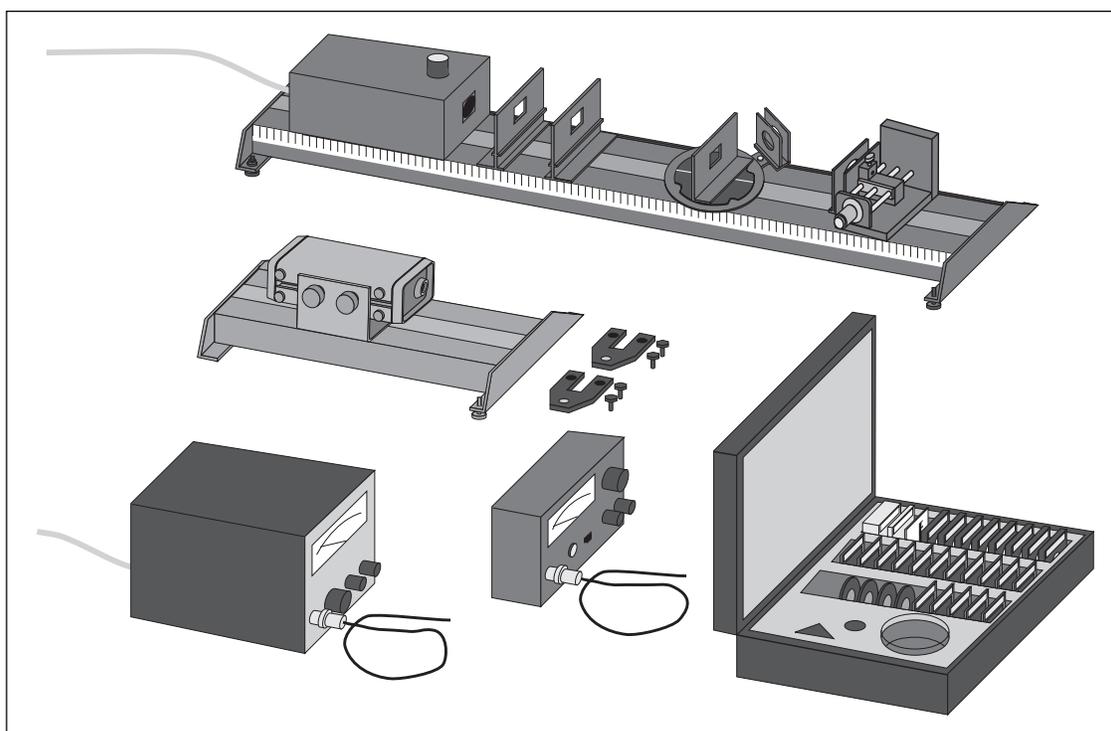


**Instruction Manual and  
Experiment Guide for the  
PASCO scientific Model  
OS-9246B, OS-9247A, OS-9250,  
OS-9251 and OS-9254B**

012-07136A  
4/99

# **ADVANCED OPTICS SYSTEM**



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# Introduction

This manual includes operating instructions, specifications, and experiments for the five PASCO Optics systems listed in Table 1. These systems comprise PASCO's "advanced" optics systems (as opposed to our OS-8500 Introductory Optics System, a less sophisticated system which is not described in this manual).

In reality, the five PASCO Optics systems described in this manual are really a single system, available in five different packages. The Complete Optics System (OS-9254A) includes all of the instruments and components available, and enables you to perform all of the experiments described in the *Experiments* section. Each of the other systems includes some subset of the instruments and components included in the Complete System, and can be used to perform some of the experiments.

The components of the five optics systems are completely interchangeable, so if you purchase any combination of systems, you can mix and match components. Moreover, if you decide to upgrade your system, all the components are available separately, so there is no need to purchase duplicate equipment. Information on all instruments and components is provided in the equipment section of this manual.

► **NOTE:** The PASCO OS-8500 Introductory Optics System (not described in this manual) is not compatible with any of the systems, instruments, or components described in this manual.

The Experiments Guide section of the PASCO Optics System manual is intended to give the student an outline of the range of optics experiments which can be performed with the PASCO system. The experiments have been written to help the student master any idiosyncracies in the system in order to use the apparatus with maximum efficiency and minimum error. Hopefully the student will gain sufficient technique to design and perform his or her own optics experiments with the PASCO Optics System.

In order to insure success with the various experiments, the student should first read the Equipment Instructions in the first portion of the manual. Also, the light patterns and images will be much easier to see and measure if the ambient room light is kept down to a minimum.

Often an experiment can be performed with either the incandescent light source or the laser. Before using the laser in these cases, the student should read the equipment description as well as Experiment 5 which cover the unique properties of the laser. The most important point to remember is that the laser is not a toy. Do Not Look Directly Into The Laser Or Its Mirror Reflection.

**Table 1: Optics Systems and Experiments**

System	Catalog Number	Experiments <sup>1</sup>
The Complete Optics System <sup>2</sup>	OS-9254A	All
The Advanced Optics System with laser	OS-9246	All
without laser	OS-9250	1-4
The Intermediate Optics System with laser	OS-9247	1-10
without laser	OS-9251	1-4

<sup>1</sup>These experiments include only those that are fully described in the Experiment section on this manual. With the wide variety of components included in the Complete Optics System, many other experiments are possible.

<sup>2</sup>The Complete Optics System includes the PASCO Interferometer, which is not mentioned in this manual. However, a separate manual is included with the Interferometer.

# Equipment

Table 2 lists the equipment included in each of the PASCO optics systems. For example, the Advanced System contains five of the OS-9107 Component Holders, while the Diffraction System contains only one. Major components are identified in Figure 1 on the following page. Minor components, such as lenses, mirrors, filters, etc., are labeled, so there should be no confusion in identifying them.

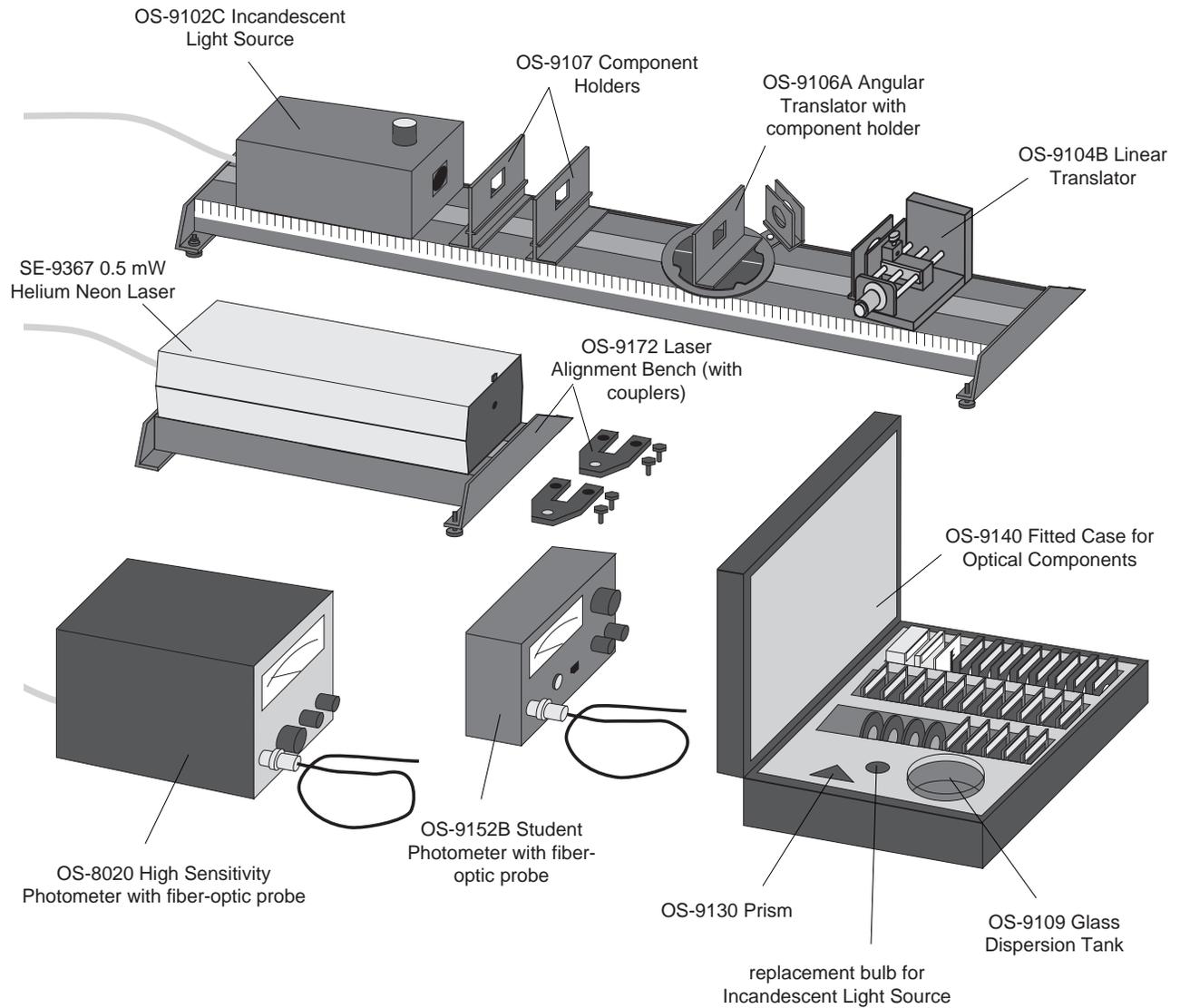
Information on setting up and using the various instruments and components is provided on the following pages.

► **NOTES:**

- ① The Complete Optics System is not listed in Table 2, because its components are identical to those of the Advanced Optics System. The difference between the two systems is that the Complete System includes the PASCO Interferometer, which comes with its own manual.
- ② If you purchased a system without the laser (OS-9250 or OS-9251), the included components are as listed in the table, but you will not have the following:
  - 0.5 mW Helium Neon Laser (SE-9367)
  - Laser Alignment Bench (OS-9172)

**Table 2: Component List**

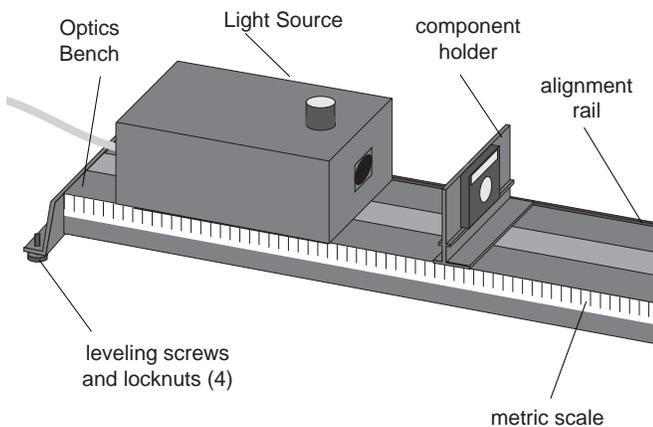
Catalog No.	Complete	Advanced	Intermediate	Description	Catalog No.	Complete	Advanced	Intermediate	Description
OS-8020	1	1		High Sensitivity Photometer	OS-9120	1	1	1	Diffuser
OS-9152B			1	Student Photometer	OS-9121	1	1	1	Crossed Arrow Target
SE-9367	1	1	1	0.5 mW HeNe Laser	OS-9165	1	1	1	Slits and Patterns (16 sets on 4 slides)
OS-9256A	1			Interferometer Accessory	OS-9126	1	1	1	Opaque Points and Fresnel Zone Plates
OS-9172	1	1	1	Laser Alignment Bench	OS-9127	1	1	1	5276 line/cm Diffraction Grating
OS-9102C	1	1	1	Incandescent Light Source	OS-9128	1	1	1	Glass Plate
OS-9103	1	1	1	Optics Bench	OS-9129	1	1	1	Acrylic Plate
OS-9104B	1	1	1	Linear Translator	OS-9130	1	1	1	Prism (90°)
OS-9106A	1	1	1	Angular Translator/Component Carrier	OS-9131	1	1	1	-22 mm F.L. Lens
OS-9107	5	5	4	Component Carrier	OS-9132	1	1	1	18 mm F.L. Lens
OS-9108	1	1		Glass Dispersion Tank	OS-9133	1	1	1	48 mm F.L. Lens
OS-9109	3	3	3	Calibrated Polarizer	OS-9134	1	1	1	127 mm F.L. Lens
OS-9110	1	1	1	Calibrated 140 nm Retarder	OS-9135	1	1	1	252 mm F.L. Lens
OS-9111	1	1		Red Spectral Filter	OS-9136	1	1	1	Flat Front Surface Mirror
OS-9112	1	1		Yellow Spectral Filter	OS-9137	1	1	1	Concave Front Surface Mirror
OS-9113	1	1		Green Spectral Filter	OS-9138	1	1	1	Viewing Screen with Metric Scale
OS-9114	1	1		Blue Spectral Filter	OS-9139	1	1	1	Aperture Mask
OS-9115	1	1	1	Hologram	OS-9140	1	1	1	Fitted Case for Optical Components
OS-9116	1	1	1	Photometer Apertures	012-01511	1	1	1	Optics System Manual
OS-9117	1	1	1	Variable Diaphragm	OS-8514	1	1	1	Laser Adapter Bracket
OS-9118	1	1	1	Light Source Apertures (0.5, 0.75)	OS-9255A	1			Precision Interferometer
OS-9119	1	1	1	Light Source Apertures (1.0, 2.0)					



**Figure 1: Advanced Optics Equipment**

## The Optics Bench

The optics bench (see Figure 2) provides a straight, rigid surface for aligning optics experiments. For best results, the bench should be placed on a reasonably flat and level surface, and the leveling screws should be adjusted so the bench rests evenly on all four screws. Once the bench is leveled, tighten the locknuts so there is no slipping.



**Figure 2: Using the Optics Bench**

The incandescent light source and the component holders attach magnetically to the bench as shown. For proper alignment, the edge of the light source and component holders should be mounted flush to the alignment rail, which is the raised edge that runs along one side of the bench. This will ensure that the optical axis of the light source and component holders are coincident, which makes it easier to align optical components.

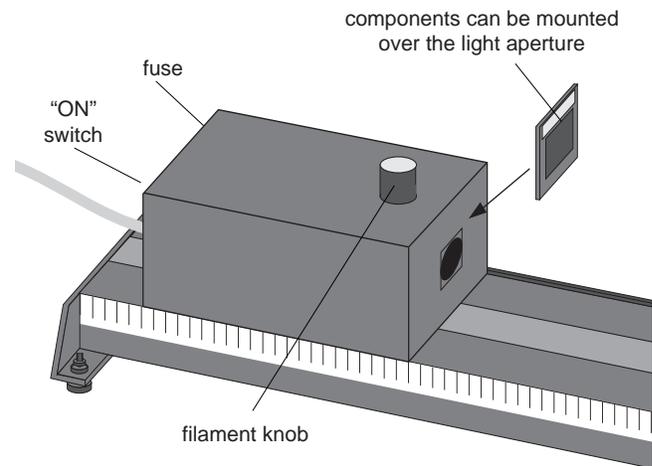
Your optics bench is guaranteed straight to within 0.25 mm over its full one meter length, and, under normal use, will retain its straightness. However the optics bench will bow slightly if heavily loaded. For example, a one kg mass placed in the center of the bench will produce a deflection of approximately 0.07 mm.

► **NOTE:** Avoid scratching or otherwise abusing the surface of the magnetic pads on the top of the optics bench. If they get dirty, use only soapy water or rubbing alcohol for cleaning. Other solvents may dissolve the magnetic surfaces.

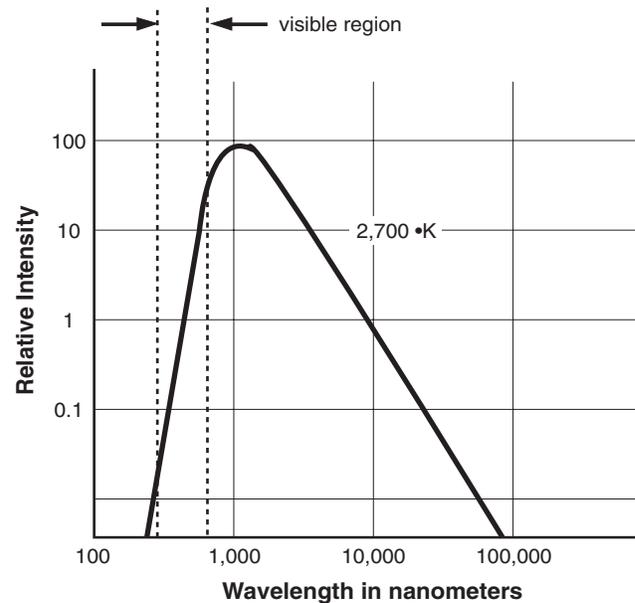
## The Incandescent Light Source

The incandescent light source (see Figure 3) provides 15 candlepower of light with the frequency spectrum

shown in Figure 4. The built-in power supply of the light source is regulated, so there's minimal variation in the intensity of the light. This is essential for obtaining accurate data in experiments where a pho-



**Figure 3: Using the Incandescent Light Source**



**Figure 4: Frequency Spectrum for the Incandescent Light Source**

tometer is being used to measure light intensities.

► **NOTE:** The distance from the front panel of the light source to the light bulb filament is approximately 22 mm.

