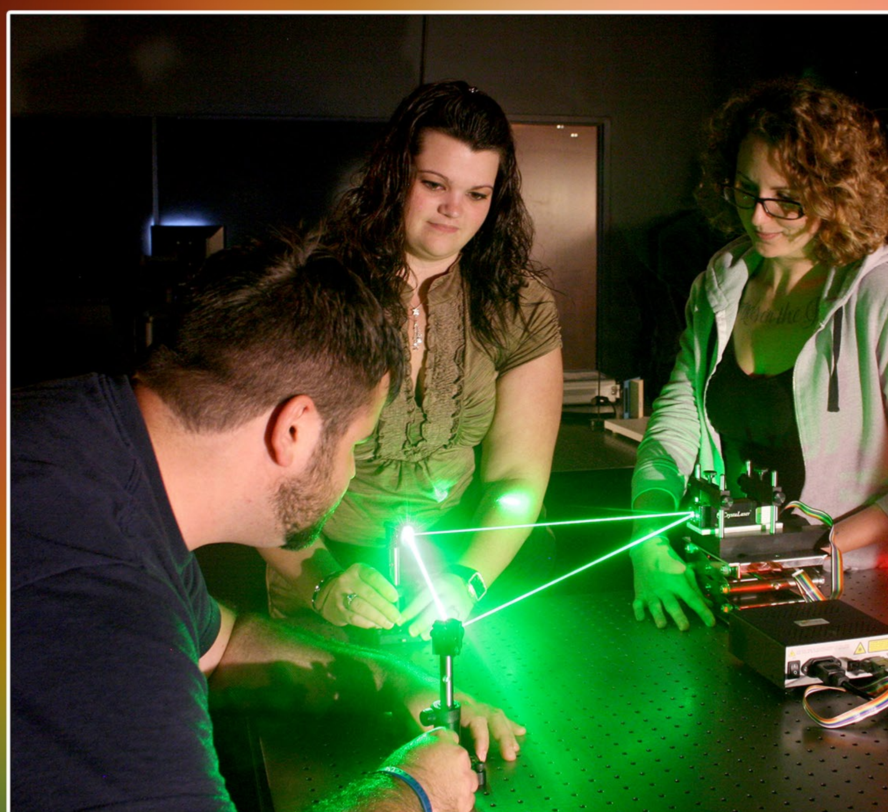
Optics and Photonics Series

Photonics Lab Manual for High Schools



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OP-TEC

Photonics Lab Manual for High Schools

OPTICS AND PHOTONICS SERIES

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PREFACE

The National Center for Optics and Photonics Education (OP-TEC) course, *Fundamentals of Light and Lasers*, is the "foundation course" for photonics technology. This course provides the basic principles of light, lasers and laser safety that are needed to study specific types of laser systems, advanced geometric and physical optics, fiber optics and optical measurements. It also provides 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.

Fundamentals of Light and Lasers is usually the first technical course taken in an A.A.S. photonics program offered by community and technical colleges throughout the U.S. The laboratories in this course are designed to demonstrate the technical principles of the course and to develop "hands-on skills" needed for further coursework and photonics technology practice.

Many high school students are exploring their interests in technical careers, as well as getting a "leg up" on college preparation, while earning valuable college credits, by enrolling in dual-credit (secondary/postsecondary) courses. *Fundamentals of Light and Lasers* is a popular, dual-credit course for photonics technology. The laboratory equipment for a 6-7 station lab, used by colleges offering this course typically costs over $50,000 (approximately $8,000 per lab station) because it contains "industry-level" equipment and devices. Often, high schools find that this level of expenditure exceeds their budgets.

OP-TEC colleges have devised alternate high school lab exercises that can be performed using less expensive equipment. While this equipment may not be "industry-grade," it nevertheless supports the hands-on learning required for this course, and develops useful "hands-on skills." These colleges have verified that high school students who successfully complete *Fundamentals of Light and Lasers*, using this lab equipment, are completely qualified to advance to the next level of postsecondary photonics courses in their curriculum.

Because the experiments are performed using different equipment, a separate "high school" lab manual has been prepared, that explains the unique lab layouts and procedures needed for this equipment. The procedures for this lab manual were prepared by Mr. Gary Beasley, Professor of Photonics at Central Carolina Community College.

We highly encourage teachers using this lab manual to require students to prepare a report on each lab that summarizes the procedures used, the data collected, the calculations made, and the results obtained. Developing skill in preparing these reports will help students process what they have learned and provide practice in communicating technical information in a written format—a skill that will pay high dividends in their future academic and career pursuits.

Daniel M. Hull, PE — June 2018
Executive Director
OP-TEC

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Using this Laboratory Manual

This laboratory manual supports the OP-TEC course, *Fundamentals of Light and Lasers*. It provides a wide variety of experiments that give students a hands-on approach to learning basic photonics concepts. Through these experiments, students sharpen their skills in making precise measurements and in collecting, organizing, and analyzing data. They have the opportunity to use optical components and equipment similar to those used in industry and science laboratories. Most importantly, students learn the value of experimentation as a means of confirming the legitimacy and accuracy of physical concepts presented in the course's text materials.

As stated in the Preface, this Laboratory Manual was written to provide high schools a less expensive option for offering the *Fundamentals of Light and Lasers* course. As you preview the text for this course, you will notice that labs are included in it. You will also notice that a vast majority of these labs are very similar to those in this lab manual. **There is one very big difference.** The labs in this manual are supported by a much less expensive set of equipment than those in the text. Though the equipment is less expensive, it still allows students to investigate the same physical concepts as those in the text and do so at same level of rigor.

If the cost of the equipment in this Lab Manual is still prohibitive, you may be tempted to teach this course without a laboratory component. We highly discourage this practice and strongly encourage educators to teach the laboratories and text materials as complementary pieces that are self-supporting. Instead of deleting these labs, we recommend you contact a college near your school and discuss the possibility of using their lab facilities or having them teach the lab component of the course.

Facilities and Equipment

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 labs in a facility that meets accepted safety standards for operating these light sources. OP-TEC has produced a companion piece for this manual called the *Photonics Program Planning Guide for High Schools* (HSPPPG). This guide provides details on a facility design that will assure students have a safe and effective environment in which to work.

The HSPPPG also provides detailed information about the equipment needed to support this Lab Manual. This information is summarized within this guide in an equipment list that is provided by Midwest Photonics Education Center (MPEC) reproduced here.

MPEC Kit Equipment List				$2,500
Equip List Ref #	Quantity	P/N	Item	Vendor
1	1	PZ9 - (MPEC Case)	Case & Custom Foam	My Case Builder
2	2	23650013650	Plano Prolatch Stowaway Tackle Box	Plano
3	2	N/A	Pocket Stowaway Fixed Compartments	Academy

4	2	BA2	Base, Mounting, 2" × 3" × 3/8"	Thorlabs
5	1	RCB	Block, Acrylic, rectangular 75 × 50 × 15 mm	BME Lab & Science
6	1	01-307	Diffraction Grating, 1000 lines/mm	Edmund Optics
7	2	DH1	Filter Holder, dual	Thorlabs
8	1	IF FS1	Filter Set, Color (RGB)	Industrial Fiber Optics
9	2	CPS635R	Laser Diode Module	Thorlabs
10	2	LDS5	Laser Diode Power Supply, 5 VDC	Thorlabs
11	1	LC1258	Plano-Concave Lens, N-BK7, Ø25 mm, f = -75.0 mm, Uncoated	Thorlabs
12	1	LB1761	N-BK7 Bi-Convex Lens, Ø1" f = 25.4	Thorlabs
13	1	LE1202	Positive Meniscus Lens, N-BK7, Ø1", f = 200 mm, Uncoated	Thorlabs
14	1	LC1259	Plano-Concave Lens, N-BK7, Ø25 mm, f = -50.0 mm, Uncoated	Thorlabs
15	2	LMR1	Lens Mount, Fixed, Inside Diam = 25mm	Thorlabs
16	2	33-501	Mirror Mount, no mirror, 25mm × 25 mm	Edmund Optics
17	2	27-453	Mirror, 25.4 × 51 × 6 mm, First Surface Mirror, Grade 2	Edmund Optics
18	1	MB1218	Optical Breadboard, 12" × 18" ×.5"	Thorlabs
19	1	IF PM	Photometer, Digital, Low Power	Industrial Fiber Optics
20	1	73-961	Polarizer, glass, Diam=23mm	Edmund Optics
21	6	58-977	Post Holders 1.5" × 1.0"	Edmund Optics
22	7	58-961	Posts 1.5" × 5"	Edmund Optics
23	1	33-0220	Prism, Equilateral, 25mm × 75mm	Arbor Scientific
24	2	33-0225	Prism, Right Angle, 32mm × 50mm	Arbor Scientific
25	2	RA90	Right-Angle Clamp or Post Holder .5"	Thorlabs
26	1	RSP1	Rotation Mount, Ø1" Optics, 8-32 Tap	Thorlabs
27	1	RP01	Rotation Stage, 2.5" × 2.5"	Thorlabs
28	1	S100R	Single Slit, (3), Double Slit (1), on one slide, 50 × 50 mm	Thorlabs
29	1	P2-7061	Spectroscope	Arbor Scientific
30	1	PT1	Translation, Stage, single axis	Thorlabs
31	1	VC3	V-Clamp, Cylindrical Laser Mount, 2.5" (2 - piece)	Thorlabs
32	1	WPMQ05M-633	Wave Plate, Multi-Order Quartz, ¼ Wave, φ=12.7mm, w/mount 25mm+B91	Thorlabs
33	1	G19 LED	LED Inspection Flashlight	Coast
34	1	07-251	Microscope Slide (72 pcs/pack)	Arbor Scientific
35	2	P2-9405	Polarizer, slide mounted (50 pcs/pack)	Arbor Scientific
36	1	Scraper Blades	Razor blades, single edge	Stanley

37	1	18” Stainless Steel	Stainless Steel Ruler with Non Slip Cork Base, English and Metric, 18", Westcott	Amazon
38	7	69207	Hex Key Set	Amazon
39	6	SH25S075	Socket Cap Screws, ¼"-20 × ¾"	Thorlabs
40	6	SS25S075	Socket Set Screw, ¼"-20 × ¾"	Thorlabs
41	5		3" × 5", white index cards	
42	1		Protractor	
43	1		1" × 1" Double-sided tape	
44	1	62-534	Optical Cleaning Kit	Edmund Optics

(One work station, *Fundamentals of Light and Lasers*, High School Lab Manual)

This equipment can be obtained as a kit from MPEC for $2,500. The equipment in the above list will support one lab station. To order the proper amount of equipment, you must decide on how many lab stations you will need. Based on the facility design presented in the HSPPPG, we recommend that you assign no more than two students to each station as a lab group. If class sizes dictate larger laboratory sections, you can add more students to each group, but we would limit, for safety and control issues, the size of sections to no more than 18 students.

Lab Manual Organization

This Lab Manual is organized into six sections with each section containing labs supporting one of modules in the *Fundamentals of Light and Lasers* course. At the beginning of each section, the general purpose for doing this group of labs is presented. This statement of purpose is then followed by specific directions for doing each individual lab. Fundamentals of Lab Safety are included at the end of Module 1-1.

Each lab starts with a statement of its objective. These are then followed, in some labs, with a brief summary of the theory supporting the lab and/or a list of the equations you will need to complete it. Next, an equipment list for the lab is presented. So you can understand the content of this list, we have included the one that appears in Lab 1-1A.

Table 1 – Lab 1-1A Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	5	Acrylic Block Lens
3	1	37	Metric Ruler
4	1	42	Protractor
5	1		8.5" × 14" White Paper
6	1		Roll of Masking Tape
7	1		Pencil

This list assigns a Lab Item (LI) number to each piece of equipment, defines the quantity of this equipment needed to perform the lab, and cross references each piece of equipment to the master equipment list presented earlier. This equipment list is then followed by a set of procedures for conducting the lab.

The lab procedures are tightly correlated to the equipment list. When a piece of equipment is first referenced in the procedures, it is followed in parentheses by the Lab Item number. This is to insure students know the proper piece of equipment that is being referenced. As an example, the following is a part of the procedures from Lab 1-1A. Note in procedure 1 and 2 the reference to the Lab Item number and their correlation to the equipment list presented previously.

Procedure

1. Tape (LI-6) white paper (LI-5) to a tabletop. Tape the laser diode module (LI-1) on the left side of the tabletop so the beam is directed left to right across the paper. Refer to Figure 1.

2. Turn the laser diode module on. Hold a pencil (LI-7) in a vertical position at the right edge of the paper where the light beam hits the center of the pencil. Mark the paper with a small dot or dash. Refer to Figure 2.

Lab Manual Features and Lab Reports

The lab manual also has several figures and photographs to assist in setting up the lab and also includes tables for recording data and recording the results of required calculations. The following are examples of these two features.

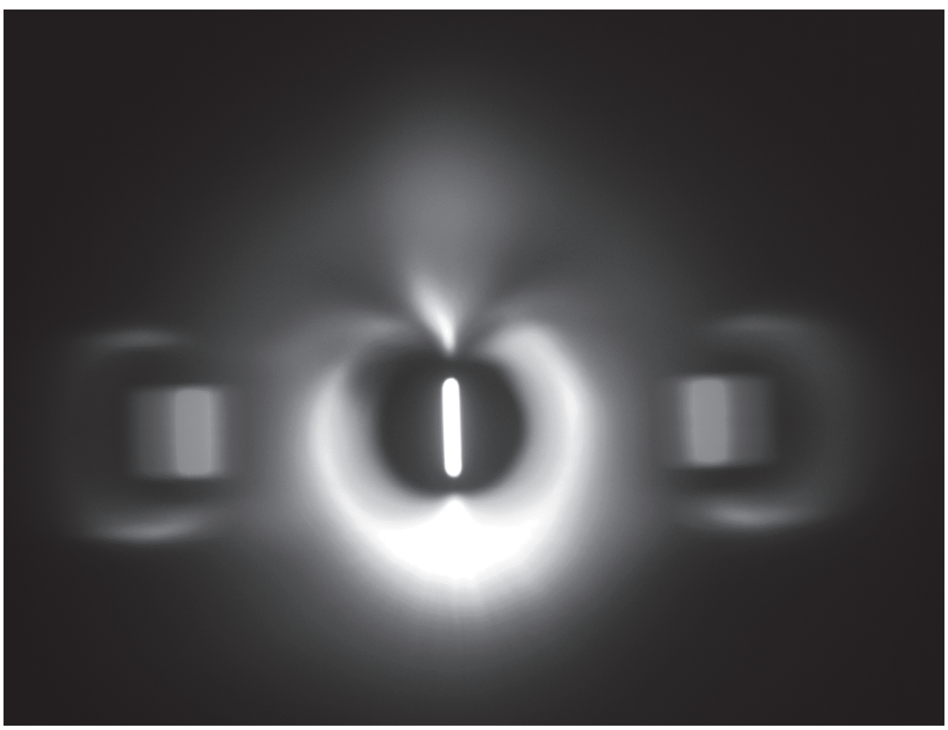

Figure 16 - Fluorescent Light Spectra

Table 8 – Wavelength versus Energy Calculations

	Color	Estimated Wavelength	Energy (eV)	Energy (Joules)
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

MODULE 1 LABS

Purpose

Examine basic properties of light such as the following:

- speed
- wavelength
- color spectrum of visible light
- polarization

Laboratory 1-1A: Finding the Speed of Red Light in Acrylic Medium

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.

Purpose

In this laboratory, you will complete the following task:

- Determine the speed of light in an acrylic medium using the property of refraction.

Theory

The speed of light in a vacuum, *c*, is exactly 299,792,485 m/s. Current physical theory asserts that nothing in our universe can have a speed greater than *c*. When light, or any electromagnetic wave, moves in any other medium it will have a speed less than *c*. In general, the speed of light through a medium depends upon both the medium and the wavelength of the light. The objective of this experiment is to use the definition of index of refraction and Snell's law to determine the speed of red light in acrylic.

Key definitions and relationships

1. The index of refraction for any medium, *n*, is defined as: $n_i = \frac{c}{\mathrm{v}_i}$ where v_i is the speed of light in medium, *i*.
2. Snell's law: $\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$
3. The speed of light in vacuum and air is the same to an accuracy of six significant figures, so we will use $n_{air} = 1.00000$.

Equipment

Table 1 – Lab 1-1A Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	5	Acrylic Block Lens
3	1	37	Metric Ruler
4	1	42	Protractor
5	1		8.5" × 14" White Paper
6	1		Roll of Masking Tape
7	1		Pencil

Procedure

1. Tape (LI-6) white paper (LI-5) to a tabletop. Tape the laser diode module (LI-1) on the left side of the tabletop so the beam is directed left to right across the paper. Refer to Figure 1.

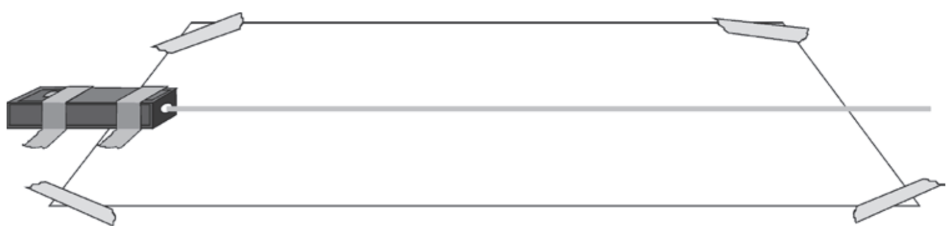

Figure 1 – Laser Line Set-up Illustrated

2. Turn the laser diode module laser diode module on. Hold a pencil (LI-7) in a vertical position at the right edge of the paper where the light beam hits the center of the pencil. Mark the paper with a small dot or dash. Refer to Figure 2.

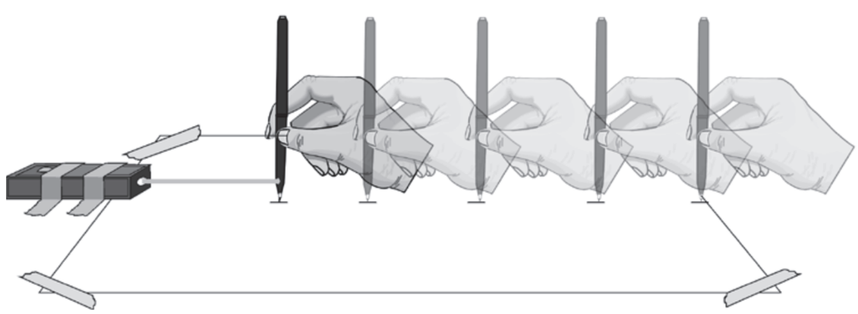

Figure 2 – Laser Line Drawing Illustrated

Move the pencil directly left one or two inches and repeat. Continue until you have five or six marks extending left to right across the paper. Turn off the laser diode module. Using your metric ruler (LI-3) draw a “best-fit” straight line through the marks. Label the point at the left end of this line point O. Refer to Figure 3.

