills Blvd.
Roseville, CA 95747-7100

Phone: (916) 786-3800
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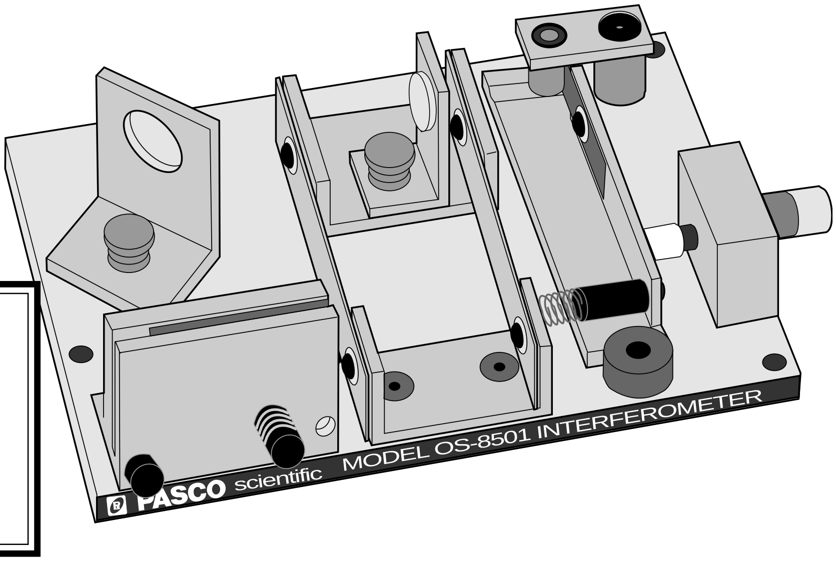
Introduction

The PASCO scientific Model OS-8501 Michelson Interferometer is a precision instrument capable of measuring the wavelength of visible, monochromatic light with an accuracy of better than 5%. With the included vacuum chamber, it can also be used for precise measurements of the index of air refraction.



➧ **CAUTION:** Avoid touching all optical surfaces on the interferometer, because minute scratches can impair the clarity of the interference image. For instructions on cleaning the optical surfaces, see the Maintenance section at the end of this manual.

Equipment

Equipment included:

- Interferometer base with built-in micrometer and leveling feet
- Movable mirror
- Beam splitter
- Three point adjustable fixed mirror
- Vacuum cell for measuring the index of air refraction
- Beam expanding lens with component holder
- Fitted case

Additional Equipment Needed:

Light source: To operate the Michelson Interferometer you will also need a monochromatic light source, preferably a laser. We recommend the PASCO 0.5 mW He-Ne Laser (Model OS-9171), but any low power laser that operates in the visible range will work. For optimum ease of alignment, the level of the beam should be 1.5 inches (3.8 cm) above the bench top. Leveling screws on the interferometer allow the height to be adjusted.

Vacuum pump: To measure the index of refraction of air, you will also need a vacuum pump. The PASCO Hand Vacuum Pump (Model OS-8502) is an accurate yet relatively inexpensive pump with a built-in gauge. It allows precise control of the vacuum level when counting fringes. However, the vacuum chamber can be used with any pump that can be connected by a 1/4 inch (0.64 cm) I.D. (inner diameter) tube.

➧ **CAUTION:** Do not use the vacuum chamber with a compressor; it is not built to withstand positive pressures.

Additional Equipment Recommended:

The PASCO Optics Bench can function as an aid in aligning the interferometer. It simplifies the alignment procedure and the magnetic pads on the bench top hold the laser and interferometer firmly in position once the system is aligned. A 1.0 m Optics Bench can be purchased separately (Model OS-9103). A 70 cm optics bench is included as an integral part of the PASCO scientific Introductory Optics System (Model OS-8500).

Theory of Operation

Interference Theory

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

If the two beams of light originate from separate sources, there is generally no fixed relationship between the electromagnetic oscillations in the beams. If two such light beams meet, at any instant in time there will be points in space where the fields add to produce a maximum field strength. However, the oscillations of visible light are much faster than the human eye can apprehend. 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 instant. The human eye averages these results and perceives a uniform intensity of light.

However, if the two beams of light originate from the same source, there is generally some degree of correlation between the frequency and phase of the oscillations of the two beams. At one point in space the light from the beams may be continually in phase. In this case, the combined field will always be a maximum and a bright spot will be seen. At another point the light from the two beams may be continually out of phase and a minima, 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 became visible. When first performed, Young's experiment offered important evidence for the wave nature of light.

Young's slits function 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, some 78 years after Young introduced his two-slit experiment, A.A. Michelson designed and built an interferometer using a similar principle. Originally Michelson designed his interferometer as a method to test for the existence of the ether, a hypothesized medium in which light could propagate. Due in part to his efforts, the ether is no longer considered a viable hypothesis. Michelson's interferometer has become a widely used instrument for measuring the wavelength of light, and for using the wavelength of a known light source to measure extremely small distances.

Figure 1 shows a diagram of a Michelson interferometer. A beam of light from the laser source strikes the beam-splitter. The beam-splitter is designed to reflect 50% of the incident light and transmit the other 50%. The incident beam therefore splits into two beams; one beam is reflected toward mirror M_1, the other is transmitted toward mirror M_2. M_1 and M_2 reflect the beams back toward the beam-splitter. Half the light from M_1 is transmitted through the beam-splitter to the viewing screen and half the light from M_2 is reflected by the beam-splitter to the viewing screen.