To turn on the light source, connect the power cord to a grounded receptacle of the appropriate line voltage

(120 VAC, 60 Hz, unless otherwise specified), and flip the switch on the rear panel to ON. If at any time the light fails to come on, chances are that the fuse is blown or the light bulb is burnt out. See the Maintenance section for replacement instructions.

The Filament knob on the top of the light source adjusts the position of the light bulb filament transverse to the optical axis of the bench. The filament moves in the same direction as the knob is turned. Components can be mounted onto the magnetic pad on the front panel of the light source, over the light aperture. The crossed-arrow target, for example, is often mounted in this way as an object for lens experiments.

► **CAUTION:** When used continuously, the light source becomes hot to the touch. Since it requires no warm-up time, we recommend it be turned on only when setting up or actually performing an experiment.

### Specifications for the Incandescent Light Source (Model OS-9102C)

Output: Approximately 15 candlepower

Filament temperature: 2700 °K

Bulb: #93, operated at 12 VDC, 1.0 A; bulb life approximately 700 hours

Regulation: Maximum intensity variation of 2% for a 10% change in line voltage.

Input Power: 105-125 VAC 60 Hz (or 210-240 VAC, 50 Hz if specified when ordered)

Fuse 0.5 A, Slo-Blo (0.25 A for 220 VAC model)

### The Helium Neon Laser

The helium neon laser is a 0.5 mW, TEM<sub>00</sub> mode laser, providing randomly polarized light at a wavelength of 632.8 nm. The built-in power supply is regulated so the output has minimum ripple and the intensity is stable to within  $\pm 2.5\%$ . A 15 minute warm up is required to reach full power, but the power on start-up is greater than 0.35 mW. If you'd like more technical specifications, and a detailed explanation of laser operation, see the instruction manual that's included with the laser.

► **CAUTION:** This is a relatively safe, low power laser. Nevertheless, we strongly recommend the following precautions:

- Never look into the laser beam, either directly, or as it is reflected from a mirror.
- Set up experiments so the laser is either above or below eye level (for both sitting and standing people).

### To Setup the Laser using the Laser Alignment Bench:

The laser is most conveniently aligned using the laser alignment bench, which can be joined to the optics bench using the bench couplers. The procedure is as follows:

- ① Place the optics bench and the laser alignment bench end to end, as in Figure 5. Notice that only one end of the laser alignment bench has holes for two level-

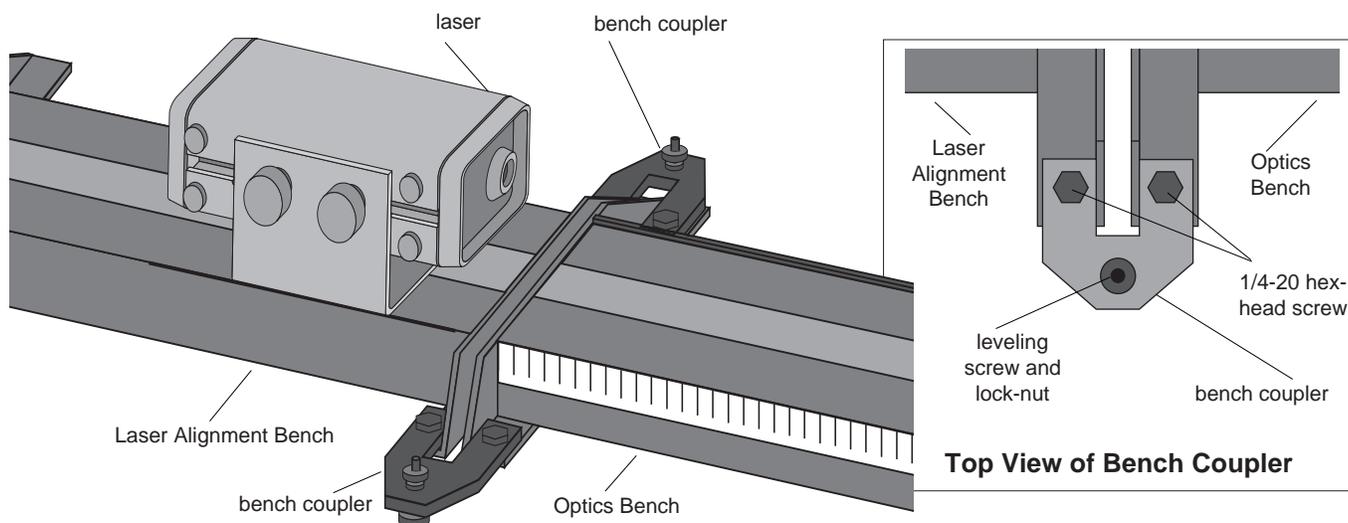


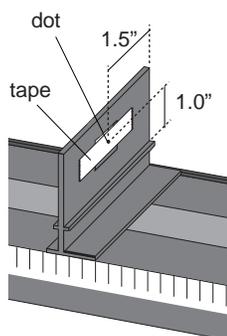
Figure 5: Connecting the Laser Alignment Bench

ing screws. That is the end that joins to the optics bench.

- ② Remove the four leveling screws on the adjoining ends of the two benches.
- ③ Use the 1/4-20, hex-head screws that are included with the bench couplers to attach the couplers to the legs of the benches, as shown. Do not yet tighten the screws.
- ④ Insert one of the leveling screws, rubber foot down, through the threaded hole in each coupler.
- ⑤ By adjusting all five leveling screws (one on the laser alignment bench, two on the optics bench, and two on the bench couplers), align the two benches so they are in a straight line. Use a meter stick or a long straight edge on top of the benches to check vertical alignment, and on the side of the bench to check horizontal alignment.
- ⑥ When the benches are aligned, tighten the locknuts on all the leveling screws, and also tighten the four hex-head screws. After tightening the screws, re-check the alignment.

#### To Align the Laser (so the laser beam is coincident with the optical axis of the bench):

- ① Place a piece of masking tape or tape a piece of paper over the square hole on the front of a component holder, as in Figure 6. Make a small dot on the tape or paper, in the center of the square hole (1-inch from the top of the component shelf, and 1.5-inch from the edge of the component holder).



**Figure 6: Locating the Optical Axis**

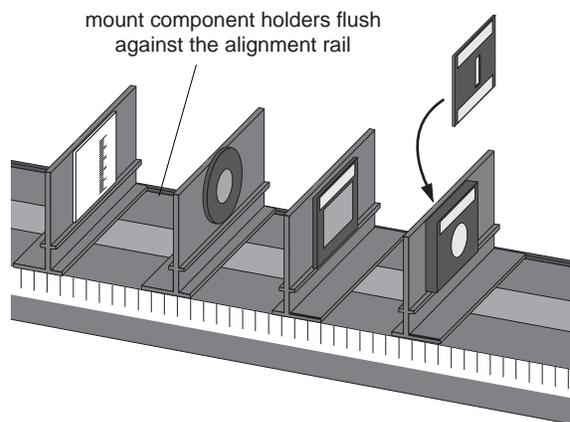
- ② Place the laser on the alignment bench, as in Figure 5. Center the laser on the bench, and make sure it is reasonably parallel with the bench.
- ③ Place the component holder on the optics bench, about 10 cm from the laser aperture. Make sure that the component holder is flush against the alignment rail of the bench. The dot on the tape now marks the optical axis of the bench.
- ④ Turn on the laser, and move the aperture end of the laser sideways, as needed, so that the laser beam falls on the dot.

- ⑤ Move the component holder about 90 cm away from the laser aperture. Again, be sure the edge of the component holder is flush against the alignment rail of the bench.
- ⑥ Without moving the aperture end of the laser, move the rear end of the laser as needed to recenter the laser beam on the dot. (You may also need to adjust the leveling screws on the laser alignment bench in order to center the laser beam vertically on the dot.)
- ⑦ Repeat steps 3 through 6 until the laser beam is aligned with the dot for both positions of the component holder.

#### The Component Holders

Each optics system includes several of the standard component holders, that attach magnetically to the optics bench, as in Figure 7. Components mount magnetically onto either side of the component holders. For proper alignment of the components along the optical axis of the bench:

- ① Mount the component holder flush against the alignment rail of the bench, as in Figure 7.

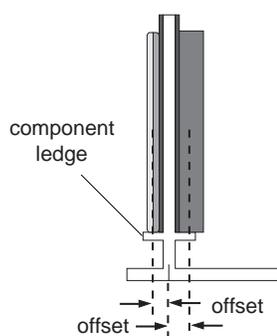


**Figure 7: Using the Component Holders**

- ② Mount the component flush against the component ledge, as in Figure 8.
- ③ Center the component horizontally on the holder.

Each component holder has two white indicator lines that help when making measurements. The line on the side of the holder, near the base, marks the position of the center of the holder against the metric scale of the optics bench. The line on the component ledge marks the angle of rotation for polarizers and for the retarder.

► **IMPORTANT:** The indicator line on the side of the base marks the center of the holder, not the optical surface of a component that is mounted on the holder (see Figure 8). For accurate measurements of component positions, Table 3 provides offset values for the various components.



**Figure 8: Measuring Component Position**

**Table 3: Component Offset Values**

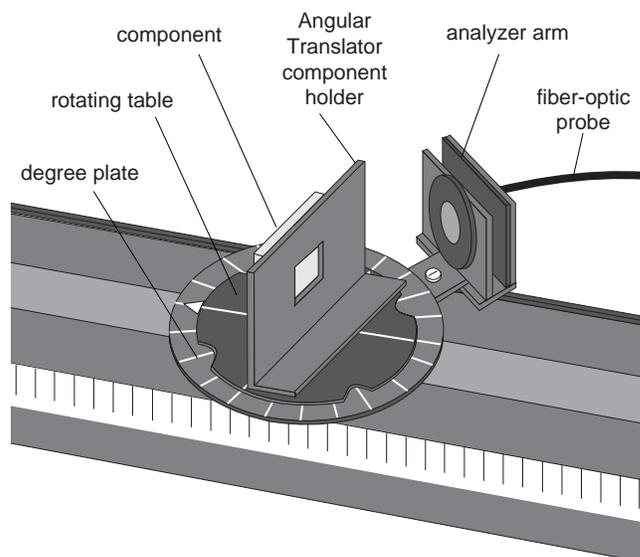
Component	Offset (mm)
Slide mounted components (filters, crossed-arrow target slits, apertures, etc.)	4.5
Lenses	6.5
Front surface mirror, plane	8.0
Front surface mirror, concave	8.0 (avg)
Variable diaphragm	10.0
Viewing Screen	4.5
Polarizers, retarder	4.5

## The Angular Translator

The angular translator is used in most experiments in which reflected, refracted, or scattered light is analyzed. The component that will deflect the light is placed in the center of the rotating table, either directly on the table, or mounted on the angular translator component holder, as shown in Figure 9. The rotating table is then set to various angles, and the angle of incidence is read on the degree plate.

The analyzer arm is rotated to intercept the deflected light. The analyzer arm has built-in component holders for mounting a viewing screen, polarizers, filters, etc. It also has a hole for attaching the fiber-optic probe of a PASCO photometer.

► **IMPORTANT:** when attaching the probe, tighten the thumbscrew **VERY GENTLY** to protect the probe.



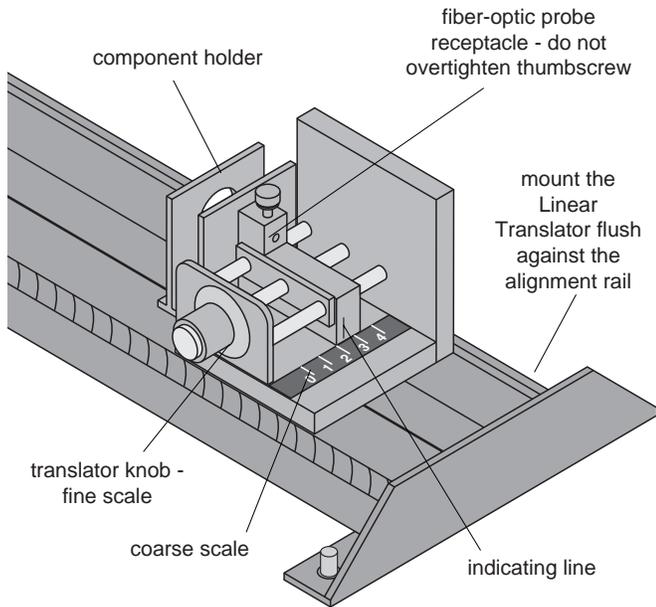
**Figure 9: Using the Angular Translator**

### Tips on Using the Angular Translator

- ① Mount the rectangular base of the translator flush against the alignment rail of the optics bench.
- ② Align the degree plate so that the zero degree mark is aligned with the optical axis of the bench. To do this, lift the rotating table off of the degree plate (it's attached magnetically), loosen the exposed screw, align the degree plate, and retighten the screw.
- ③ When attaching the fiber-optic probe, push the probe all the way into the hole, so the tip of the probe is just at the surface of the rear component holder. You can then place the photometer apertures slide on the rear component holder to clearly define the area of interest.
- ④ If you are mounting a polarizer (or a retarder) on the analyzer arm, mount it on the front component holder. It has a line that indicates the angle of polarization.
- ⑤ Use the Angular translator component holder only on the angular translator. It will not hold components at the proper height if used directly on the optics bench.

### The Linear Translator

The linear translator (Figure 10) is used to position the fiber-optic probe of a PASCO photometer transverse to the optical axis of the optics bench. It will resolve the position of the probe to within 0.1 mm and can be



**Figure 10: Using the Linear Translator**

mounted so that the probe movement is either horizontal or vertical.

Up to three analyzing components, such as filters, polarizers, apertures, etc., can be mounted on the built-in component holders. Polarizers and retarders are best mounted on the front holder, since it has an indicating line for measuring polarization angle. Photometer apertures should be mounted on the rear holder, so they are as close as possible to the tip of the fiber-optic probe.

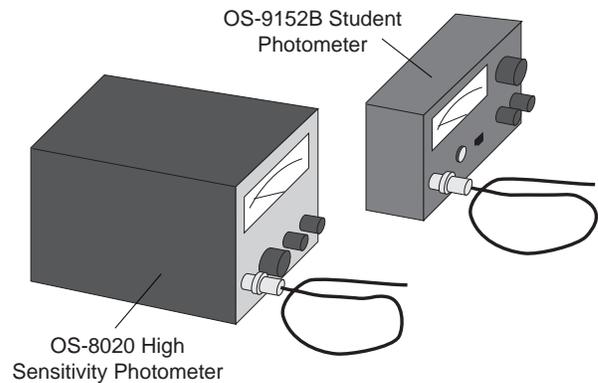
To use the translator, place the fiber-optic probe in the hole in the rear of the translator. Push it all the way

into the hole, so that the surface of the probe is flush with the surface of the rear component holder. Then the photometer apertures slide can be placed on the rear holder to clearly define the area of interest. Important: when securing the probe in the hole, tighten the thumbscrew **VERY GENTLY** to protect the probe.

Mount the translator on the optics bench, and turn the translator knob to move the probe. Read the probe position to the nearest millimeter using the coarse scale in the rear of the translator. Then read the position to the nearest 0.01 mm using the fine scale on the translator knob.

### The Photometers

Depending on which PASCO optics system you're using, you have one of two Photometers: the PI-8020 High Sensitivity Photometer or the OS-9152B Student Photometer (see Figure 11). Both these instruments:

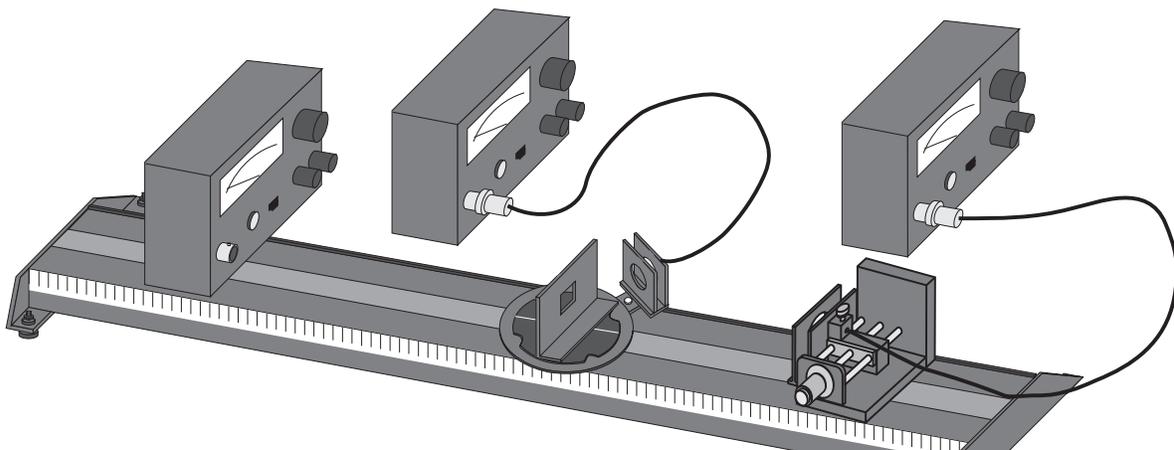


**Figure 11: The Photometers**

Setup 1: For measuring absolute intensities - position the Photometer so the light probe input connector is aligned with the optical axis of the optics bench. Do not use the fiber-optic probe.

Setup 2: For measuring intensity versus angle - connect the fiber-optic probe to the Angular Translator.

