Introduction to Lasers and Optics

Student Guide
Laboratories and Demonstrations

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National Center for Optics and Photonics Education

This text was developed by the National Center for Optics and Photonics Education (OP-TEC), University of Central Florida, under NSF ATE grant 1303732. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Published and distributed by
OP-TEC
University of Central Florida
http://www.op-tec.org

ISBN 978-0-9998536-0-3

Preface

The National Center for Optics and Photonics Education (OP-TEC) has developed *Introduction to Lasers and Optics,* a course that can be taught to students who have limited prior knowledge of lasers, optics, or photonics. The purpose of this course is to provide entering students with an overview of the technology and its applications. This modular course requires no prerequisites, and can be taught for one or two-credits in the first term. The text contains 15 modules that cover topics such as the spectrum of light, laboratory safety, polarization, mirrors and lenses, and more. These modules can be used all together, or faculty can select the appropriate number of modules to fit the desired breadth and depth of study for the course. This course introduces the basic principles of light, lasers and laser safety that are needed to study specific types of laser systems. It also provides exposure to the topics that make up the foundation for studying the applications of lasers in telecommunications, electro-optical displays, biomedical equipment, manufacturing/materials processing, defense/homeland security, environmental monitoring, and nanotechnology.

There are seven laboratory demonstrations and activities that support hands-on learning, and illustrate key concepts that are covered in *Introduction to Lasers and Optics*. It is recommended that the activities contained in this resource be set up by a teaching assistant or instructor, and then used to demonstrate concepts discussed in the modules of the course. The seven demonstrations are Spectrum of Light, The Polarization of Light, Optical Filters, Prisms and Lenses, Interference and Diffraction with a Single Slit, Interference and Diffraction with a Pinhole, and Beam Divergence.

CONTENTS

USING THIS RESOURCE

Photonics experiments often involve the use of lasers or high intensity light sources. Both have the potential, if misused, of causing damage to the eye. To mitigate this potential, it is important to conduct these activities in a facility that meets accepted safety standards for operating these light sources.

Each activity has a list of equipment at the beginning, and a detailed, comprehensive list is available in Appendix A. The equipment listed will support one lab station. The instructor will determine the number of stations needed for the course, based on class size and available resources.

This text is organized by activity. Each section starts with a safety note, followed by an equipment list, set-up instructions, and instructions or questions for the demonstration.

The set-up for each activity is intended to be completed by the instructor or a laboratory assistant, allowing more time for students to watch and participate in the activities. If possible, students should be allowed to handle the equipment.

LABORATORIES AND DEMONSTRATIONS

Spectrum of Light

SAFETY NOTE: Never look directly into the beam of any laser. Use an index card to determine the position of the laser beam at any given time. Also, keep in mind that some laser light is reflected when it strikes a surface. This reflected light is not powerful enough to be considered hazardous if a laser pointer is used.

Equipment

Table 1 - Spectrum of Light Lab Equipment List

Lab Item	Quantity	Description
1	1	Energizer LED Pen Flashlight
2	1	76.2 MM V-Block Mount
3	1	Base Plate
4	2	1.5″ Post Holder
5	2	1.5″ Post
6	1	Mounting Base
7	1	Diffraction Grating
8	1	Dual Filter Holder
9	1	8.5″ × 14″ White Paper
10	1	Roll of Masking Tape
11	1	Metric Ruler
12	1	Primary/Secondary Color sheets

Set-Up

Using the V-block mount for laser, a 1.5″ post, and a 1.5″ post holder, mount the LED flashlight to the base plate. Mount a 1.5″ post holder onto a mounting base. Insert a 1.5″ post into the 1.5″ post holder. Mount the dual filter holder to the post inserted into the post holder. Insert the diffraction grating into the filter holder. Place the diffraction grating assembly in line with the LED flashlight 1 meter from the LED flashlight. Tape white paper to an upright surface 1 meter from the diffraction grating assembly. Turn on LED flashlight.

Demonstration

1. Focus the light perpendicularly onto the grating surface. Refer to Figure 1.

Figure 1 *Spectrum Analysis Set-up*

2. With the room lights turned off, move the diffraction grating and light source if necessary, up or down until you clearly see both the light transmitted straight through the grating, forming a white spot on the paper, and the first order spectrum of colors.
3. Draw, or have students draw lines through each color you can identify in the spectrum, and label each line with its color.
4. Hold a red Primary/Secondary Color sheet (transmission filter) between the laser pointer/LED light and the grating. What is the color of the center spot where light is transmitted straight through the grating? List all the colors that you can clearly identify in the diffracted spectrum on either side of the center spot.
5. Replace the red Primary/Secondary Color sheet with the other filters in this order: green, blue, purple, yellow, and orange. For each filter list all the colors you can identify in the diffracted spectrum of the light formed on either side of the center spot.
6. Answer the following questions with complete sentences.
   (a) Why are red, green, and blue primary colors?
   (b) What colors of light must be combined to make purple light?
   (c) What colors of light must be combined to make yellow light?
   (d) How can a color TV produce any color it needs when it has only red, green, and blue sources?

The Polarization of Light

SAFETY NOTE: Never look directly into the beam of any laser. Use an index card to determine the position of the laser beam at any given time. Also, keep in mind that some laser light is reflected when it strikes a surface. This reflected light is not powerful enough to be considered hazardous if a laser pointer is used.

