Introduction to Lasers and Optics

Reference Guide for Instructors

National Center for Optics and Photonics Education

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PREFACE

This Reference Guide was developed by the National Center for Optics and Photonics Education (OP-TEC) as a resource for instructors teaching with *Introduction to Lasers and Optics Student Guide.*

Introduction to Lasers and Optics is an introductory course for students who have limited prior knowledge of lasers, optics, or photonics. The purpose of the course is to provide entering students with an overview of the technology and its applications. The modular course requires no prerequisites, and can be taught for one or two-credits in the first term. The coarse contains 15 modules that cover topics such as the spectrum of light, laboratory safety, polarization, mirrors, and lenses. These modules can be used all together or faculty can select the appropriate number of modules to fit the desired breadth and depth of study for the course.

The Student Guide contains seven laboratory demonstrations and activities that illustrate key concepts and support hands-on learning. It is recommended that the activities be set up by a teaching assistant or instructor and used to demonstrate concepts discussed in the modules of the course. The seven demonstrations are Spectrum of Light, The Polarization of Light, Optical Filters, Prisms and Lenses, Interference and Diffraction with a Single Slit, Interference and Diffraction with a Pinhole, and Beam Divergence. This Reference Guide contains graphics that can be displayed or distributed to students while teaching the course. Digital copies of these graphics are available by request from OP-TEC.

The demonstrations can be performed with the same equipment used for OP-TEC's college level course, *Fundamentals of Light and Lasers*; the "foundation course" for Photonics Technology. It introduces the basic principles of light, lasers and laser safety that are needed to study specific types of laser systems. It also provides exposure to the topics that make up the foundation for studying the applications of lasers in telecommunications, electro-optical displays, biomedical equipment, manufacturing/materials processing, defense/homeland security, environmental monitoring, and nanotechnology.

Alternatively, schools can use the detailed equipment list in Appendix A to purchase equipment that is suitable for high schools at a lower cost; typically about $1,500 per lab station. While this equipment is not "industry-grade" it, nevertheless, supports hands-on learning and real-life demonstrations.

Another option for high schools to consider is an equipment kit available from the Midwest Photonics Education Center (MPEC), www.midwestphotonics.org. For approximately $2,500, schools can purchase a boxed kit, complete with case, which contains the necessary equipment for all the laboratory exercises in the *Fundamentals of Light and Lasers* course.

CONTENTS

MODULE OUTLINES

Note: Faculty may select as many modules as needed to build a custom course.

Module 1: Spectrum of Light [Classroom]

- UV through IR (electromagnetic spectrum)
- Types of light sources (lasers, LEDs, blackbody radiators, etc.)
- Passive devices (lenses, prisms, filters, etc.)
- Detectors
- Absorption and scattering of light

Module 2: Demonstrations and Safety, Spectrum of Light Hands-On [Demonstration]

- Basic Demonstration procedure and safety
- Safety goggles and optical density (revisit filters)
- Discuss real-world applications: polarized sunglasses, passenger mirrors on cars, etc.
- Use a laser pointer or other low-power laser to observe collimation, reflection, & refraction.

Module 3: Technical Societies and Social Networks [Classroom]

- Introduce students to SPIE, OSA, and other technical societies, and show resources available.
- Discuss the benefits of LinkedIn for networking and job searching.
- Invite members of local chapter to speak if available.

Module 4: Visible Light Spectrum Hands-On [Demonstration]

- Use a spectrometer with different light sources (fluorescent, incandescent, etc.)
- Use a diffraction grating with a white-light source to view the color spectrum.
- Use a diffraction grating with a single-color source.

Module 5: Applications and Careers I [Classroom]

- Videos, employer presentations, or guest speaker(s) to discuss photonics careers
- Possible jobs and advancement potential
- Recent program graduates are ideal as speakers.

Module 6: Math used in Photonics [Classroom]

- Summary of mathematics required in photonics
- Use images/diagrams of Total Internal Reflection (TIR) and other phenomena as basis for math problems.
- Demonstrate math videos and point students to math resources available.