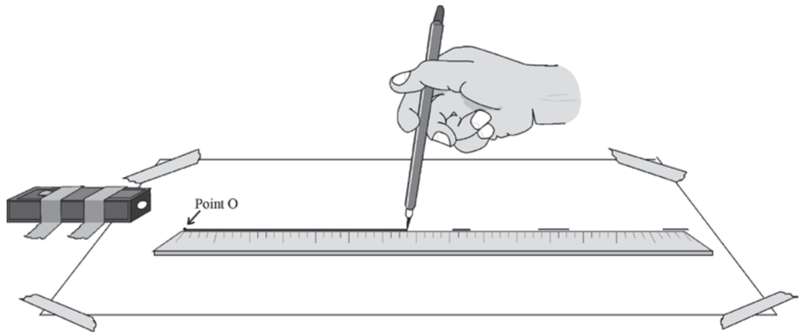

Figure 3 – Laser Line Drawing Illustrated

3. Place the acrylic block (LI-2) with the large surface down. The left face of the block should intersect the line on the paper at a 40- to 50-degree angle, and the light beam should hit the left face about 1 cm from its lower left corner. Hold the block firmly in place and draw an outline of the block on the paper. Refer to Figure 4.

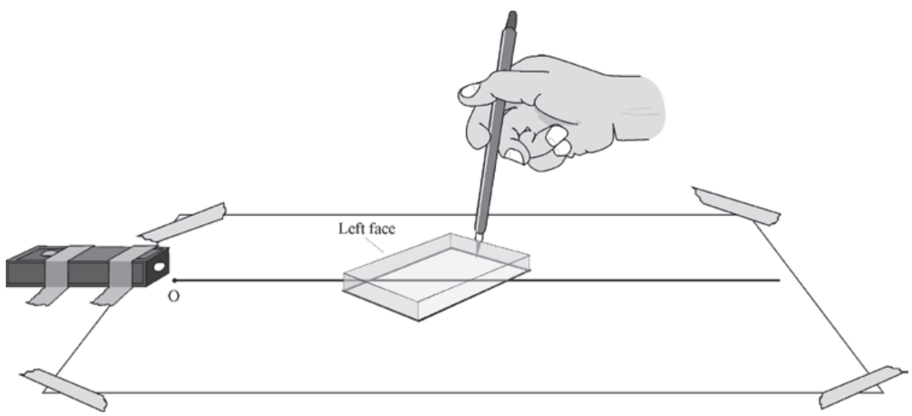

Figure 4 – Acrylic Block Set-up Illustrated

4. Turn the laser diode module on. The beam is refracted by the block and should exit it through the right face. Move your pencil along the right edge of the paper until you find the beam. Mark the location of this exit beam at five or six places on the paper just as you did for the beam in step 2. Refer to Figure 5.

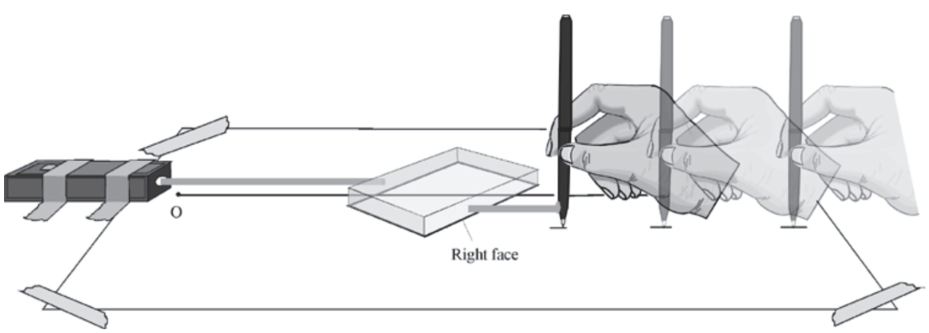

Figure 5 – Refracted Beam Drawing Illustrated

5. Remove the block. Draw a best-fit straight line through the marks along the exit beam path. Refer to Figure 6.

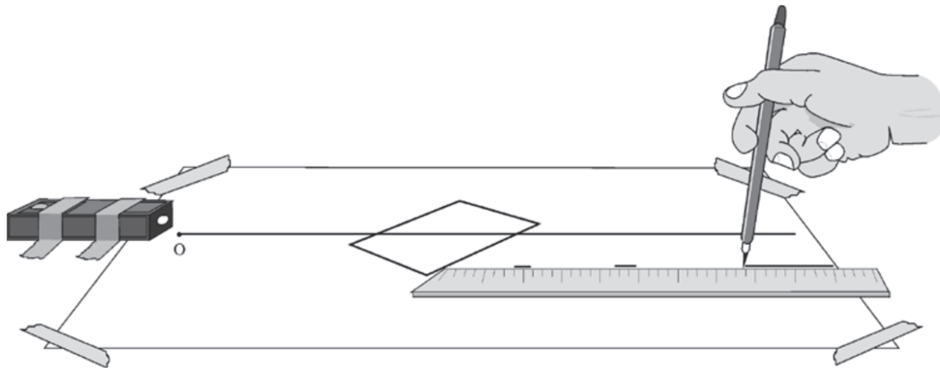

Figure 6 – Refracted Beam Drawing Illustrated

Mark the right end of the line as point D. Extend this line to the left until it intersects the line marking the lower edge of the block. This is the point where the beam left the block. Mark this point as point B. Mark the point where the incident beam (drawn in step 2) hit the left face of the block as point A. Connect points A and B with the line segment AB. Refer to Figure 7.

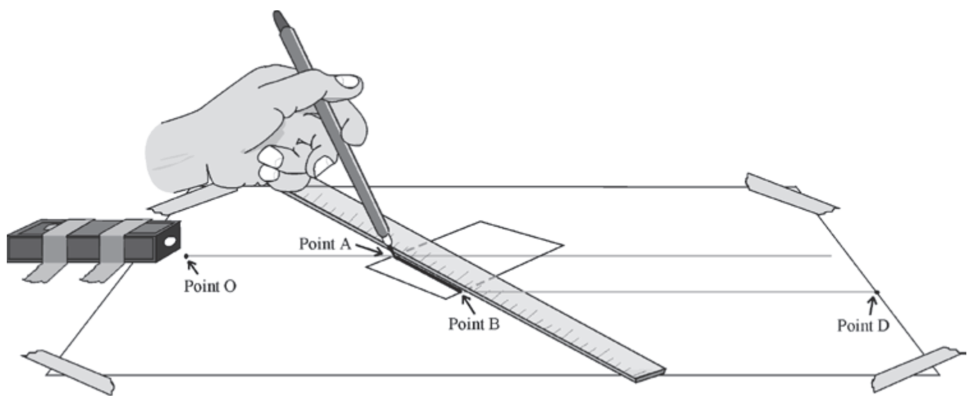

Figure 7 – Refracted Beam Drawing Illustrated

Note: The line segment OA describes the path of the light beam that is incident on the block. The line segment AB describes the path of the refracted beam through the block. The segment BD describes the beam's path after it exits the block.

6. Use the protractor (LI-4) to draw a line through point A that is perpendicular to the left face of the block. Draw another line through point B that is perpendicular to the right face of this block. Refer to Figure 8 and Figure 9.

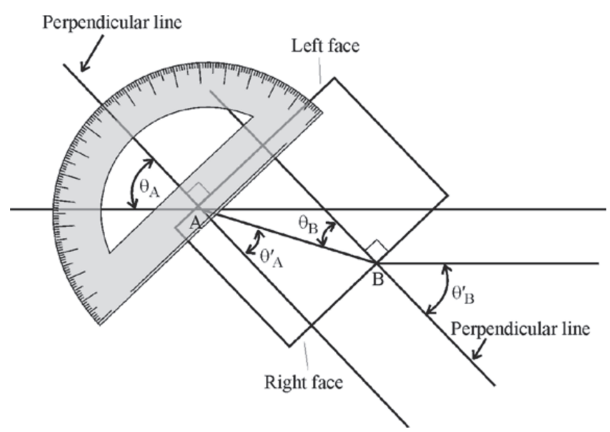

Figure 8 – Protractor Measurements Illustrated

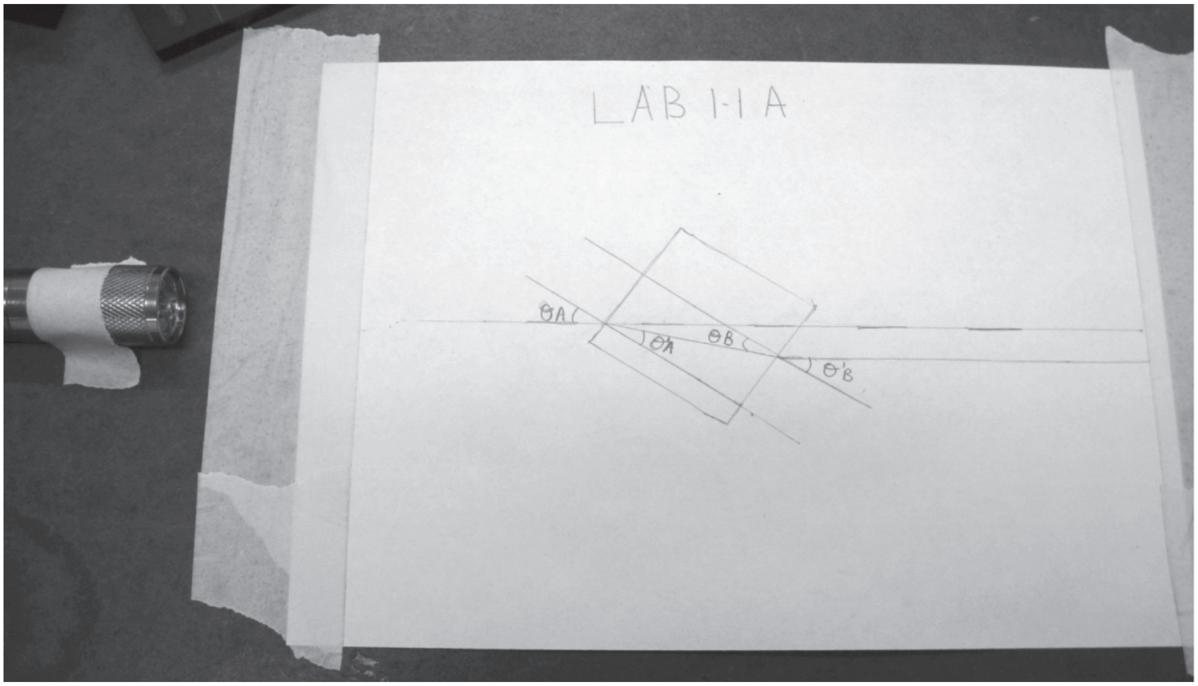

Figure 9 – Sketches of Incident and Refracted Beams

7. Measure and record the angle θ_A between the incident beam and the normal line at the left face of the block (point A). Do the same for the refracted beam at this face. This is angle θ'_A. Refer to Figure 8 and Figure 9.
8. Measure the angle between the normal line and the incident and refracted (exit) beams at the right face of the block (point B). Label these as θ_B and θ_B'. Refer to Figure 8 and Figure 9.
9. Using θ_A and θ_A', use Snell's law to find the ratio $\frac{n_{\text{air}}}{n_{\text{plastic}}}$ at the left interface between air and acrylic.
10. Using θ_B and θ_B', use Snell's law to find the ratio $\frac{n_{\text{plastic}}}{n_{\text{air}}}$ at the right interface between acrylic and air.
11. The index of refraction of air, n_{air}, has a value of 1.00000. Use this and the results of steps 9 and 10 to find the numerical value of n_{acrylic} from your measurements at A and at B. Average the two values to determine your final estimate of n_{acrylic}.
12. Use the definition of index of refraction and the known value of speed c in a vacuum to calculate the speed of light in the acrylic block.

Laboratory 1-1B: Determining the Wavelength of Red 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.

Objective

In this laboratory, you will complete the following task:

- Determine the wavelength of light using the property of diffraction.

Theory

When a beam of light is incident on a diffraction grating, part of the light will pass straight through. Part of the light is diffracted to paths that diverge at different angles on both sides of the original path. The angle θ at which the light diverges is related to the wavelength and spacing of the lines on the grating. The relationship is described by

$m\lambda = a \sin\theta_m$ where λ is the wavelength of the incident light in meters, a is the spacing between lines on the grating in meters, m is an integer that takes on the values 0, 1, 2, …., and θ_m is the diffraction angle for a particular diffraction order m.

If the diffraction angle θ_m can be measured for a particular order m and the grating spacing a is known, the wavelength of the light can be calculated.

Equipment

Table 2 – Lab 1-1B Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	2	21	1.5" Post Holder
5	2	22	1.5" Post
6	1	4	Mounting Base
7	1	6	Diffraction Grating
8	1	7	Dual Filter Holder
9	1		8.5" × 14" White Paper
10	1		Roll of Masking Tape
11	1		Metric Ruler

Procedure

1. Using the V-Clamp for laser (LI-2), a 1.5" post (LI-5), and a 1.5" post holder (LI-4), mount the laser diode module (LI-1 and LI-2) to the optical breadboard (LI-3). Mount a 1.5" post holder onto a mounting base (LI-6). Insert a 1.5" post into the 1.5" post holder. Mount the dual filter holder (LI-8) to the post inserted into the post holder. Insert the diffraction grating (LI-7) into the filter holder. Place the diffraction grating assembly in line with the laser between 6 inches and 12 inches from the laser. Tape (LI-10) white paper (LI-9) to an upright surface 6 to 12 inches from the diffraction grating assembly. Turn the laser diode module on. Point the beam so that it goes through the grating perpendicular to the grating surface and onto the upright surface. There it produces a center spot with diffracted spots on both sides as shown in Figure 10.

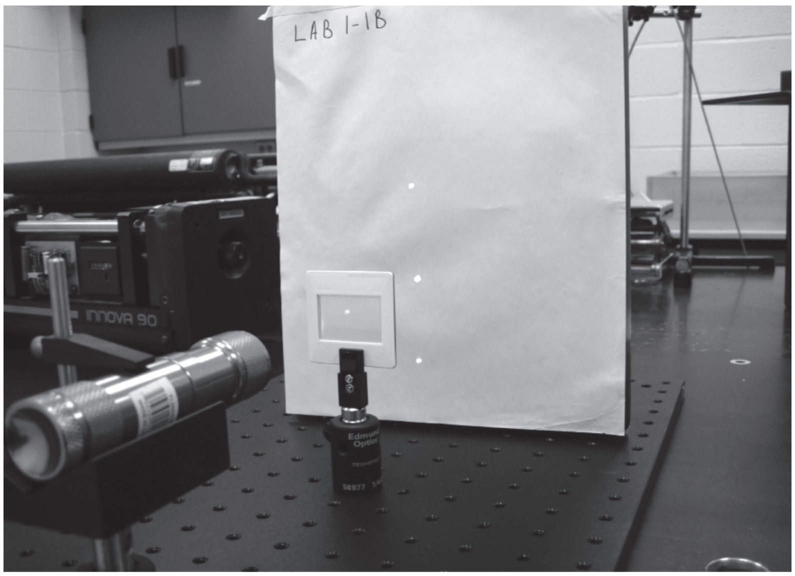

Figure 10 – Diffraction Grating Pattern Set-up

2. Using the metric ruler (LI-11) measure the vertical distance from the grating to the paper taped on the upright surface. Record this as *L*.
3. Measure the distances from the center spot to the first diffracted spots on both sides. Average these two distances and record the average as Δx. For these nearest diffracted spots, $m = 1$.
4. Calculate the diffraction angle using $\theta = \tan^{-1}\left(\frac{\Delta x}{L}\right)$.
5. Calculate the wavelength of the light source using this first-order diffraction angle, θ_1 where $m = 1$. The equation is then

$$\lambda = \frac{a \sin\theta_1}{1}$$

Laboratory 1-1C: The Spectrum of Colored 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.

Objective

In this laboratory, you will complete the following task:

- Analyze an optical spectrum.

Equipment

Table 3 – Lab 1-1C Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	33	LED Flashlight
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	2	21	1.5" × 1" Post Holder
5	2	22	1.5" × 5" Post
6	1	4	Mounting Base
7	1	6	Diffraction Grating
8	1	7	Dual Filter Holder
9	1	8	Filter Set, Color
10	1		8.5" × 14" White Paper
11	1		Roll of Masking Tape
12	1		Metric Ruler

Procedures

Part 1. The spectrum of white light

1. Using the V-Clamp for laser (LI-2), a 1.5" post (LI-5), and a 1.5" post holder (LI-4), mount the LED Flashlight (LI-1) to the optical breadboard (LI-3). Mount a 1.5" post holder onto a mounting base (LI-6). Insert a 1.5" post into the 1.5" post holder. Mount the dual filter holder (LI-8) to the post inserted into the post holder. Insert the diffraction grating (LI-7) into the filter holder. Place the diffraction grating assembly in line with the LED flashlight 1 meter from the LED flashlight. Tape (LI-11) white paper (LI-10) to an upright surface 1 meter from the diffraction grating assembly. Turn on the LED flashlight.
2. Focus the light perpendicularly onto the grating surface. Refer to Figure 11.

Figure 11 – Spectrum Analysis Set-up

3. 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.
4. Using a ruler (LI-12) draw lines through each color you can identify in the spectrum, and label each line with its color.

Part 2. The components of different colors of light

5. Hold a red color filter (LI-9) (transmission filter) between the LED flashlight 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.
6. 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.
7. 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?

Laboratory 1-1D: 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.

Objective

In this laboratory, you will complete the following task:

- Examine polarization properties of light.

Equipment

Table 4 – Lab 1-1D Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	33	LED Flashlight
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	1	21	1.5" Post Holder
5	1	22	1.5" Post
6	1	4	Mounting Base
7	2	20	Polarizer, glass, Diam=23mm
8	1	34	Microscope Slide

Procedure

Part 1. Polarizers and Analyzers

1. Using the V-Clamp for laser (LI-2), a 1.5" post (LI-5), and a 1.5" post holder (LI-4), mount the LED flashlight (LI-1) to the mounting base (LI-6). Turn on the LED flashlight. Adjust the mounted LED flashlight source 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.