Equipment

Table 2 – Polarization Lab Equipment List

Lab Item (LI)	Quantity	Description
1	1	Energizer LED Pen Flashlight
2	1	76.2mm V-Block Mount
3	1	Base Plate
4	1	1.5″ Post Holder
5	1	1.5″ Post
6	1	Mounting Base
7	2	Left-Handed Circular Polarizing Film
8	1	Microslides

Set-Up

Using the V-clamp mount for laser, a 1.5″ post, and a 1.5″ post holder, mount the LED flashlight to the mounting base. Turn on the LED flashlight. Adjust the LED flashlight with the beam projected horizontally about five feet above the floor. It should be arranged so that it is easy to look directly into the light when you are five or six feet from the LED flashlight.

Demonstration

1. Hold one 1″ round glass polarizer at arm's length in front of you and look at the light through the polarizer. The light you see is now polarized in the preferred direction of the polarizing filter.
2. Hold a second 1″ round glass polarizer (analyzer) with your other hand. Place it between you and the first polarizing filter. Rotate the second 1″ round glass polarizer about the axis of the light beam. Notice the change in intensity of the light transmitted through both polarizing filters.
3. What can you say about the relation between the polarizing direction of the two polarizing filters when the light transmitted has its maximum brightness?

4. What can you say about the relation between the polarizing direction of the two polarizing filters when the light transmitted has its minimum brightness?
5. Adjust the LED flashlight assembly from Part 1 so that it sits about 2.5 inches high at an angle so the beam hits the base plate about 5 inches in front of the light source. Place a microscope slide on the table at the position of the focused spot. Refer to Figure 2.

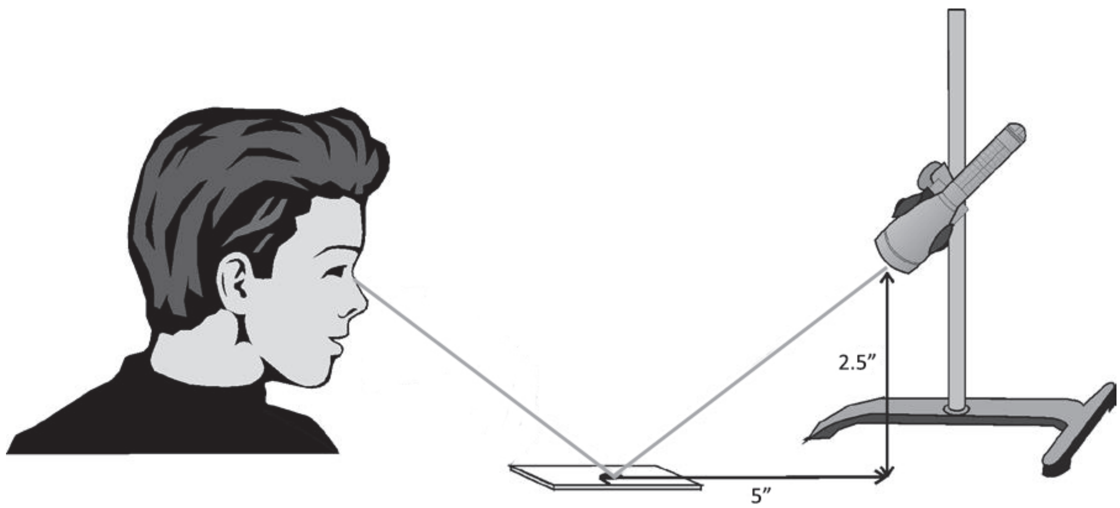

Figure 2 *Polarizer with Analyzer Illustrated*

6. Position yourself in line with the microscope slide and the LED flashlight. Move until you can see the reflection of the individual LEDs on the microscope slide. This makes the effect of the polarizing filters much easier to notice. Refer to Figure 3.

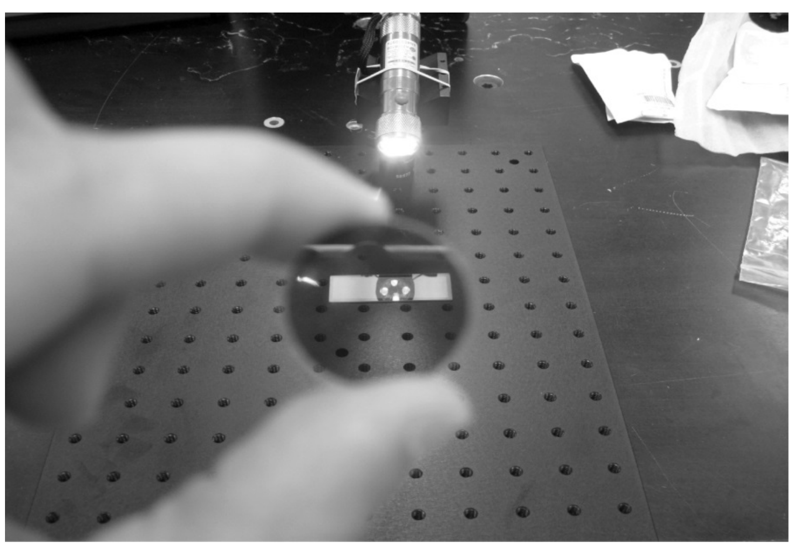

Figure 3 *Polarization by Reflection Set-up*

7. Hold a 1″ round glass polarizer so you can see the reflection through the filter. Rotate the filter about the axis of the reflected beam. Refer to Figure 4. What do you observe about the brightness of the reflection as you rotate the filter?