Module 7: Math used in Photonics Hands-On [Demonstration]

- Use a laser pointer or other low-power laser to observe collimation, reflection, & refraction.
- Short activities with lenses, mirrors, and prisms
- Perform calculations based on measurements taken in the Demonstration.

Module 8: Electrical equipment and Computers [Classroom]

- Introduce students to more complex tools and equipment used in the workplace.
- Discuss computer usage and types of programs used.
- Discuss the types of tools used in the workplace where the industry tour will take place.

Module 9: Industry Tour [Off-Campus]

- Work environment
- Hands-on applications
- Review a lab notebook (if possible)
- If possible, ask a program graduate to give a tour and show the students the graduate's workstation.

Module 10: Lab Notebooks and Lab Reports [Classroom]

- Distribute an example of a lab notebook.
- Discuss importance of keeping an accurate log of work procedures and collected data.
- Ask students to suggest scenarios where a well-kept notebook is necessary.
- Show an example of a lab report.
- Require students to practice writing a lab report.

Module 11: Beam Divergence and Collimation Hands-On [Demonstration]

- Measure the divergence of a laser beam.
- Use lenses as a collimator and re-measure beam divergence.
- Perform calculations using divergence equations.

Module 12: Applications and Careers II [Classroom]

- Use videos, employer presentations, or guest speaker(s) to discuss photonics careers.
- Discuss possible jobs and advancement potential for photonics technicians.
- Consider recent program graduates as speakers.

Module 13: Detectors and Filters [Demonstration]

- Discuss different types of detectors.
- Show students how to read and adjust detectors.
- Use a filter to reduce the output power from a laser and discuss what type of light was blocked by the filter.
- Use detectors to take power readings.

Module 14: Fibers and TIR [Classroom]

- Discuss optical fibers and how they work
- Show videos on telecommunications and other uses of optical fibers.

Module 15: Fibers and TIR Hands-On [Demonstration]

- Project light through fibers, rods, and other media (like a stream of water).
- Measure the input beam power and output power out from an optical fiber.
- Discuss optical power loss within fibers and possible ways to reduce it.

REFERENCE MATERIAL

Spectrum of Light

Light consists of electromagnetic waves moving through space. The span of frequencies and wavelengths covered by electromagnetic radiation is indicated by Figure 1a. Lasers generally produce laser light in the frequency and wavelength range indicated by Figure 1b. This range includes the spectral regions commonly identified as the *infrared*, *visible*, and *ultraviolet* regions. The human eye responds to the narrow visible region shown in Figure 1c, spanning a frequency from 4.3 x 10^{14} Hz to 7.5 x 10^{14} Hz or, correspondingly from a wavelength of 0.7 x 10^{-6} m to 0.4 x 10^{-6} m.