   Hold one polarizing filter (LI-7) 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 polarizing filter (analyzer) with your other hand. Place it between you and the first polarizing filter. Rotate the second polarizing filter 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?

Part 2. Polarization by reflection

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 optical breadboard about 5 inches in front of the light source. Place a microscope slide (LI-8) on the table at the position of the focused spot. Refer to Figure 12.

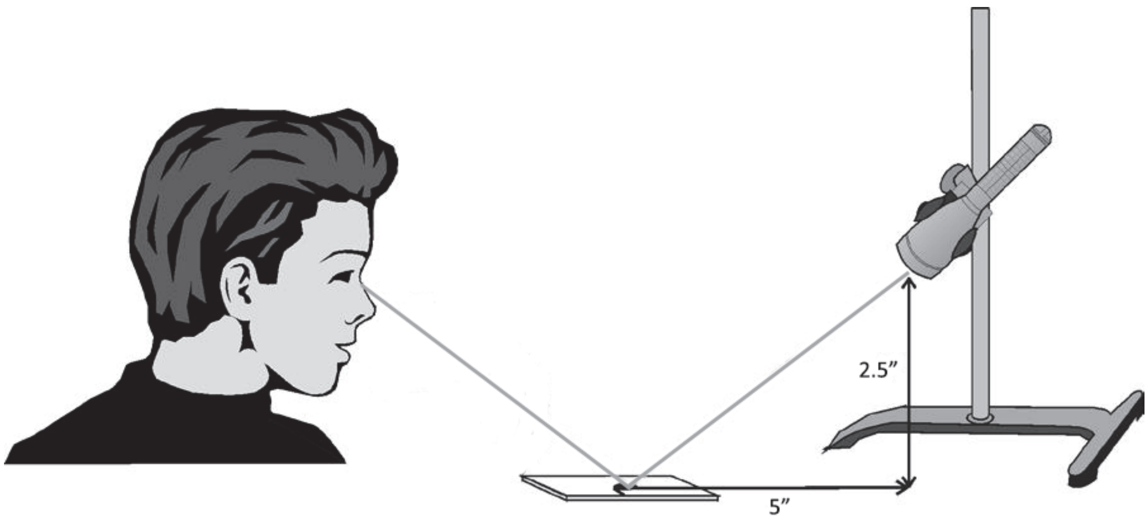

Figure 12 – Polarizer with Analyzer Illustrated

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 13.

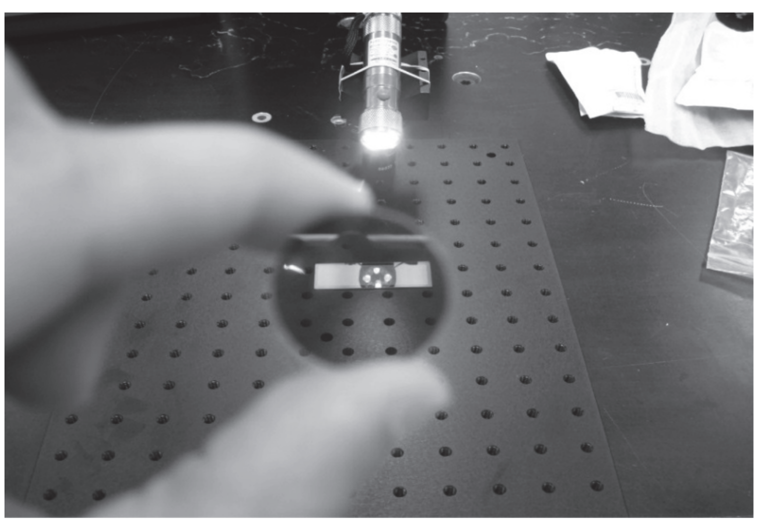

Figure 13 – Polarization by Reflection Set-up

7. Hold a polarizing filter so you can see the reflection through the filter. Rotate the filter about the axis of the reflected beam. Refer to Figure 14. What do you observe about the brightness of the reflection as you rotate the filter?

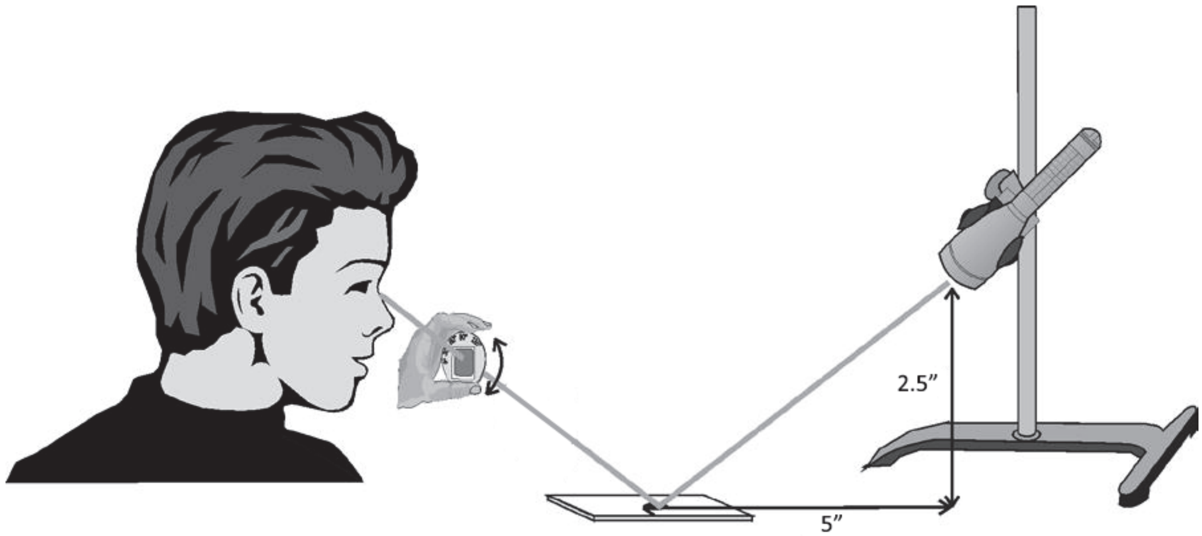

Figure 14 – Polarizer with Analyzer Illustrated

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.

MODULE 1-2 LABS

Purpose

Examine basic optical equipment and practice proper techniques for maintaining components.

Laboratory 1-2A: Familiarization with Optical Equipment and Components

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.

Objective

In this laboratory, you will complete the following tasks:

- Familiarize yourself with the optical equipment and components found in a typical photonics lab.
- Prepare a purchase requisition for a new set of parts.

Equipment

Optical components provided by your instructor.

Procedure

Identify all the parts provided by your instructor and complete the following purchase requisition. Obtain prices from the internet.

Table 5 – Equipment Inventory List

Item	Description	Qty	Part no.	Unit cost	Total cost

Item	Description	Qty	Part no.	Unit cost	Total cost

Laboratory 1-2B: Care and Cleaning of High Grade Optical Components

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.

Objective

In this laboratory, you will complete the following tasks:

- Practice the "drop and drag" technique.
- Practice the "forceps and pad" method.
- Demonstrate the proper procedure for cleaning a mirror.
- Research other methods for cleaning optical components.

Equipment

Table 6 – Lab 1-2B Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1		11, 12, 13 and 17	Lenses and Mirror
2	1	44	Optical Cleaning Kit

Procedure

1. Use the lens cleaning kit to practice the "drop and drag" technique on selected lenses and mirror (LI-1). Repeat until you are comfortable with this method.
2. Use the lens cleaning kit to practice the "forceps (LI-2) and pad" method on selected lenses and mirrors. Repeat until you are comfortable with this method.

3. When ready, demonstrate competency to your instructor by cleaning a lens or mirror using the "drop and drag" and the "forceps and pad" method.
4. Research other cleaning methods. Document your findings. Practice your researched method and demonstrate your proficiency to the instructor.

Notes

For reference, a brief description of each cleaning method is presented:

Drop and Drag Method

1. Lens tissue is folded to a width slightly larger than the optic.
2. Tissue is placed over optic and a few drops of cleaning solution are applied until tissue adheres to optic.
3. Tissue is pulled across optic.

Forceps and Pad Method

1. Fold lens tissue into a square about the same size as the optic to be cleaned. Refer to Figure 15.
2. Hold tissue with forceps. Apply cleaning solution.
3. Each side of the square tissue can be wiped across the optic. Use each side only once.

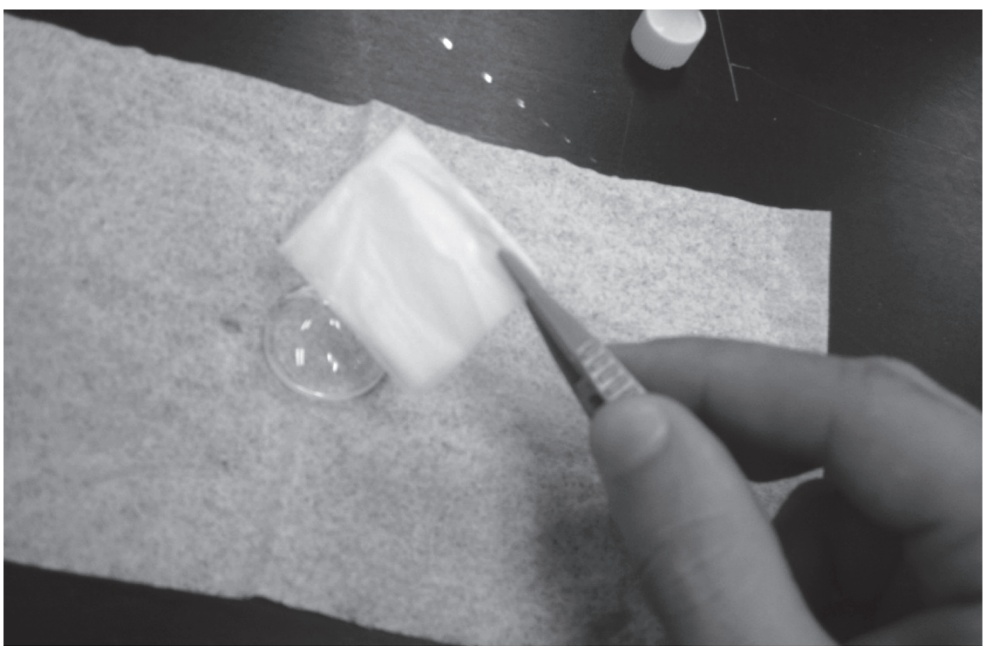

Figure 15 – Forceps and Pad Cleaning Method

Laboratory 1-2C: Building an Inexpensive Spectrometer

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.

Objective

In this laboratory, you will complete the following tasks:

- Observe the light spectrum of a fluorescent and incandescent light.
- Determine the energy of the photons in the observed spectral bands, lines, and/or continuum.

Equipment

Table 7 – Lab 1-2C Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	29	Spectroscope
2	1		Colored Pencils

Procedure

1. Using the Spectroscope (LI-1), observe light spectra from a fluorescent and incandescent light source. These light sources will probably be providing illumination for your laboratory facility. In the space provided, draw a rough sketch of each spectrum using colored pencils (LI-2). Identify each spectrum as line, band, or continuum. To check the accuracy of the rough sketches, compare them with spectra of the same light source produced by higher resolution spectroscopes. These more refined spectra can typically be found on the internet.

   a. Fluorescent Light (See Figure 16.)

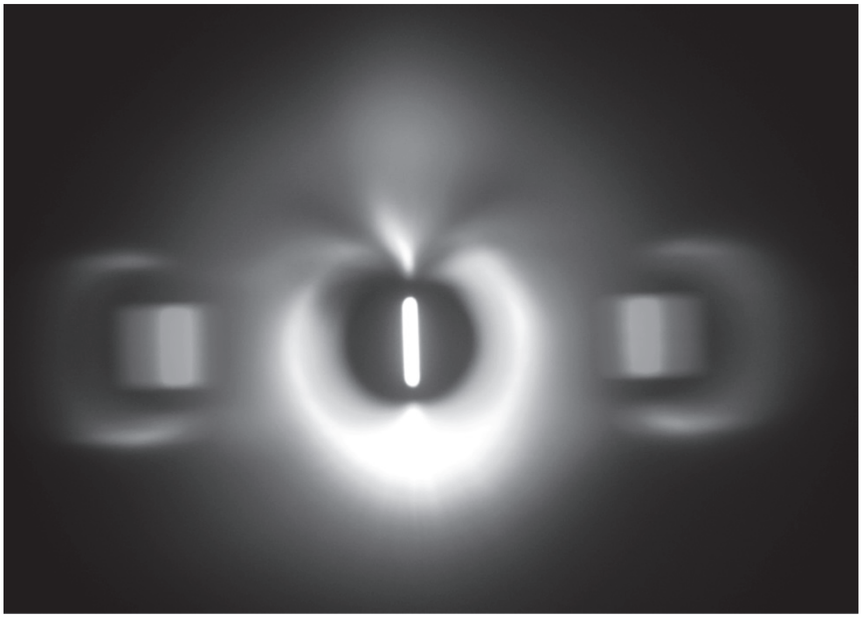

Figure 16 – Fluorescent Light Spectra

b. Incandescent Light (See Figure 17.)

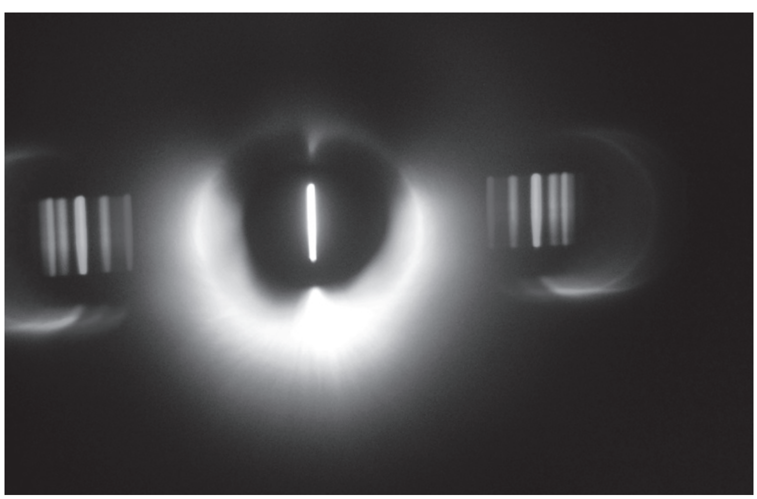

Figure 17 – Incandescent Light Spectra

2. Use a reference book or internet search to estimate the wavelength of the colors observed in the spectra. Enter this information in Table 8.
3. Complete Table 8 below based on your observations and estimations. Use the equations below to determine the photon energy of each of the estimated wavelengths.

Table 8 – Wavelength versus Energy Calculations

	Color	**Estimated Wavelength**	**Energy (eV)**	**Energy (Joules)**
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

Energy of a Photon in $eV = hv = hc/\lambda$

where $h = 4.14 \times 10^{-15}\ eV \bullet s$ and
$c = 3 \times 10^{8}$ m/s

1 $eV = 1.602 \times 10^{-19}$ Joules (J)

MODULE 1-3 LABS

Purpose

Examine methods for using an optical photometer to determine:

- Irradiance
- Laser Safety Parameters
- Absorption Properties of Windows and Mirrors
- Absorption Properties of Optical Filters

Laboratory 1-3A: Irradiance

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.

Objective

In this laboratory, you will complete the following task:

- Measure the irradiance of a light source under various conditions.

Discussion

As discussed in the text, irradiance is defined as power per unit area and is an important concept in regard to laser safety.

Equipment

Table 9 – Lab 1-3A Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	2	21	1.5" Post Holder
5	2	22	1.5" Post
6	1	15	Fixed Lens Mount, 25mm
7	1	11	Plano-Concave Lens
8	1	19	Photometer, Digital, Low Power
9	1	7	Dual Filter Holder

Procedure

In this laboratory exercise, you will use an photometer (LI-8) to determine the power and irradiance of laser light. The power and area of a laser beam will be expanded with a diverging lens and the irradiance will be determined at several distances. From collected data, you will prepare a graph of irradiance-versus-distance.

A. Power and irradiance of a laser beam

1. Using the V-Clamp mount for laser (LI-2), a 1.5" post (LI-5), and a 1.5" post holder (LI-4), mount the laser diode module (LI-1) to the optical breadboard (LI-3). Turn the laser diode module on.
2. Position the sensor head of the photometer (LI-8) as close to the output aperture of the laser as possible. Turn on the photometer to a full-scale range. Measure the laser beam power and record in Table 10.
3. Calculate and record the area of the beam and the irradiance of the beam in Table l0.

Table 10 - Power and Irradiance of a Laser Beam

Laser power using photometer:	
	$P =$ _______________ mW
Beam diameter:	$d =$ _______________ mm = __________________ cm
Beam area:	$A = \dfrac{\pi d^2}{4}$
	$A =$ _______________ cm^2
Irradiance:	$E = \dfrac{P}{A}$
	$E =$ _______________ mW/cm^2

B. Irradiance of a diverging beam

1. Turn the laser diode module on.
2. Mount a 1.5" post holder onto a optical breadboard approximately 10 cm from the laser aperture. Insert a 1.5" post into the 1.5" post holder. Mount the dual filter holder (LI-9) to the post inserted into the post holder. Mount a Plano-Concave Lens (LI-7) into a 1" Fixed Lens Mount (LI-6). Mount the 1" Fixed Lens Mount onto the 1.5" post. Refer to Figure 18. Be careful of reflections off the lens when inserting the lens in the beam. Be sure that the expanded laser beam does not enter the eye directly.

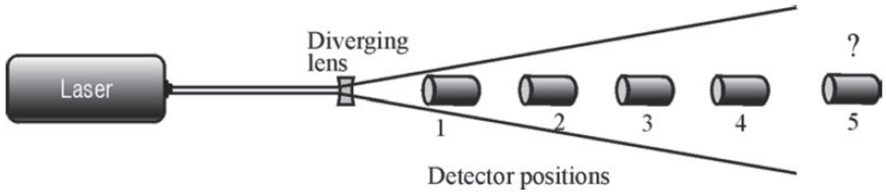

Figure 18 – Irradiance of an Expanded Beam Illustrated

Determine the detector area of the photometer and record in Table 11.

3. Using the photometer, measure the power of the expanded beam at four distances from the diverging lens, as indicated in Figure 18, Figure 19, and Figure 20. The beam should be larger than the detector at the nearest point and all measurements should be made with the beam centered on the detector. Record distances and corresponding powers in Lab Table 11.