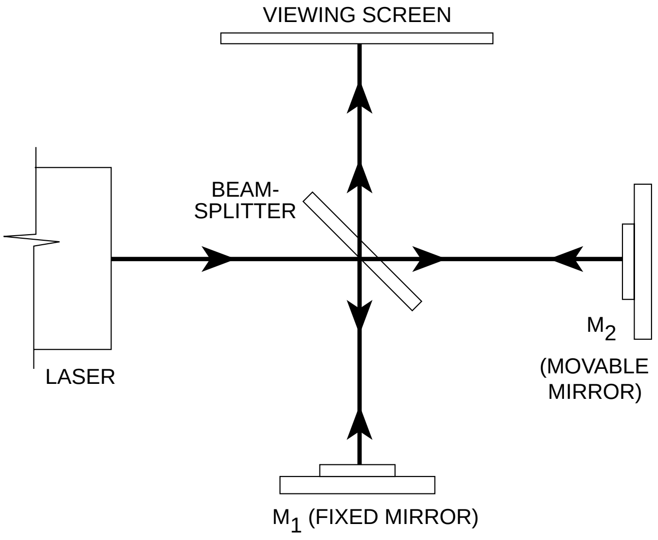


Figure 1 MICHELSON INTERFEROMETER

In this way the original beam of light splits, and portions of the resulting beams are brought back together. The beams are from the same source and their phases highly correlate. When a lens is placed between the laser source and the beam-splitter, the light ray spreads out. An interference pattern of dark and bright rings, or fringes, is seen on the viewing screen, as shown in Figure 2.

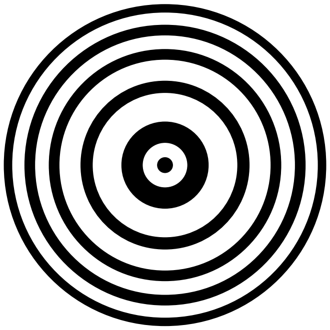


Figure 2 INTERFERENCE PATTERN

➡ **NOTE:** Do not be concerned if your pattern shows irregularities or has fewer fringes. As long as fringes are clearly visible, measurements will be accurate.

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 mirror M_2, the path length of one of the beams can be varied. Since the beam traverses the path between M_2 and the beam-splitter twice, moving M_2 1/4 wavelength nearer the beam-splitter 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 M_2 is moved an additional 1/4 wavelength closer to the beam-splitter, the radii of the maxima will again be reduced so maxima and minima trade positions. However, this new arrangement will be indistinguishable from the original pattern.

By slowly moving M_2 a measured distance $\mathbf{d_m}$, and counting **m**, the number of times the fringe pattern is restored to its original state, the wavelength of the light (λ) can be calculated as:

$$\lambda = \frac{\mathbf{2d}}{\mathbf{m}}$$

If the wavelength of the light is known, the same procedure can be used to measure $\mathbf{d_m}$.

Operation

The Interferometer

The Michelson Interferometer is shown in Figure 3. The alignment of the beam-splitter and the movable mirror, M_2, is easily adjusted by loosening the thumbscrews that attach them to the interferometer. The fixed mirror, M_1, is mounted on an alignment bracket. The bracket has two alignment screws to adjust the angle of the mirror.

The movement of M_2 toward and away from the beam-splitter is controlled and measured using the micrometer knob. Each division of the knob corresponds to 1 micrometer (10^{-6} meter) of mirror movement.

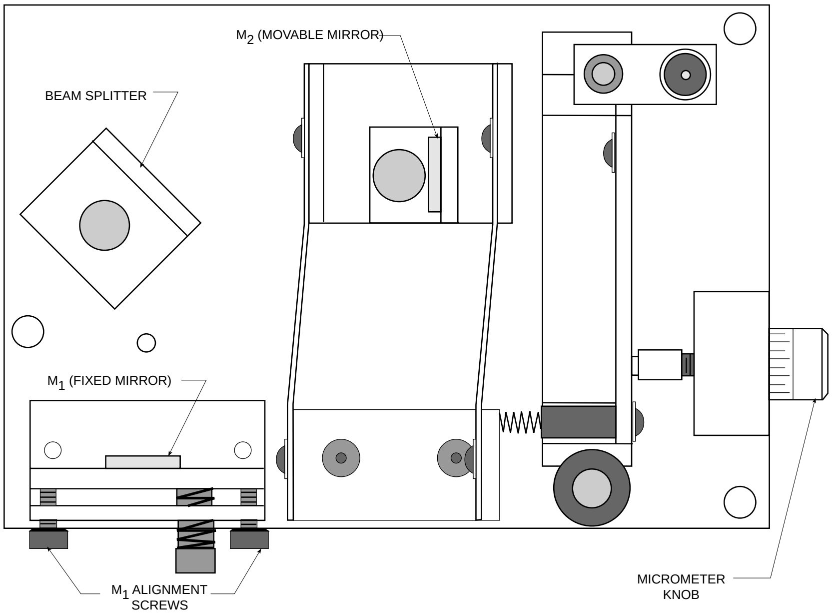


Figure 3 INTERFEROMETER

The Movable Mirror

To measure the wavelength of light, the movement of M_2 must be measurable for distances about 10^{-6} meters. Also, as the mirror moves, its reflective surface must remain perpendicular to the axis of the incident light beam.

A taut-band carriage is used to maintain the alignment of the reflective surface of M_2 as it moves. The mirror is mounted in a cradle that is fixed to two semi-rigid aluminum bands. With this set-up the mirror is free to move, but its movement is constrained to a line parallel with the beam axis.

The micrometer mechanism controls and measures the movement of M_2. The cradle of M_2 is attached to a mylar strip that is attached to a lever arm. The displacement of the lever is controlled with the micrometer knob.