Setup 3: For measuring intensity versus vertical or horizontal position - connect the fiber-optic probe to the Linear Translator



**Figure 12: Setting Up the Photometers**

- measure relative intensities of incident light.
- include a 70 cm long, fiber optic probe that allows the measurement of light intensities with a spatial resolution of approximately 1 mm. (The linear and angular translators are used to accurately position the probe.)
- use a selenium photovoltaic cell as the light sensor
- provide a recorder output that is proportional to the measured light intensity
- have a variable sensitivity control that allows a full scale reading at any light intensity within the range of the instrument.

The key differences between the two photometers are:

- The OS-8020 High Sensitivity Photometer has a broader choice of intensity ranges ( $\approx 0.1 - 1,000$  lux), an illuminated scale, and a built-in power supply.
- The OS-9152B Student Photometer has a narrower choice of intensity ranges ( $\approx 1 - 300$  lux), and is powered by a 9 V battery.

### Setting Up the Photometers

The photometers can be used with or without the fiber-optic probe, as shown in Figure 12 (the figure shows only the Student Photometer, but both photometers are used in the same way).

When used without the probe, the light must fall directly onto the Light Probe Input connector. In most experiments in which the probe is not used, the photometer is positioned so that the connector is aligned with the optical axis of the bench.

When used with the probe, the intensity of the incident light can be sampled over very small areas ( $\approx 1 \text{ mm}^2$ ), providing accurate measurements of intensity versus position. To use the probe, connect the probe to the Light Probe Input connector. Then connect the free end of the probe to the probe receptacle in either the linear or angular translator. The probe can now be positioned very accurately to measure intensity versus angle (in a reflection or refraction experiment, for example) or intensity versus vertical or lateral position (in a diffraction experiment, for example).

► **IMPORTANT:** To prolong the life and efficiency of the fiber-optic probe:

- ① Do not bend the probe to a radius of less than 2 inches at any given point (do not coil tighter than a 4" circle).
- ② Do not bend the probe within three inches of either end.
- ③ Take care not to scratch or mar the end of the probe. If the probe end becomes scratched or dirty, you can either clean it by lightly grinding the end on a fine grinding stone, or you can just cut off the tip of the probe with a razor blade. If you do, be sure that the cut is square.

### Making Measurements with the Photometers

For the most part, the operation of the two photometers is the same. In the following description, instructions that apply to only one of the photometers are marked with the appropriate icon. If there is no icon, the instructions apply to both instruments.

#### ① Zero the Meter Mechanically

- Before plugging in the OS-8020 Photometer, use a small screwdriver to adjust the Mechanical Zero screw (directly under the meter face) so that the meter reads zero. 

- Before turning on the OS-9152B Photometer, use a small screwdriver to adjust the Mechanical Zero screw (directly under the meter face) so that the meter reads zero. 

#### ② Connect the Power/Battery Check

- Plug the power cord into a standard 117 VAC, 60 Hz power outlet (or 220 VAC if so designated). 
- Set the power switch to the "Batt. Test" position. The meter needle should be deflected to the right of the "Replace Batt." line. If it isn't, then replace the battery (Note: The photometer is shipped with a battery, but it must be installed. To install or replace a battery, see the Maintenance section at the end of the manual.) 

#### ③ Zero the Meter Electronically:

- Cover the Light Probe Input connector so that no light reaches the sensor. A good technique is to place a rubber cork tightly over the input connec-

tor. A finger over the connector will not shut out the light effectively enough. (Note: a finger over the input connector *will* shut out the light effectively enough for the less sensitive Student Photometer.)

- With the input connector covered, set the sensitivity Range switch to the most sensitive range, and turn the Zero Adjust knob until the meter reads zero. The instrument is now zeroed on all ranges. Now turn the sensitivity Range switch to the highest range.

#### ④ Measuring Relative Intensities

► **IMPORTANT:** The photometer reading is proportional to the energy of the light that falls on its photovoltaic cell, which is in turn proportional to the intensity of the incident light and to the area of the cell that is illuminated. Therefore, for accurate and consistent results, the incident light should fall directly onto the Light Probe Input connector or fiber-optic probe, with a zero degree angle of incidence.

When using the photometers, intensity measurements are always made relative to some established reference value. If you were measuring the intensity of light after it passes through a polarizer, for example, you would first measure the intensity of light for a particular orientation of the polarizer (usually, but not necessarily, the orientation producing a maximum intensity of light). When measuring this reference intensity, you would adjust the photometer sensitivity so that the meter read 10 (full scale). You could then measure the intensity for different orientations of the polarizer. These subsequent measurements would be recorded as a percentage of the original measurement. For example, if the meter read 6.5, you would record the intensity as 65% of the reference value.

In general, to use the photometer to measure relative intensities:

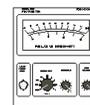
- Arrange the photometer to measure your reference intensity, usually the maximum intensity of light that you expect to measure.
- Turn the sensitivity Range switch clockwise until the photometer reads off scale.
- turn the sensitivity adjust knob counterclockwise until the meter reads exactly 10 (full scale).

- now - without touching the photometer controls - arrange the photometer to measure the other intensities you wish to measure. Read the intensities as a percentage of the original measurement.

► **NOTE:** After measuring your reference intensity, you can still use the sensitivity Range switch to change the range of the measurement. Just take into account the effect on the reading, as you would for any measuring instrument. For example, if the sensitivity Range switch were set to 100 when the reference source was measured, and then switched to 30, you would use the 0 - 3 scale and read your value as 0 - 30%. In a similar manner, if the sensitivity Range switch were turned to the 300 setting, you would use the 0 - 3 scale, and read your value as 0 - 300%.

#### ⑤ Output Jacks

- A pair of output jacks are located on the back panel of the photometer. These jacks provide a voltage that is proportional to the meter reading. The voltage for a full scale meter reading is 140 mV - 10 V @ 1 mA, depending on the range selection. The recorder output voltage is independent of the setting of the Variable sensitivity knob.



- A miniature phone jack is located on the front panel of the Model OS-9152B Photometer. This will provide approximate 1.5 V at 1 mA for a full scale meter reading. Important: The recorder output voltage is independent of the setting of the Variable sensitivity knob.



#### Specifications

##### For the OS-8020 only:

Sensitivity: approximately 0.1 to 1,000 Lux full scale in 1x and 3x ranges.

Meter: 8 cm scale length with 0 - 10 and 0 - 3 graduations.

Output: 140 mV at 1 mA. Banana jack connections on rear panel.



##### For the OS-9152B only:

Sensitivity: approximately 1 to 300 Lux full scale in 1x and 3x ranges.

Meter: 5 cm scale length with 0 - 10 and 0 - 3 graduations.



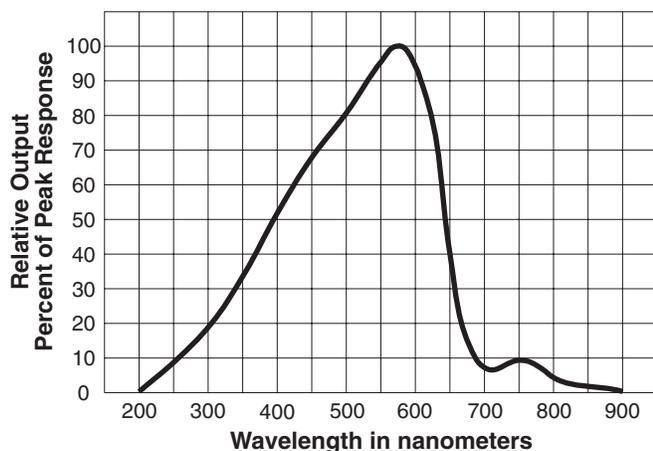
Output: 1.5 V at 1 mA. Miniature microphone connector.

Battery: One Burgess 2U6 or Eveready 216 9 volt battery. Approximately 100 hours life.

### For both photometers:

**Sensitivity:** The sensitivity Adjust knob permits any input within the dynamic range of the instrument to be used to provide a full scale reading. When photometer sensitivity is varied using the Range switch, measurements are proportional to the range setting, but only if the sensitivity Adjust knob remains unmoved between measurements.

**Spectral Response** - Typical selenium cell response (see Figure 13).



**Figure 13: Spectral Response of the Photometers**

**Controls:** Sensitivity Range, Sensitivity Adjust, Zero Adjust

**About Absolute Intensity Measurements:** The PASCO photometers are most effectively used for making relative light measurements only. However, accurate absolute measurements in units of lux can be made, subject to the following considerations.

- The selenium cell in the PASCO photometers does not have a corrected photo-optic response. The instrument is calibrated to a 2700°K tungsten filament lamp, such as is used in the OS-9102C Incandescent Light Source, and will indicate the correct intensity only for that source. If other light sources are used, absolute intensity measurements will be approximate only. (Accurate relative intensity measurements can be made with any light source.)

- Intensity readings are dependent on the total light energy striking the selenium cell, as well as on the spectrum of that light. Therefore, for accurate absolute measurements, the light must be incident on the full area of the selenium cell. This means that the light must fall with normal incidence directly into the Light Probe Input Connector. The light beam must be broad enough to cover the full area of the connector, and the intensity of the light must be uniform over the full area that strikes the connector.
- The fiber-optic probe restricts both the area and the intensity of the light that reaches the selenium cell. Therefore, when using the fiber-optic probe, only relative measurements can be accurately made.

## Components

The following section provides information and specifications on all of the optical components included in the OS-9254A Complete Optics System, which includes all the components available from PASCO scientific. For a list of the components that are included in each PASCO optics system, see Table 2 in the *Equipment* section of the manual.

➤ **NOTE:** All the components in the PASCO optics systems have been constructed to stand up under normal laboratory use. The holders are strong and the components, where possible, are recessed for protection. However, care should be taken to avoid touching or scratching the optical surfaces of all components.

When cleaning components:

- Use a very soft cloth, or better yet, use lens tissue, for the optical surfaces.
- Use only alcohol or mild, soapy water as a cleaning agent. Other solvents may attack the plastic holders.

## Lenses and Mirrors



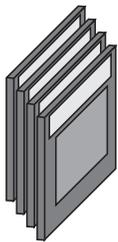
All lenses are made of glass. The mirrors are made of front-surface, aluminum-coated glass. Lenses and mirrors are mounted in 50 x 50 mm acrylic holders, and are recessed to protect the optical surface. The type of component and its focal length (if it has one) is printed on the label on each holder.

The available lenses and mirrors are listed in Table 4.

**Table 4: Available Lenses and Mirrors**

Catalog Number	Focal Length	Type
Lenses:		
OS-9131	-22 mm	Concave
OS-9132	18 mm	Convex
OS-9133	48 mm	Convex
OS-9134	127 mm	Convex
OS-9135	252 mm	Convex
Mirrors:		
OS-9136	N/A	Flat
OS-9137	25 mm	Concave

**Spectral Filters (four slides)**

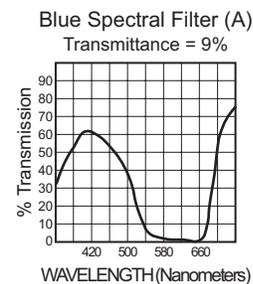
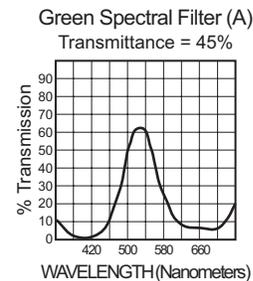
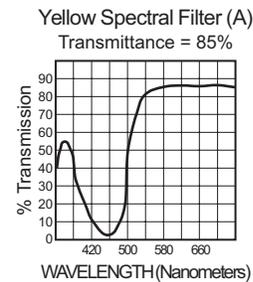
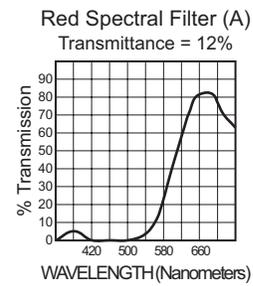


Four spectral filters are listed in Table 5.

**Table 5: Available Spectral Filters**

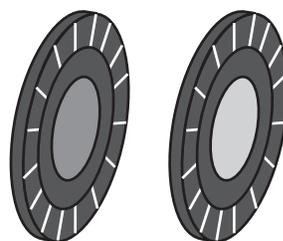
Catalog Number	Color
OS-9111	Red
OS-9112	Yellow
OS-9113	Green
OS-9114	Blue

The spectrophotometric absorption curves for the filters are shown in Figure 14.



**Figure 14: Spectrophotometric Absorption Curves for PASCO Colored Filters**

**Polarizer, 140 nm Retarder**



The polarizers and the retarder are mounted in round acrylic holders with degree scales. The shoulder on the back of the holder fits into the rectangular hole of the component holders, and the components are easily

turned to vary the angle of polarization or the retarding axis. The indicator line on the ledge of the component holder indicates the angle.

The polarizing and retarding materials are mounted in the holders with the polarizing and retarding axes parallel ( $\pm 2^\circ$ ) to a line passing between the  $0^\circ$  and  $180^\circ$  graduations on the degree scale.

The polarizing material is Polaroid Type HN-32. It is a neutral color linear polarizer having a total luminous transmittance of 32%, and an extinction transmittance of about 0.005%. The transmittance spectrum for this material is shown in Figure 15.

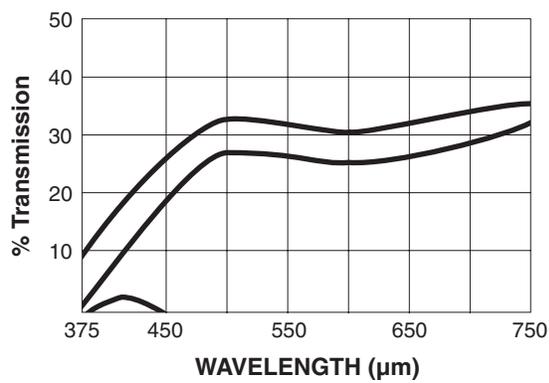


Figure 15: Polar Transmittance Spectrum

The retardance of the retarder may be increased by varying the angle of incidence. Figure 16 shows the increase of retardance as a function of the incident angle. A good method for varying the angle is to mount the retarder in the special component carrier of the angular translator. By rotating the translator table, the angle of incidence can be accurately varied.

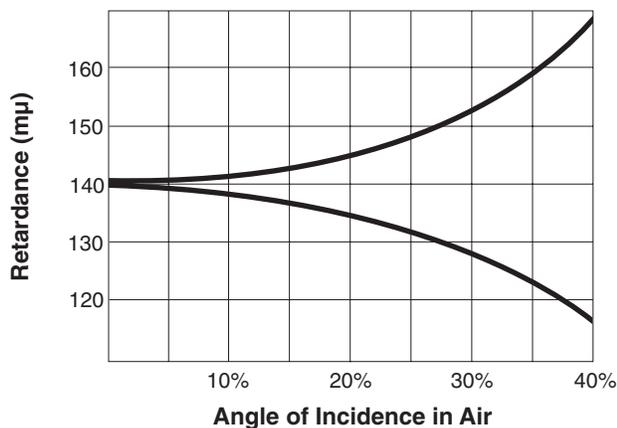
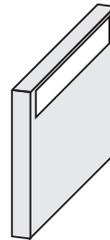


Figure 16: Retardance Versus Angle of Incidence

► **CAUTION:** The surfaces of the polarizers and retarder are very easily scratched, and should be touched as little as possible. (The surfaces are cellulose acetate butyrate.)

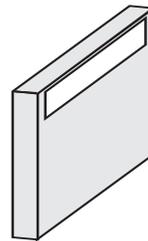
### Glass Plate



Size: 50 x 50 x 6 mm

Refractive Index: 1.518 (at 588.9 nm)

### Acrylic Plate



Size: 50 x 50 x 19 mm

Refractive Index: 1.48 - 1.50

### Prism



Angles:  $90^\circ$ ,  $45^\circ$ ,  $45^\circ$

Refractive Index: 1.5

Material: BK-7 Glass

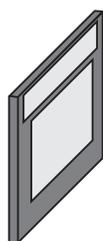
► **NOTE:** the magnetic pads are strong enough to hold the prism with the steel base in a vertical position.

### Crossed-Arrow Target



The crossed-arrow target is a useful object for object/image experiments. The fine lines on the horizontal arrow are a millimeter scale, which, when used in conjunction with the millimeter scale on the viewing screen, provides a convenient measure of magnification. The sharp edges and symmetrical shape are helpful for observing and analyzing spherical and chromatic aberration.

### Diffuser



The diffuser scatters light for experiments in which a relatively uniform illumination is required. The diffuser material is a thin sheet of acetate with a matte finish.

### Variable Diaphragm

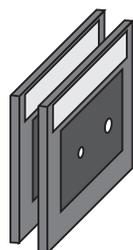


Aperture limits: 1.25 - 10.0 mm

Number of leaves: 10

To vary the aperture, push the handle up or down.

### Light Source Apertures (two slides—OS-9118, OS-9119)



Aperture widths: 0.5, 0.75 mm (OS-9118)  
1.0, 2.0 mm (OS-9119)

Use the light source apertures to collimate the light coming from the incandescent light source. You can place the slide on a component holder, or directly over the aperture of the light source.

### Photometer Apertures



Aperture Widths: 0.1, 0.2, 0.5, and 1.0 mm

The photometer apertures can be used to vary the resolution of the fiber optic probe of the photometer. For accurate resolution, the tip of the optic probe must be flush against the aperture. This is most easily accomplished using the linear or angular translator as follows (see Figure 17).