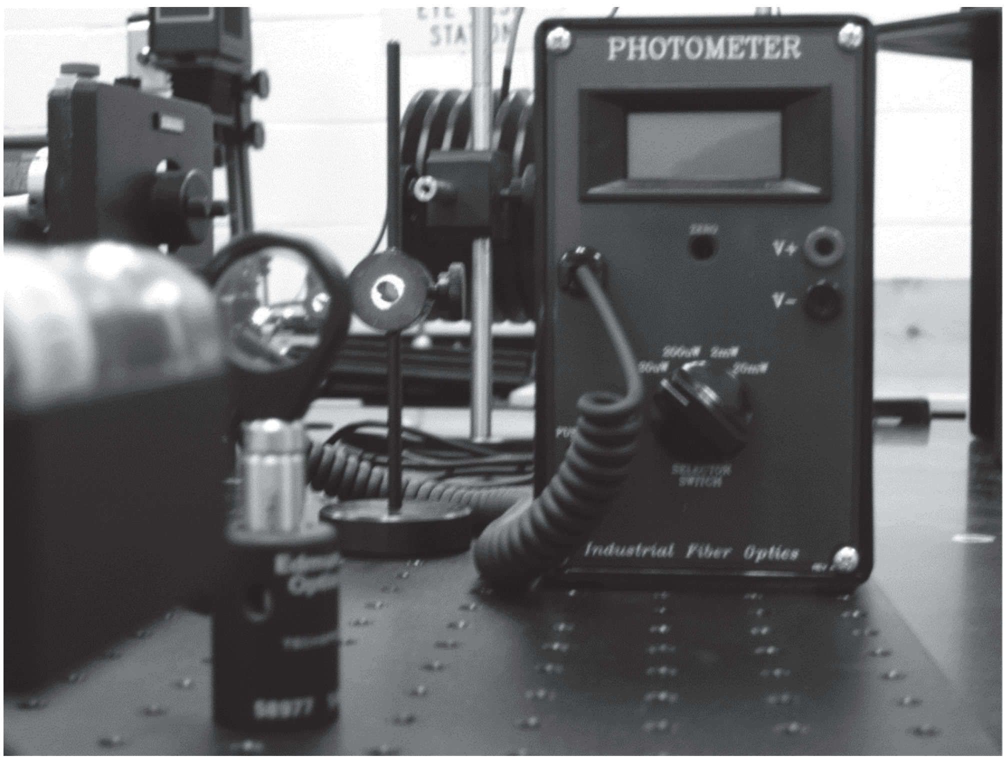

Figure 19 – Expanded Beam Power Measurement Set-up

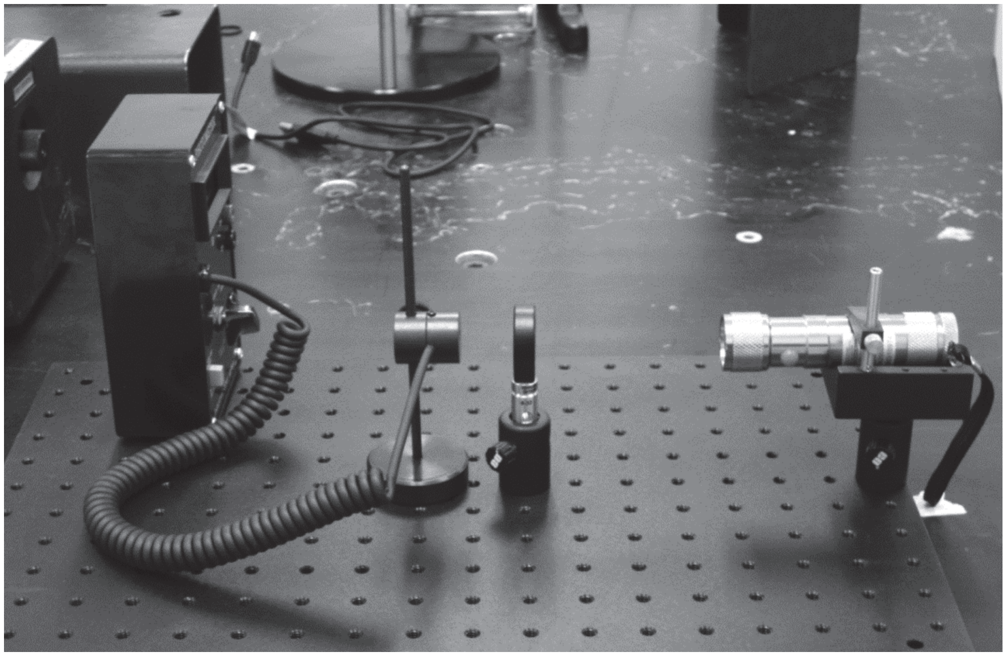

Figure 20 – Expanded Beam Power Measurement Set-up

Table 11 - Data Table Irradiance of a Diverging Beam

Detector area: A = __________ cm²

Position	Distance (cm)	Power (mW)	Irradiance (mW/cm²)
1			
2			
3			
4			
5			

4. Calculate the irradiance at each point by dividing the power detected by the receiving area on the detector—or the area of the opening of an ambient light shade if one is used.
5. Draw a graph of irradiance-versus-distance from the data collected in Step 4.
6. Select a fifth distance beyond the fourth measurement. Use your graph to predict the irradiance of the expanded beam distance. Measure the power at the fifth distance, calculate the irradiance, and compare the calculated value with your predicted value.
7. Describe the effect a diverging lens has on the irradiance of a laser beam.

Laboratory 1-3B: Laser Eye Protection Equipment

Objective

In this laboratory, you will complete the following tasks:

- Determine the optical density of the eye protection needed to safely use a specified laser.
- Find suppliers that provide this eye protection at the least expensive price.

Equipment

None

Procedure

1. Assume you had to work with a Nd:YAG laser operating in continuous mode. The power and wavelength of the laser are:

   Power = 75 Watts , Wavelength = 1064 nm .
2. Using the formulas of module 3, determine the minimum optical density of the eye protection you need.
3. Search the Internet for best prices from at least two different suppliers.

Laboratory 1-3C: Windows and Mirrors

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.

Objective

In this laboratory, you will complete the following tasks in two separate laboratories:

- Observe Fresnel reflection in an optical window.
- Measure reflection and transmission coefficient of an optical window.
- Measure and compare reflection and transmission coefficients of front and rear surface mirrors.

Laboratory 1-3C.1

Equipment

Table 12 – Lab 1-3C.1 Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	1	21	1.5" Post Holder
5	1	22	1.5" Post
6	1	5	Acrylic Block Lens
7	1	19	Photometer, Digital, Low Power
8	Varies with Thickness		Books
9	1		Silly Putty or Equivalent

Note on accuracy: The results of this lab are HIGHLY sensitive to the condition of the optical surfaces. Make sure that any optical surfaces the laser strikes are very clean. (See Lab 1-2B.) Any oils from your fingers will drastically affect your results. In addition, scratches will affect your results, so choose surfaces that are as smooth as possible.

Procedure

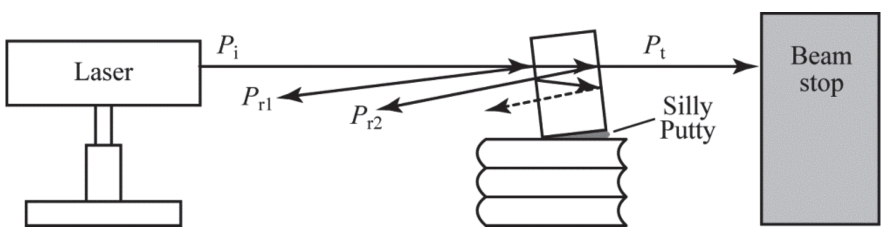

Figure 21 – Acrylic Block Power Measurements Set-up

1. Using the V-Clamp mount for laser (LI-2), a 1.5" post (LI-5), and a 1.5" post holder (LI-4), mount the laser diode module (LI-1) to the optical breadboard (LI-3). Turn the laser diode module on. Using books (LI-8) and silly putty (LI-9), position an acrylic block (LI-6) at an angle where two separate reflected beams, one from the front surface P_{r1} and one from the rear surface P_{r2} are visible. The angle of the block should cause P_{r1} and P_{r2} to be in a location that the fiber optics digital photometer (LI-7) can measure each separately. Refer to Figure 21 and Figure 22.

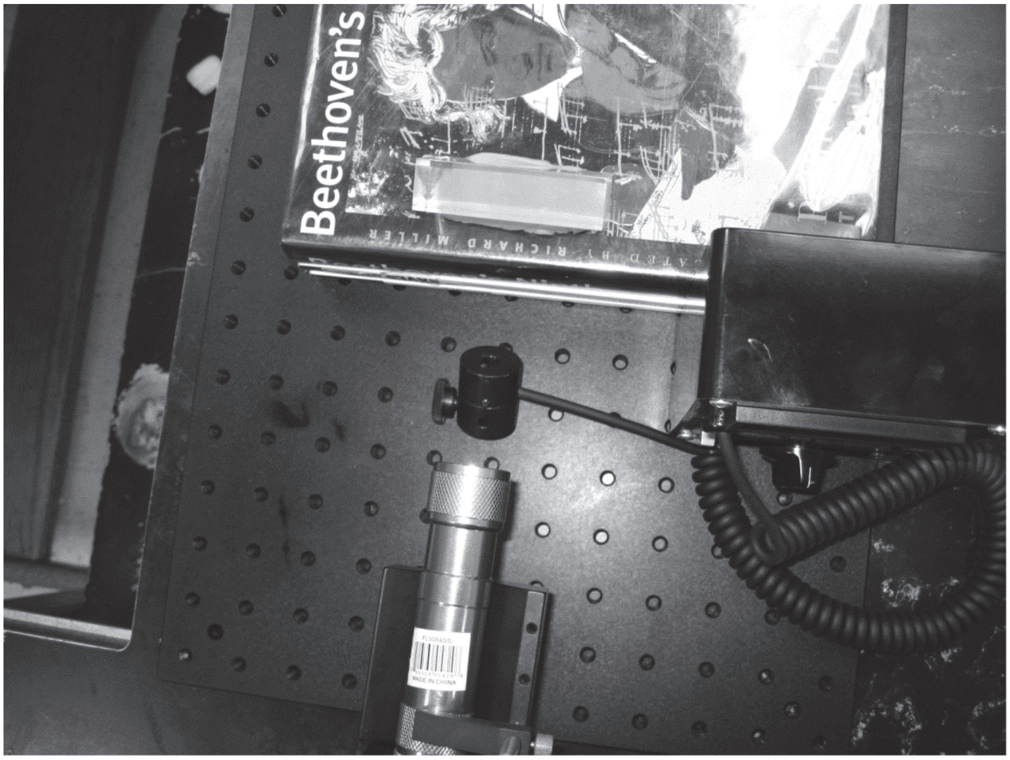

Figure 22 – Acrylic Block Power Measurements Set-up

2. Measure each of the following values.

   P_i = _______ P_{r1} = _______ P_{r2} = _______ P_t = _______

3. Determine the approximate power absorbed by the acrylic block (P_a).
   Formula: $P_a = P_i - P_t - P_{r1} - P_{r2}$

4. Determine the predicted value for P_{r1}.
   Formula: $P_{r1} = P_i * R$
   $R = [(n-1)^2/(n+1)^2]$

5. Determine the predicted value for P_{r2}.
   Formula: $P_{r2} = (P_i - P_{r1(\text{predicted})} - P_a) * R * (1 - R)$

6. Determine the predicted value for P_t.
   Formula: $P_t = P_i - P_{r1(\text{predicted})} - P_a - P_{r2(\text{predicted})}$

7. Determine the % error for your measured values of P_{r1}, P_{r2}, and P_t.

8. Determine the "Absorption Coefficient" (α) of the acrylic material.
   Formula: $E = E_o\,(e^{-\alpha x})$

Laboratory 1-3C.2

Equipment

Table 13 – Lab 1-3C.2 Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	1	21	1.5" Post Holder
5	1	22	1.5" Post
6	1	17	Mirror, 25 mm
7	1	19	Photometer, Digital, Low Power
8	Varies with Thickness		Books
9	1		Silly Putty or Equivalent

Note on accuracy: The results of this lab are HIGHLY sensitive to the condition of the optical surfaces. Make sure that any optical surfaces the laser strikes are very clean. (See Lab 1-2B.) Any oils from your fingers will drastically affect your results. In addition, scratches will affect your results, so choose surfaces that are as smooth as possible.

Procedure

1. Using the V-Clamp mount for laser (LI-2), a 1.5" post (LI-5), and a 1.5" post holder (LI-4), mount the laser diode module (LI-1) to the optical breadboard (LI-3). Turn the laser diode module on. Most mirrors on the walls of bathrooms are rear surface mirrors. Using the 25 mm mirror (LI-6), identify the coated surface. Using books (LI-8) and silly putty (LI-9), position the mirror, such that the coated surface is facing the laser, at an angle where the fiber optics digital photometer (LI-7) can be used to measure the reflected power P_r. Refer to Figure 23.

2. Measure P_i and P_r and determine the reflectivity of the mirror coating.
   Formula: $R_{coating} = P_r/P_i$

P_i = ____________ P_r = _____________

$R_{coating}$ = _______________

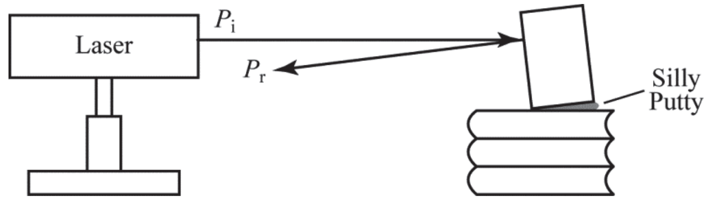

Figure 23 – Front Surface Mirror Power Measurements Set-up

3. Keep in mind that this mirror is made with crown glass (n = 1.52). Your next task will be to turn the mirror around (coated surface is facing away from laser) and measure the properties of a rear surface mirror. To simplify calculations and measurements, we will assume that no power is absorbed by the glass.
4. Measure and record each of the following values in Figure 24. Refer to Figure 25 and Figure 26 for experimental set-up.

P_i = ________ P_{r1} = ________

P_{r2} = ________ P_t = ________

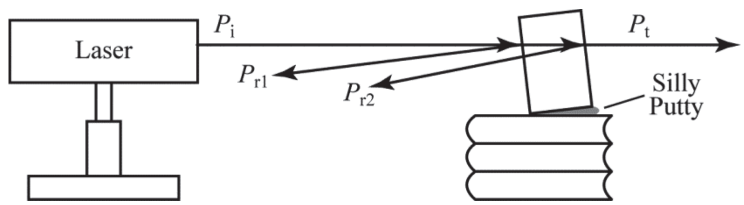

Figure 24 – Rear Surface Mirror Power Measurements Set-up

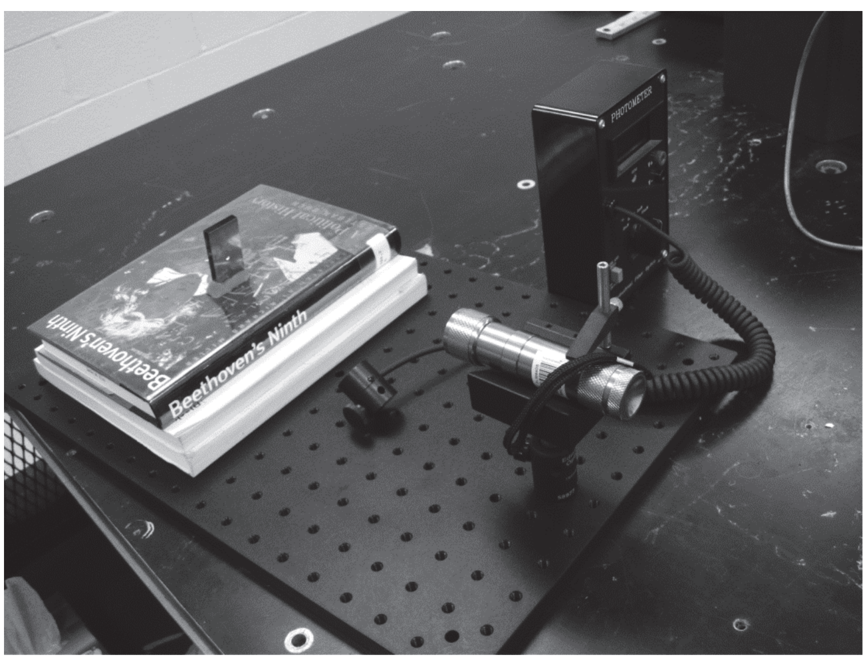

Figure 25 – Mirror Power Measurements Set-up

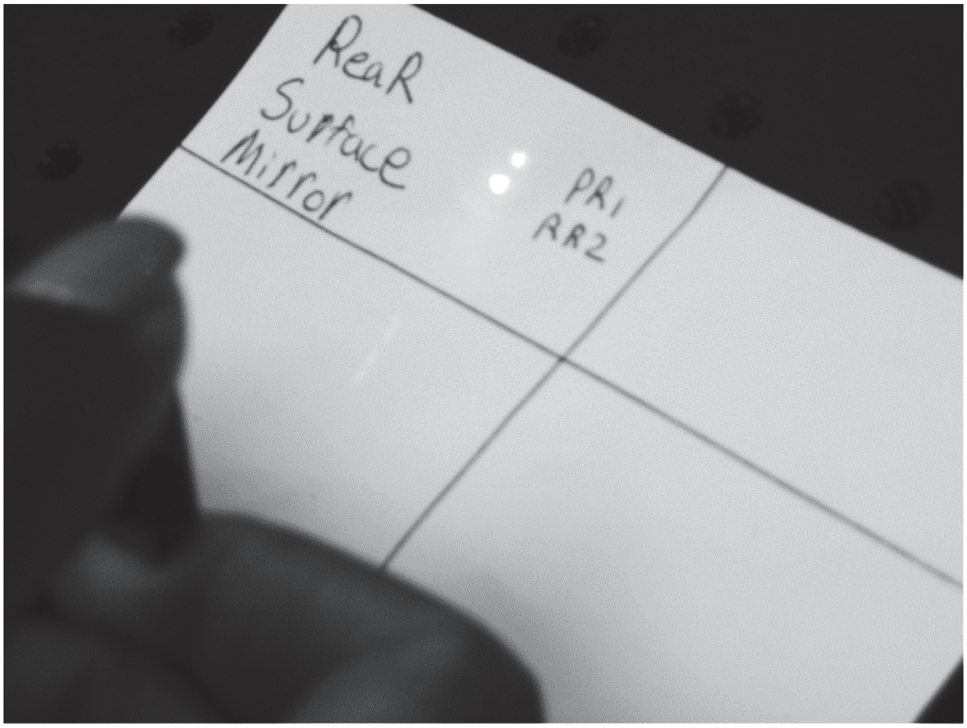

Figure 26 – Rear Surface Mirror Power Measurement

5. Determine the predicted value for $P_{r1.}$
   Formula: $P_{r1} = P_i * R$

   $$R = \left[(n-1)^2 / (n+1)^2 \right]$$

6. Determine the predicted value for P_{r2}.
   Formula: $P_{r2} = (P_i - P_{r1(\text{predicted})}) * R_{\text{coating}}\ (1 - R)$
   R_{coating} is the result obtained in Step 2.