Suppose the micrometer knob is turned so it pushes the lever in by a distance **d** (see Figure 4). The angle of the lever arm changes by an amount $\boldsymbol{\theta}$ such that $\mathbf{d = R \tan\theta}$, as shown. Since the angle change is always small,
$\mathbf{R \tan\theta = R\,\theta}$, to a close approximation. This change in the lever arm angle causes the mylar strip to be pulled further around the lever post by an amount $\mathbf{r\,\theta}$, where **r** is the radius of the lever post. The mirror is therefore pulled away from the beam-splitter by the amount, $\mathbf{r\,\theta}$.

In this way, a relatively large displacement of the lever ($\mathbf{d = R\,\theta}$) results in a much smaller displacement of the mirror ($\mathbf{d_m = r\,\theta}$). By selecting appropriate values for **r** and **R**, the motion of M_2 is controlled so that each division on the micrometer dial corresponds to 1 micron of mirror movement.

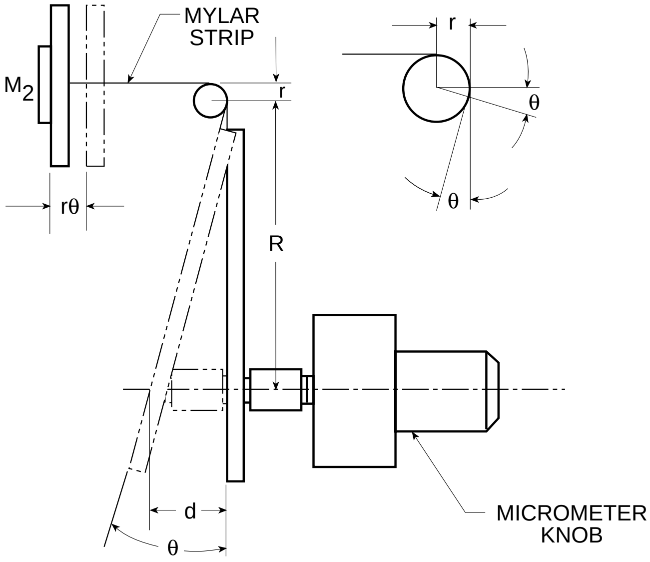


Figure 4 MIRROR MOVEMENT MECHANISM

Aligning the Interferometer

➦ **NOTE:** This alignment procedure is for those using a PASCO scientific Optics Bench. If you are not using an Optics Bench, tape a straightedge to a flat level surface. The straightedge will provide a substitute for the alignment rail of the optics bench.

① Place the laser and the interferometer on the Optics Bench, approximately 10 - 20 cm apart (Figure 5). Be sure that the edges of both units are flush against the alignment rail of the bench. Place a viewing screen as shown. (A blank sheet of white paper taped to the cover of a book provides a convenient screen.) Turn on the laser.

② Loosen the thumbscrew that holds the beam-splitter and rotate the beam-splitter so it is out of the beam path of the laser as shown in Figure 5. Then loosen the thumbscrew that holds M_2, the movable mirror. Adjust the rotation of M_2 so the laser beam is reflected directly back toward the aperture of the laser. (The reflected beam need not be at the same height as the incident beam, but it should strike the front panel of the laser along a vertical line through the aperture.) Hold M_2 in position and tighten the thumbscrew.

③ Rotate the beam-splitter so its surface is at an angle approximately 45^o with the incident beam from the laser (see Figure 6). You will see two sets of laser spots on the viewing screen, corresponding to the two paths that the beam takes in reaching the screen. (Each path results in more than one laser spot because of multiple reflections within the beam-splitter.) Adjust the beam-splitter so the two sets of laser spots are as close as possible, then tighten the thumbscrew to secure the beam-splitter.

④ Using the alignment screws, adjust the angle of M_1 until the two sets of laser spots are superimposed on the viewing screen (the two brightest spots must be superimposed).

⑤ Place the lens holder on the optical bench as shown in Figure 7. Be sure its edge is flush against the alignment rail. Then place the 18 mm focal length lens on the lens holder (it attaches magnetically). Adjust the position of the lens on the holder so the light from the laser, now spread out by the lens, strikes the center of the beam-splitter. If you have performed the alignment correctly, you will see an interference pattern of concentric rings on the viewing screen. If the alignment is not just right, the center of the fringe pattern may not be visible on the screen. Adjust the alignment screws on M_1 very slowly as needed to center the pattern.