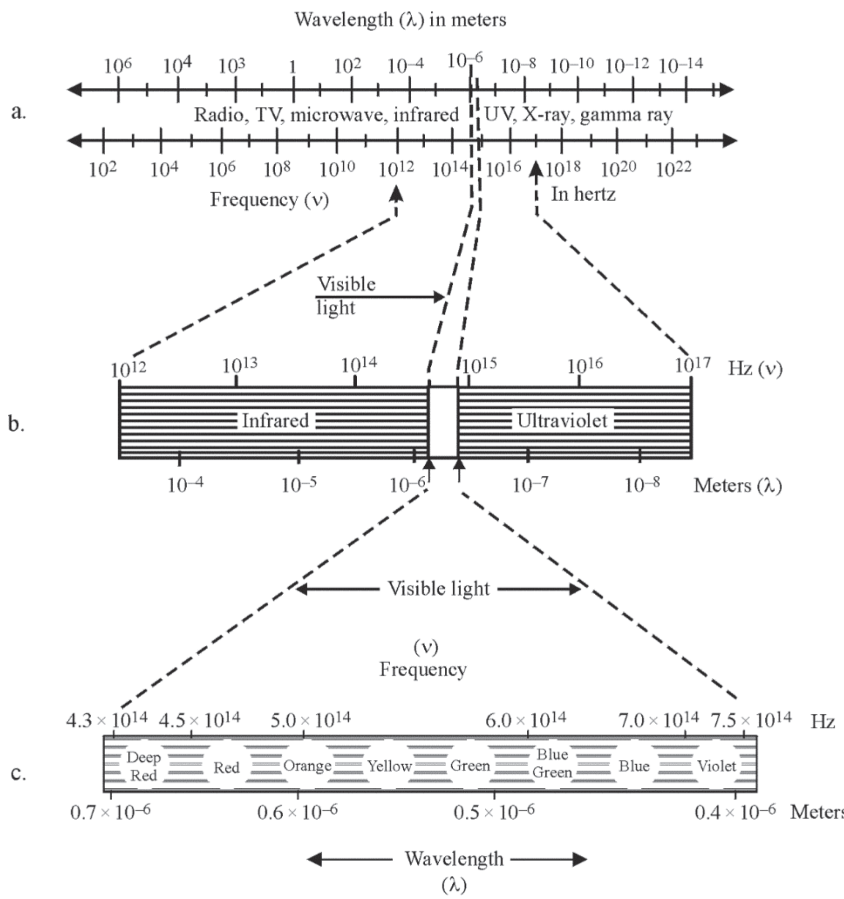


Figure 1 *The electromagnetic spectrum and its principal wavelengths*

Laser Light

Unlike ordinary light, laser light is monochromatic, directional, and coherent. Monochromaticity is the laser light's property of containing only one pure color and a narrow range of wavelengths. Directionality is the laser light's property of spreading, or diverging, very little as it travels. Coherent light waves have the same phase, as shown in Figure 2a. Figure 2b shows incoherent light, with curves crossing the vertical line YY' at different phase angles.