7. Determine the predicted value for P_t.
   Formula: $P_t = P_i - P_{r1(\text{predicted})} - P_{r2(\text{predicted})}$

8. Determine the % error for your measured values of P_{r1}, P_{r2}, and P_t.

9. Based on your measurements, what is one advantage and one disadvantage that a rear surface mirror has over a front surface mirror? Describe an application in which a rear surface mirror would be the best choice. Describe an application in which a front surface mirror would be the best choice.

Laboratory 1-3D: 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.

Objective

In this laboratory, you will complete the following tasks:

- Measure the power incident on and power transmitted through four different color filters
- Measure the power incident on and power transmitted through three filter sets.
- Calculate the transmission through these various filters.
- Calculate the optical density of these various filters.

Definition of Terms and Required Formulas

Terms

T_{meas} = Transmission through a filter (measured)

T_{tot} = Transmission of multiple filters

OD_{tot} = Optical Density of multiple filters

P_{in} = Power into filter

P_{out} = Power out of filter

OD = Optical density

Formulas

$T_{\text{meas}} = P_{\text{out}}/P_{\text{in}}$

$OD = \log_{10}(T_{\text{meas}})$ $\quad$ $T_{\text{meas}} = 10^{-OD}$

$T_{\text{tot}} = T_1 * T_2 * \ldots. * T_n$ $\quad$ $OD_{\text{tot}} = OD_1 + OD_2 + \ldots + OD_n$

Equipment

Table 14 – Lab 1-3D Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	2	21	1.5" Post Holder
5	2	22	1.5" Post

6	1	8	Filter Set, Color
7	1	19	Photometer, Digital, Low Power
8	1	7	Dual Filter Holder
9	1	4	Mounting Base

Procedure

1. Using the V-Clamp for laser (LI-2), a 1.5" post (LI-5), and a 1.5" post holder (LI-4), mount the laser diode module (LI-1) to the optical breadboard (LI-3). Mount a 1.5" post holder onto a mounting base (LI-9). Insert a 1.5" post into the 1.5" post holder. Mount the dual filter holder (LI-8) to the post inserted into the post holder. Place the dual filter holder assembly in line with the laser diode module. Turn the laser diode module on. Refer to Figure 27.
2. Using the fiber optics digital photometer (LI-7), measure P_{in} and P_{out} for the laser diode module, using the blue, yellow, green, and red filters of the color filter set (LI-6). P_{in} is the power incident on the color sheets and P_{out} is the power transmitted through the color sheets. Record this data in Table 15 and Table 16. Do the necessary calculations to complete Table 15. Make sure to control the ambient room light in order to get consistent measurements.

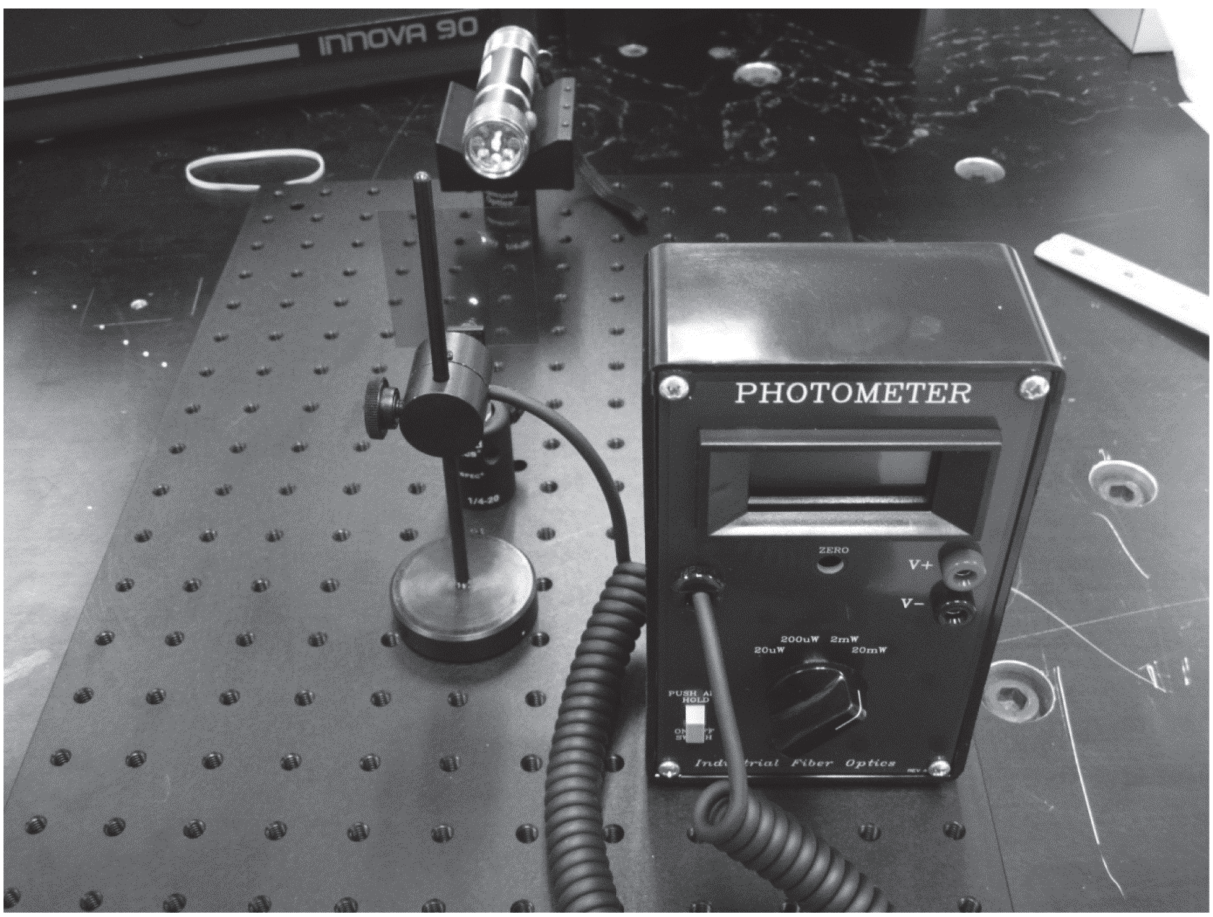

Figure 27 – Filter Power Measurement Set-up

Table 15 – Individual Filter Power Readings and Calculations

Measurements of Filters at 630 nm

Filter Color	P_{in} (mW)	P_{out} (mW)	T_{meas}	*OD*
Blue				
Yellow				
Green				
Red				

3. Next, prepare to measure three filter sets. Refer to Figure 28.

    Set 1: green and yellow

    Set 2: green and red

    Set 3: green, red, and yellow

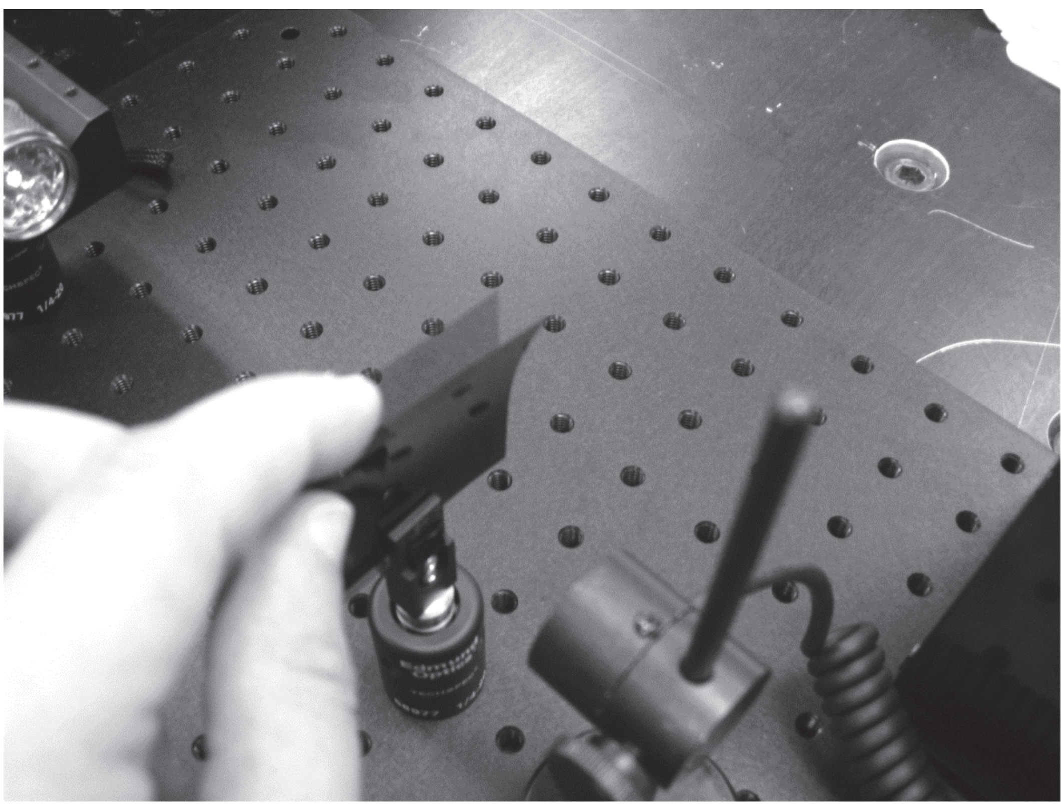

Figure 28 – Power Measurement Set-up for Combination Filters

4. Calculate the transmission of each combination (Refer to formula for T_{tot}). Record in the column labeled "$T_{predicted}$" in Table 16.
5. Measure P_{in} and P_{out} for each filter set and determine $T_{meas} = P_{out}/P_{in}$. Compare your results by determining the % Error. Record your data in Table 16.

Table 16 –Power Readings and Calculations for Combination Filters

Filter Set	P_{in} (mW)	P_{out} (mW)	T_{meas}	$T_{predicted}$	% Error
Green + Yellow					
Green + Red					
Green + Red + Yellow					

Laboratory 1-3E: Optical Photometer Use and Stability

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.

Objective

In these laboratories, you will complete the following tasks:

- Become familiar with an optical photometer.
- Learn how to determine the specifications of an optical photometer.
- Learn how to properly use an optical photometer.

Laboratory 1-3E.1

Equipment

Table 17 – Lab 1-3E.1 Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	19	Photometer, Digital, Low Power, Manual

Procedure

Read the manual for the fiber optics digital photometer (LI-1).

Questions

Use the manual to answer the following questions:

1. What kind of power supply is used? Describe what voltage?

2. Describe the detector.

3. Over what range of wavelengths will the photometer work?

4. Is the photometer calibrated for all wavelengths? If not, at what wavelength is it calibrated? What would you have to do to calibrate the photometer for other wavelengths?

5. What is the accuracy?

6. What is the operating temperature range?

7. How large is the detector active area?

8. What is the maximum optical input?

9. What would happen if you exceed the maximum optical input by a small amount?

10. What might happen if you exceed the maximum optical input by an excessive, large amount?

11. What does it mean to “zero” the meter?

12. Describe how to zero the meter.

13. When should you zero the meter?

14. What would you need to calibrate the photometer?

15. What should you do when you finish using the photometer? What will happen if you don't?

16. What is the purpose of the "+V" and "–V" jacks?

17. What is the digital resolution of the LCD?

18. What is the purpose of the detector housing?

Laboratory 1-3E.2

Equipment

Table 18 – Lab 1-3E.2 Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	2	21	1.5" Post Holder
5	2	22	1.5" Post
6	1	19	Photometer, Digital, Low Power

Procedure

1. Using the V-Clamp for laser (LI-2), a 1.5" post (LI-5), and a 1.5" post holder (LI-4), mount the laser diode module (LI-1) to the optical breadboard (LI-3). Turn the laser diode module on.
2. Hold the detector of the fiber optic digital photometer (LI-6) approximately 10 cm from the laser diode module and make a power measurement. Record this measurement in Table 19.
3. Take the photometer outside and measure the power of sunlight. Record this measurement in Table 19.
4. Discuss the difference in readings. Is this what you expected?

Table 19 – Measured Power Readings for Lab 1-3E.2

Sun Power Reading	Laser Power Reading	% Difference

Laboratory 1-3E.3

Equipment

Table 20 – Lab 1-3E.3 Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	2	21	1.5" Post Holder
5	2	22	1.5" Post
6	1	19	Photometer, Digital, Low Power

Procedure

1. Before doing this experiment, make certain the fiber optics digital photometer (LI-6) has not been exposed to any intense light source for 20 minutes.
2. Using the V-Clamp for laser (LI-2), a 1.5" post (LI-5), and a 1.5" post holder (LI-4), mount the laser diode module (LI-1) to the optical breadboard (LI-3). Turn the laser diode module on. Using the photometer, take and record power measurements of the mounted laser diode module in Table 21. Starting at $t = 0$ (first initialization of the laser beam) and continue at five second intervals for the first minute, and then one minute intervals for 15 to 20 minutes, or until you think that the readings have reached stability.
3. Calculate the % change in the readings.
4. Explain reasons for any instability in the readings?

Table 21 – Lab 1-3E.3 Power Readings versus Time

Reading at time equal zero ____________________

Time Elapsed	Reading	% Change

MODULE 1-4 LABS

Purpose

Use experimental techniques to validate the principles of geometric optics as they relate to:

- Prisms
- Lenses
- Optical Alignment
- Focal Length
- Total Internal Reflection
- Law of Reflection

Laboratory 1-4A: 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.

Objective

In this laboratory, you will perform the following simple experiments with prisms and lenses:

- Determine the index of refraction of a prism material.
- Examine the concept of Total Internal Reflection
- Determine the focal lengths of convex lens.

Part 1-4A.1. Index of refraction of a prism material

Equipment

Table 22 – Lab 1-4A.1 Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	23	Equilateral Prism
3	1	41	Index Cards
4	1	42	Protractor
5	1		8.5" × 14" White Paper
6	1		Roll of Masking Tape

Procedure

1. Arrange the laser diode module (LI-1), equilateral prism (LI-2), and a white cardboard screen made from “Index Cards” (LI-3) on a flat tabletop as shown in Figure 29 and Figure

30. Center the prism over a sheet of white paper (LI-5). Secure the white paper, cardboard screen, and laser diode module with masking tape (LI-6). Turn the laser diode module on.

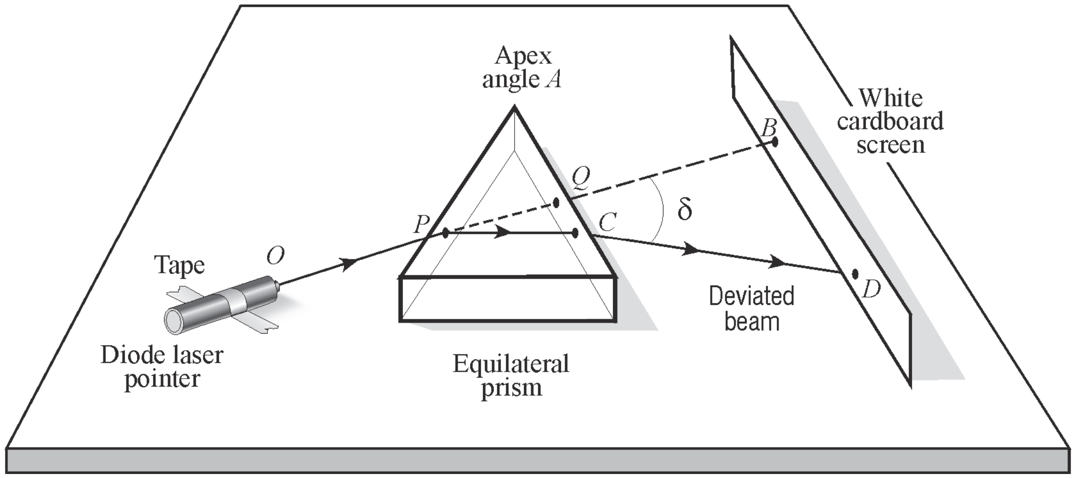

Figure 29 – Minimum Angle of Deviation Set-up

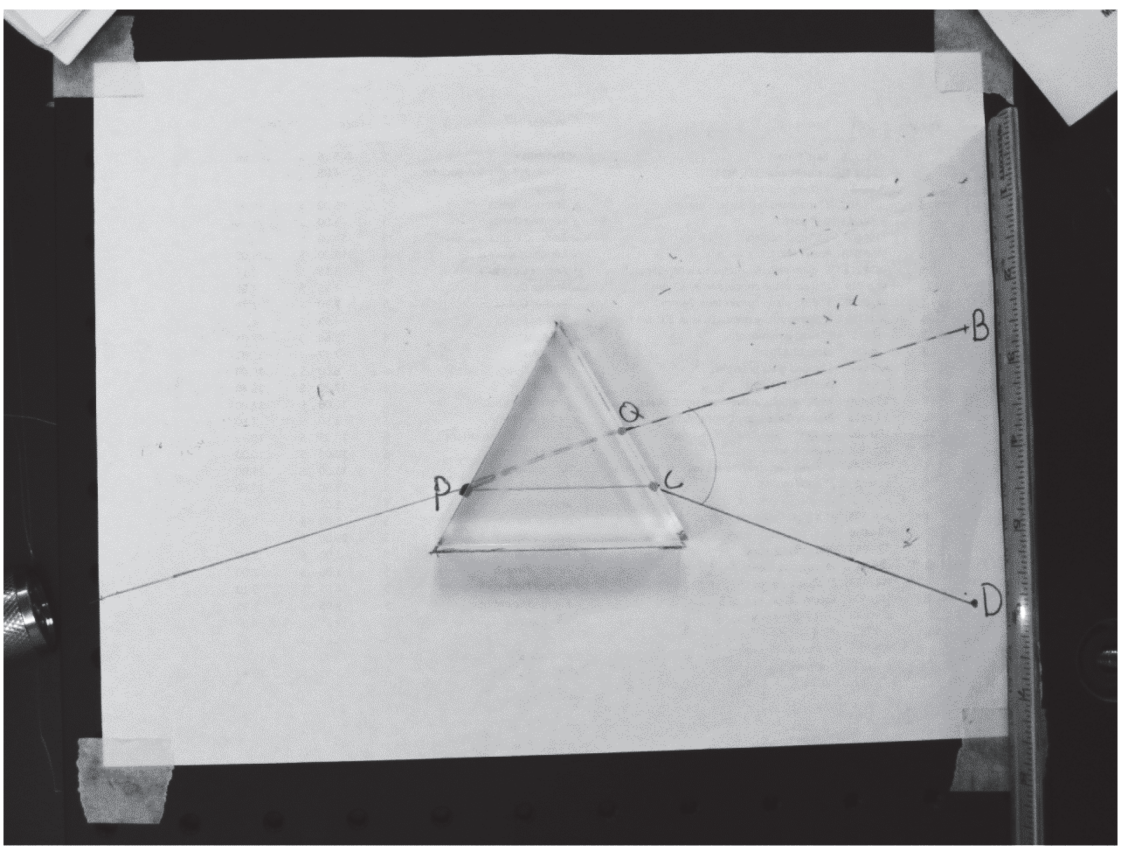

Figure 30 – Minimum Angle of Deviation Set-up

2. Rotate the prism relative to the incident laser beam, the laser spot *D* on the screen moves, so the angle of deviation δ will become larger or smaller. By experimentation, determine the *smallest angle of deviation* (δ_m) between an original beam direction *OB* and the

deviated beam *CD*. (It should be clear that the farther the screen is from the prism the more precise will be your determination of δ_m, since small changes in the position of spot *D* will then be more exaggerated.)