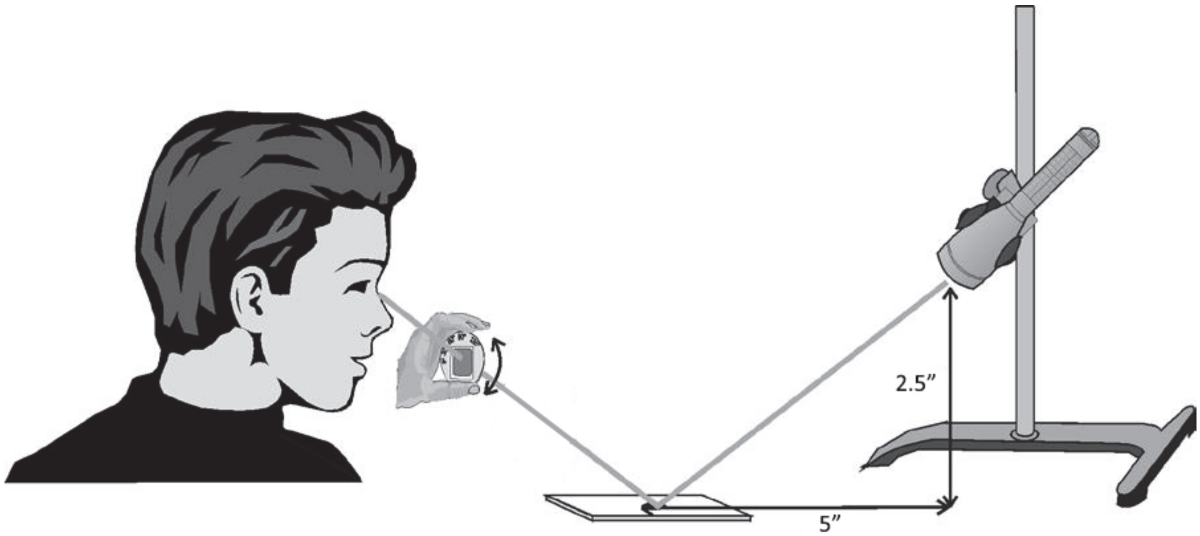

Figure 4 *Polarizer with Analyzer Illustrated*

8. Using the results from Part 1, describe how the polarization of the light from the LED flashlight is affected by reflection off the microscope slide.

Optical Filters

SAFETY NOTE: Never look directly into the beam of any laser. Use an index card to determine the position of the laser beam at any given time. Also, keep in mind that some laser light is reflected when it strikes a surface. This reflected light is not powerful enough to be considered hazardous if a laser pointer is used.

Definition of Terms and Required Formulas

Terms

P_{in} = Power into filter

P_{out} = Power out of filter

Equipment

Table 3 – Optical Filters Lab Equipment List

Lab Item (LI)	Quantity	Description
1	1	Frey Scientific Laser Pointer
2	1	76.2mm V-Block Mount
3	1	Base Plate
4	2	1.5″ Post Holder
5	2	1.5″ Post
6	1	Primary/Secondary Color Sheets
7	1	Industrial Fiber Optics Digital Photometer
8	1	Dual Filter Holder
9	1	Mounting Base

Set-Up

Using the V-block mount for laser, a 1.5″ post, and a 1.5″ post holder, mount the laser pointer/LED light to the base plate. Mount a 1.5″ post holder onto a mounting base. Insert a 1.5″ post into the 1.5″ post holder. Mount the dual filter holder to the post inserted into the post holder. Place the dual filter holder assembly in line with the laser pointer. Turn the laser pointer. Refer to Figure 5.

Demonstration

1. Using the industrial fiber optics digital photometer, measure P_{in} and P_{out} for laser pointer, using the blue, yellow, green, and red filters of the primary/secondary color sheets. P_{in} is the power incident on the color sheets and P_{out} is the power transmitted through the color sheets. Have students record these data in Table 4 and Table 5. Make sure to control the ambient room light in order to get consistent measurements.