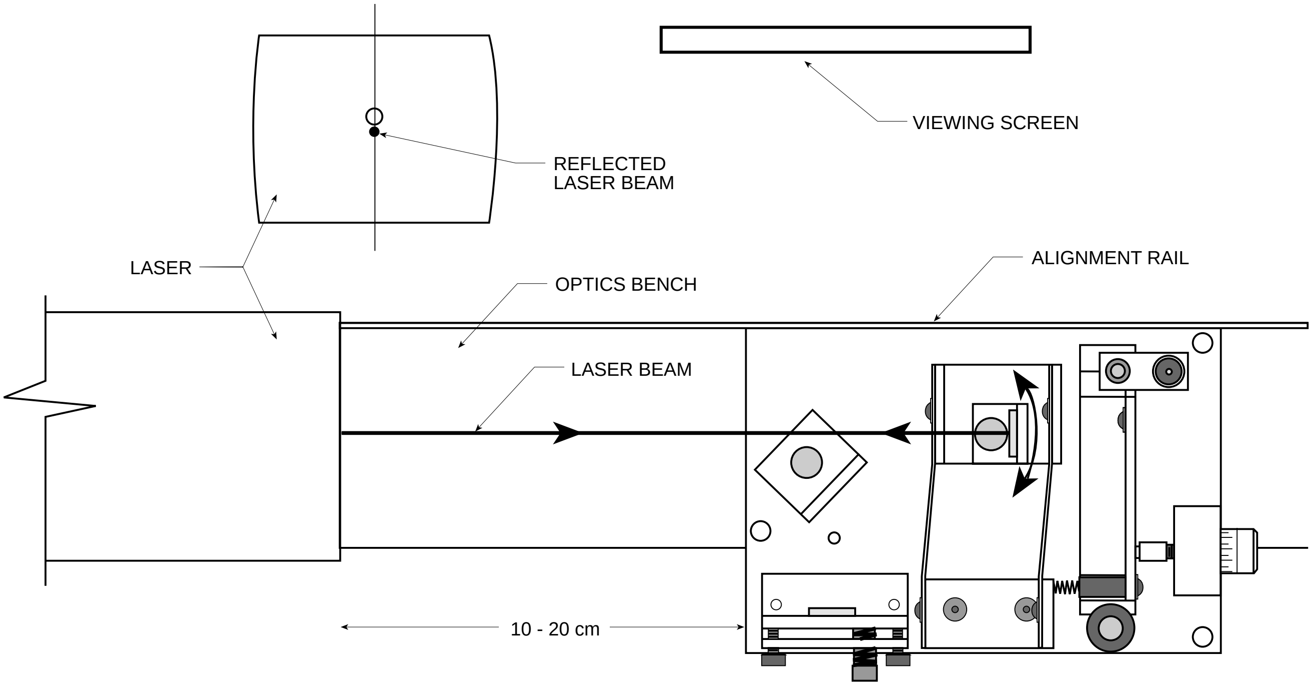


Figure 5 ADJUSTING M_1

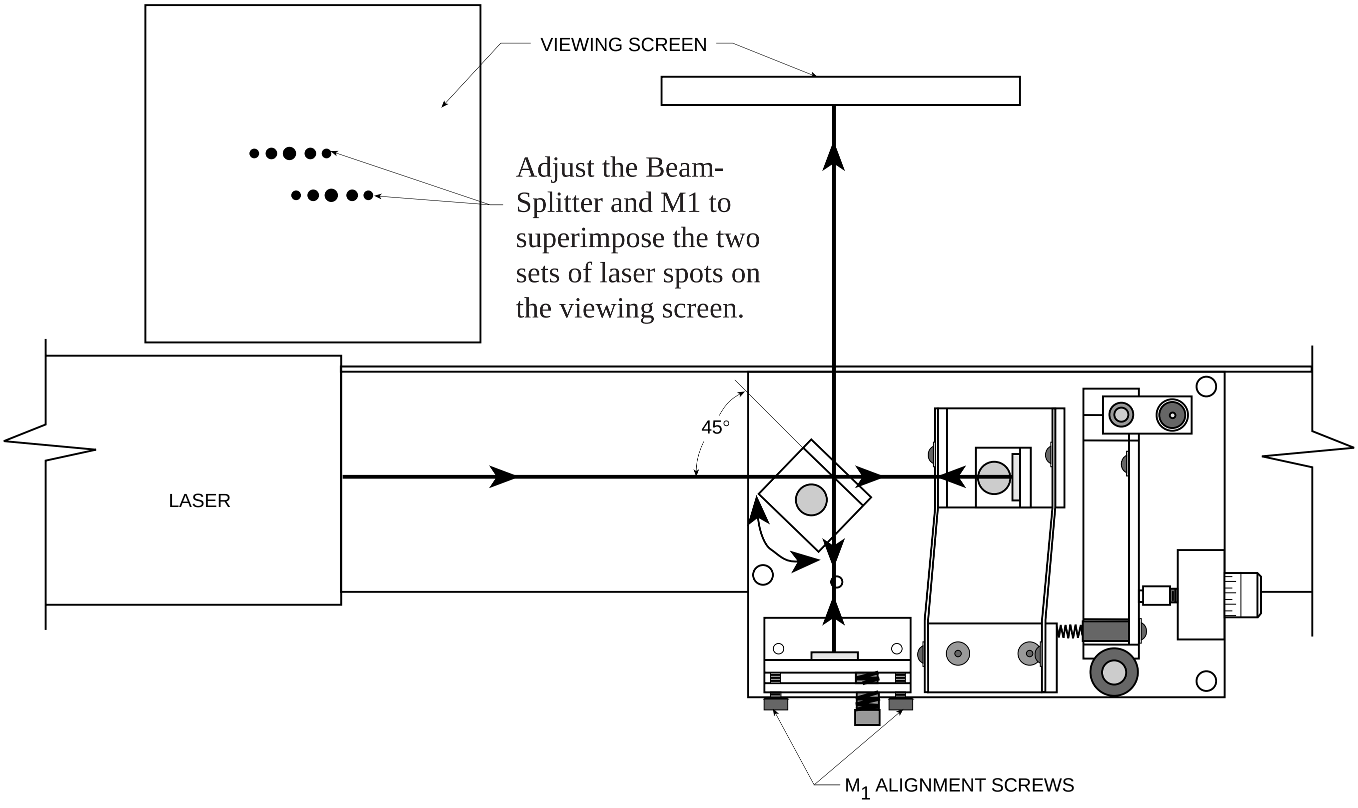


Figure 6 ALIGNING THE LASER SPOTS

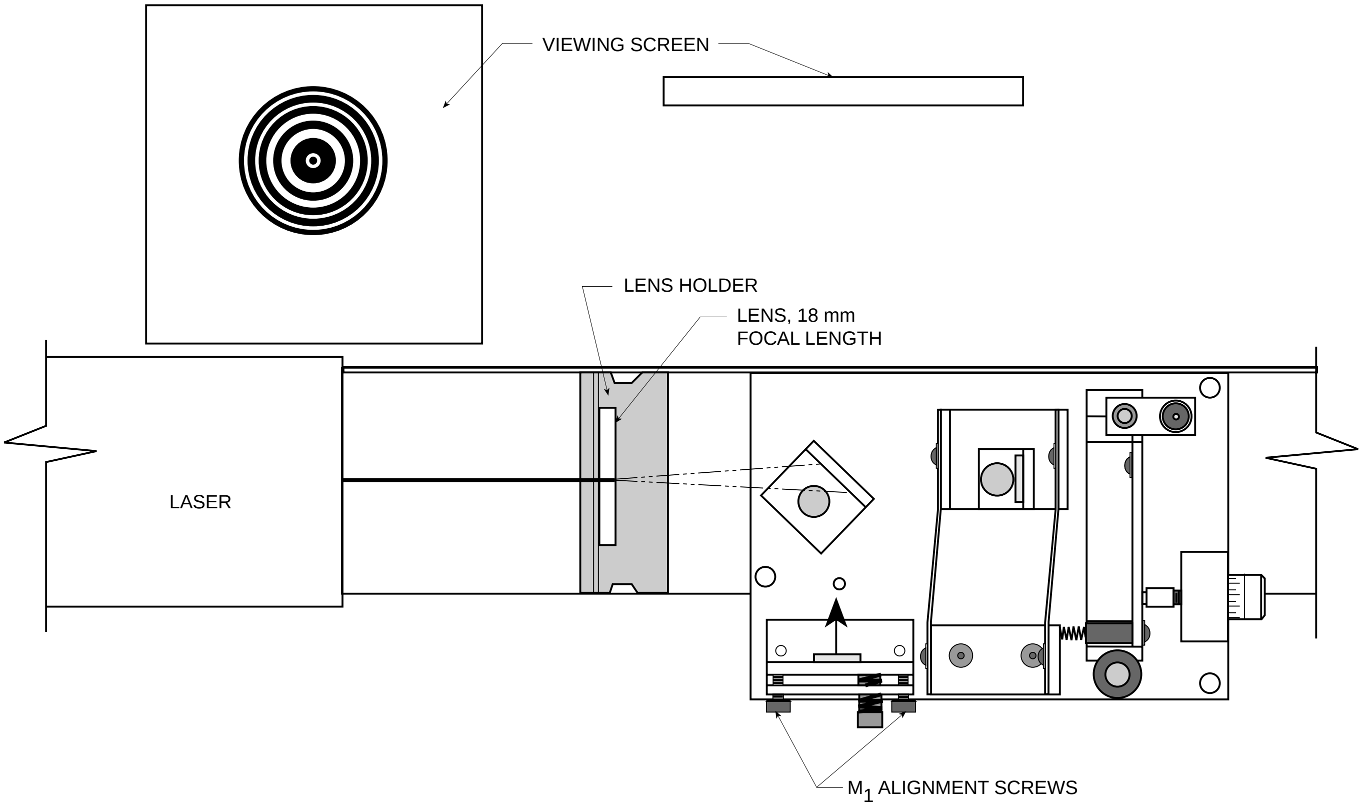


Figure 7 POSITIONING THE LENS

Exp 1: Measuring the Wavelength of Light

Theory

In many scientific and industrial uses of interferometers, a light source of a known wavelength is used to measure incredibly small displacements - about 10^{-6} meters. However, if you know the distance of mirror movement, you can use the interferometer to measure the wavelength of a light source. In this experiment you will use the interferometer to measure the wavelength of your laser light source.

Procedure

① Align the laser and interferometer as described in the preceding section, so an interference pattern of circular fringes is clearly visible on your viewing screen.

② Adjust the micrometer knob so the lever arm is approximately parallel with the edge of the interferometer base. In this position the relationship between knob rotation and mirror movement is most nearly linear.

③ Turn the micrometer knob one full turn counterclockwise. Continue turning counterclockwise until the zero on the knob is aligned with the index mark.

➦ **NOTE:** Whenever 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 any mechanical system involving reversals in direction of movement. By beginning with a full counterclockwise turn, and then turning only counterclockwise when counting fringes, you can eliminate backlash in your measurement.

④ If you are using a blank piece of paper as your viewing screen, make a reference mark on the paper between two of the fringes. 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.

⑤ Rotate the micrometer knob slowly counterclockwise. Count the fringes as they pass your reference mark. Continue until a predetermined number of fringes has passed your reference 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.

⑥ Record $\mathbf{d_m}$, the distance that the movable mirror moved toward the beam-splitter as you turned the micrometer knob. Remember, each division on the micrometer knob corresponds to one micron (10^{-6} meters) of mirror movement.

$\mathbf{d_m}$ = _______________

⑦ Record m, the number of fringes that crossed your reference mark.

m = _______________

⑧ Calculate the wavelength of the laser light ($\boldsymbol{\lambda = 2d_m/m}$).

⑨ Calculate the percentage difference between your measured value for the wavelength of the laser light and the value recorded in the laser specifications. (Check with your teacher for the laser specifications.)

Exp 2: Measuring the Index of Refraction for Air

Theory

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

$$\lambda = \lambda_o/\mathbf{n};$$

where λ_o 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. In this experiment, you will use the interferometer to measure the index of refraction for air.