3. When you have achieved the minimum angle for δ, carefully tape the prism in place. Trace on the paper the prism edges, the straight segments *OP* and *QB* along the *original direction,* and the segment *CD*. (Note: You must mark on the paper the location of laser spots *Q* and *C* and *B* and *D* to be able to draw segments *QB* and *CD*.) With the line segments drawn, remove the prism and measure the minimum angle δ_m with a protractor (LI-4). Complete a ray trace of the incident beam through the prism, deviated at angle δ_m. Is the segment *DC* parallel to the prism base? Should it be?
4. Record the measured angle δ_m and the apex angle *A*. Use the formula

$$n = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\frac{A}{2}}$$

to calculate the index of refraction *n*. Compare your value with values given in Table 4-1 in the text, or an internet researched value for the index of refraction for acrylic. Does it agree with any value? What is your best guess for the prism material?

Part 1-4A.2 Total internal reflection (TIR)

Equipment

Table 23 – Lab 1-4A.2 Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	2	24	Right Angle Prism
4	1	41	Index Cards
5	1	42	Protractor
6	1		Roll of Masking Tape
7	1		8.5" × 14" White Paper

Procedure

1. Set a right-angle prism (LI-2) on a sheet of white paper (LI-7). With the roll of masking tape (LI-6), tape the prism to the paper. Shine a laser diode module (LI-1), 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. Use index cards (LI-4) 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. Label the angles of incidence and reflection and their values at the face where TIR takes place. What would you need to know to determine the critical angle at this face? Is the incident angle on the face where TIR occurs larger or smaller than the critical angle?
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. Measure the angles at the faces where TIR occurs with a protractor (LI-5).
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 31 and 32. 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 and label the incident and reflected angles at each position.

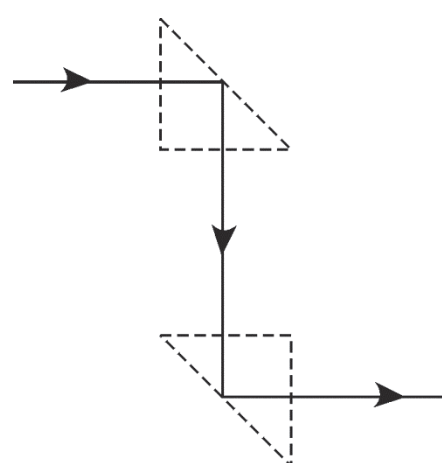

Figure 31 – Total Internal Reflection Set-up

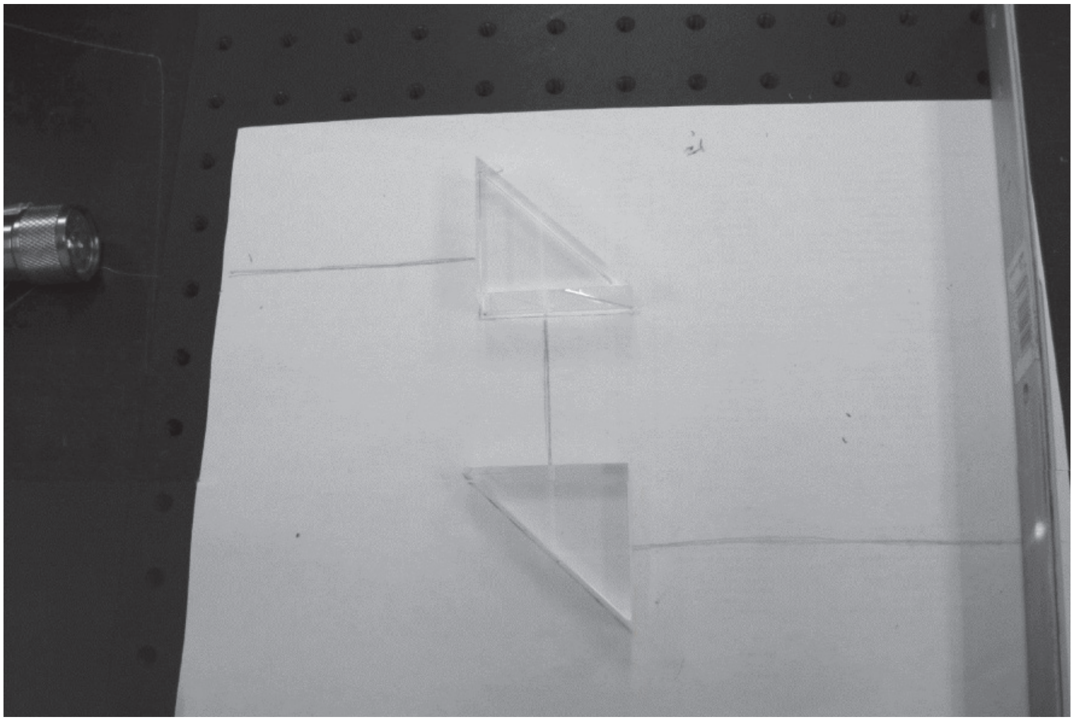

Figure 32 – Total Internal Reflection Set-up

Part 1-4A.3 Measuring the focal lengths of thin lenses

Equipment

Table 24 – Lab 1-4A.3 Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	33	LED Flashlight
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	3	21	1.5" Post Holder
5	3	22	1.5" Post
6	1	4	Mounting Base
7	1	15	Fixed Lens Mount, 25mm
8	1	12	Bi-Convex Lens
9	1	7	Dual Filter Holder
10	1	41	Index Cards
11	1	37	Metric Ruler

Procedure

1. Refer to Figure 33 for these procedures. Using the V-Clamp for laser (LI-2), a 1.5" post (LI-5), and a 1.5" post holder (LI-4), mount the LED flashlight (LI-1) to the optical breadboard (LI-3). Turn the laser diode module on.

2. Mount a 1.5" post holder onto the optical breadboard in line and a few inches from the flashlight beam. Mount the bi-convex lens (LI-8) into the fixed lens mount (LI-7). Mount the lens/lens mount assembly onto a 1.5" post. Insert this 1.5" post into the post holder mounted to the optical breadboard.
3. Mount a 1.5" post holder onto a mounting base (LI-6). Mount the dual filter holder (LI9) onto a 1.5" post. Place an index card (LI-10) in the filter holder. Insert the 1.5" post, with dual filter holder and index card, into the post holder on the mounting base.
4. Find the focal point by placing the index card as close to the lens as possible. Slowly move it away from the lens until the LED flashlight beam incident on the index card is at its minimum diameter. This distance is the focal length of the lens.
5. Measure and record the focal length with the metric ruler (LI-11).
   Focal Length = ______________.

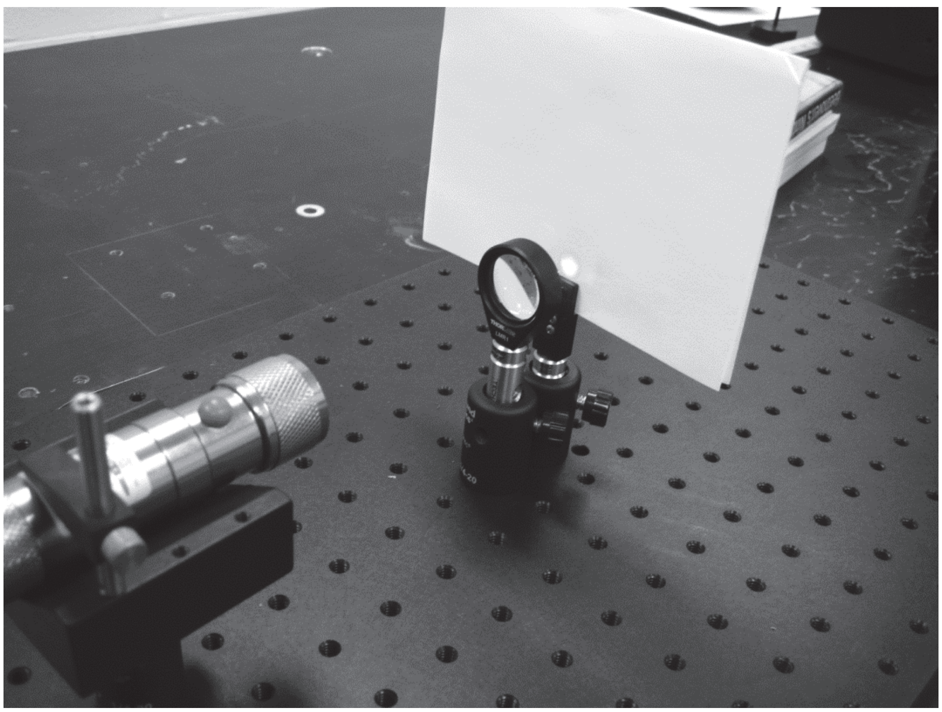

Figure 33 – Lens Focal Length Measurement Set-up

Laboratory 1-4B: Optical Alignment Techniques

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.

Objective

In this laboratory, you will complete the following task:

- Practice basic optical alignment techniques using an optical breadboard.

Equipment

Table 25 – Lab 1-4B Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	3	21	1.5" Post Holder
5	3	22	1.5" Post
6	1	27	Rotational Stage
7	2	16	Mirror Mount
8	2	17	Round Mirror, Grade 2,
9	1	7	Dual Filter Holder
10	1	41	Index Cards
11	1	4	Mounting Base

Part 1-4B.1 Alignment

Procedure

1. Using the V-Clamp for laser (LI-2), a 1.5" post (LI-5), and a 1.5" post holder (LI-4), mount the laser diode module (LI-1) to the optical breadboard (LI-3). The laser assembly should be mounted near a corner of the optical breadboard so that the beam follows the outermost row of holes. Turn the laser diode module on.
2. Mount a post holder five optical breadboard holes from the laser output along the laser beam axis.
3. Mount a post holder along the laser axis five holes from the far end of the optical breadboard.
4. Mount a 1.5" post holder onto a mounting base (LI-11). Mount the dual filter holder (LI-9) onto a 1.5" post. Insert an index card (LI-10) into the filter holder. Insert the 1.5" post, with dual filter holder and index card, into the post holder mounted on the mounting base nearest the laser. Draw a cross (+) on the index card centered on the row of holes over which the laser beam travels. (Refer to Figure 34.) Adjust the height of the index card so that the beam spot is centered on the cross.
5. Place the index card post assembly in the post holder farthest from the laser. Is the laser beam centered on the cross? If not, make the necessary adjustments to the laser mount until it does.

6. Place the index card post assembly again in the post holder nearest the laser. Is the beam still centered on the cross? If it is, proceed to Lab 1-4B.2. If not, make adjustments to the laser mount to center the spot and proceed to Step 7.
7. Repeat steps 6 and 7 until you have a true horizontal beam.

Figure 34 – Index Card Cross Target Set-up

Part 1-4B.2 Setting-up an Optical Axis with Retroreflection

Theory

When inserting components into the optical axis, you can begin with the first added component and proceed outward, away from the laser; however, the preferred method is to begin with the farthest component and proceed inward, toward the laser. Most components are aligned on-axis, using the method of retroreflection. As a component is added to the system, it is positioned so that the beam is reflected back through the system and is centered on the laser output aperture. Thus, when a component is added to the system, the orientation of the component is adjusted until retroreflection occurs.

When you need to use a component in the system that is intended to deflect the beam, such as a mirror or beam splitter, they must be aligned using the retroflection principle described previously.

1. This procedure assumes that a flat horizontal optical axis was established in Part 1-4B.1 and still remains.

2. Mount a 1.5" post holder to the rotational stage (LI-6), and mount this assembly near the corner of the optical breadboard along the optical axis of the laser beam.
3. Mount a mirror (LI-8) to a mirror mount (LI-7). Mount the mirror mount, with mirror mounted, to a 1.5" post. Insert this post into the post holder supporting the rotational stage. We will call this assembly one.
4. Adjust assembly one's mirror up and down on the post holder until the laser beam hits approximately the center of the mirror.
5. Using the kinematic adjustment, adjust assembly one's mirror until the retroreflected beam is centered in the laser aperture.
6. Mount the other round mirror to the other kinematic mirror mount. Mount the kinematic mirror mount, with mirror mounted, to a 1.5" post. Mount a post holder in a position on the optical breadboard that is on the opposite side of the rotational stage assembly and makes a 90° angle with the laser beam. Refer to Figure 35. Insert the second mirror assembly post into this post holder. We will call this assembly two.
7. Rotate the rotational stage, so that the reflected laser beam is projected onto the mirror of assembly two. It is important not to adjust the kinematic adjustments of assembly one.
8. Adjust assembly two's mirror up and down in the post holder until the laser beam hits approximately the center of the mirror.
9. Adjust the kinematic mirror adjustments of assembly two until the retroreflected beam is centered in the laser aperture. You have now established an optical axis using retroreflection.

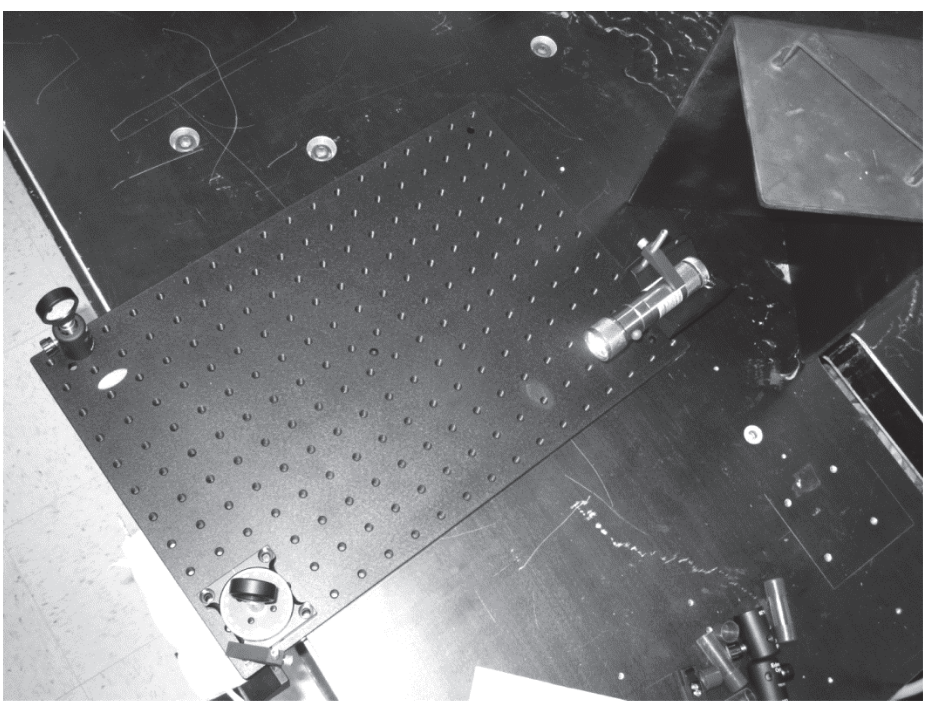

Figure 35 – Retroreflection Alignment Set-up

Laboratory 1-4C: Law of Reflection

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.

Objective

In this laboratory, you will complete the following task:

- Observe that a beam is deflected from a mirror at an angle that is **twice** the angle of rotation of the mirror.

Equipment

Table 26 – Lab 1-4C Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	2	21	1.5" Post Holder
5	2	22	1.5" Post
6	1	27	Rotational Stage
7	1	15	Fixed Lens Mount
8	1	17	Round Mirror
9	1		Tape Measure
10	1		8.5" × 14" White Paper
11	1		Roll of Masking Tape

Procedure

1. Locate the optical breadboard (LI-3) near a wall.
2. Using the V-clamp (LI-2), a 1.5" post (LI-5), and a 1.5" post holder (LI-4), mount the laser diode module (LI-1) to the optical breadboard. The laser assembly should be mounted near a corner of the optical breadboard that is close to the wall, and the beam should be directed away from the wall.
3. Mount a 1.5" post holder to the rotational stage (LI-6), and mount the rotational stage, with post holder attached, near the corner of the optical breadboard along the optical axis of the laser beam, so that the beam will be reflected toward the wall.
4. Mount a round mirror (LI-8) to a 1" fixed lens mount (LI-7). Mount the 1" fixed lens mount, with mirror mounted, to a 1.5" post. Insert this post into the post holder mounted on the rotational stage. Refer to Figure 36, Figure 37, and Figure 38.