- ① Place the aperture slide on the rear-most holder of the linear or angular translator (the holder closest to the hole for the fiber-optic probe).
- ② Before inserting the probe, look through the hole and position the aperture slide so the desired aperture is centered in the hole.
- ③ Insert the fiber-optic probe into the hole so that the tip is flush against the aperture.

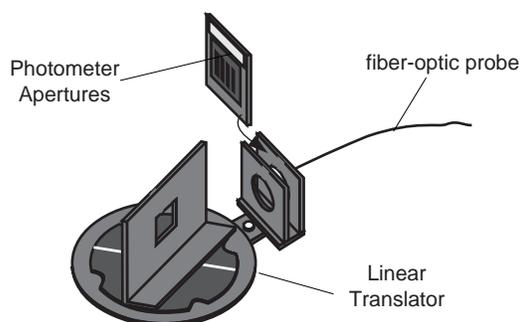
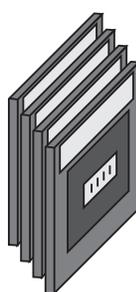


Figure 17: Using the Photometer Apertures

### Interference and Diffraction Apertures (4 slides—OS-9165A, B, C, and D)



Slide 1 (OS-9165A): Four single slit apertures of different widths

Slide 2 (OS-9165B): Four double slit apertures of different widths and slit spacing

Slide 3 (OS-9165C): Four multiple slit apertures (2 - 5 slits), constant slit width and slit spacing

Slide 4 (OS-9165D): Two circular apertures and two aperture arrays

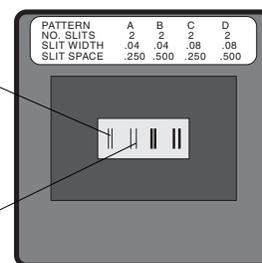
Material: 0.005 mm electroformed nickel

Tolerances:  $\pm 0.005$  mm

Pattern A is a double slit pattern. Each slit is 0.04 mm wide, and the distance between the two slits, from center to center, is 0.25 mm.

Pattern B is also a double slit pattern. Each slit is 0.04 mm wide, and the distance between the two slits, from center to center, is 0.50 mm.

The dimensions of patterns C and D are determined similarly.

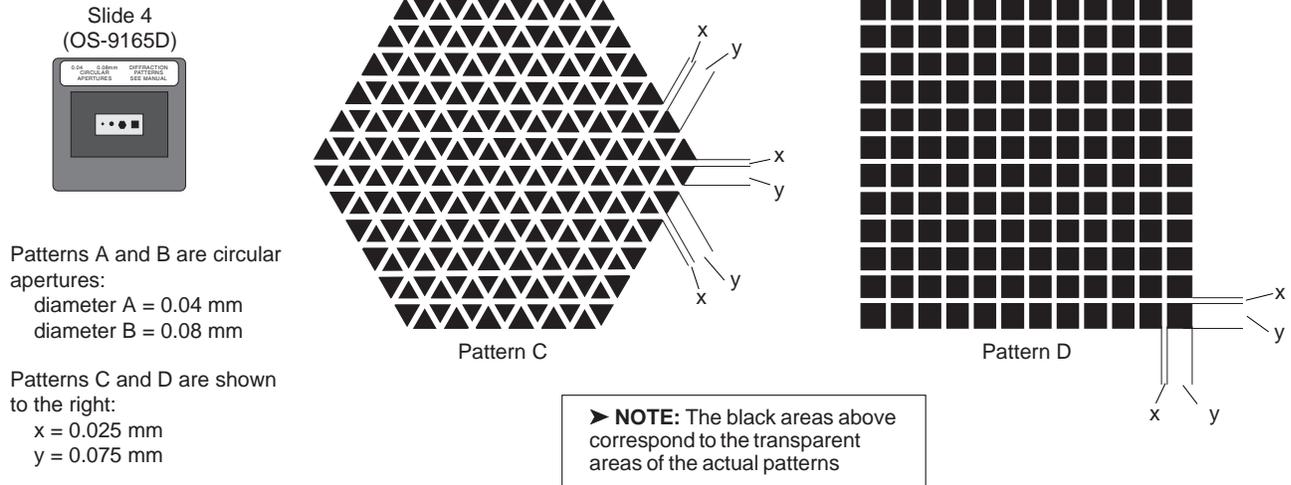


Slide 2 (OS-9165A)

Figure 18: Slit Dimensions

This collection of 4 slides contains 16 slit and aperture patterns appropriate for interference and diffraction experiments. These aperture patterns can be illuminated using either the incandescent light source or the laser. However, if you wish to project the diffraction patterns onto the viewing screen, the laser should be used.

Each slide is labeled with the dimensions of its four patterns. On each slide, the aperture patterns are labeled from A - D, with A corresponding to the left-



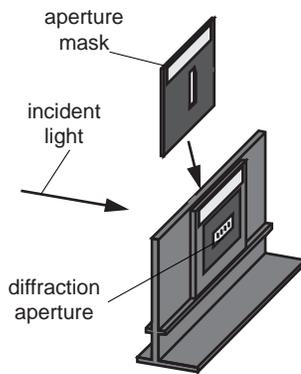
**Figure 19: Circular Apertures and Aperture Arrays**

most pattern, and D corresponding to the right-most pattern.

Slides 1 - 3 are for single, double, and multiple slit diffraction. See Figure 18 for an explanation of the slit dimensions. Note: Slit Space, the spacing between slits, is measured from the center of one slit to the center of the adjacent slit.

Slide 4 is for diffraction from circular apertures and aperture arrays. The diameter of the circular apertures, patterns A and B, are indicated on the slide (0.04 and 0.08 mm, respectively). The dimensions for the aperture arrays are shown in Figure 19.

**NOTE:** When using these slides, it's important that the light illuminate only one aperture pattern at a time. You can use the Aperture Mask (OS-9139) for this purpose, as shown in Figure 20. Just place the slide with the diffraction aperture on one side of a component holder and the aperture mask on the other.



**Figure 20: Using the Aperture Mask**

**Diffraction Grating**



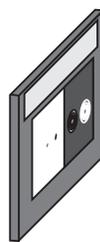
Type: Transmission, plastic replica diffraction grating  
Ruling: 6000 lines per centimeter

**Viewing Screen with Metric Scale**



40 mm scale on 45 x 45 mm white screen

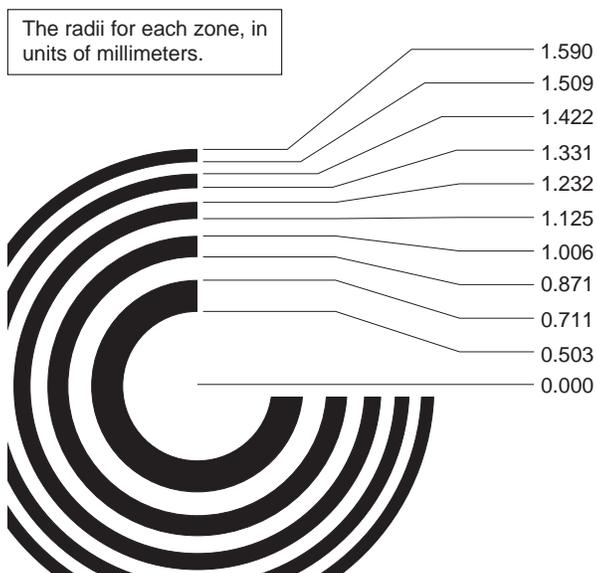
**Opaque Points and Fresnel Zone Plates**



Opaque Points: Circular shape, with diameters of 0.25, 0.50, and 1.0 mm.

Tolerances:  $\pm 0.05$  mm

Fresnel Zone Plates: Figure 21 shows the radii of the zones. The two zone plates on the slide are complementary; the opaque zone of one is the transparent zone of the other. So the radii of the zones are the same for both plates.



**Figure 21: Fresnel Zone Radii**

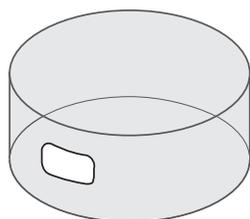
**Aperture Mask**

Aperture Size: 5 x 18 mm



The aperture mask is most frequently used with a set of slits or apertures to insure that light is incident on only one set of slits or one aperture. Place the slit or aperture on a component holder, and place the aperture mask on the other side of the same holder (see Figure 20).

**Glass Dispersion Tank**



The dispersion tank is 90 mm in diameter, 50 mm in depth, and is made of Pyrex. It is used to hold a solution for experiments in light scattering.

**Hologram**

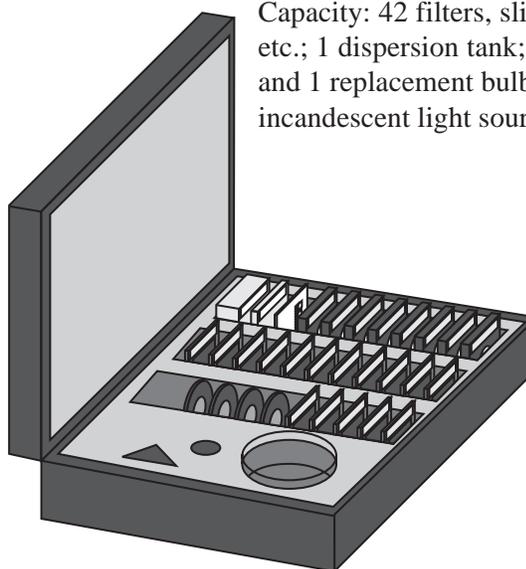


Transmission type hologram

Picture: Chessman

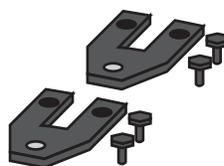
See Experiment 13 for instructions on viewing the hologram.

**Fitted Case for Optical Components**



Capacity: 42 filters, slits, lenses, etc.; 1 dispersion tank; 1 prism; and 1 replacement bulb for the incandescent light source.

**Optical Bench Couplers**



The optical bench couplers are used to connect and align two or more PASCO optics benches, and also to connect and align the laser alignment bench with the optics bench. For instructions on using the couplers, see the procedure for setting up the Laser Alignment Bench in the *Using the Equipment* section, earlier in the manual.

**Adapting non-PASCO Components**

**Using Adhesive Backed Steel Foil**

Adhesive backed steel foil is available in assorted sizes (OS-9148). It is easily cut and can be attached to non-PASCO components so that they will mount magnetically onto the PASCO component holders.

To use the adhesive backed steel foil:

► **IMPORTANT:** When using the adhesive backed steel, note that the adhesive on the back of the foil is strong and permanent. Position the foil correctly the first time; there's no second chance.

- ① Cut the foil to the proper size with an ordinary pair of scissors. If the scissors produce a burr in the foil, cut in such a manner that the burr is toward the adhesive (paper covered) side of the foil.
- ② Before removing the protective paper backing, bend the foil very slightly so that the paper-covered side is slightly concave. This will prevent the edges of the foil from peeling away once the foil is mounted.
- ③ Remove the protective paper, align the foil over its proper position, and press down.

## Experiments with the Advanced Optics Systems

This manual includes detailed instructions for 13 experiments that can be performed with the various PASCO optics systems. Of course, considering the variety of the components, it isn't possible to present all the possible experiments. A more complete list of possible experiments is provided in Table 6.

**Table 6: Systems and Experiments**

<b>Complete System</b>	
<b>Advanced System</b>	
<b>Intermediate System</b>	
<p><b>1. Reflection:</b></p> <ul style="list-style-type: none"> <li>- angle of incidence = angle of reflection</li> <li>- reflection from media interfaces (air, mirror, glass, acrylic)</li> <li>- reflection, transmission, and absorption coefficients.</li> </ul>	<p><b>6. Wave Nature of Light:</b></p> <ul style="list-style-type: none"> <li>- Young's experiment</li> <li>- spatial coherence.</li> </ul>
<p><b>2. Refraction:</b></p> <ul style="list-style-type: none"> <li>- Snell's Law</li> <li>- indices of refraction (air, mirror, glass, acrylic)</li> <li>- critical angle</li> <li>- prisms: (dispersion, angle of minimum deviation).</li> </ul>	<p><b>7. Diffraction:</b></p> <ul style="list-style-type: none"> <li>- from single and multiple slits</li> <li>- airy disk</li> <li>- resolution limit of lenses</li> <li>- Fresnel zone plates</li> <li>- diffraction gratings (transmission and reflection types).</li> </ul>
<p><b>3. Thin-lens Optics:</b></p> <ul style="list-style-type: none"> <li>- focal points</li> <li>- image formation and magnification</li> <li>- spherical aberration, coma, and astigmatism, depth of field, Foucault knife test.</li> </ul>	<p><b>8. The Laser:</b></p> <ul style="list-style-type: none"> <li>- laser theory</li> <li>- laser beam characteristics</li> <li>- spatial filtering</li> <li>- beam spreader.</li> </ul>
<p><b>4. Interference from Multiple Reflections.</b></p>	<p><b>9. Polarization II:</b></p> <ul style="list-style-type: none"> <li>- retardation plates</li> <li>- by scattering</li> <li>- circular polarization</li> </ul>
<p><b>5. Polarization I:</b></p> <ul style="list-style-type: none"> <li>- dichroic polarizers</li> <li>- Brewster's angle.</li> </ul>	<p><b>10. Holography (transmission type).</b></p>
	<p><b>11. Optical Activity.</b></p>
	<p><b>12. Scattering:</b></p> <ul style="list-style-type: none"> <li>- Rayleigh</li> <li>- diffraction.</li> </ul>
	<p><b>13. Interferometry:</b></p> <ul style="list-style-type: none"> <li>- Michelson</li> <li>- Fabry-Perot</li> <li>- Twyman-Green</li> <li>- indices of refraction in gases.</li> </ul>

## *Experiment 1: Reflection*

### EQUIPMENT NEEDED

- Incandescent Light Source (OS-9102C) – Flat Front Surface Mirror (OS-9136)
- Optics Bench (OS-9103) – Viewing Screen with Metric Scale (OS-9138)
- Angular Translator (OS-9106A) – Aperture Mask (OS-9139)
- Component Carrier (OS-9107) – Photometer with optic probe (optional)
- Glass Plate (OS-9128) – 0.5 mW Laser (optional)
- Acrylic Plate (OS-9129)

### Purpose

Light is a series of electromagnetic waves, and, according to laws of propagation of such waves, they theoretically should be reflected to a certain degree at the interface between two mediums (such as air and glass) which have sufficiently different characteristics. Everyday we observe light reflected from silvered surfaces such as mirrors, from the surface of water, and from ordinary window glass. The purpose of this experiment is to find out if light “obeys” any specific laws during reflection.

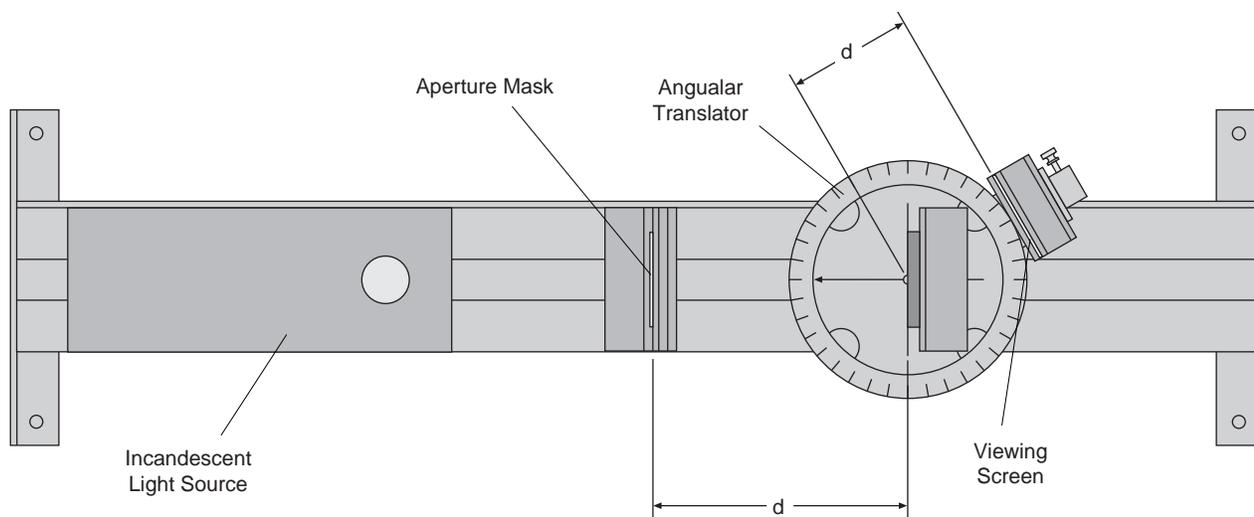
### Theory

Although light behaves as a wave, if the dimensions used in an experiment are sufficiently large, we can neglect diffraction and interference effects. Hence, in this experiment we represent the propagation of light as a series of rays which follow straight lines (in optically homogeneous mediums). All the results from ordinary geometry can then be used to aid our investigation.

### Procedure

#### *Part I: Angles Of Incidence And Reflection*

- ① Position the incandescent light source on the left end of the optical bench, and place the angular translator about 25 cm. From the end of the light source housing. Make sure the  $0^\circ$  marks lie on a line parallel to the bench. Finally adjust the rotating table so that the scored line run perpendicular and parallel to the bench.
- ② Attach the aperture mask to the standard component carrier and place it between the light source and angular translator so that the mask is  $d$  centimeters from the center of the translator. The distance  $d$  (about 6.5 cm) is the measured distance from the center of the angular translator to the first analyzer holder on the movable arc (see Figure 1.1).
- ③ Center the viewing screen of the special component carrier designed for use with the angular translator, and place the assembly on the rotating table of the translator so that the front surface of the viewing screen coincides with the scored line on the table which runs perpendicular to the optical bench.