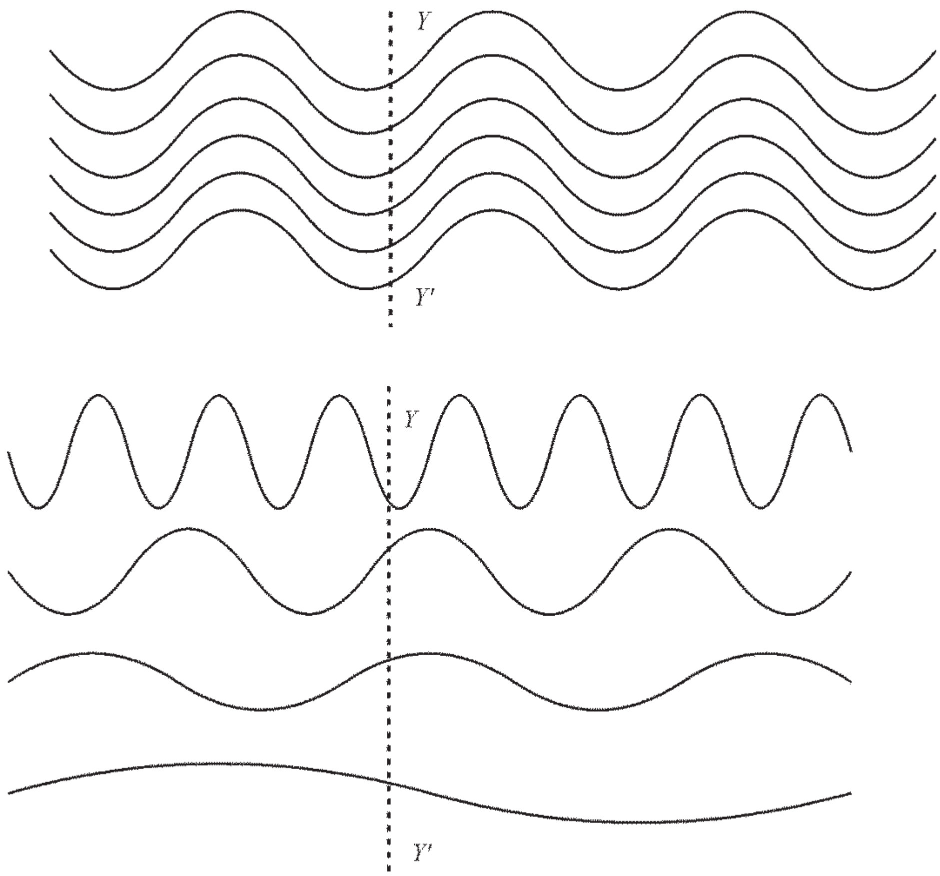


Figure 2 *Comparing coherent and incoherent light*

Laboratory Safety

As in all aspects of laboratory, field, classroom, or industrial safety, the best safety measures are a positive attitude and common sense. The following list of precautions is not all-inclusive for every application.

Laser Beam Safety Hazards

The following safety rules apply for all lasers, regardless of output power level:

1. Avoid looking directly into any laser beam or at its reflection.
2. Remove, or block all unnecessary specular (shiny) reflecting surfaces from the work area.
3. Operate lasers in well-defined areas where access can be controlled. Entrances to the lab area should be posted with appropriate signs to alert persons passing by the area that a potential hazard exists.
4. Laser systems should be operated only by, or under the direct supervision of, a person who is knowledgeable of the hazards and control methods for both beam and nonbeam conditions. This individual is usually the laser safety officer (LSO) who is designated by the administration of the company, hospital, or educational institution. The LSO shall have the authority and the responsibility to effect monitoring and enforce the control of laser hazards and to achieve the knowledgeable control of laser hazards.
5. All accidents (or incidents) should be reported immediately to the responsible safety and medical authorities. If there is an accidental exposure to the eye, an examination by an ophthalmologist should be sought.

Other (Nonbeam) Safety Hazards

There are five well-known nonbeam potential hazards associated with the use of lasers and laser systems.

1. Cluttered labs where operations are performed in a dark environment:
   - Equipment, cables and other items that should be stored.
   - Electrical equipment cables that are lying in pathways.
2. Fire hazards: from flammable substances or electrical problems
3. Explosion hazards: from chemicals or large capacitors
4. Electrical hazards: from wires and connectors that are not insulated
5. Chemical hazard: cleaning, solutions and active laser mediums

Polarization

The polarization of light refers to the orientation or direction of vibration of the electric field as the wave propagates through space. Unpolarized light has no specific orientation of electric field, seen in Figure 3a. Plane-polarized light is light in which the electric field oscillates in one plane only, seen in Figure 3b and 3c.

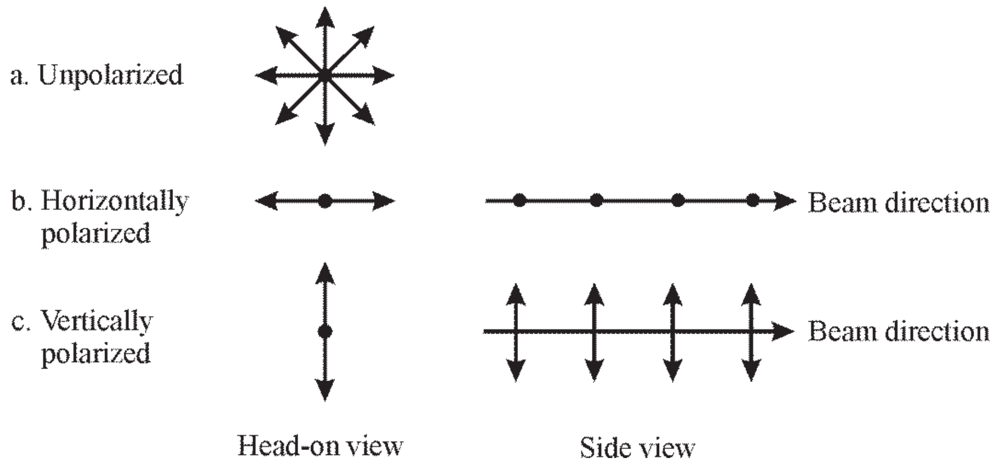
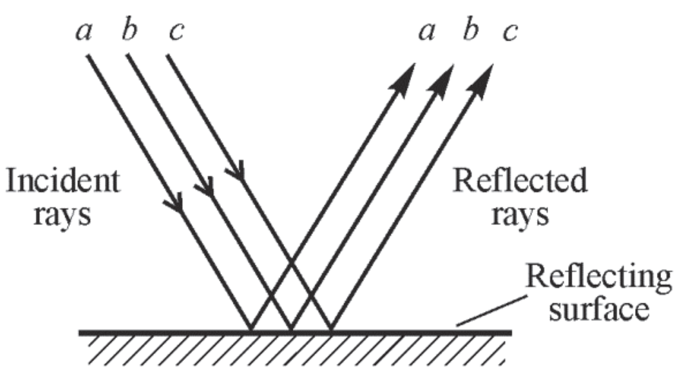