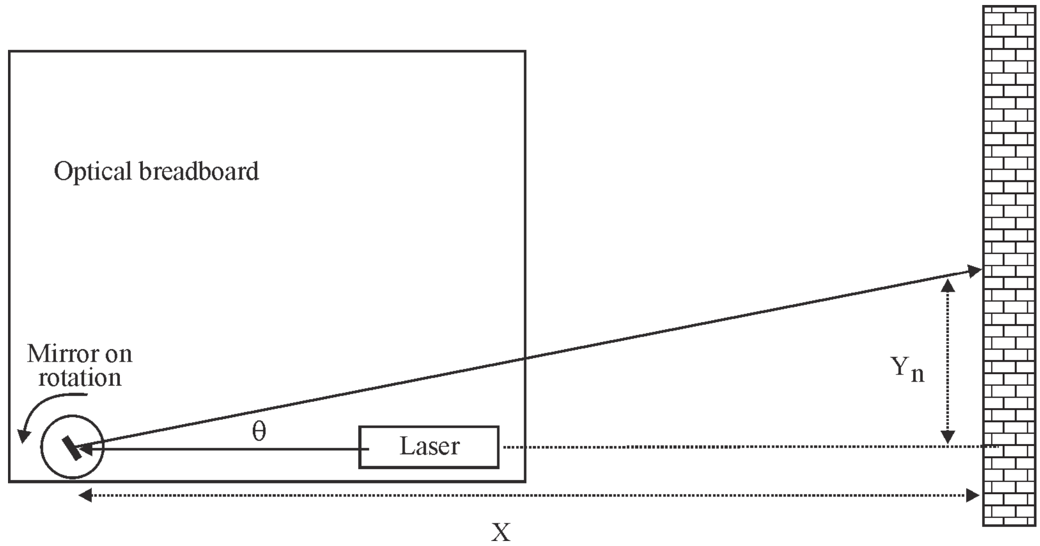

Figure 36 – Law of Reflection Set-up

5. Turn the laser diode module on. Adjust the rotational stage to read 0 degrees. Then adjust the mirror to reflect the beam back onto the laser aperture without changing the rotational stage reading.
6. Turn the vertical adjustment on the mirror to place the beam on a piece of paper (LI-10) taped (LI-11) to the wall above and behind the laser. Mark the location of the spot and call it "Y_0."
7. Rotate the mirror by turning the rotational stage and mark on the paper the new location of the spot. Record the angle from the rotational stage in Table 27. Repeat this for five different angles that produce beam positions separated by a foot or more.
8. Using a tape measure (LI-9) measure and record, using Table 27, the distance "X" from the mirror to the wall. Measure and record, using Table 27, the distances from "Y_0" to the marks on the piece of paper. Call these measurements "Y_1," "Y_2," etc. Use these measurements along with your knowledge of trigonometry to determine the angle, θ, between the laser axis and the reflected beam. Record these angles in Table 27 in the column labeled Deviation Angle Measured.
9. Fill in the column labeled Deviation Angle Expected in Table 27 with your expectation, based on the Law of Reflection, of what the value of the deviation angle should be.
10. Using the values of the Measured and Expected Deviation Angle, calculate the percent error. Assume your Expected Deviation Angle is correct. Record this value in Table 27.
11. Compare the deviation angle (total reflected angle) to the error angle of rotation (incident angle). You should find that the total reflected angle is twice the incident angle.

Table 27 – Law of Reflection Data and Calculations

Angle of Rotation (degrees)	**X** (m)	**Y_n** (m)	**Deviation Angle (Degrees)**		**Error** (%)
			Measured	Expected	

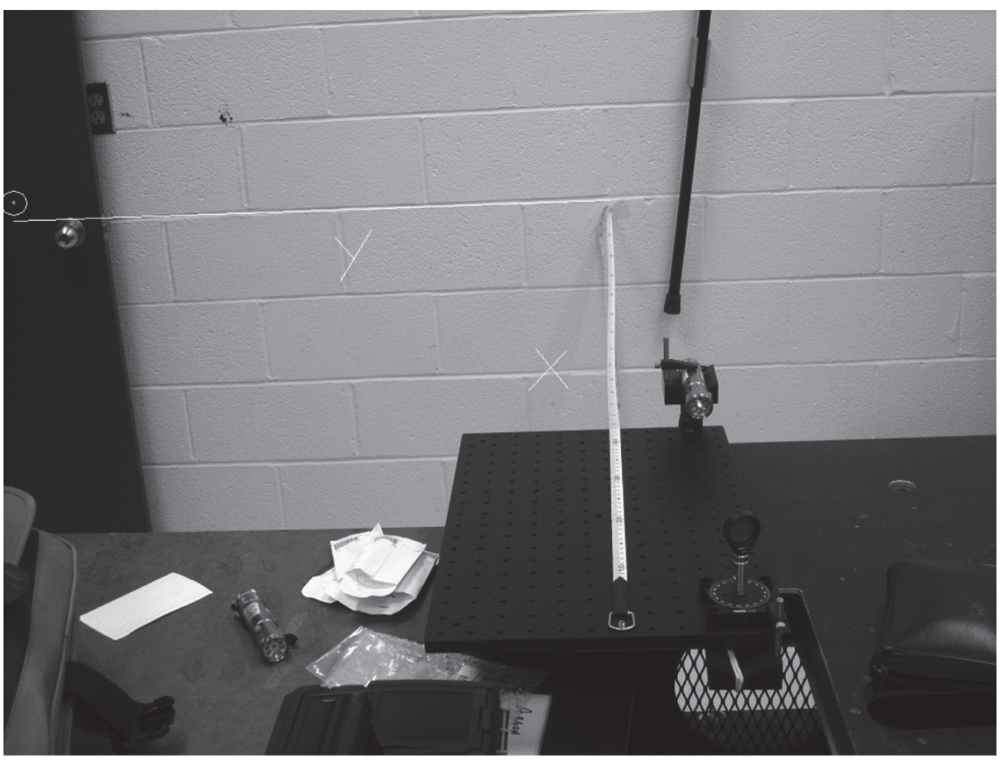

Figure 37 – Law of Reflection Set-up

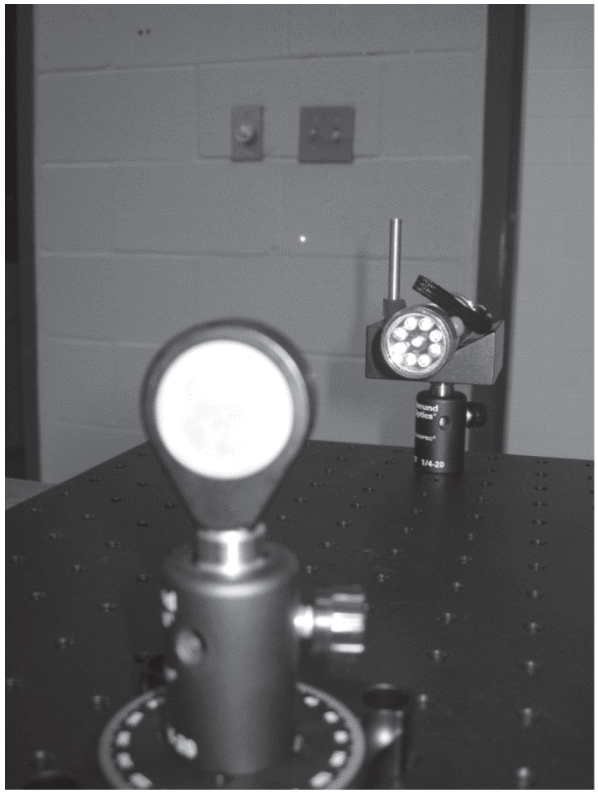

Figure 38 – Law of Reflection Set-up

MODULE 1-5 LAB

Purpose

Examine the wave properties of light as they relate to optical components and optical systems. The following laboratories for Module 1-5 will address:

- Interference
- Diffraction Patterns
- Slit Effects
- Pinhole Effects
- Diffraction Grating Effects
- Polarization

Laboratory 1-5A & B: Interference and Diffraction

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.

Objective

In this laboratory, you will complete the following task:

- Measure diffraction effects from a single slit and pinhole

Background Information

When light passes through a small slit, it is diffracted and generates a diffraction pattern. This pattern consists of a central bright fringe, bordered by narrower regions of dark and bright. The distance from the central bright fringe to any dark area is given by

$$y_m = \frac{m\lambda L}{b}$$

where: m = 1, 2, 3…
λ = wavelength of the light
L = distance from the slit to the central bright spot
b = the width of the aperture

Laboratory 1-5A: Slit

Equipment

Table 28 – Lab 1-5A Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	2	21	1.5" Post Holder
5	2	22	1.5" Post
6	1	7	Dual Filter Holder
7	1	4	Mounting Base
8	1	28	Single Slit
9	1	37	Metric Ruler
10	1		8.5" × 14" White Paper
11	1		Roll of Masking Tape

Procedure

1. Tape (LI-11) a piece of white paper (LI-10) on a wall that can be used for directing a laser beam coming from the laser diode module (LI-1) mounted on the optical breadboard (LI-3), positioned at a distance approximately 1 meter from the wall.
2. Mount a 1.5" post holder (LI-4) onto a mounting base (LI-7). Mount a dual filter holder (LI-6) onto a 1.5" post (LI-5). Secure the 1.5" post into the 1.5" post holder on the mounting base. Place the single slit (LI-8) into the dual filter holder. Place the mounting base with the single slit assembly exactly 1 meter from the wall. 1 meter will be the length, *L,* for performing calculations in Step 7.
3. Using the V-clamp for laser (LI-2), a 1.5" post, and a 1.5" post holder, mount the laser diode module to the optical breadboard. The laser diode module should be mounted along one side of the optical breadboard that is farthest from the wall.
4. Turn the laser diode module on. Direct the laser beam through the single slit such that a diffraction pattern is formed on the wall as shown in the Figure 39.

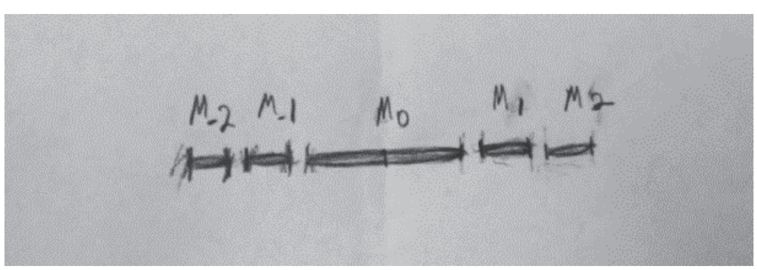

Figure 39 – Single Slit Set-up

5. Turn off the lights and trace the diffraction pattern you observe with a pencil.
6. Take down the paper and using the metric ruler (LI-9), measure the distance from the central bright fringe to the first minima (y_1), second minima (y_2), third minima, etc… and record these values in Table 29.
7. Calculate b (width of the slit) for each measurement using the formula given below. All values of b should be about the same. Express the average of all measurements of b as your final answer.

   Formula: $b = (m * \lambda * L)/y_m$

Table 29 – Single Slit Measurements and Calculations

m	y_m	B
1		
2		
3		
4		
5		

b_{average} = ________________________________.

Laboratory 1-5B: Pinhole

Background information

For this laboratory, you will use a pinhole made out of an index card and needle. Note also that the formula is slightly different for circular apertures than for rectangular slits. This difference in shape accounts for the factor of 1.22 shown in the formula below.

Formula: $D = 1.22 * \lambda * Z'/R$

where D = diameter of pinhole
Z' = pinhole to central bright disk distance
R = Radius of Airy disk
λ = wavelength

Equipment

Table 30 – Lab 1-5B Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	31	V-Clamp
3	1	18	Optical Breadboard

4	2	21	1.5" Post Holder
5	2	22	1.5" Post
6	1	7	Dual Filter Holder
7	1	4	Mounting Base
8	1	37	Metric Ruler
9	1	41	Pinhole (Index Card and Needle)
10	1		8.5" × 14" White Paper
11	1		Roll of Masking Tape

Procedure

1. Tape (LI-11) a piece of white paper (LI-10) on a wall that can be used for directing a laser beam coming from the laser diode module (LI-1) mounted on the optical breadboard (LI-3), positioned at a distance approximately 1 meter from the wall.
2. Mount a 1.5" post holder (LI-4) onto a mounting base (LI-7). Mount a dual filter holder (LI-6) onto a 1.5" post (LI-5). Secure the 1.5" post into the 1.5" post holder on the mounting base. Created a pinhole (LI-9) by placing an index card on a hard surface and use a needle to make a tiny hole in the center of the card. Place the pinhole into the dual filter holder. Place the mounting base with the pinhole assembly exactly 1 meter from the wall. 1 meter will be the length, Z' for performing calculations in Step 7.
3. Using the V-clamp for laser (LI-2), a 1.5" post, and a 1.5" post holder, mount the laser diode module to the optical breadboard. The laser assembly should be mounted along one side of the optical breadboard that is farthest from the wall.
4. Turn the laser diode module on. Point the laser beam through the pinhole such that a diffraction pattern is formed on the wall as shown in the Figure 40.
5. Turn off the lights and trace the diffraction pattern you observe with a pencil.
6. Take down the paper and using the metric ruler (LI-8), measure the diameter of the Airy disk.
7. Use the following formula to calculate the diameter of the pinhole.
   Formula: $D = 1.22 * \lambda * Z'/R$

   $D =$ ______________________________.

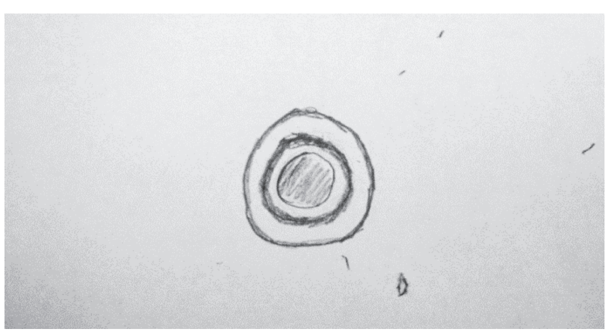

Figure 40 – Pin Hole Set-up

Laboratory 1-5C: Diffraction Grating Using a Laser Source

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.

Objective

In this laboratory, you will complete the following task:

- Measure the diffraction effects of a diffraction grating.
- Experimentally measure the groove spacing of a diffraction grating.

Background information

Light has properties of both particles and of waves. We generally talk about light in terms of its wavelength. The wavelength can be calculated by using the equation $\lambda = c/\nu$ where λ is the wavelength, c is the speed of light $c = 3.00*10^8$ m/s, and ν is the light's frequency. For instance, the frequency of a typical AM radio wave is about 1 MHz, so it will have a wavelength of about 300 m. Light from a laser diode module has a frequency of about 474 THz, so it will have a wavelength of about 632.8 nm.

Light and radio waves are both forms of electromagnetic radiation; we can easily sense the wave properties of radio signals while we cannot easily see the wave properties of light. Objects on the order of 300 m and smaller would interfere or absorb a radio signal. This can easily be observed (or heard). Conversely, we need a laser beam to interact with very small objects to observe its wave properties.

A diffraction grating is one such small object. The interference of light can be summarized by the relationship a (sin θ_p) = mλ where a is the distance between the grooves in the diffraction grating, λ is the wavelength of the light source, m is the order number, and θ_p is the angle measured from the symmetry axis, locating the mth order fringe of the grating diffraction pattern. The diffraction effect is symmetrical, so we only need to develop an equation for the m=+1 case. Refer to Figure 41.

For *m* = 1

θ_p can be found by geometry since $\tan \theta_p = y_1/L$.

Taking the inverse tangent results in $\theta_p = \tan^{-1}(y_1/L)$.

Then calculate θ_p and place it into the grating equation to find a.

$a = \lambda/\sin \theta_p$

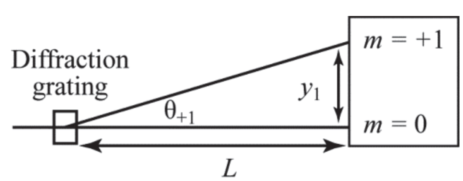

Figure 41 – Diffraction Grating Set-up

Equipment

Table 31 – Lab 1-5C Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	2	21	1.5" Post Holder
5	2	22	1.5" Post
6	1	7	Dual Filter Holder
7	1	4	Mounting Base
8	1	6	Diffraction Grating
9	1	37	Metric Ruler
10	1		8.5" × 14" White Paper
11	1		Roll of Masking Tape

Procedure

1. Tape (LI-11) a piece of white paper (LI-10) on a wall that can be used for directing a laser beam coming from the laser diode module (LI-1) mounted on the optical breadboard (LI-3), positioned at a distance approximately 1 meter from the wall.
2. Mount a 1.5" post holder (LI-4) onto a mounting base (LI-7). Mount a dual filter holder (LI-6) onto a 1.5" post (LI-5). Secure the 1.5" post into the 1.5" post holder on the mounting base. Place the diffraction grating (LI-8) into the dual filter holder. Place the mounting base with the diffraction grating assembly exactly 1 meter from the wall. 1 meter will be the length, *L,* for performing calculation in Steps 6–8.
3. Using the V-clamp for laser (LI-2), a 1.5" post, and a 1.5" post holder, mount the laser diode module to the optical breadboard. The laser diode module should be mounted along one side of the optical breadboard that is farthest from the wall.
4. Turn the laser diode module on. Direct the laser beam through the diffraction grating such that a diffraction pattern is formed on the wall as shown in the Figures 42 and 43.
5. Turn off the lights and trace the diffraction pattern you observe with a pencil.
6. Using the metric ruler (LI-9), measure the distance "y_1" as shown in Figure 42 and record this value for "y_1" in the "Grating" part of Table 32. y_1 is the distance from the central bright fringe to the $m = 1$ fringe in the grating diffraction pattern. Use 1 meter for "L." Calculate "θ_p" from the formula in Table 32. Calculate "a," using the formula in Table 32, assuming $\lambda = 630$ nm. Record your calculated value for "a," and compare it to the value for "a" given to you by your instructor. Calculate and record in Table 32 your percent error for $a_{accepted}$ versus a_{mean}.

Table 32 – Lab 1-5C Data Table

Grating $\theta_p = \tan^{-1}(y_1/L)$	$a = \lambda/\sin\theta_p$
$L =$ ______	$\lambda =$ ______
$y_1 =$ _______	$\theta_p =$ _______
$a_{meas} =$ ______	$a_{accepted} =$ ______
%Error = ______	

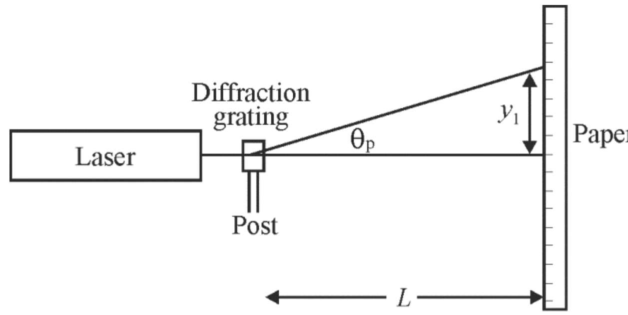

Figure 42 – Laser Diffraction Grating Set-up

Figure 43 – Laser Diffraction Grating Pattern

Laboratory 1-5D: Diffraction Grating Using a Light Emitting Diode (LED)

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.