**Figure 1.1: Experiment Setup**

- ④ Now switch on the light and adjust the aperture mask's position (don't move the component carrier), until the entire image is on the viewing screen. With the aid of the millimeter scale marked on the screen, center the image horizontally. Turn the screen  $90^\circ$  and center the image vertically.
- ⑤ Now replace the viewing screen with the flat surface mirror such that the mirror surface coincides with the perpendicularly scored line. Move the viewing screen to the first analyzer holder on the movable arm.
- ⑥ Rotate the table a set number of degrees (for example,  $30^\circ$ ), and then move the arm until the reflected image is centered horizontally on the viewing screen. Record the angle which the arm marks with the mirror. Repeat for various settings of the rotating table. What is the relation between the angle of incidence and the angle of reflection? (Angle of incidence is the angle the incident ray makes with the normal to the reflecting surface; similarly for the angle of reflection.)
- ⑦ Rotate the viewing screen and measure the vertical position of the reflected image. Now measure the vertical position of the aperture mask. With this data determine what spatial relationship exists between an incident ray of light, the reflected ray, and the normal to the mirror at the point of reflection. (e.g. Do they lie in the same plane?).

## **Part II: Reflections From Glass And Acrylic**

- ① Replace the flat mirror in Part I with the glass plate, taking care that the front surface of the glass coincides with the scored line.
- ② Rotate the table until the glass plate rests at a convenient angle with the optical bench.
- ③ Move the arm until the reflected image is visible on the viewing screen. How many images of the rectangular aperture are there? Why?
- ④ The brightest image (the one on the left) is the reflection from the front surface of the glass. Center this image on the screen and record the angle which the translator arm makes with the glass plate. Repeat the procedure with the rotating table set at several different angles. What is the relation between the angle of incidence and angle of reflection?

- ⑤ Measure the height of the middle of the reflected image. As in Part I, determine whether the incident ray, reflected ray, and normal to the glass at the point of reflection are all in the same plane.
- ⑥ Replace the glass plate with the acrylic plate and repeat 1-4. Does the law asserting equality between the angles of incidence and reflection seem to vary with the material used as the reflecting surface?

**Optional**

- ① Secure the fiber optic probe in the hole behind the analyzer holders, and use the photometer to detect the relative intensities of reflected and transmitted light for varying angles of the glass plate. Graph your results. Ambient room light must be kept low when using the photometer.
- ② The entire experiment can be performed very nicely using the laser instead of the incandescent source. The aperture mask is not needed with the laser. Take care to adjust the laser beam as in the equipment instructions so that the beam is parallel to the bench. With the laser, you should be able to see three or four multiple reflections from the glass plate.

**Notes:**

## ***Experiment 2: Refraction***

### **EQUIPMENT NEEDED**

- Incandescent Light Source (OS-9102C) – Flat Front Surface Mirror (OS-9136)
- Optics Bench (OS-9103) – Viewing Screen with Metric Scale (OS-9138)
- Angular Translator (OS-9106A) – Aperture Mask (OS-9139)
- Component Carrier (OS-9107) – Photometer with optic probe (optional)
- Glass Plate (OS-9128) – 0.5 mW Laser (optional)
- Acrylic Plate (OS-9129)

The velocity of light in free space is very close to  $3 \times 10^{10}$  cm/sec., and moreover, the velocity is the same for all wave lengths. The situation is different in most material substances. With few exceptions, the velocity of light in material substances is less than the velocity in free space. Not only is the velocity less, it varies with the wavelength of the light passing through the medium.

If light travels through two mediums with different velocities, the wave nature of the light causes its direction to be altered as it passes from one medium to the other. This phenomenon is referred to as refraction. We can define the index of refraction ( $n$ ) of a material to be the ratio of the velocity of light in free space ( $c$ ) to its velocity in the given material ( $v$ ). Since the velocity ( $v$ ) varies with wavelength, we must specify the corresponding wavelength when referring to an index of refraction.

The purpose of this experiment is to determine the relation between the direction of the incident ray, the direction of the refracted ray, and the index of refraction. The index of refraction for glass (for example) only varies by less the 2% throughout the visible spectrum. Therefore using the incandescent light source in the experiment doesn't introduce much error. With the laser we can theoretically gain much more accuracy.

### **Procedure**

#### ***Part I: Index Of Refraction***

- ① Take a square piece of paper about 5 centimeters on a side, and carefully draw a millimeter scale across the middle (you can trace the scale printed on the viewing screen.)
- ② Using the same equipment setup as in Experiment 1, put the paper between the glass plate and the special component carrier on paper between the glass plate and the special component carrier on the angular translator. The magnetic surface will hold the glass plate and paper in place. The millimeter scale should run horizontally.
- ③ Adjust the position of the special component carrier until the back surface of the glass plate coincides with the perpendicularly scored line on the table.
- ④ With the glass plate sitting perpendicular to the bench, adjust the position of the aperture mask so that one vertical edge of the image on the paper lines up with the scored line on the table which is parallel to the bench. If the glass does not alter the light's path, the vertical edge which was centered should remain centered although the translator's table is rotated.

- ⑤ Rotate the table and record what happens to the previously centered edge. Is the incident ray refracted toward or away from the normal to the glass? Figure 2.1 shows how to calculate the index of refraction given the angle of rotation and the edge displacement of the image.

► **NOTE:** Using this method, a small error is introduced since we are not certain that the light very near to the image's edge was exactly perpendicular to the glass plate in the beginning (Why?). Hence the measured value of  $\theta$  (as in the figure) is not accurate. The methods under Part II give more accurate results.

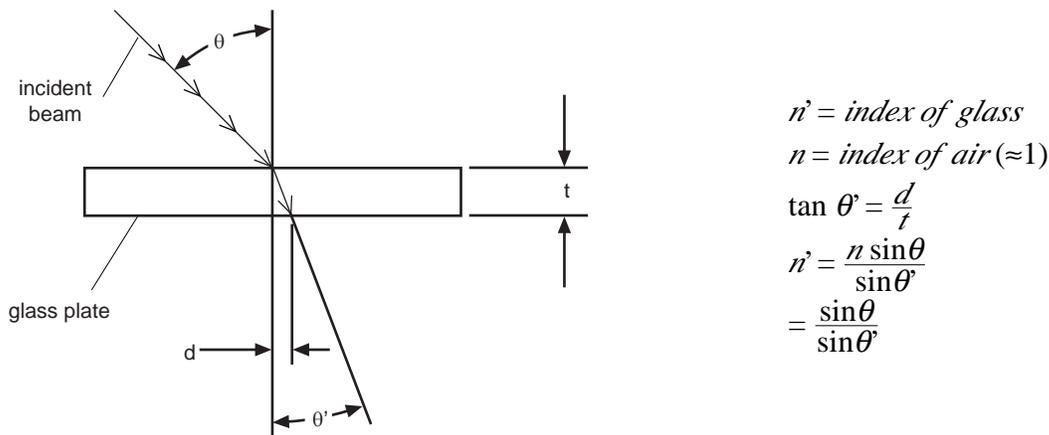


Figure 2.1: Calculating the Index of Refraction

- ⑥ Replace the glass plate with the acrylic plate and determine the index of refraction for acrylic.

## Part II: Alternate Methods

- ① Remove the paper from between the glass plate and component carrier. With the glass plate perpendicular to the bench, put the viewing screen directly behind the plate and adjust the aperture mask to center the image on the screen. Rotate the table to a convenient angle. Light is refracted toward the normal when passing from air to glass. Is the same true when light propagates from glass to air? By observing the position of the image on the viewing screen, you can see that the refraction must be away from the normal at a glass-air interface. (See Figure 2.2)
- ② The ray passing out of the glass is parallel to, but displaced from the incident ray. By measuring the displacement of both vertical edges of the image, and averaging we can closely estimate the displacement of a ray in the middle of the image. Such a ray was perpendicular to the glass plate before it was rotated.

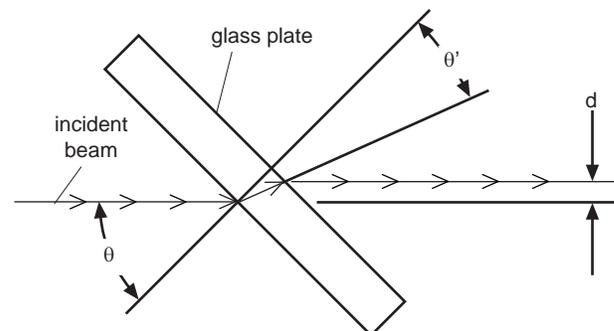


Figure 2.2

- ③ Let  $d$  be the displacement of the image,  $\theta$  the angle of incidence (i.e. between refracted ray and normal), and  $t$  the thickness of the glass plate. Then compute  $\theta'$  from the formula,

$$(\cos\theta) (\tan\theta') = (\sin\theta) \times \frac{d}{t}$$

- ④ Taking the index of refraction of air ( $n$ ) to be 1.0, verify that

$$n' = \frac{n \sin\theta}{\sin\theta'}$$

is a constant for various  $\theta$ . In fact, this is Snell's law where  $n'$  is the index of refraction of the material used.

- ⑤ Another method of calculating the refractive index is to observe the reflected images. There should be at least two reflected images from the plate. Measure the distance between them (i.e. between their centers). Then if  $d$  is the distance separating them,  $t$  is the plate thickness,  $\theta$  is angle of incidence, and  $\theta'$  is angle of refraction, we have,

$$\tan\theta' = \frac{d}{2t \cos\theta}$$

- ⑥ Repeat both methods with the acrylic plate.

As an option, a laser can be used in all three methods to calculate the index of refraction. No aperture is then needed.

### Part III: Critical Angles And Deviation

- ① Remove the special component carrier from the translator table and replace it with the  $90^\circ - 45^\circ - 45^\circ$  prism.

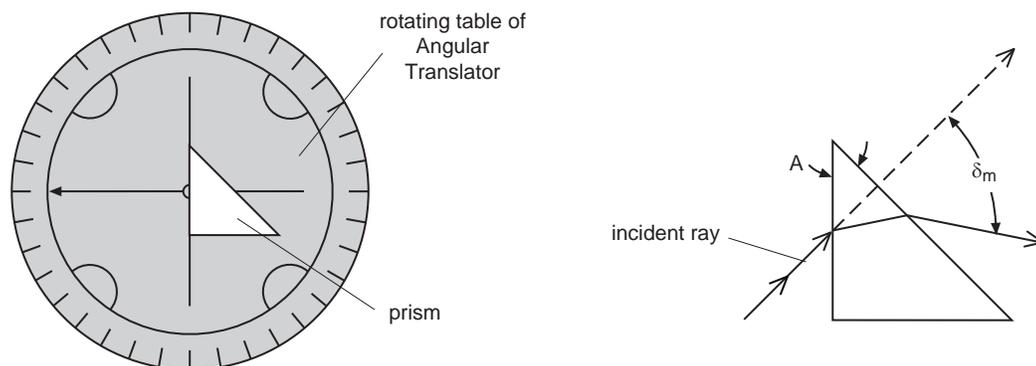
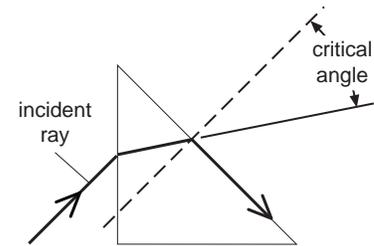


Figure 2.3: Experiment Setup

- ② With the scored lines running perpendicular and parallel to the bench, position the prism so that one of the small faces is centered on the table and coincides with the perpendicularly scored line. (See Figure 2.3).

- ③ Check the position of the aperture mask so that the center of the light beam travels directly over the center of the table and parallel to the bench.
- ④ Move the arm until the refracted beam is imaged on the viewing screen.
- ⑤ Now rotate the table and watch the movement of the image (move the arm if necessary). Although the prism is continually rotated in the same direction, note that the image moves in one direction, and then begins moving in the other direction. The point where the image reverses direction coincides with the angle of minimum deviation. That is, at that particular angle of incidence, the light beam is deviated least from its original path.
- ⑥ Knowing the angle corresponding to minimum deviation (see Figure 2.3), calculate the index of refraction of the prism material from:

► **NOTE:** The edges of the image are colored. Why? This phenomenon is called dispersion.



**Figure 2.4**

- ⑦ Rotate the table until the refracted beam is parallel to the large surface (slanted surface) of the prism. In this position no light propagates through the slanted surface; all the light is internally reflected. (See Figure 2.4)
- ⑧ Knowing the angle of incidence ( $\theta$ ) at which this occurs we can calculate the angle of incidence ( $\theta'$ ) of the light in the prism as it reaches the slanted surface. The angle  $\theta'$  is called the critical angle.
- ⑨ The  $90^\circ - 45^\circ - 45^\circ$  prism is designed so that any light normal to the slanted surface is totally internally reflected. Position the prism to observe this phenomenon.

### Optional

Collimate the incandescent beam with the 48 mm and 18 mm lenses. Then adjust the prism for maximum deviation. By placing spectral filters over the light source, note how the prism refracts the various colors.

## Experiment 3: Lenses

### EQUIPMENT NEEDED

- Incandescent Light Source (OS-9102C) – 48 mm F.L. Lens (OS-9133)
- Optics Bench (OS-9103) – 127 mm F.L. Lens (OS-9134)
- Component Carrier (4) (OS-9107) – 252 mm F.L. Lens (OS-9135)
- Variable Diaphragm (OS-9117) – Aperture mask (OS-9139)
- Crossed Arrow Target (OS-9121) – 0.5 mW Laser (optional)
- -22 mm F.L. Lens (OS-9131) – angular translator/component carrier (optional)
- 18 mm F.L. Lens (OS-9132) – 25mm F.L. concave front surface mirror (opt.)

### Purpose

A lens is merely an optical system which includes two or more refracting surfaces. From the geometry of light rays, it turns out that spherical refracting surfaces are most interesting and most practical. We define the first focal point of a lens to be the point  $F_1$  such that if a point source of light is placed at  $F_1$ , all rays will be parallel after passing through the lens. Similarly, the second focal point  $F_2$  is the common point which parallel light rays pass through after passing through the lens. In the case of a lens which is relatively thin compared to the distance from one surface to  $F_1$  or  $F_2$  the first and second focal lengths are the respective distances from  $F_1$  and  $F_2$  to the center of the lens. If the refractive index of the materials on either side of the lens is the same (e.g. if the lens is in air), the first and second focal lengths are equal to a common value ( $f$ ).

### Theory

If in a thin double convex lens, we take the radius of curvature ( $R_1, R_2$ ) to be positive for both surfaces, we can derive the equation ( $n$  is the refractive index of the lens material),

$$\frac{1}{f} = (n - 1) \left( \frac{R_1 + R_2}{R_1 R_2} \right)$$

In a lens system the image of an object often appears to be larger than the object itself; this is referred to as magnification. If  $s$  is the distance from the object to the lens, and  $s'$  the distance from the lens to the image, then the magnification  $m$  is calculated by;

$$m = \frac{s'}{s}$$

Moreover if  $d = s - f$  (i.e. distance from the object to the closest focal point) and  $d' = s' - f$ , then;

$$m = \frac{f}{d} = \frac{d'}{f}$$

In this experiment we wish to verify these theoretical results and to investigate the distortion (called aberration) that spherical lenses introduce into images.

## Procedure

### ***Part I: First Local Length***

- ① Position the incandescent light source at the left end of the optical bench.
- ② Attach a double convex lens to one component carrier and the viewing screen to another.
- ③ Position the lens and screen at the extreme right end of the bench so that the lens is between the light source and the screen. The further the lens is from the light the more parallel are the rays entering the lens.
- ④ Adjust the position of the screen until the image is as thin as possible. Then the distance between the middle of the lens and the screen is an approximation of the first focal length. Enumerate all the possible errors. Find the focal length of the other double convex lens. (The focal lengths of the plano-convex lenses are so large compared to the length of the optical bench that the incident light rays are not parallel enough to measure the focal length with any accuracy. We will use another method outlined below).
- ⑤ Attach the plano-concave lens to one side of a component carrier and attach the aperture mask to the other side. Position the assembly about 40 cm from the light source.
- ⑥ Place the screen behind the lens and notice that as you move the screen further from the lens, the image expands.
- ⑦ Measure the image width and corresponding distance from the lens to the screen for two different screen positions. Using simple geometry, calculate where the rays diverged by the lens would theoretically converge in a point in front of the lens. This is an approximation of the focal length.

### ***Part II: Second Focal Length***

- ① Attach a double convex or plano convex lens to a component carrier.
- ② The light source is a line filament, so if we consider only lateral dimensions the source is essentially a point source. The equipment instructions give the distance from the filament to the front surface of the light source (approximately 21 mm).
- ③ Adjust the lens position so that the image on the screen is the same width no matter where the screen is placed (i.e. the emergent rays are parallel). The distance from the lens to filament is the second focal length. Compare to the first focal length.
- ④ You cannot use the above method to measure the focal lengths of the 18 mm F.L. convex lens of the -22 mm F.L. plano-concave lens. These lenses cannot be positioned sufficiently close to the filament. Thus, as an alternative, place the 48 mm F.L. double convex lens between the light and the lens to be measured. The focal point of the first lens now becomes the point source for the second.