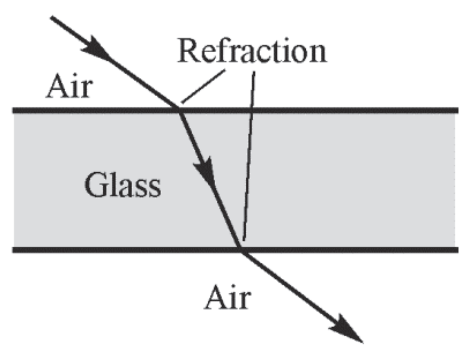
Figure 3 *Representation of polarized light*

Light Interactions

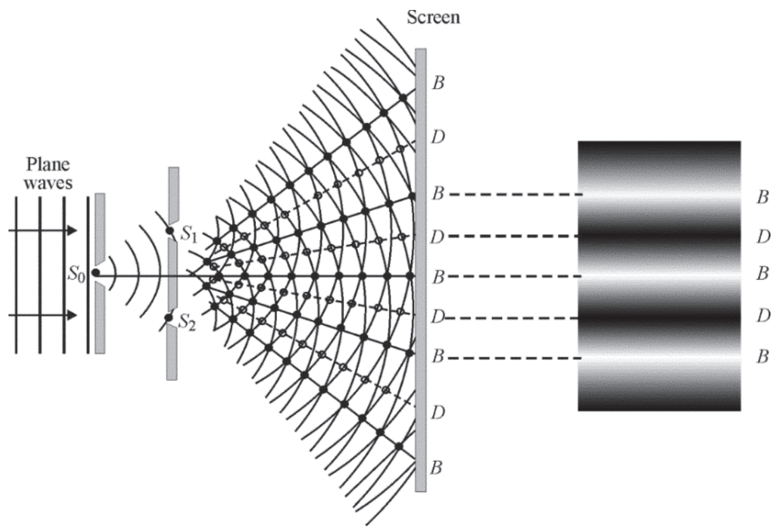
Light can interact with surfaces and other light waves through reflection (Figure 4a), refraction (Figure 4b), interference (Figure 4c), diffraction (Figure 4d), absorption (Figure 4e), or scattering (Figure 4e).