Objective

In this laboratory, you will complete the following task:

- Experimentally measure the wavelength range of visible light.

Equipment

Table 33 – Lab 1-5D Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	33	LED Flashlight
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	2	21	1.5" Post Holder
5	2	22	1.5" Post
6	1	7	Dual Filter Holder
7	1	4	Mounting Base
8	1	6	Diffraction Grating
9	1	37	Metric Ruler
10	1		8.5" × 14" White Paper
11	1		Roll of Masking Tape

Procedure

Table 34 – Lab 1-5D Data Table

$\theta = \tan^{-1}(y/L)$	$\lambda = a * \sin\theta$
Violet Light (end of spectrum)	
$L =$ ______	$y_{\text{violet}} =$ _______
$\theta_{\text{violet}} =$ _______	$\lambda =$ ______
Red Light (end of spectrum)	
$L =$ ______	$y_{\text{red}} =$ _______
$\theta_{\text{red}} =$ _______	$\lambda =$ ______

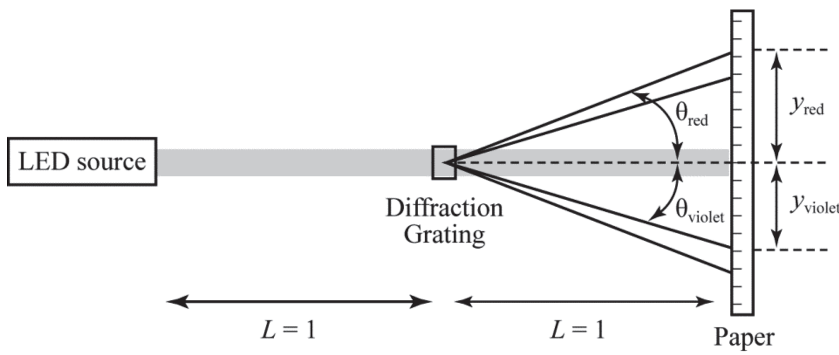

Figure 44 – LED Flashlight Diffraction Grating

1. Tape (LI-11) a piece of white paper (LI-10) on a wall that can be used for locating an LED flashlight beam coming from the LED flashlight (LI-1) mounted on the optical breadboard (LI-3), positioned at a distance approximately 2 meters from the wall.
2. Mount a 1.5" post holder (LI-4) onto a mounting base (LI-7). Mount a dual filter holder (LI-6) onto a 1.5" post (LI-5). Secure the 1.5" post into the 1.5" post holder on the mounting base. Place the diffraction grating (LI-8) into the dual filter holder. Place the mounting base with the diffraction grating assembly exactly 1 meter from the wall. 1 meter will be the length, L, for performing calculations in Step 6. See Figure 44.
3. Using the V-clamp for laser (LI-2), a 1.5" post, and a 1.5" post holder, mount the LED flashlight to the optical breadboard. The LED flashlight assembly should be mounted along one side of the optical breadboard that is farthest from the wall.
4. Turn the LED flashlight on and direct it through the diffraction grating such that a spectrum is formed on the wall as shown in the Figure 45. You should be able to see a spectrum of colors on each side of the grating.
5. Turn off the lights. Note the shadow of the grating on the wall. The center of this shadow is your reference point.

6. Using the metric ruler (LI-9), measure the distance "y_{violet}" from the center of the grating to the violet end of the spectrum as shown in Figure 44 and record this value for "y_{violet}" in the "Grating" part of Table 34. Likewise, measure and record the distance between the center of the grating and the red end of the spectrum. Record this value for "y_{red}." Use 1 meter for "L." Calculate and record "θ_{violet}" for the violet end of the spectrum and "θ_{red}" for the red end using the formula in Table 34.
7. The value of "a" will be given to you by your instructor. Calculate and record the wavelength "λ" of each end of the spectrum using the formula in Table 34. You should get approximately 390 nm for the violet end of the spectrum and approximately 720 nm for the red end of the spectrum.

   Note: Ambient light affects this experiment very much. In a very dark room, a wider spectrum will be measured. The spectrum, however, should be centered at about 555 nm.

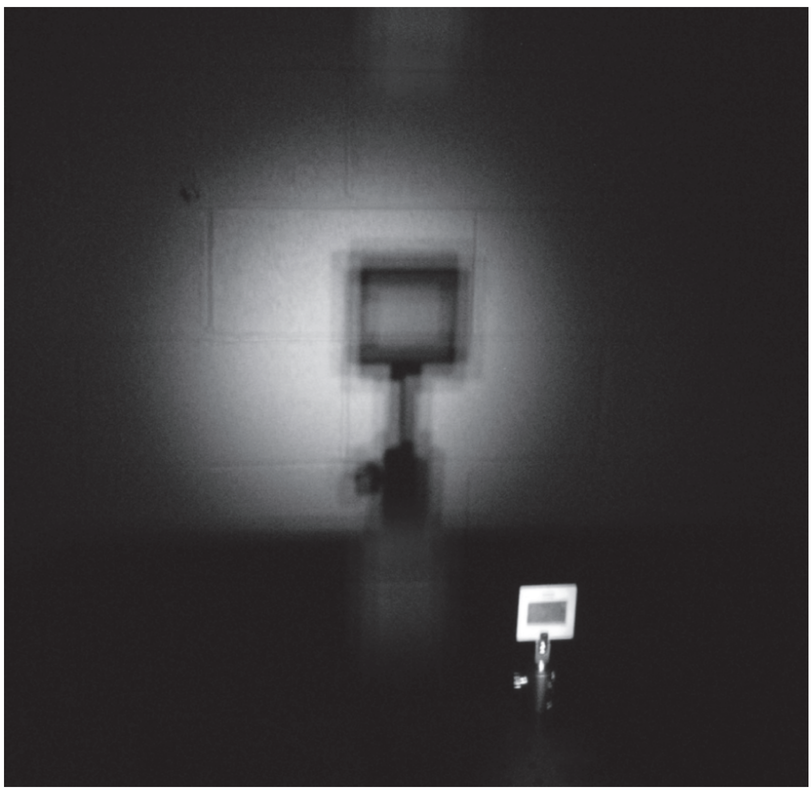

Figure 45 – LED Flashlight Diffraction Grating Pattern

Laboratory 1-5E: Polarization

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.

Objective

In this laboratory, you will complete the following tasks:

- Investigate the Law of Malus.

Background information

The Law of Malus states that $I = I_0(\cos\theta)^2$. As long as the detector captures the entire laser beam, we can simplify this equation to be $P = P_0(\cos\theta)^2$. P_0 is the power transmitted through the polarizer and the analyzer when the analyzer is aligned at zero degrees with respect to the polarizer.

Equipment

Table 35 – Lab 1-5E Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	3	21	1.5" Post Holder
5	3	22	1.5" Post
6	2	15	1" Fixed Lens Mount
7	2	20	Polarizer, glass, Diam=23mm
8	1	27	Rotational Stage
9	1	19	Photometer, Digital, Low Power
10	1		Roll of Masking Tape

Procedure

1. Using the V-clamp for laser (LI-2), a 1.5" post (LI-5), and a 1.5" post holder (LI-4), mount the laser diode module (LI-1) to the optical breadboard (LI-3). The laser assembly should be mounted at the center on one side of the optical breadboard with the beam directed toward the center of the optical breadboard.
2. This lab will make use of polarizing filter (LI-7). When both of them are used in line with one another, with the same light beam traveling through them, the first polarizer polarizes the light, and the second one is considered an analyzer. Refer to Figure 46 and Figure 47.

3. Mount the first polarizing filter in the 1" fixed lens mount (LI-6). In order to mount this polarizer in the lens mount, you will have to use the insert ring of both 1" fixed lens mounts. The polarizer must be positioned between the insert rings, so that it will not fall out of the lens mount. Mount this polarizer/lens mount assembly to a 1.5" post. Mount a 1.5" post holder to the optical breadboard approximately four inches from the laser diode module /LED light and near the center of the optical breadboard. Insert the 1.5" post with the polarizer/lens mount assembly into the 1.5" post holder mounted on the optical breadboard.
4. The second polarizing filter will be mounted on the rotational stage (LI-8). Tape (LI-10) the second polarizing filter to the center of the rotational stage. This assembly is the analyzer assembly. Mount the analyzer assembly to a 1.5" post. Mount a 1.5" post holder to the optical breadboard approximately four inches from the polarizer assembly mounted on the optical breadboard in step 3. Insert the 1.5" post with the analyzer assembly into the 1.5" post holder.

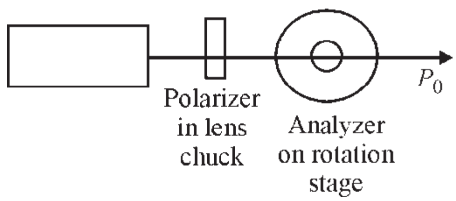

Figure 46 – Polarizer/Analyzer Set-up

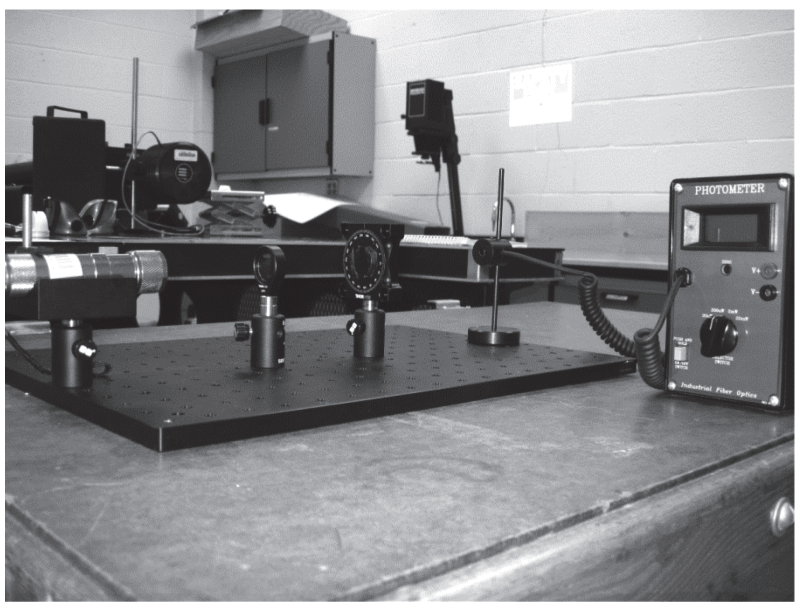

Figure 47 – Polarizer/Analyzer Set-up

5. Turn on the laser diode module. Adjust the positions of the laser diode module, polarizer and analyzer such that the laser light beam is directed through the polarizer and the analyzer.

6. Use the photometer (LI-9) to measure the power being transmitted through the polarizer and analyzer.
7. Adjust the analyzer for maximum power transmitted "P_0." Record this data in Table 36. The position of the rotation platform, where maximum transmitted power occurs, becomes the "zero" point, or reference point of rotation, between the polarizer and analyzer.
8. Measure and record the power transmitted through the system at 5 degree increments. Record this data in Table 36.
9. Use the Law of Malus ($P = P_0\cos^2\theta$) for calculating transmitted power versus analyzer position. Use the P_0 value measured at zero degrees. Compare the measured power versus the calculated power at each five degree increments, and calculate the percent error. Record all data in Table 36.

Table 36 – Law of Malus Data Table

Angle (degrees)	**Measured *P* (mW)**	**Calculated *P* (mW)**	**% Error (%)**
0	P_0 = _____	N/A	N/A
5			
10			
15			
20			
25			
30			
35			
40			
45			

Angle (degrees)	**Measured *P* (mW)**	**Calculated *P* (mW)**	**% Error (%)**
50			
55			
60			
65			
70			
75			
80			
85			
90			

MODULE 1-6 LABS

Purpose

Examine the properties of a laser beam and research other sources of laser information.

Laboratory 1-6A: Measurement of 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.

Objective

In this laboratory, you will complete the following tasks:

- Measure the divergence of a laser beam.

Equipment

Table 37 – Lab 1-6A Equipment List

Lab Item (LI)	Quantity	Equipment List Reference Number	Description
1	1	9 and 10	Laser Diode Module and Power Supply
2	1	31	V-Clamp
3	1	18	Optical Breadboard
4	1	21	1.5" Post Holder
5	1	22	1.5" Post
6	1	37	Metric Ruler
7	1	41	Index Card
8	1		Roll of Masking Tape

Procedure

1. Using the V-clamp for laser (LI-2), a 1.5" post (LI-5), and a 1.5" post holder (LI-4), mount the laser diode module (LI-1) to the optical breadboard (LI-3). The laser assembly should be mounted on the optical breadboard for the maximum distance between the laser output and some point in the room where a target will be mounted.
2. Tape (LI-8) an index card (LI-7) as a target for the laser beam on the wall at the position selected in Step 1.
3. Turn on the laser diode module. Adjust the position of the laser diode module until the laser beam hits the index card taped to the wall in Step 2. Refer to Figure 48 and Figure 49.

4. Using the metric ruler (LI-6), measure the diameter of the laser beam at the aperture of the laser diode module. Designate this measurement as "d_1." Record in Table 38
5. Using the metric ruler, measure the diameter of the laser beam on the index card at the wall. Designate this measurement as "d_2." Record in Table 38.
6. Using the metric ruler, measure the distance from the laser diode module aperture to the wall. Designate this measurement as "L." Record in Table 38.
7. Complete Table 38 by calculating the Beam Divergence.

Table 38. Calculation of Beam Divergence

d_1 = ___________	d_2 = ___________
L = ___________	
Beam Divergence (radians) = $\frac{d_2 - d_1}{L}$	
Beam Divergence = ____________	

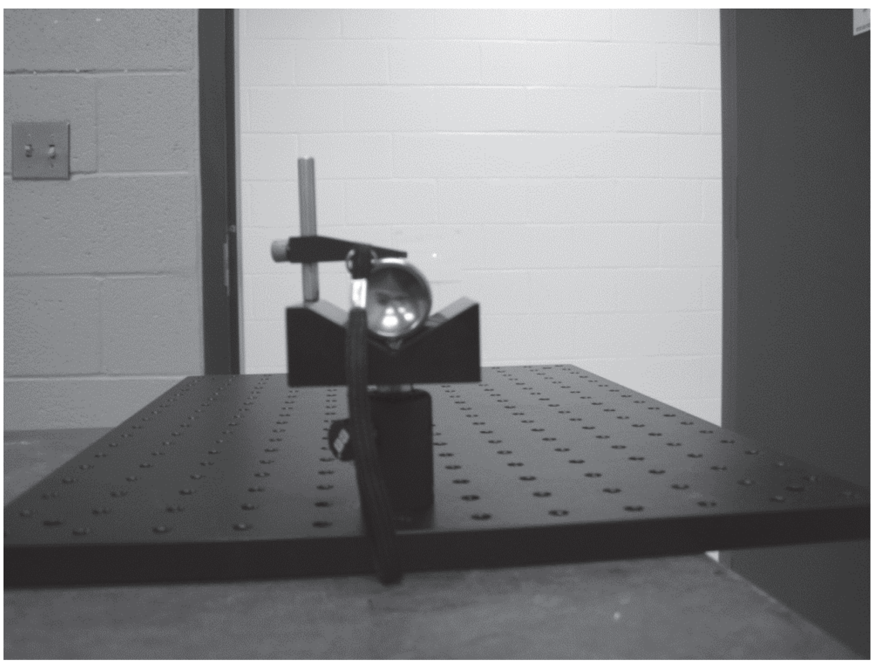

Figure 48 – Beam Divergence Measurement Set-up

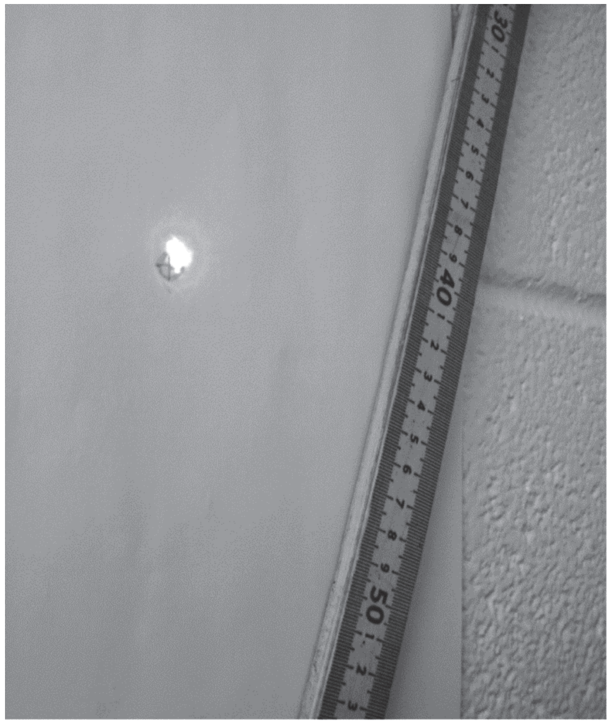

Figure 49 – Target Beam Spot for Lab 1-6A

Laboratory 1-6B: Laser Basics

Objective

In this laboratory, you will complete the following tasks:

- Explore the history of lasers and review laser fundamentals.

Equipment

None required

Procedure

Answer the following questions about Laser Technology.

1. Use the internet or some other reference medium to answer the following questions:
   A. What does the Acronym LASER stand for?
   ____

   B. What scientist first proposed stimulated emission was possible?
   ____________________ What year? ___

   C. Who built the first operating laser? _______________________
   What year?_______

D. For a gas laser, explain the following terms:

Gain Medium

Pumping Source

Absorption

Metastable State

Polarization

Resonant Cavity

E. Clearly describe three ways in which laser light is different than normal light.

2. Review the link (*http://www.howstuffworks.com/laser/htm*) and answer the following questions:

A. Compare and contrast the operation of a Coleman lantern to that of a laser.

B. Explain each of the following terms.

Population Inversion

Stimulated Emission

C. Explain how laser light is created in a three level laser system (Ruby Laser)

D. List and provide an example from each of the five different types of active media. State the wavelength of each cited example.