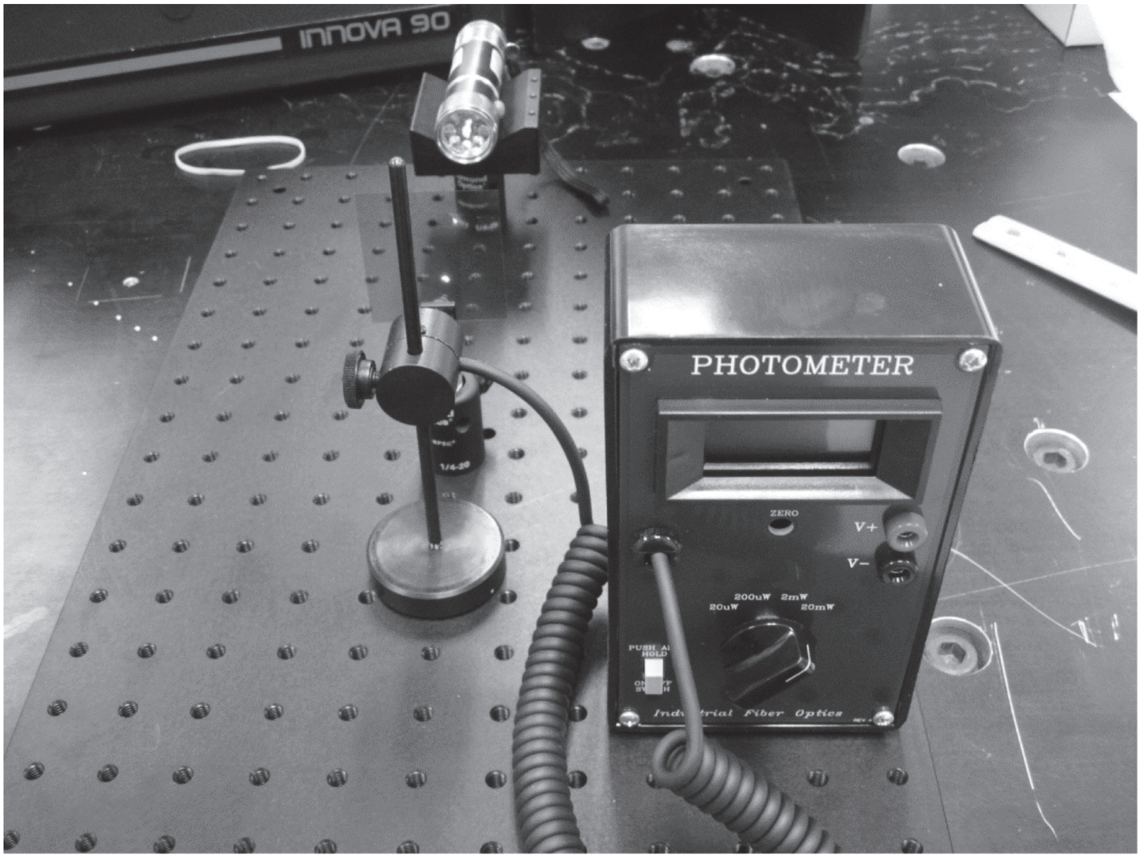

Figure 5 *Filter Power Measurement Set-up*

Table 4 – Individual Filter Power Readings

Filter Color	P_{in} (mW)	P_{out} (mW)
Blue		
Yellow		
Green		
Red		

2. Discuss with students why the transmitted power (P_{out}) changes with the different filters. What do students think will happen when filters are used together?

3. Prepare to measure three filter sets. Refer to Figure 6.
   Set 1: green and yellow
   Set 2: green and red
   Set 3: green, red, and yellow

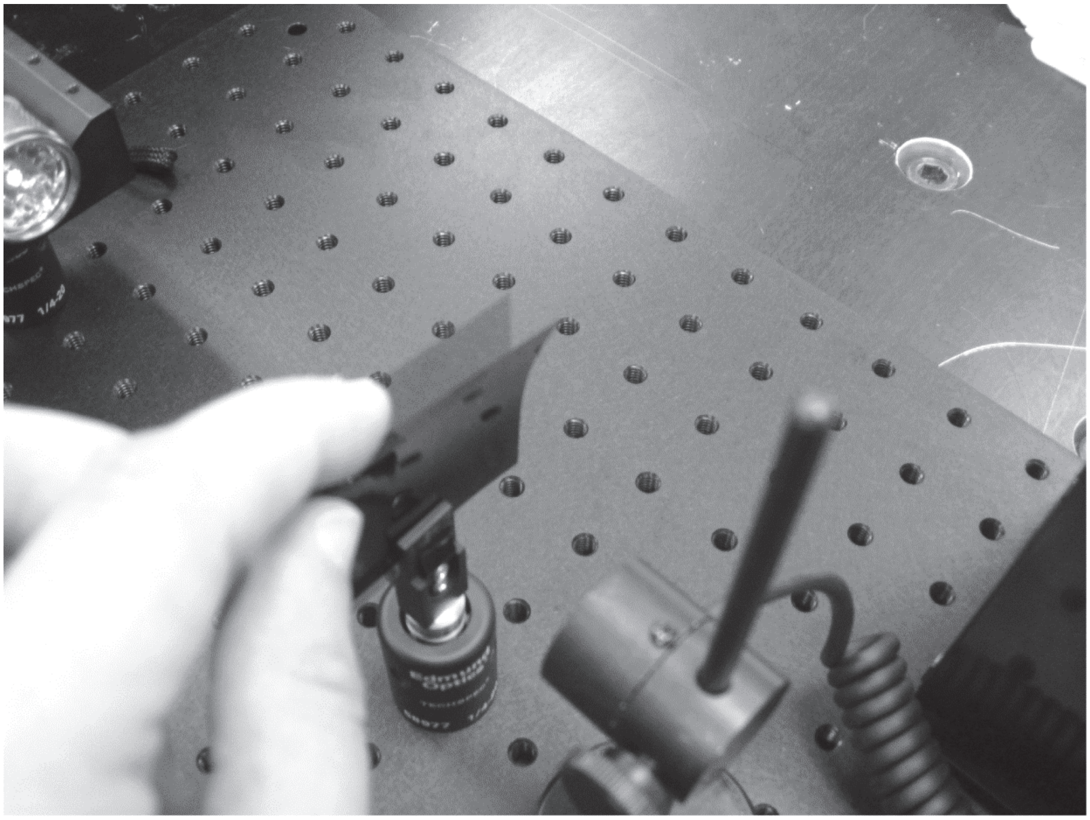

Figure 6 *Power Measurement Set-up for Combination Filters*

Table 5 –Power Readings for Combination Filters

Filter Set	P_{in} (mW)	P_{out} (mW)
Green + Yellow		
Green + Red		
Green + Red + Yellow		