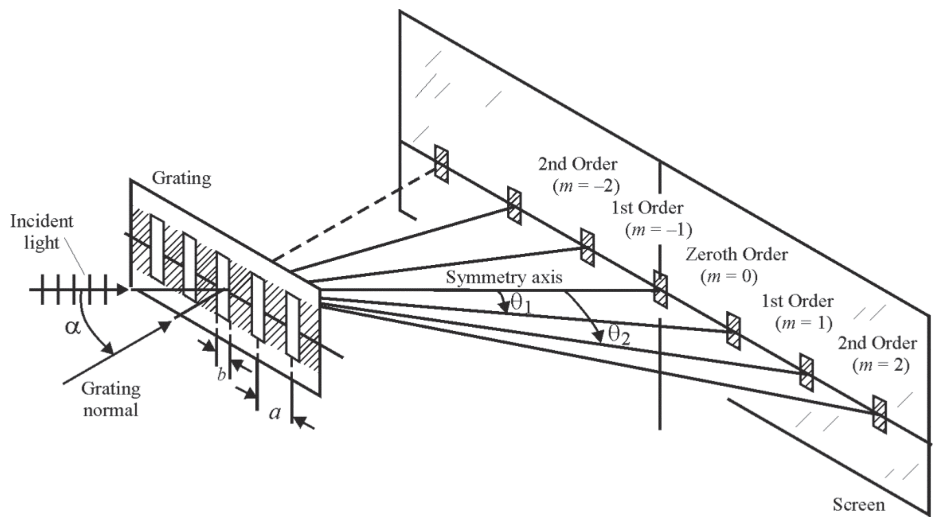
(a) *Reflection off a planar surface*



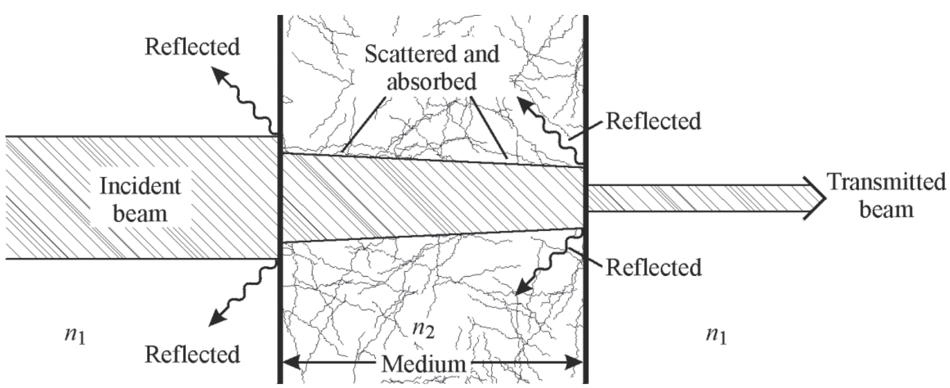
(b) *Refraction between two mediums*



(c) Interference as demonstrated by Young's double slit experiment



(d) Light through a diffraction grating under Fraunhofer conditions



(e) Scattering and absorption of light as it passes through a medium

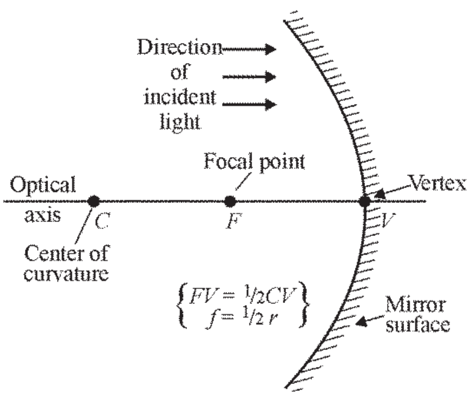
Figure 4 *Light Interactions*

Plane Mirrors

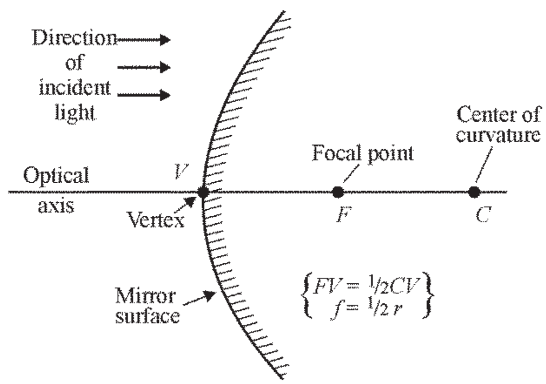
Each ray of light incident on a mirror from a point on an object obeys the law of reflection at the plane mirror surface. A point source of light in front of a mirror forms a virtual image as far behind the mirror as the point source is in front. Plane mirrors form virtual images that are the same size as the original objects, so the factor of magnification is equal to 1.