For reasonably low pressures, the index of refraction for a gas varies linearly with the gas pressure. Of course for a vacuum, where the pressure is zero, the index of refraction is exactly 1. A graph for the refraction index versus gas pressure is shown in Figure 8.

The measurements you make in this experiment will allow you to calculate the slope of this graph for air. From that, numerical values can be determined for the index of air refraction at various pressures.

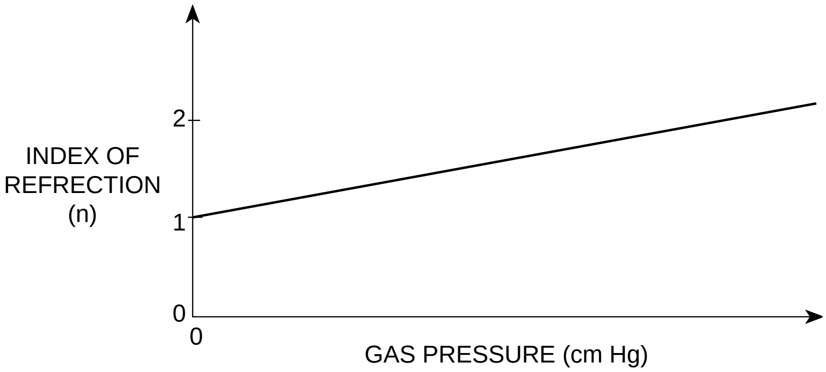


Figure 8 GRAPH, INDEX OF REFRACTION VS PRESSURE

Procedure

① Align the laser and interferometer as described earlier in this manual.

② The experimental set-up is shown in Figure 9. Push the air hose of the vacuum pump over the air outlet hole of the vacuum chamber. Then plug the banana plug of the vacuum chamber into the hole in the interferometer base – between the fixed mirror and the beam-splitter.

③ Adjust the alignment screws of the fixed mirror 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 chamber.)

④ Notice that the banana plug of the vacuum chamber is free to rotate in its hole. For accurate measurements, the end-plates of the vacuum chamber must be perpendicular to the laser beam. Rotate the chamber slowly and observe the effect on the interference fringes. Based on your observations, how can you be sure that the end-plates of the vacuum chamber are properly aligned?

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⑤ Be sure that the air in the vacuum chamber is at atmospheric pressure. If you are using a PASCO Hand Vacuum Pump, this is performed by flipping the vacuum release toggle switch. (Alternatively, many people find it more convenient to begin with the vacuum chamber evacuated – they then let air into the chamber as the fringes are counted. Use whichever

④

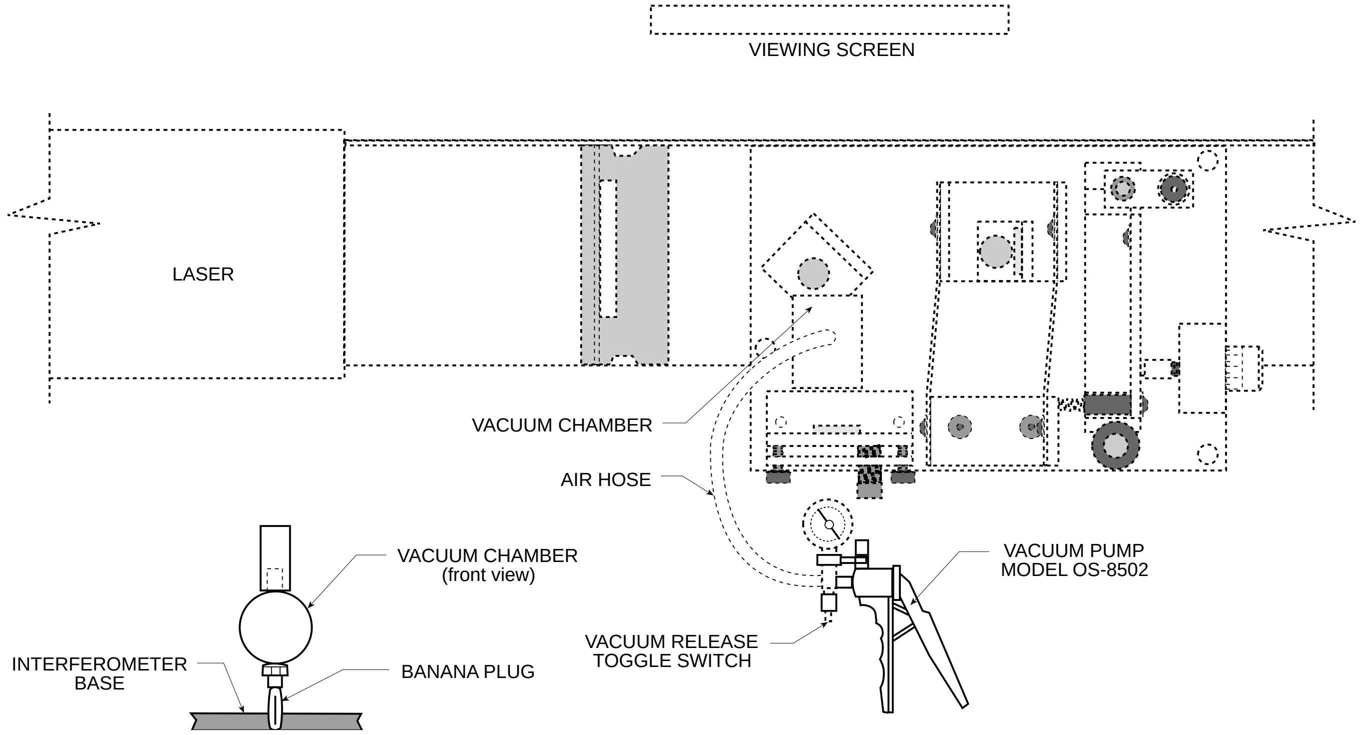

Figure 9 EXPERIMENTAL SETUP

method you find to be easier for controlling the air flow.)