4. Discuss with students why the transmitted power (P_{out}) changes with the different combinations of filters.

Prisms and Lenses

SAFETY NOTE: Never look directly into the beam of any laser. Use an index card to determine the position of the laser beam at any given time. Also, keep in mind that some laser light is reflected when it strikes a surface. This reflected light is not powerful enough to be considered hazardous if a laser pointer is used.

Part 1 Refraction in a prism

Equipment

Table 6 – Prism and Lens Lab Equipment List

Lab Item (LI)	Quantity	Description
1	1	Frey Scientific Laser Pointer
2	1	Lens and Prism Acrylic Set
3	1	8.5″ × 14″ White Paper
4	1	Roll of Masking Tape
5	1	Metric Ruler
6	1	Index Cards
7	1	Protractor

Set-Up

Arrange the laser pointer, equilateral prism of the “Lens and Prism Acrylic Set”, and a white cardboard screen made from “Index Cards” on a flat tabletop as shown in Figure 7 and Figure 8. Center the prism over a sheet of white paper. Secure the white paper, cardboard screen, and laser pointer with masking tape. Turn the laser pointer on.

Demonstration

1. Rotate the prism relative to the incident beam. Allow students to watch the refraction within the prism, and how the exiting beam changes as the prism rotates.

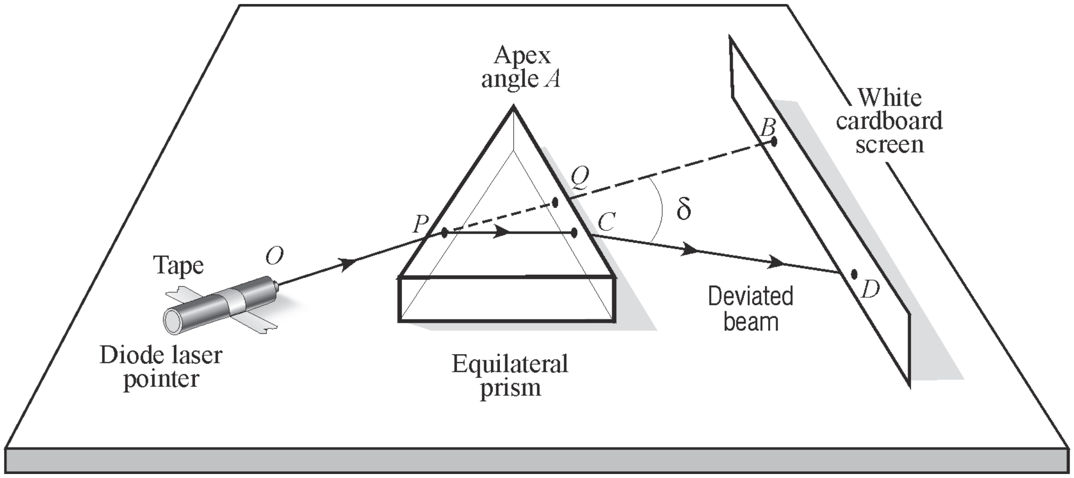

Figure 7*Minimum Angle of Deviation Set-up*

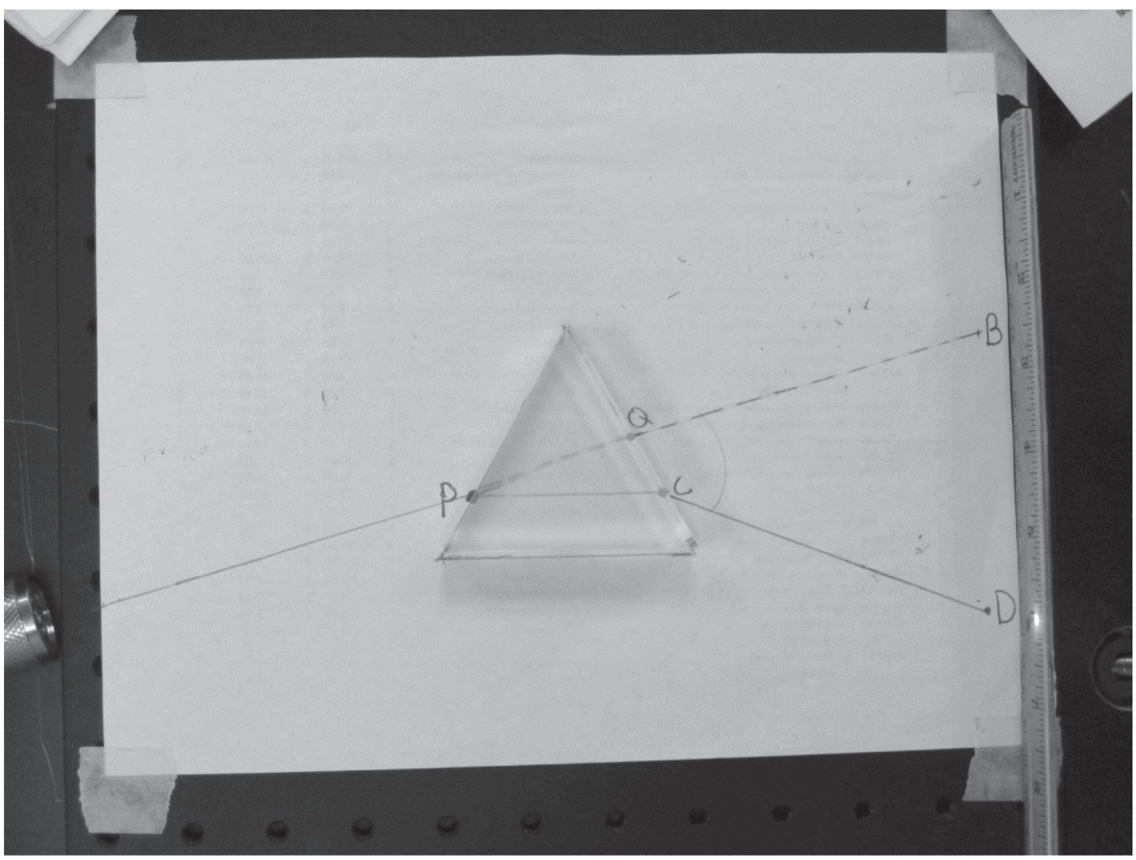

Figure 8 *Minimum Angle of Deviation Set-up*

Part 2 Total internal reflection (TIR)

Equipment

Table 7 – TIR Lab Equipment List

Lab Item (LI)	Quantity	Description
1	1	Frey Scientific Laser Pointer
2	2	Lens and Prism Acrylic Set