Concave and Convex Mirrors

Curved mirrored surfaces are defined by the center of curvature, the focal point, and the vertex. Concave surfaces curve inward, like the topside of a spoon (where the food goes). Convex surfaces curve outward, like the underside of a spoon.



(a) *Concave mirror surface*

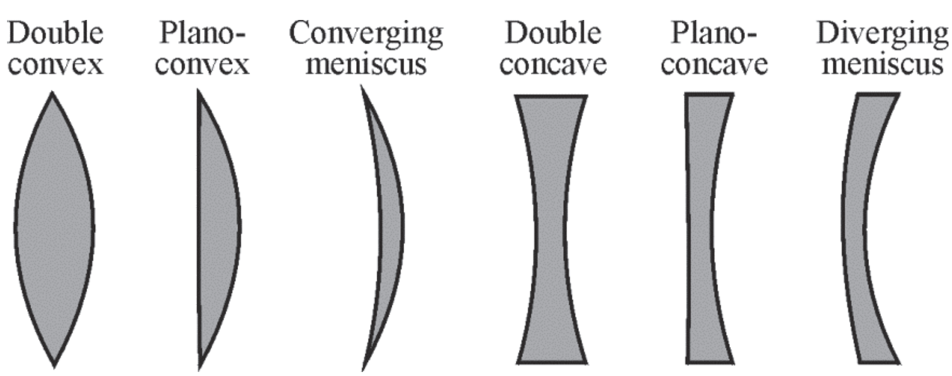


(b) *Convex mirror surface*

Figure 5 *Mirror surfaces*

Lenses

There are two types of lenses: converging and diverging. Parallel light rays passing through a converging lens will bend towards each other to focus to a single point. Parallel light rays passing through a diverging lens will spread out as they leave the lens.



Converging lenses *Diverging lenses*

Figure 6 *Simple lenses*

Beam Divergence

An ideal laser would have no beam divergence (or spread) as it moves forward. Such an ideal beam is monochromatic and hence will have an infinite coherence length. However, a real laser does have a beam divergence. Laser beams tend to spread out after exiting the laser cavity, meaning they are diverging. This divergence is a measurable phenomenon. In fact, beam divergence is indirectly a measure of the coherence of the beam. Smaller beam divergences are indications of better coherence and longer coherence lengths. An exaggerated, diverging laser beam is shown in Figure 7.