⑥ Record P_i, the initial reading on the vacuum pump gauge.

$\mathbf{P_i}$ = ________________cm Hg

➡ **NOTE:** $\mathbf{P_i}$ and $\mathbf{P_f}$ (see below) must be absolute pressure readings. Most vacuum gauges measure vacuum pressure with respect to atmospheric pressure (e.g., when the gauge reads 34 cm Hg, it means that the pressure is actually 34 cm Hg BELOW atmospheric pressure). In this case, the absolute pressure reading must be calculated as:

$$\mathbf{P_{absolute} = 76\ cm\ Hg - P_{gauge}}$$

Of course, your room pressure may vary slightly from 76 cm Hg. If you have a more accurate way of measuring room pressure, you can use that value to replace 76 cm Hg in the above equation.

⑦ Mark a reference point between a pair of fringes on your viewing screen. Slowly pump out the air in the vacuum chamber to some convenient pressure level. As you do this, count Δ **m**, the number of fringes that pass your reference point. Record Δ **m**, below. Also record $\mathbf{P_f}$, the final reading on the vacuum gauge.

Δ **m** = ______________

$\mathbf{P_f}$ = ________________cm Hg.

Analyzing Your Data

As the laser beam passes back and forth between the beam-splitter and the fixed mirror, it passes twice through the vacuum chamber. Outside the chamber the optical path-lengths of the two interferometer beams do not change throughout the experiment. Inside the chamber, however, the wavelength of the light gets longer as the pressure is reduced.

Suppose that originally the chamber length **d** was 10 wavelengths long (it is actually much longer). As you slowly pump out the chamber, the wavelength increases until, at some point, the chamber is only 9-1/2 wavelengths long. Since the laser beam passes twice through the chamber, the light now goes through one less oscillation as it passes through the chamber. 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 will have passed by the reference mark on the viewing screen.

Originally there are $\mathbf{m_i = 2\ d/\lambda_i}$ wavelengths of light within the chamber (counting both passes of the laser beam). At the final pressure there are $\mathbf{m_f = 2\ d/\lambda_f}$ wavelengths within the chamber. The difference between these values, $\mathbf{m_i = m_f}$, is just $\mathbf{\Delta\ m}$, the number of fringes you counted as you evacuated the chamber. Therefore:

$$\mathbf{\Delta\ m = 2\ d/\lambda_i - 2d/\lambda_f}$$

However, $\lambda_i = \lambda_o/\mathbf{n_i}$ and $\lambda_f = \lambda_o/\mathbf{n_f}$; where $\mathbf{n_i}$ and $\mathbf{n_f}$ are the initial and final values for the refraction index of the air inside the chamber. Therefore $\mathbf{\Delta\ m = 2\ d\ (n_i = n_f)\ /\lambda_o}$, so that $\mathbf{n_i - n_f = \Delta m \lambda_o/2d}$. The slope of the **n** vs pressure graph is therefore calculated as:

$$\frac{n_i - n_f}{P_i - P_f} = \frac{\Delta m\ \lambda_o/2d}{P_i - P_f}$$

where $\mathbf{P_i}$ = the initial air pressure

$\mathbf{P_f}$ = the final air pressure

$\mathbf{n_i}$ = the index of refraction of air at P_i

$\mathbf{n_f}$ = the index of refraction of air at P_f

$\mathbf{\Delta\ m}$ = the number of fringes that passed the reference point during evacuation

$\mathbf{\lambda_o}$ = the wavelength of the laser light in vacuum (obtain this value from your teacher)

d = the length of the vacuum chamber (3.0 cm)

⑧ Calculate the slope of the **n** vs pressure graph for air.

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⑨ On a separate piece of paper, draw the **n** vs pressure graph. From your graph, what is $\mathbf{n_{atm}}$, the refraction index for air at a pressure of 1 atmosphere (76 cm Hg).

$\mathbf{n_{atm}}$ = ______________

➦**NOTE:** Remember that at zero pressure, **n = 1** exactly. Using this as a fixed data point, use your calculated slope to construct the graph. The slope will be very slight, since large pressure changes result in very small changes in n. Adjust the scale of your graph as needed so that you can accurately determine the small shift in n that occurs between zero pressure and atmospheric pressure.

Appendix

Maintenance

➧ **IMPORTANT:** All mirrors on the interferometer should be cleaned ***ONLY*** with alcohol and a soft cloth. Other cleaning solvents, such as Windex, may scratch or dissolve the aluminized front surface of these mirrors.

Besides cleaning the mirrors, no other maintenance is required. If the mylar strip gets damaged, or a severe shock causes the interferometer to lose its alignment, return the unit to PASCO scientific for repair.

Replacement Parts

The following spare parts are available from PASCO scientific:

Item	**PASCO Part No.**
Vacuum cell assembly	003-02197
Convex lens, 18 mm Focal Length	003-02281
Three point adjustable mirror assembly	003-02671
Beam-Splitter assembly	003-02672
Movable mirror assembly	003-02673
Component Holder	648-02696

Inteferometry with a Spectral Light Source

Although the Michelson Interferometer works best with a laser light source, interferometry measurements can be successfully made using any monochromatic source of sufficient brightness. However, unless a laser is used, it is generally not possible to project the interference fringes onto a screen. The fringes are viewed, instead, by looking into the beam-splitter.