3	1	8.5″ × 14″ White Paper
4	1	Roll of Masking Tape
5	1	Metric Ruler
6	1	Index Cards
7	1	Protractor

Set-Up

Set a right-angle prism from the Lens and Prism Acrylic Set on a sheet of white paper. With the roll of masking tape, tape the prism to the paper. Shine a laser pointer onto a face of the prism so that it *undergoes total internal reflection* (TIR) inside the prism and exits the prism at 90° to its original direction of entry.

Demonstration

1. Use index cards as a screen to "locate" the laser beam outside the prism. On the paper, trace the edges of the prism, the incident beam, the path through the prism, and the exit beam.
2. Move the right-angle prism to a different position on the paper and tape it down. Direct the laser beam onto a face so that the beam returns along a direction parallel to its entering direction. Use index cards to "locate" the beam path. When you have achieved this condition of *retroreflection*, trace the edges of the prism, the entering beam, the path through the prism, and the exit beam.
3. Move two right-angle prisms to a new location on the paper. Arrange them to produce "periscope action." This action requires, for example, that a horizontal beam that enters at one level be deflected downward 90° and exits horizontally at a different level, as shown in Figures 9 and 10. Here the dashed triangles indicate the locations of the two prisms. Use index cards to locate the beam through the prism arrangement.

   When you have achieved the "periscope" geometry, tape the prisms down. Trace their edges, and trace the laser beam path from initial entry to final exit. Indicate where TIR occurs.