### **Part III: Improved Method**

- ① From the formulas in the introduction to this experiment, if the magnification is 1.0, then  $s=s'$ ,  $d=d'$ , and  $f=d$ . Hence, at such a lens position,  $s+s' = 4f$ .
- ② Place a double convex lens or a plano-convex lens between the crossed-arrow target and the screen. (All components on separate carriers.)
- ③ Adjust the position of the lens and screen until the image is in focus and is the same size as the original object. (The target has a millimeter scale on it.) At the final position, the distance from target to screen is four times the focal length.
- ④ With the focal length, use the formula in the introduction to compute the radius of curvature for the lenses (Assume  $R_1 = R_2$  for the double convex lenses; the radius of curvature of a plane is infinite.) Also verify Gauss' formula;

$$\left(\frac{1}{S}\right) + \left(\frac{1}{S'}\right) = \left(\frac{1}{f}\right)$$

### **Part IV: Magnification**

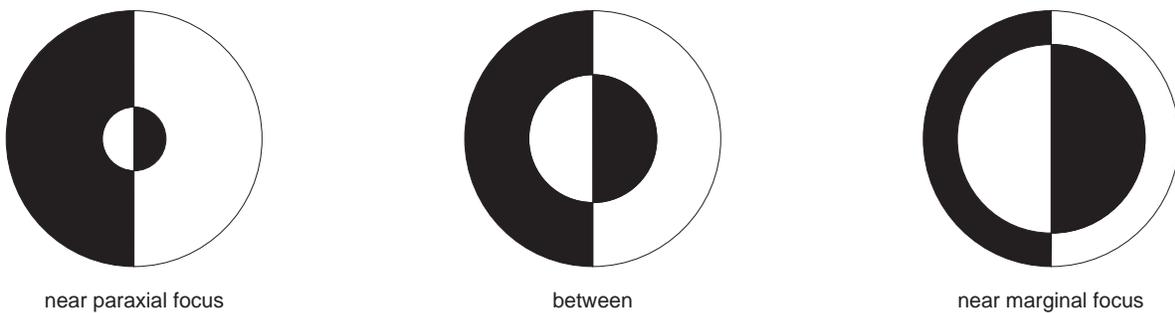
- ① Position a double convex lens or plano-convex lens between the crossed-arrow target and screen.
- ② Adjust the position of the lens until the image is focused.
- ③ Measure the distance from the target to the lens and from the screen to the lens. Calculate the theoretical magnification. (Use both equations).
- ④ Measure the actual magnification by measuring the distance between the scale markings on the image. Compare with theoretical results.
- ⑤ Repeat using several combinations of lenses.  
You can now assemble a beam spreader for the laser.
- ⑥ Attach the 18 mm F.L. double convex lens to the face of the laser.
- ⑦ Attach the 48 mm F.L. double convex lens to a component carrier and position the assembly so that the focal points of both lenses coincide. The beam should now have a larger cross-section but should still be parallel.

### **Part V: Aberrations**

#### **Spherical Aberration**

A spherical surface lens does not form a point image of a point object originally positioned on the lens axis. Instead the image is a line segment collinear with the lens axis. Thus there is no exact screen position where the image is “in focus”. Conversely, the point object can be moved slightly along the axis and still appear to be in focus. The amount of movement which maintains a given image sharpness is called the depth of field.

- ① Position the 18 mm F.L. double convex lens in front of the incandescent light source (about 30 cm. away). Attach a sharp razor blade to a component carrier, and position the assembly to the right of the 18 mm lens. Adjust the assembly position until the razor blade is in the focal plane of the lens. The lens image on the razor blade should be a small dot.



**Figure 3.1**

- ② Carefully adjust the razor blade on the carrier until the sharp edge cuts across the center of the focused dot. Place the viewing screen to the right of the razor blade and examine the image. It should resemble one of the patterns in Figure 3.1. Move the razor blade assembly slightly forward or backward and observe the pattern changes. (Note that the patterns only approximate Figure 3.1, since razor edges are not usually optically perfect.) This technique is the Foucault knife test for lenses. Convince yourself that the patterns are due to spherical aberrations. Try using the 48 mm F.L. lens.
- ③ Place the variable diaphragm just in front of the test lens. By varying the opening, notice that the patterns degenerate. A smaller aperture gives a more unique focal point. If you place the crossed-arrow target between the light source and the variable diaphragm, you can observe that the point where the image is in focus becomes more distinct as the aperture closes. Thus, depth of field varies inversely with aperture size. This phenomenon is familiar to all photographers.

### Coma

A point off the lens axis of a spherical surface lens is imaged in three dimensions. The tendency of a lens to spread the image of a point over a plane perpendicular to the lens axis is referred to as coma.

- ① Place the 48 mm F.L. lens to the right of the light source and position the 18 mm F.L. lens about 5 cm to the left of the first lens.
- ② Place the viewing screen on the far right and adjust the position of all components until a small sharp dot is focused on the screen.
- ③ Now carefully move the 18 mm lens (component carrier and all) perpendicular to the

bench and watch the image. The point will change into a small comet-like shape. This effect is due to coma.

### **Astigmatism**

This form of distortion arises from the same aberration as coma. However, astigmatism refers to the tendency of the lens to image an off-axis point in a dimension parallel to the lens axis.

- ① To observe astigmatism, use the Coma setup as described above.
- ② While the 18 mm lens is off center, move the screen forward or backward and observe that the image gradually changes from an ellipse to a distorted circle (circle of least confusion) to an ellipse perpendicular to the first one.

### **Optional**

- ① Using the concave mirror on the angular translator, investigate focal points and magnification of the mirror.
- ② The laser works just as well as the incandescent source in the above experiments. However, laser “noise” may make some images difficult to detect properly.

**Notes:**

## ***Experiment 4: The Wave Nature Of Light***

### **EQUIPMENT NEEDED**

- Incandescent Light Source (OS-9102C) – Diffuser (OS-9120)
- Optics Bench (OS-9103) – Electroformed Diffraction Slits (OS-9165B)
- Component Carrier (3) (OS-9107) – photometer with optic probe (optional)
- Photometer Apertures (OS-9116) – linear translator (optional)

### **Purpose**

Around 1800, the English scientist Thomas Young designed and performed an experiment which produced seemingly unexplainable phenomena. At least it was unexplainable in terms of the early “corpuscular” theory of light. Young observed the image of light passing through first one slit, then two slits closely spaced and parallel to one another. He used filtered light from a mercury arc to insure that he had nearly monochromatic light. The first slit insured that light striking the double slit further on had a definite phase relationship among various points on the wave front (i.e. coherence). The image that Young observed was a series of light and dark areas which did not represent a plain geometrical image of double slits. Furthermore, a point on the screen which was illuminated when one of the double slits was covered became dark when both slits were uncovered. A “corpuscular” theory (i.e. light = series of particles) cannot adequately explain this phenomenon.

We can reperform Young’s experiment and in fact eliminate the first slit. If we place the double slits far enough from the light source, the first single slit becomes unnecessary. This shows that there is a definite phase relationship between points on the wave front which pass through the double slits. In other words, in a small angle, light from an incandescent source is spatially coherent.

### **Procedure**

- ① Position the light source at the left end of the optical bench.
- ② Attach the diffuser, double-slits, and photometer apertures to three separate component carriers.
- ③ Position the double-slits about 20 cm from the light source. Place the photometer apertures between the light source and double slits.
- ④ Pick a sufficiently large single slit on the photometer aperture slide and adjust the position of this slit until one set of double slits is fully illuminated.
- ⑤ Position the diffuser behind the double slits and adjust its distance from the slits until there is a sharp geometrical image of the two slits. (View the image from the side of the diffuser which faces away from the light source.)
- ⑥ Move the diffuser slowly away from the slits until the sharp geometrical image becomes an interference pattern with several maxima and minima.
- ⑦ Adjust the single slit (i.e. one of the photometer apertures) until only one of the double slits is illuminated. Observe the image (it is not a clear image, but rather a diffraction pattern).

there is a sharp geometrical image of the two slits. (View the image from the side of the diffuser which faces away from the light source.)

- ⑥ Move the diffuser slowly away from the slits until the sharp geometrical image becomes an interference pattern with several maxima and minima.
- ⑦ Adjust the single slit (i.e. one of the photometer apertures) until only one of the double slits is illuminated. Observe the image (it is not a clear image, but rather a diffraction pattern).
- ⑧ Now illuminate both slits and observe the image. Notice that some points previously illuminated are now dark.
- ⑨ Move the double slits and diffuser to the far right of the bench and observe that the single slit is no longer necessary. (However, you still need some sort of edge to cover one of the double slits in order to examine the two different patterns. It is convenient to attach the aperture mask to the same component carrier as the double slits. Adjust the mask's position to allow one or two slits to be illuminated.)

### Optional

- ① Attach the photometer's fiber optic probe to the linear translator and use the translator to scan the images. Place a small aperture such as the light source apertures in front of the probe on the rear surface of the analyzer holder. Adjust the aperture so that light incident on it enters the probe. Using the aperture minimizes effects due to ambient light. Plot intensity versus position for both one slit uncovered and two slits uncovered.
- ② Measure the intensity of the bright middle band ( $I_{max}$ ) and then measure the intensity at the middle of the first shaded bands on either side ( $I_{min}$ ). Calculate the Michelson visibility coefficient ( $V$ ) from:

$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

This coefficient gives a measure of the coherence of the incident light. The value 1.00 indicates nearly perfect coherence.

## Experiment 5: The Laser

### EQUIPMENT NEEDED

- |   |   |
|---|---|
| <ul style="list-style-type: none"> <li>– Photometer (PI-8020 or OS-9152B)</li> <li>– 0.5 mW Laser (SE-9367)</li> <li>– Optics Bench (OS-9103)</li> <li>– Linear Translator (OS-9104A)</li> <li>– Component Carrier (5) (OS-9107)</li> <li>– Variable Diaphragm (OS-9117)</li> </ul> | <ul style="list-style-type: none"> <li>– Electroformed Diffraction Slits (OS-9165B)</li> <li>– -22 mm F.L. lens (OS-9131)</li> <li>– 18 mm F.L. lens (OS-9132)</li> <li>– 48 mm F.L. lens (OS-9133)</li> <li>– Viewing screen with metric scale (OS-9138)</li> <li>– Aperture mask (OS-9139)</li> </ul> |
|---|---|

### Purpose

This experiment is designed to familiarize the student with the basic characteristics of laser light. The laser is based on the phenomenon of stimulated emission. If an electron of a given atom is in an excited state (i.e. higher energy level than normal), and if a photon of proper frequency interacts with this electron, the electron is triggered into deexciting itself by emitting a photon. Moreover, the original photon continues on its way unchanged. This process continues in a chain reaction causing a “photon cascade”. When the cascade is sufficiently intense, it bursts through the partially reflecting mirrors of the laser cavity. This burst of light is almost perfectly coherent since the photons are all in phase. We can test the coherence in a manner similar to Experiment 4. Moreover, since the photons have the same frequency, the light is nearly monochromatic.

➤ **NOTE:** Due to the design of the lasing cavity, the laser beam is collimated (i.e. waves are “parallel”). Thus there is little loss of energy flux (i.e.  $\frac{\text{energy}}{\text{cm}^2}$ ) due to divergence of the light beam. The .5 mW he-Ne gas laser produces about 1/4 the energy flux of the sun. Although this energy level seems to be way below that which causes permanent eye damage, in order to insure safety, never look directly into the laser beam or its mirror reflection.

➤ **NOTE:** Allow the laser 1-1/2 hours to warm up before using it in any experiment requiring measurement of beam intensities. Otherwise the expansion of the glass laser tube causes the mirrors to move and hence the beam intensity varies radically.

### Procedure

#### Part I: Beam Characteristics

- ① Position the laser on the optical bench and align the beam following the procedure in the equipment instructions. The beam should then be parallel to the bench.

➤ **NOTE:** It is safe to view the laser beam’s image on the viewing screen, since the laser light reaching your eye is only a small fraction of the original beam. The rest of the beam has been diffused or absorbed by the screen.

- ② In a darkened room observe the color of the beam. There should be an intense red spot (from light emitted by neon) and perhaps some incoherent blue or green light (from light emitted by the helium).
- ③ Write on a white sheet with various colored marking pens. Attach the -22 mm F.L. lens to the front of the laser and view the colored writing as it is illuminated by the diverging laser light. (Keep the room dark.) Explain your observation.
- ④ With the beam still passing through the lens, observe the image on the screen. The irregularities in the image are due to impurities in the gas mixture and to imperfection in the laser tube.
- ⑤ Remove the lens. Observe the size of the beam's image at various distances from the laser (up to, say, 10 meters away). You can make accurate measurements with the photometer and calculate the divergence of the beam. To do this, we arbitrarily define the diameter of the beam as follows. If  $I$  is the intensity at the center of the beam at any given position, the diameter is the maximum distance between points of intensity,

$$\left(\frac{1}{2}\right) I$$

Since the beam is so intense, the photometer's shutter must be nearly closed in order to keep the readings on scale. (Observe also how  $I$  changes with the distance from the laser.)

## Part II: Coherence

- ① Following the same procedure as in Experiment 4 (except that the single slit is not needed), note the interference pattern.
- ② Use the photometer to make the measurements necessary to calculate the Michelson visibility coefficient (see Experiment 4).

**NOTE:** The laser beam also has a temporal coherence (i.e. the wave stays in a given phase for a length of time) which can be measured with an interferometer.

## Part III: Beam Spreader

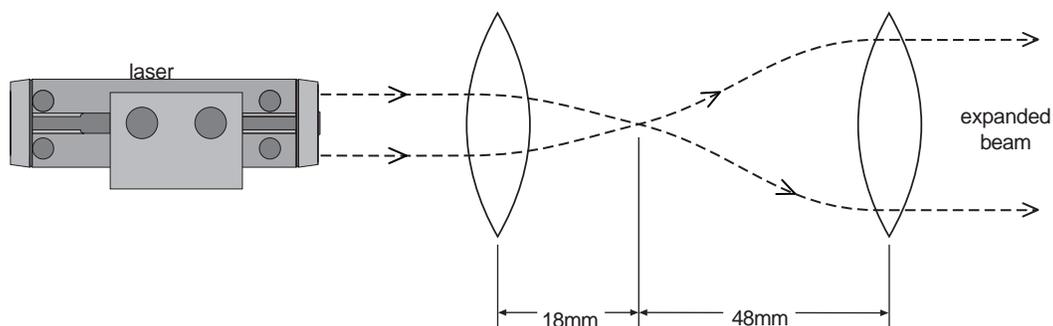


Figure 5.1: Experiment Setup

- ① Attach the 18 mm F.L. lens and 48 mm F.L. lens to component carriers and position them as in Figure 5.1. (The 18 mm F.L. lens on the front of the laser.)
- ② Adjust the position of the 48 mm F.L. lens until the emerging beam is again collimated. Check the collimation by observing the image size at various positions along the bench. If the beam is collimated, the image should remain fairly constant. This enlarged collimated beam makes some experiments much easier to perform.

### ***Part IV: Spatial Filtering***

Imperfections in the laser optics introduce unwanted “noise” into the beam. Some of the noise can be removed with the following procedure.

- ① Set up the beam spreader as in Part III.
- ② Attach the variable diaphragm to a component carrier and adjust the aperture to as small as possible. (The smaller light source apertures can also be used.)
- ③ Position the aperture assembly between the two lenses so that the focal point of the first lens falls at the center of the aperture.
- ④ The emerging beam will be much cleaner and gives sharper interference and diffraction patterns.

#### **Questions**

- ① When the beam is incident on a piece of paper, why does the image appear “grainy”? (See Experiment 6.)

**Notes:**

## ***Experiment 6: Interference From Multiple Reflections***

### **EQUIPMENT NEEDED**

- 0.5 mW Laser (SE-9367)
- Optics Bench (OS-9103)
- Component Carrier (5) (OS-9107)
- Glass Plate (OS-9128)
- Acrylic Plate (OS-9129)
- 18 mm F.L. Lens (OS-9132)
- 48 mm F.L. Lens (OS-9133)
- Viewing Screen with Metric Scale (OS-9138)

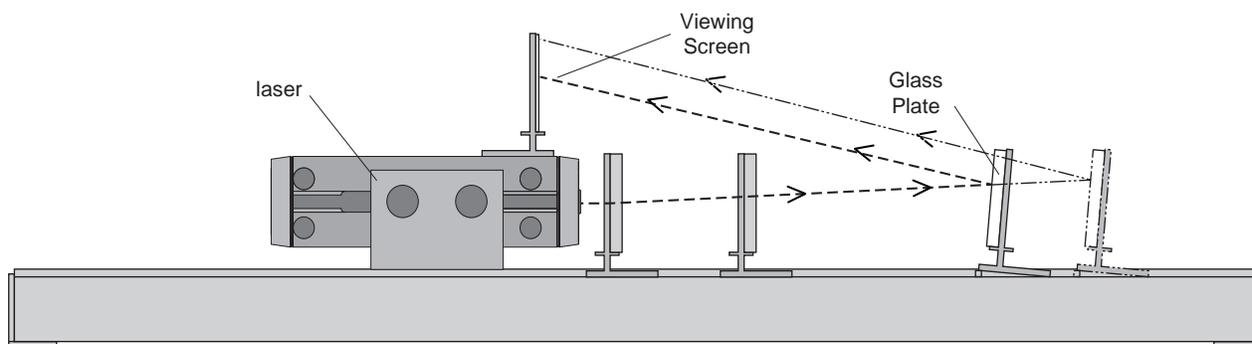
### **Purpose**

The patterns of light observed in Young's experiment (Experiment 4) are partially due to a wave phenomenon called interference. When two light waves are coincident and in phase, they re-enforce each other resulting in a wave of greater amplitude (i.e. brighter) than either. If the two waves are coincident and  $180^\circ$  out of phase, they cancel each other. Of course there are various degrees of re-enforcement or cancellation between total re-enforcement (called constructive interference) and total cancellation (called destructive interference).