A spectral light source such as the PASCO Model OS-9287 Low Pressure Sodium Light Source works well for this application. In addition to the spectral light source, a diffuser is needed, such as PASCO Model OS-9120.

To use the interferometer with a spectral or other monochromatic light source:

① Tape two thin pieces of wire or thread to the surface of the diffuser to form cross-hairs.

② Set up the equipment as shown below, and turn on the light source. The light source should be on a level with the interferometer mirrors.

③ Adjust the alignment screws on the Fixed Mirror (M_1) until the front and back plates of the alignment bracket for M_1 are approximately parallel.

④ While looking through the beam-splitter toward M_1, adjust the rotation of the beam-splitter until you see an image of the cross-hairs reflected from M_1.

⑤ Now adjust the rotation of the Movable Mirror (M_2) until you see a second image of the cross-hairs. Adjust the alignment screws on M_1 until the two cross-hair images are superimposed. The interference fringes should now be visible when looking through the beam-splitter at M_1.

➦ **NOTE:** If you are using a spectral light source with spectral lines at several different wavelengths, it may be necessary to use a filter that blocks all but one of the spectral wavelengths.

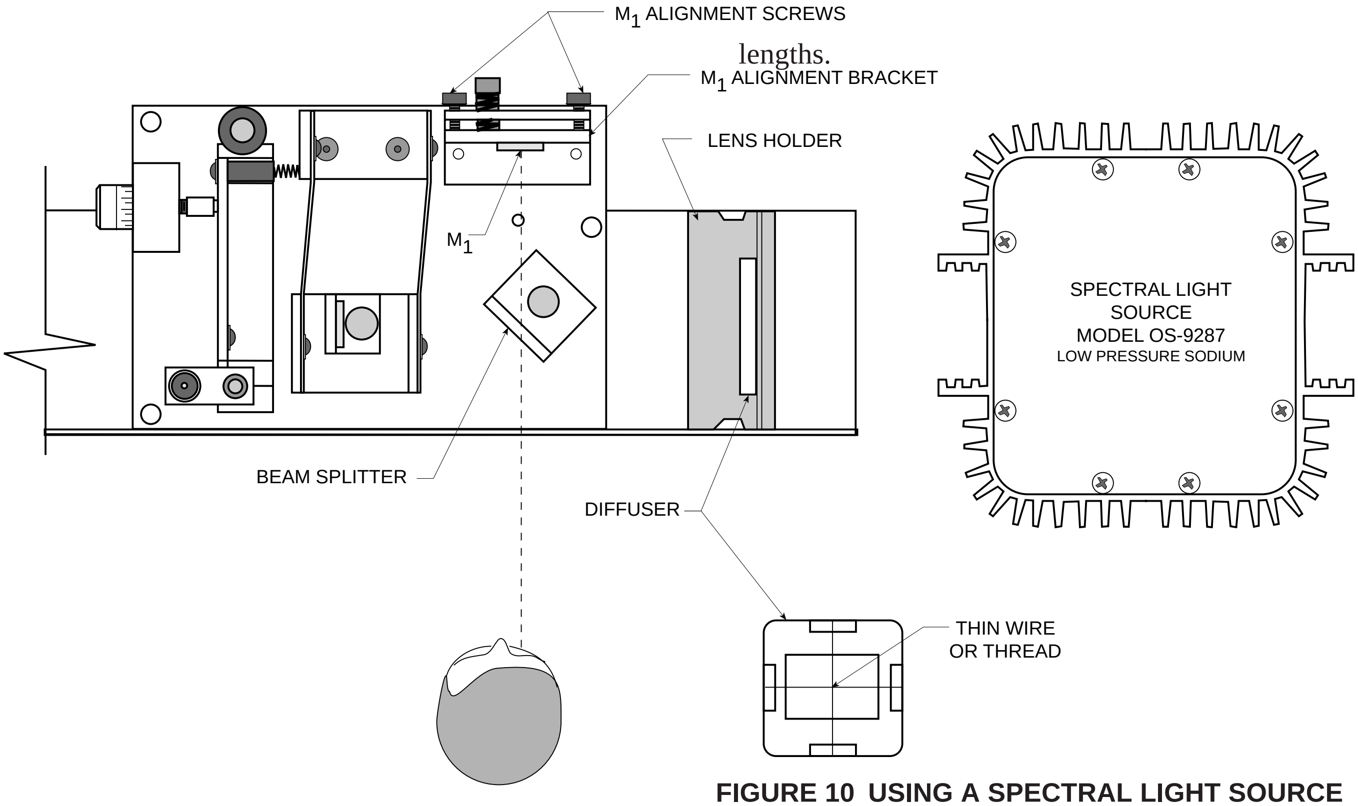

FIGURE 10 USING A SPECTRAL LIGHT SOURCE

Technical Support

Feedback

If you have any comments about the product or manual, please let us know. If you have any suggestions on alternate experiments or find a problem in the manual, please tell us. PASCO appreciates any customer feedback. Your input helps us evaluate and improve our product.

To Reach PASCO

For technical support, call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

fax: (916) 786-3292

e-mail: techsupp@PASCO.com

web: www.pasco.com

Contacting Technical Support

Before you call the PASCO Technical Support staff, it would be helpful to prepare the following information:

➤ If your problem is with the PASCO apparatus, note:

- Title and model number (usually listed on the label);
- Approximate age of apparatus;
- A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.);
- If possible, have the apparatus within reach when calling to facilitate description of individual parts.

➤ If your problem relates to the instruction manual, note:

- Part number and revision (listed by month and year on the front cover);
- Have the manual at hand to discuss your questions.