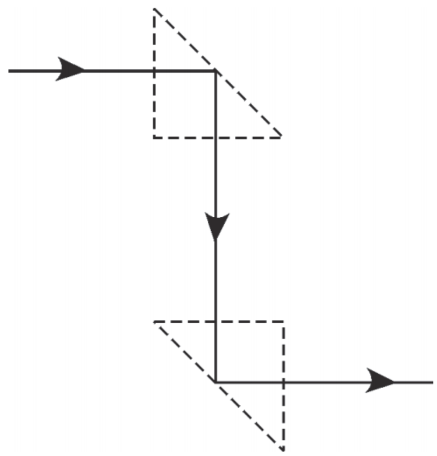

Figure 9 *Total Internal Reflection Set-up*

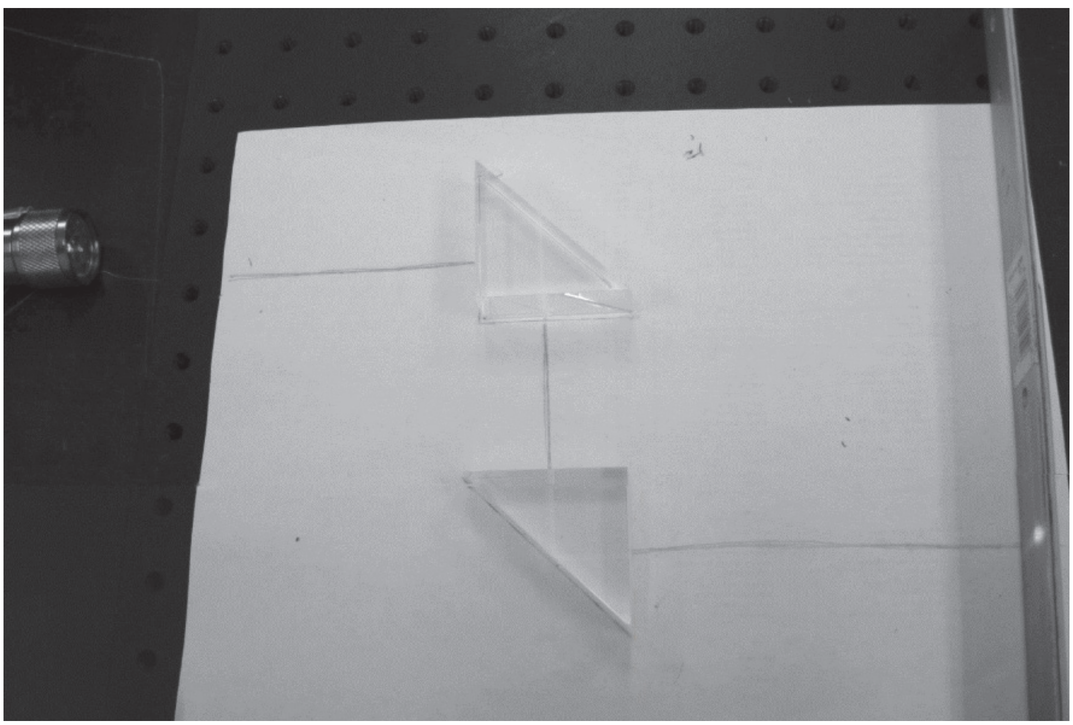

Figure 10 *Total Internal Reflection Set-up*

Interference and Diffraction with a Single Slit

SAFETY NOTE: Never look directly into the beam of any laser. Use an index card to determine the position of the laser beam at any given time. Also, keep in mind that some laser light is reflected when it strikes a surface. This reflected light is not powerful enough to be considered hazardous if a laser pointer is used.

Equipment

Table 8 – Single Slit Diffraction Lab Equipment List

Lab Item (LI)	Quantity	Description
1	1	Frey Scientific Laser Pointer
2	1	76.2mm V-Block Mount
3	1	Base Plate
4	2	1.5″ Post Holder
5	2	1.5″ Post
6	1	Dual Filter Holder
7	1	Mounting Base
8	1	Mounted Slit 100µm
9	1	Metric Ruler
10	1	8.5" × 14" White Paper
11	1	Roll of Masking Tape

Set-Up

Tape a piece of white paper on a wall that can be used for directing a laser beam coming from the laser pointer mounted on the base plate, positioned at a distance approximately 1 meter from the wall. Mount a 1.5″ post holder onto a mounting base. Mount a dual filter holder onto a 1.5″ post. Secure the 1.5″ post into the 1.5″ post holder on the mounting base. Place the single slit, from the target set into the dual filter holder. Place the mounting base with the single slit assembly exactly 1 meter from the wall. Using the V-clamp mount for laser, a 1.5″ post, and a 1.5″ post holder, mount the laser pointer to the base plate. The laser assembly should be mounted along one side of the base plate that is farthest from the wall. Turn the laser pointer on. Direct the laser beam through the single slit such that a diffraction pattern is formed on the wall as shown in the Figure 11.

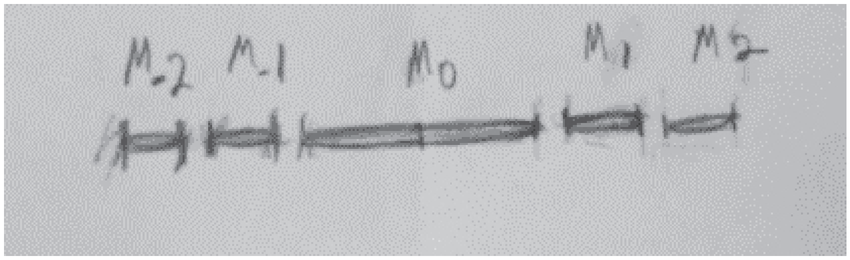

Figure 11 *Single Slit Set-up*

Demonstration

1. Turn off the lights and trace the diffraction pattern you observe with a pencil.
2. Discuss the diffraction pattern with students, including changes in intensity, spacing, and other observable features.

Interference and Diffraction with a Pinhole

Equipment

Table 9 – Pinhole Diffraction Lab Equipment List

Lab Item (LI)	Quantity	Description
1	1	Frey Scientific Laser Pointer
2	1	76.2 mm V-Block Mount
3	1	Base Plate
4	2	1.5″ Post Holder
5	2	1.5″ Post
6	1	Dual Filter Holder
7	1	Mounting Base
8	1	Precision Pinhole 25mm Mount, 25µm
9	1	Metric Ruler
10	1	8.5″ × 14″ White Paper
11	1	Roll of Masking Tape

Set-Up

Tape a piece of white paper on a wall that can be used for directing a laser beam coming from the laser pointer mounted on the base plate, positioned at a distance approximately 1 meter from the wall. Mount a 1.5″ post holder onto a mounting base. Mount a dual filter holder onto a 1.5″ post. Secure the 1.5″ post into the 1.5″ post holder on the mounting base. Place the pinhole, from the target set into the dual filter holder. Place the mounting base with the pinhole assembly exactly 1 meter from the wall. Using the V-block mount for laser, a 1.5″ post, and a 1.5″ post holder, mount the laser pointer to the base plate. The laser assembly should be mounted along one side of the base plate that is farthest from the wall. Turn the laser pointer on. Point the laser beam through the pinhole such that a diffraction pattern is formed on the wall as shown in the Figure 12.