The interference from two slits was dealt with qualitatively in Experiment 4 and will be dealt with quantitatively in Experiment 7. Therefore, in the present experiment, we will consider another case of interference; that is, interference from multiple reflections.

### **Procedure**

- ① Set up the laser. Position the lens to form a beam spreader.
- ② Attach the screen and glass plate to component carriers and position them as shown in Figure 6.1.



**Figure 6.1: Experiment Setup**

- ③ Use a small plate of some sort to prop the glass plate at a small angle. Adjust the angle until the image is seen on the screen above the laser.
- ④ Note the interference pattern. The irregularity of the pattern is due to deviations in the flatness of the glass plate. Move the plate on the carrier and observe the fringe changes.
- ⑤ Move the second lens of the beam spreader until the emerging beam diverges slightly. Observe the interference fringes.

- ⑥ Move the glass plate further down the bench so that its angle of inclination is reduced. Note the fringes. Can you explain the change of pattern, if any?
- ⑦ Repeat the procedure using the acrylic plate instead of the glass one. Account for the differences in the interference pattern.

## *Experiment 7: Diffraction By Slits*

### EQUIPMENT NEEDED

- |  |  |
|--|--|
| <ul style="list-style-type: none"> <li>– Photometer (PI-8020 or OS-9152B)</li> <li>– 0.5 mW Laser (SE-9367)</li> <li>– Optics Bench (OS-9103)</li> <li>– Linear Translator (OS-9104A)</li> <li>– Component Carrier (3) (OS-9107)</li> <li>– Photometer Apertures (OS-9116)</li> <li>– Aperture Mask (OS-9139)</li> </ul> | <ul style="list-style-type: none"> <li>– Electroformed Diffraction Slits (OS-9165A)</li> <li>– Electroformed Diffraction Slits (OS-9165B)</li> <li>– Electroformed Diffraction Slits (OS-9165C)</li> <li>– Electroformed Diffraction Slits (OS-9165D)</li> <li>– 48 mm F. L. Lens (OS-9133)</li> <li>– Viewing Screen with Metric Scale (OS-9138)</li> </ul> |
|--|--|

### Purpose

When light passes near the edge of an opaque object and then onto a screen, there appears to be some illumination in the area of the geometrical shadow. In other words, light fails to travel in straight lines when passing sharp edges. This phenomenon is called diffraction and occurs because of the wave nature of light.

There are basically two categories of diffraction effects. The first is Fraunhofer diffraction, which refers to diffraction produced when both the light source and screen are an infinite distance from the given obstacle. Fresnel diffraction is the second type and refers to diffraction produced when either the source or screen or both are at finite distances from the obstacle. We can observe Fraunhofer diffraction experimentally by using a collimated light source and placing the viewing screen at the focal plane of a double convex lens located behind the obstacle.

### Theory

Since light does not travel in straight lines near a sharp edge, there are many different path lengths from the obstacle to the screen. If there is sufficient difference in path length, two waves reaching the same point on the screen may be  $180^\circ$  out of phase resulting in destructive interference. On the other hand, constructive interference may also occur. The complete explanation of patterns observed in Young's experiment depends on both interference and diffraction effects.

If we use the incandescent source in studying diffraction, we still get interference patterns (see Experiment 4), but, since interference patterns depend on the wavelength of the light and since white light contains light of various wavelengths, the patterns are not sharp. The coherence and monochromaticity of laser light make it ideal for this experiment.

### Procedure

- ① Position the laser at the left end of the bench and align the beam as in the equipment instructions.
- ② Attach the slide of single slits on a component carrier and position the assembly midway down the bench.
- ③ attach the viewing screen to a component carrier and position it at the right end of the bench.
- ④ Adjust the slit position until the laser beam is incident on the full width of the slit.

- ⑤ Observe the diffraction pattern on the screen. Adjust the screen position if necessary to obtain image clarity. This is an example of Fresnel diffraction.
- ⑥ With the slits attached to the side of the component carrier facing the laser, attach the 48 mm F.L. lens to the other side.
- ⑦ Move the screen to the focal plane of the lens (i.e. 48 mm from the center of the lens) and observe the diffraction pattern. This is an example of Fraunhofer diffraction.
- ⑧ Now replace the screen with the linear translator (with fiber optic probe attached). Check that the unobstructed laser beam is at the proper level to be incident on the photometer probe (adjust if necessary). With the photometer shutter closed, adjust the translator so that the beam strikes the center of the probe. Now place the photometer aperture slide on the rear surface of the translator's analyzer holder so that the 0.1 mm slit crosses the center of the beam. With this set up, only light incident on the small slit will be read by the photometer.
- ⑨ Form another diffraction pattern and slowly scan the pattern with the translator. Plot intensity versus position. Verify that relative intensity falls off as;

$$\left(\sin \frac{\theta}{\theta}\right)^2$$

(See a standard text for theoretical derivation.) (If the laser has not warmed up for at least 1-12 hours, there may be fluctuations in the beam intensity due to the expanding glass laser tube.)

- ⑩ Form the diffraction pattern of multiple slits and slits of varying sizes and separation. (If the images are too small, magnify them with a system of lenses.)
- ⑪ Spread the beam of the laser and illuminate the special patterns on slide OS-9125. Observe the diffraction pattern (Fraunhofer and Fresnel). Attempt to deduce the dimensions of the original aperture arrangement.

## ***Experiment 8: Diffraction At Circular Edges***

### **EQUIPMENT NEEDED**

- Photometer (PI-8020 or OS-9152B) – Light Source Apertures (OS-9118)
- 0.5 mW Laser (SE-9367) – Light Source Apertures (OS-9119)
- Optics Bench (OS-9103) – Opaque Points and Fresnel Zone Plates (OS-9126)
- Linear Translator (OS-9104A) – -22 mm F. L. lens (OS-9131)
- Component Carrier (OS-9107) – 18 mm F.L. lens (OS-9132)
- Photometer Apertures (OS-9116) – 48 mm F. L. lens (OS-9233)
- Viewing Screen with Metric Scale (OS-9138)

### **Purpose**

Diffraction in all cases is due to the same property of light. However, in certain circumstances, the pattern is easily predicted with mathematical methods. Such is the case with the circular apertures. Airy was the first (1835) to calculate the diffraction pattern of a circular aperture, and hence the bright disk in the center of the pattern is referred to as the “Airy” disk.

A circular lens also tends to diffract the incident light waves. This is due to the fact that the incident wave travels through more glass at the center of the lens than at the edges. The resultant bending of light forms diffraction patterns with an Airy disk. The smallest size of such a disk represents the resolution limit of the lens. That is, the lens cannot distinguish between two points which are closer together than the diameter of the smallest Airy disk.

### **Theory**

Fresnel studied diffraction by considering the intensity at a given point due to approaching spherical wave fronts. He divided the wave front into annular sections such that the distance from the given point to the edge of the first disk is one-half wave length greater than from the point to the center of the disk. Similarly for the distance from the point to the edge of the second disk, as compared to the distance to the edge of the first disk. By blocking out alternate zones, we have in effect a lens. The diffraction effect focuses incident light at the given point. This sort of lens is the familiar Fresnel zone plate, and its design depends on the wavelength of the incident light, as well as the desired focal point.

### **Procedure**

#### ***Part I: Airy Disk***

- ① Position the laser on the bench and align the beam.
- ② Attach the smallest light source apertures to a component carrier and position it a few centimeters in front of the laser so that the beam is incident on the entire aperture.
- ③ Put the screen on a component carrier and place the assembly about 40 cm. from the circular aperture. Observe the pattern.

- ④ Try various sizes of apertures and then use the linear translator and photometer to scan the pattern (see Experiment 7). Compare your results with the theory.

## **Part II: Lens Diffraction**

- ① Attach the -22 mm F.L. lens on the front of the laser.
- ② Place the 48 mm F.L. lens on a carrier positioned such that the diverging beam completely covers the lens. This will be the “test” lens.
- ③ The diverging lens tends to place a point source 22 mm to the left of the lens (i.e., somewhere inside the laser). Calculate where the 48 mm lens should image such a point (use Gauss’s formula,

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

Set the screen at the image point and observe the Airy disk.

- ④ If the pattern is too small, try magnifying it with the 18mm lens.

### **Optional**

- ⑤ Place a variable aperture in front of the test lens and note that the Airy disk increases with smaller lens openings.

## **Part III: Fresnel Zone Plates**

- ① Put the zone plate on a carrier positioned in front of the laser. You probably will have to assemble a beam spreader (see Experiment 5) to insure that the beam covers the zone plate.
- ② The zone plates in the system are designed with a focal length of about 40 cm. Place the screen at the focal point and observe the bright central dot.
- ③ Scan the pattern with translator and photometer and compare the intensity of the central dot with the intensity of the unobstructed beam. In order to compare intensities, cover the fiber optic probe with a light source aperture which is at least as small (if possible) as the central dot in the Fresnel pattern. Then use the same aperture when scanning the unobstructed beam.
- ④ Try the “opposite” zone plate, as well as the plane opaque points. Scan all the patterns for intensity distributions.

## Experiment 9: Determining The Wavelength Of Light

### EQUIPMENT NEEDED

- 0.5 mW Laser (SE-9367)
- Optics Bench (OS-9103)
- Component Carrier (2) (OS-9107)
- 6000 line/cm. diffraction grating (OS-9127)
- 48 mm F.L. Lens (OS-9122)
- Viewing Screen with Metric Scale (OS-9138)
- steel machinist's scale (about 1/64" markings)

### Purpose

A plane diffraction grating is a series of many thousands of slits placed close together. In a transmission grating, light passes through the slits and is diffracted causing interference. The slits are so narrow and so numerous that the interference is rather sharp with well-spaced fringes. By measuring these fringe separation, we can calculate the wavelength of the diffracted light.

### Theory

Referring to Figure 9.1, if  $f$  is the focal length of a lens placed behind the grating, and if we approximate the size of very small angles, the distance  $x$  from the lens axis to the  $m$ th maximum on the screen is given by:

$$x = \frac{(\lambda fm)}{d}$$

where  $\lambda$  is the wavelength of light and  $d$  is the slit separation (distance between mid-points of two adjacent slits).

A rather nice experiment can be performed using a common machinist scale as a reflection grating. Light is reflected from between scale markings, but not from the markings themselves. The interference pattern exhibits well defined fringes if the scale markings are sufficiently close together. Again we can calculate the wavelength of light from the measured fringe separations.

If we approximate the cosine function, we find that if  $d$  is the separation of adjacent markings on the ruler, and if  $x_n$  is the distance from the ruler's plane to the  $n$ th maximum (see Figure 9.2), then

$$\lambda = d \frac{(x_n^2 - x_0^2)}{2nL^2}$$

where  $L$  is the distance from the screen to the midpoint of the beam's incidence on the ruler and  $x_0$  is the position of the directly reflected beam.

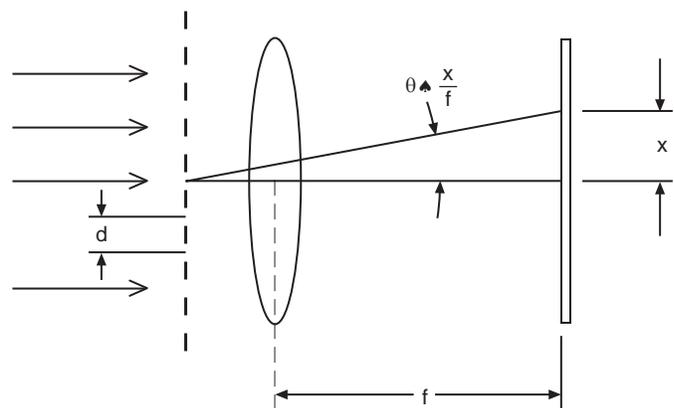


Figure 9.1

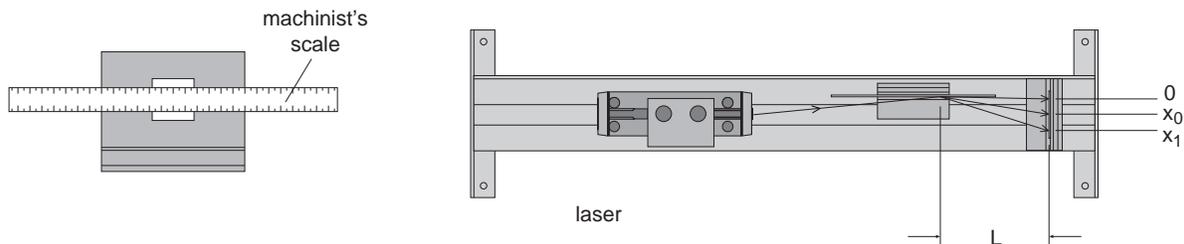
## Procedure

### **Part I: Diffraction Grating Method**

- ① Set up the laser. Place the diffraction grating and 48 mm lens on opposite sides of the same component carrier.
- ② Position the grating so that it faces the laser and place the screen in the focal plane of the 48 mm lens.
- ③ With the beam passing through the grating and lens, you should be able to see the central maximum and the first order maximum on either side. Measure the separation and calculate the wavelength. (You may improve your accuracy slightly by using the linear translator and photometer to measure the distance between fringes).
- ④ Try using the incandescent light source in place of the laser. For a sharper image, collimate the light beam first; (just placing the 18 mm F.L. lens on the front of the incandescent source is sufficient). Cover the source with each of the color (spectral) filters in turn and observe the corresponding image.

### **Part II: Machinist's Scale Method**

- ① Set up the laser and attach the machinist's scale to a component carrier as in Figure



**Figure 9.2: Experiment Setup**

9.2.

- ② Set the scale assembly on the bench so that the machinist's scale is parallel to the center of the bench but displaced slightly from the center line. Place the viewing screen at the right end of the bench.
- ③ Now adjust the laser alignment so that the beam just grazes the scale (see Figure 9.2).
- ④ Adjust the scale's position on the carrier so that the beam grazes the scale on the scale markings.
- ⑤ Observe the diffraction pattern (it may be necessary to pull the screen off the bench to see several orders of maxima).
- ⑥ Make the necessary measurements and compute the wavelength of the laser.

## ***Experiment 10: Polarization***

### **EQUIPMENT NEEDED**

- Photometer (PI-8020 or OS-9152B)
- 0.5 mW Laser (SE-9367)
- Incandescent Light Source (OS-9102C)
- Optics Bench (OS-9103)
- Angular Translator (OS-9106A)
- Component Carrier (3) (OS-9107)
- Calibrated Polarizer (3) (OS-9109)
- Calibrated 140 nm Retarder (OS-9110)
- Acrylic Plate (OS-9129)
- Prism (90°) (OS-9130)
- Flat Front Surface Mirror (OS-9136)
- Viewing Screen with Metric Scale (OS-9138)
- Aperture Mask (OS-9139)

### **Purpose**

Diffraction and interference effects occur with any type of wave. However, since light is a transverse electromagnetic wave, it exhibits one property not common to all waves. This unique property is polarization. As a light wave travels through a medium, the electric and magnetic fields oscillate in a plane perpendicular to the direction of travel. If all light waves from a given source are such that their electric field vectors are parallel, the light is said to be linearly polarized.

Some crystalline substances which exhibit a property called dichroism are useful in producing polarized light. A dichroic substance tends to absorb light to varying degrees depending on the polarization form of the incident beam. With proper engineering, the light transmitted through such a substance is linearly polarized. Using PASCO polarizers, the transmitted light is linearly polarized with the electric vector parallel to the  $0^\circ$  - $180^\circ$  axis of the polarizer. Other crystals exhibit a property called birefringence or double refractions. With proper orientation of the crystal, an incident light wave normal to the crystal face is split into two beams, one of which is delayed by a fraction of a wavelength. By carefully choosing orientation and thickness of birefringent crystals, we can devise a retardation plate.

The PASCO retardation plate causes one wave to lag behind the other by 140 nm ( that is,  $1/4$  wavelength if the light's wavelength is 560 nm) . If a polarizer and  $1/4$  wave retardation plate are sandwiched together with polarized (either left- or right-handed).

Another way of producing linearly polarized light is by reflection. Electromagnetic wave theory predicts that light is reflected to a greater or lesser degree depending on its form of polarization relative to the surface of the reflecting medium. Hence, as Sir David Brewster discovered in 1812, there is a predictable angle of incidence at which light reflected from a medium is totally linearly polarized.

### **Procedure**

#### ***Part I: Dichroic Polarizers***

- ① Set up the laser. Place a polarizer on a carrier and let the laser beam pass through it.
- ② Rotate the polarizer and observe varying intensities of the image. Is the laser light polarized? Using the photometer, check beam intensity versus time.