Demonstration

1. Turn off the lights and trace the diffraction pattern you observe with a pencil.
2. Take down the paper and using the metric ruler, measure the diameter of the Airy disk.
3. Discuss the diffraction pattern with students, including changes in intensity, spacing, and other observable features.

Figure 12 *Pin Hole Set-up*

Beam Divergence

SAFETY NOTE: Never look directly into the beam of any laser. Use an index card to determine the position of the laser beam at any given time. Also, keep in mind that some laser light is reflected when it strikes a surface. This reflected light is not powerful enough to be considered hazardous if a laser pointer is used.

Equipment

Table 10 – Beam Divergence Lab Equipment List

Lab Item (LI)	Quantity	Description
1	1	Frey Scientific Laser Pointer
2	1	76.2mm V-Block Mount
3	1	Base Plate
4	1	1.5″ Post Holder
5	1	1.5″ Post
6	1	Metric Ruler
7	1	Industrial Fiber Optics Digital Photometer
8	1	Roll of Masking Tape
9	1	Index Card

Set-Up

Using the V-clamp mount for laser, a 1.5″ post, and a 1.5″ post holder, mount the laser pointer to the base plate. The laser assembly should be mounted on the base plate for the maximum distance between the laser output and some point in the room where a target will be mounted. Tape an index card as a target for the laser beam on the wall. Turn on the laser pointer on. Adjust the position of the laser pointer until the laser beam hits the index card taped to the wall. Refer to Figure 13 and Figure 14.

Demonstration

1. Using the metric ruler, measure the diameter of the laser beam at the aperture of the laser pointer/LED light. Designate this measurement as "d_1."
2. Using the metric ruler, measure the diameter of the laser beam on the index card at the wall. Designate this measurement as "d_2."
3. Discuss the difference between d_1 and d_2, and how divergence can be corrected.

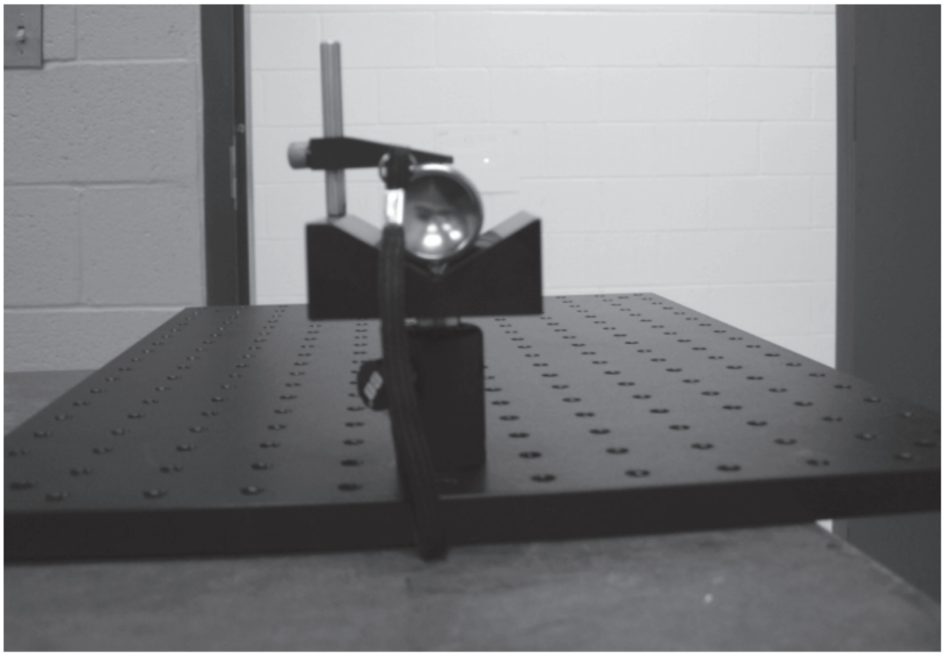

Figure 13 *Beam Divergence Measurement Set-up*

Figure 14 *Target Beam Spot*

APPENDIX A: EQUIPMENT LIST

Quantity	Part Number	Description	Vendor
1	1323155	Energizer LED Pen Flashlight	Frey Scientific
1	1400712	Laser Pointer, 1.2 cm Dia, Red	Frey Scientific
1	VB-1	76.2 mm V-Block Mount	Newport
1	MB1218	Base Plate	Thorlabs
1	DH1	Dual Filter Holder	Thorlabs
1	BA2	Mounting Base	Thorlabs
2	88-084	Left-Handed Circular Polarizing Film	Edmund Optics
2	M58-977	1.5″ Post Holder	Edmund Optics
2	M58-961	1.5″ Post	Edmund Optics
1	M54-038	Industrial Fiber Optics Digital Photometer	Edmund Optics
1	755230	Diffraction Grating	Carolina Biological Supply Co.
1	33-0175	Primary/Secondary Color sheets	Arbor Scientific
1	420577	Microscope slide	Arbor Scientific
1	160446	Lens and Prism Acrylic Set	Ward's Science
1	43-5263-000	Precision Pinhole 25mm Mount, 25um	Ealing
1	S100R	Mounted Slit 100um	Thorlabs
1	N/A	Protractor	N/A
1	N/A	Metric Ruler	N/A
5	N/A	8½″ × 14″ White Paper	N/A
5	N/A	Index Cards	N/A
1	N/A	Roll of Masking Tape	N/A