► **NOTE:** The laser beam's polarized components vary slightly with temperature. For accurate results, carefully monitor the changes. There are no such variations if the incandescent light source is used.

③ Attach a second polarizer to the special component carrier of the angular translator and place it on the rotating table so that it is perpendicular to the bench. (The angular translator is used here only so that we can attach the fiber optic probe to the arm and use the photometer later.)

④ Adjust the first polarizer so that the  $0^\circ$  -  $180^\circ$  axis is vertical.

Place the screen on the movable arm and adjust the arm position until the beam strikes the screen.

⑤ Observe the image intensity as you rotate the second polarizer.

⑥ remove the screen and attach the photometer's fiber optic probe. Again rotate the polarizer and record intensity of the transmitted beam for various angles. Verify that if  $I_m$  is the maximum intensity of transmitted light, then

$$I = I_m \cos^2 \theta \text{ (Malus' law)}$$

where  $I$  is the intensity of the transmitted beam and  $\theta$  is the angle which the second polarizer's axis ( $0^\circ$  -  $180^\circ$  line) makes with the first polarizer's axis.

⑧ Adjust both polarizers so that their polarizing axes are perpendicular to each other. Observe that no light is transmitted onto the screen.

⑨ Now insert a third polarizer (mounted on a carrier) between the original two in such a way that the polarizing axis of the third makes an angle of  $45^\circ$  with the axis of the first polarizer. Is any light transmitted now? Why?

## Part II: Circularly Polarized Light

① On one component carrier attach both a polarizer and the retardation plate such that the  $0^\circ$  -  $180^\circ$  axis of the retarder makes a  $45^\circ$  angle with that of the polarizer.

② Place the assembly on the bench with the polarizer facing the laser.

③ Use the viewing screen and a second polarizer to determine if the beam transmitted through the polarizer-retarder combination is polarized or not.

④ Now put the flat surface mirror to the right of the polarizer-retarder assembly and reflect the beam back through the assembly. Note the image intensity on the laser's face (the mirror must be set at a slight angle so you can see the image on the laser's face). Rotate the retarder and note the image intensity.

► **NOTE:** Circularly polarized light can be either left - or right-handed in orientation (depending on the relative orientation of retarder and polarizer axes). However, an assembly which circularly polarizes light into one form will not transmit circularly polarized light of the other form. In the above experiment, the mirror changes the form of the circularly polarized light. Hence, the reflected beam is not transmitted.

► **CAUTION:** The retarder is not exactly a  $1/4$  wave plate for the laser light.)

The retarder's effect can be varied by changing the angle of the incident beam. Set up the apparatus to investigate this variation.

### ***Part III: Brewster's Angle***

- ① Leave the first polarizer in front of the laser and adjust the  $0^\circ$  - $180^\circ$  axis so that it is horizontal.
- ② Attach the glass coincides with one of the scored lines.
- ③ Put the viewing screen on the movable arm and adjust both the rotating table and the arm until the reflected image is on the screen.
- ④ Continue rotating the table until the image intensity is a minimum. Note the incidence angle for such a minimum. This is the Brewster angle.
- ⑤ At the angle of minimum reflection, remove the first polarizer and attach it on the first holder on the movable arm. Move the screen to the second holder.
- ⑥ Verify that all light being reflected is linearly polarized. In what plane is it polarized?
- ⑦ check to see if the transmitted light is polarized.
- ⑧ Use the photometer to plot the degree of polarization of both reflected and transmitted beams for various angles of incidence.
- ⑨ Repeat the procedure using the acrylic plate.
- ⑩ Repeat the procedure using the incandescent source instead of the laser. Room light must be very low in order to see the images clearly.

**Notes:**

## Experiment 11: Optical Activity

### EQUIPMENT NEEDED

- Photometer (PI-8020 or OS-9152B)
- 0.5 mW Laser (SE-9367)
- Optics Bench (OS-9103)
- Angular Translator (OS-9106A)
- Component Carrier (OS-9107)
- Glass Dispersion Tank (OS-9108)
- Calibrated Polarizer (HN-32) (2) (OS-9109)
- Photometer Apertures (OS-9116)

### Purpose

A linearly polarized light wave may be considered to be the resultant wave upon superimposing two circularly polarized waves — one right-handed and one left-handed. Some crystals and some solutions tend to split linearly polarized light into these two circularly polarized components. As the two wave components travel through the substance, one lags behind the other. Since the two waves are still coincident, when they emerge the resultant wave is again linearly polarized. However, because of the retardation of one component, the emerging light is linearly polarized in a different direction.

If the direction of polarization is rotated to the right (relative to looking in the direction which the light is travelling), the substance is said to be dextrorotatory. Substances which rotate the polarization to the left are called laevorotary. Solutions of cane sugar are dextrorotatory due to the asymmetry of the sugar molecule.

### Procedure

- ① Fill the glass dispersion tank with a cane sugar and water solution (by weight: 15%-20% sugar).
- ② Place the filled tank on the rotating table of the angular translator which should be positioned on the bench.
- ③ Position the laser at the left of the bench and put a polarizer (on a carrier) between the laser and tank.

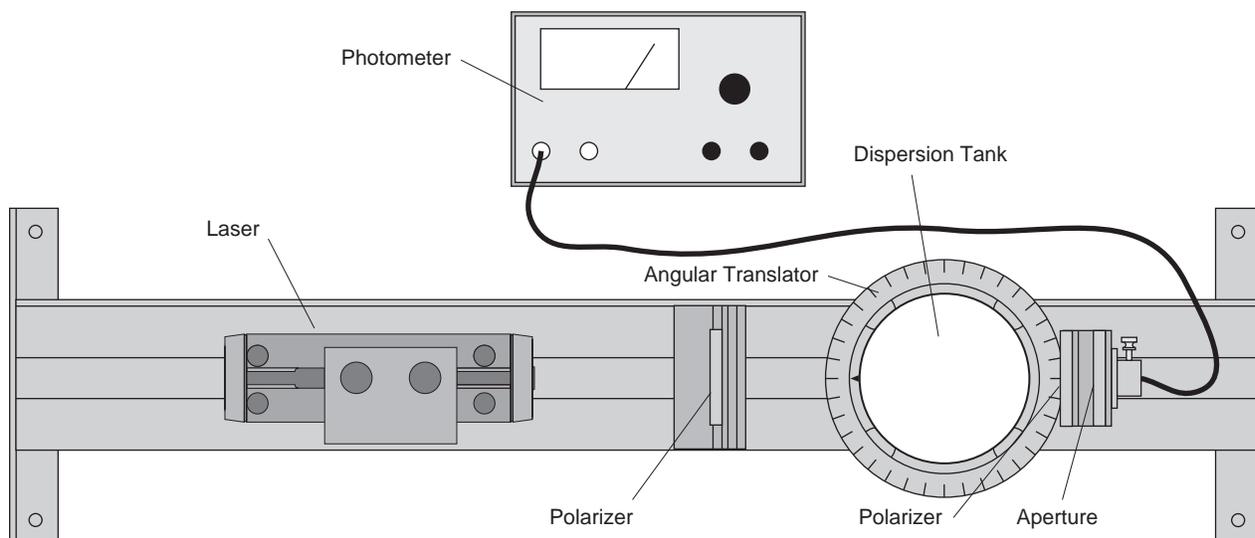


Figure 11.1: Experiment Setup

- ④ Attach a second polarizer to the front surface of the analyzer holder on the moveable arm of the angular translator. Put a photometer aperture on the rear surface of the analyzer holder. (See Figure 11.1)
- ⑤ With the fiber optic probe attached behind the photometer aperture, use the potometer to measure the transmitted beam's intensity as the second polarizer is rotated.
- ⑥ From the intensity results, determine the direction of polarization of the transmitted beam. Compare to the original polarization direction.
- ⑦ Repeat the procedure for differing concentration is sufficiently high to considerably rotate the polarization direction. However, the photometer gives much more useful and quantitative results.)

► **NOTE:** The Photometer is not necessary if very rough results are sufficient and if the sugar concentration is sufficiently high to considerably rotate the polarization direction. However, the Photometer gives much more useful and quantitative results.

## Experiment 12: Scattering

### EQUIPMENT NEEDED

- |   |   |
|---|---|
| <ul style="list-style-type: none"> <li>– Photometer (PI-8020 or OS-9152B)</li> <li>– Incandescent Light Source (OS-9102C)</li> <li>– Optics Bench (OS-9103)</li> <li>– Angular Translator (OS-9106A)</li> <li>– Component Carrier (2) (OS-9107)</li> <li>– Glass Dispersion Tank (OS-9108)</li> <li>– Calibrated Polarizer (HN-32) (OS-9109)</li> </ul> | <ul style="list-style-type: none"> <li>– 48 mm F. L. Lens (OS-9133)</li> <li>– Red Spectral Filter (OS-9111)</li> <li>– Yellow Spectral filter (OS-9112)</li> <li>– Green Spectral filter (OS-9113)</li> <li>– Blue Spectral filter (OS-9114)</li> <li>– Photometer Apertures (OS-9116)</li> <li>– 18 mm F.L. Lens (OS-9132)</li> </ul> |
|---|---|

### Purpose

Why is the sky blue (without smog)? And why is light from the sky linearly polarized (check with a polarizer)? Both observations are due mostly to a light phenomenon referred to as scattering. There are two basic types of scattering — Rayleigh scattering and diffraction (or Mei) scattering. If the particles causing scattering are small compared with the wavelength of the incident light, then Rayleigh scattering is more predominate. As particle size increases, the light is diffracted to a greater degree. Of course, the transparency of the particles greatly affects the results in either case.

Rayleigh scattering is the main factor in accounting for a blue sky. When a light wave from the sun strikes a molecule in the atmosphere (see Figure 12.1), the oscillating electric field sets the charged particles in the molecule oscillating. This oscillation can be separated into two components: one along the X axis and one along the Y axis. These two components of oscillation act as miniature antennas which radiate perpendicular to the direction of oscillation. Hence, light is scattered in the XY plane Figure 12.1 shows the component breakdown of one wave which is linearly polarized.

The oscillation of the molecule is a forced oscillation, and hence the amplitude increases as the frequency of the incident light gets closer to the resonant frequency of the molecule. The frequencies of visible light are generally less than resonant frequencies of molecules in the atmosphere, yet the higher the frequency (i.e., near blue light), the higher the amplitude of the scattered light. Thus, blue light is scattered more than red light.

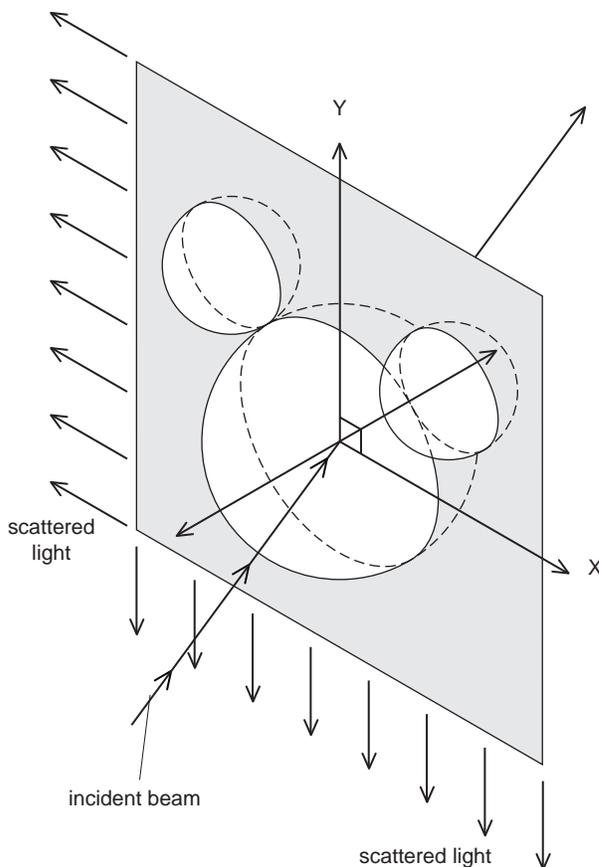


Figure 12.1: Scattering

During the day, the light which reflects off other particles of the atmosphere is mostly blue scattered light. Direct sunlight minus the blue light which is scattered appears yellow or red. Toward evening sunlight travels through more atmosphere and, hence, loses more blue light from scattering. When the resulting light reflects off a cloud, the observer sees reddish-colored light. Thus, sunsets often appear to have a red hue.

In this experiment we will use a milk solution and examine the scattered light from milk globules. There will be a combination of Rayleigh and diffraction scattering (see a standard text for theoretical predictions). Using a concentrated silver nitrate solution, we can observe the effect of decreasing particle size.

## Procedure

- ① Place the incandescent light source and angular translator on the optical bench.
- ② Attach the aperture mask to a component carrier and position it between the light source and translator.
- ③ Fill the dispersion tank with water and mix in a few cubic centimeters of milk to make the solution just slightly cloudy.
- ④ Place the filled tank on the rotating table of the angular translator.
- ⑤ Adjust the aperture mask and tank position so that the incident beam is perpendicular to the tank's surface.
- ⑥ With the fiber optic probe in position and the photometer aperture on the rear surface of the analyzer holder, use the photometer to measure light intensity at several points around the tank. (Room light must be very low.)
- ⑦ Now place one of the color (spectral) filters (transmission curves in the equipment instructions) on the front of the light source over the beam. Again measure intensities at various points around the tank. Plot intensity versus angle. Repeat for each filter. Which light is scattered more? (In interpreting your results, remember that the milk globules also cause diffraction effects.)
- ⑧ Repeat the procedure for a concentrated solution of silver nitrate in water.

### Optional

- ⑨ Replace the incandescent source with the laser and observe scattering at that particular wavelength.

## Experiment 13: Holography

### EQUIPMENT NEEDED

- 0.5 mW Laser (SE-9367)
- Red Spectral filter (optional)
- Optics Bench (OS-9103)
- Green Spectral filter (optional)
- Component Carrier (OS-9107)
- Blue Spectral filter (optional)
- Hologram (OS-9115)
- 18 mm F.L. lens (optional)
- -22 mm F.L. Lens (OS-9131)
- 48 mm F.L. lens (optional)
- incandescent light source (optional)

### Purpose

Holography is a method of lensless photography which allows one to record and later reproduce three-dimensional images. In ordinary photography, only the light intensities are recorded on film. No information concerning phase relations is saved. However, in holography a reference beam interferes with the reflected beams from an object. A film plate records the corresponding interference pattern. After developing, the film at this grating, the first order diffracted waves are exact replicas of the original reflected beams from the object.

Because of the high coherence and monochromaticity of laser light, using lasers in preparing and reproducing a hologram increases the quality of the reproduced image. In the following demonstration, we will examine some of the properties of a transmission hologram.

### Procedure

- ① Position the laser at the left of the optical bench and align the beam.
- ② Attach the -22 mm F.L. lens to the front of the laser
- ③ Attach the hologram to a component carrier and position on the hologram.
- ④ Now look through the hologram towards the laser with your eyes off the central axis of the beam so that you don't look directly into the laser beam. Focus on a point several centimeters behind the hologram and observe the images. Move your head from side to side to observe the parallax effects and hence verify that the image is three-dimensional. (See Figure 13.1)

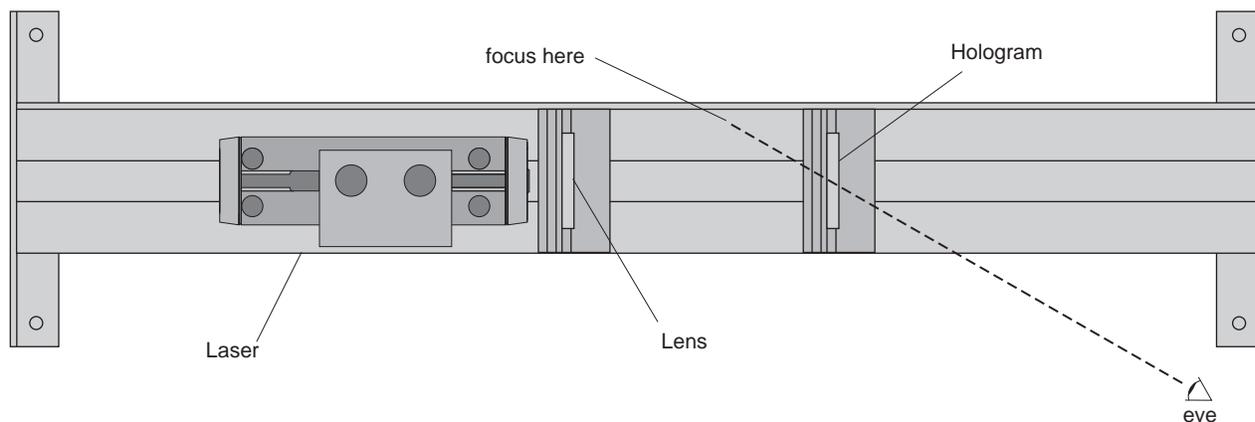


Figure 13.1: Experiment Setup

- ⑤ Now cover half of the hologram with the aperture mask or similar opaque object. Again, look at the image. Is the entire image still visible? This is one striking property which photography does not exhibit.

**Optional**

- ⑥ Use the incandescent light source instead of the laser. Try both with and without collimating the beam.
- ⑦ Observe the image. Why the colors?
- ⑧ Place each of the color (spectral) filters in turn over the light source. Observe the image.

# ***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](mailto:techsupp@pasco.com)

web: [www.pasco.com](http://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.