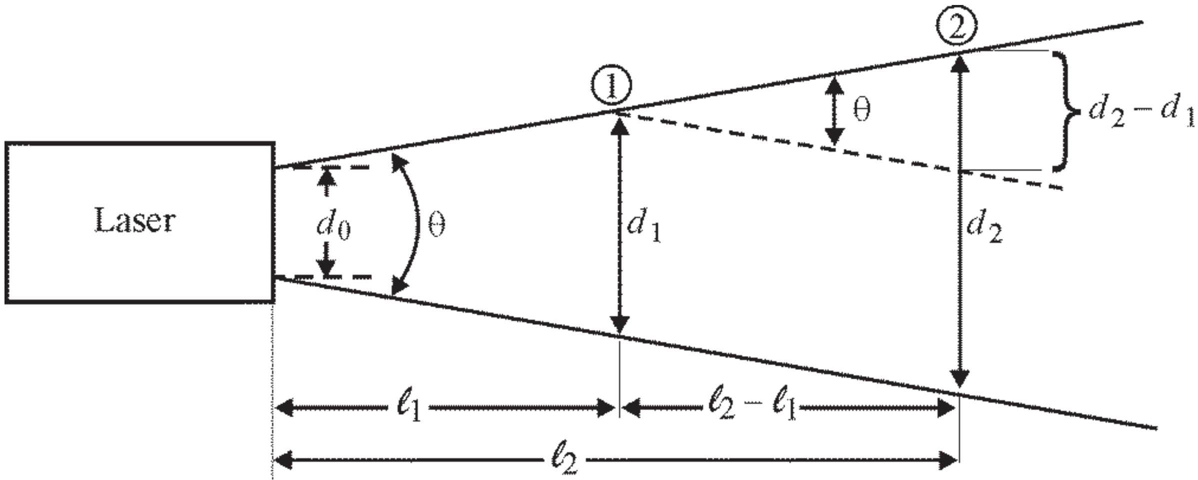


Figure 7 *Beam divergence of a laser beam*

The diameter of the beam at the output mirror of the laser is d_0. At a distance ℓ along the beam, the beam diameter is d. This beam diameter is given by Equation 1.

$$d = (\ell \times \theta) + d_0 \qquad (1)$$

where: d is the beam diameter at distance ℓ from the laser,
d_0 is the beam diameter as it exits the laser,
ℓ is a distance along the beam at which the beam diameter is d, and
θ is the beam divergence, generally measured in radians.

A more useful equation can be written in terms of two diameters d_1 and d_2 at distances ℓ_1 and ℓ_2 as shown in Figure 7. The beam divergence can now be given by Equation 2 as:

$$\theta = \frac{d_2 - d_1}{\ell_2 - \ell_1} \qquad (2)$$

By measuring the beam diameters at two different places along the beam, the beam divergence can be determined. Measurement of the beam diameter has to be done carefully and correctly in order to determine θ accurately. We will revisit this concern later.

Index of Refraction

Transparent optical media can be distinguished from one another by a constant called the index of refraction, generally labeled with the symbol n. It is the ratio of the speed of light in a vacuum to the speed of light in the medium, as given in Equation 3.

$$n = \frac{c}{\mathrm{v}} \qquad (3)$$

Where: c = speed of light in free space (vacuum)
v = speed of light in the medium
n = index of refraction of the medium

The index of refraction for free space (a vacuum) is exactly *one*. For air and most gases it is very nearly one, so in most calculations it is taken to be 1.0. For other optical materials—such as glass, silicon, diamond, gallium arsenide, and germanium— it has values greater than one.

Snell's Law

Snell's Law is a relation between the angles of incidence and refraction, and the refractive indexes of the incident and refractive media. It can be written as shown in Figure 8, but it is more commonly written as given in Equation4.

$$n_i \sin i = n_r \sin r \qquad (4)$$

Snell's Law

$\frac{\sin\ i}{\sin\ r} = \frac{n_r}{n_i}$, where

i = the angle of incidence

r = the angle of refraction

n_i = the refractive index in the incident medium

n_r = the refractive index in the refracting medium

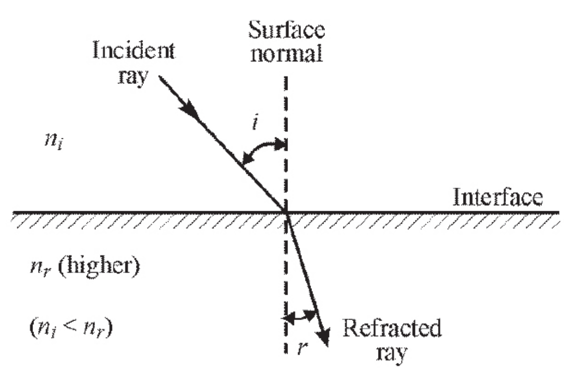


Figure 8 *Snell's Law: formula and geometry*

Total Internal Reflection (TIR)

Critical Angle and Total Internal Reflection—When light travels from a medium of *higher index to one of lower index*, the beam may be bent or reflected.

In the following figure, four rays of light are shown, originating from point O in the higher-index medium. Each ray is incident on the interface at a different angle of incidence.

Ray ① is incident on the interface at 90° (normal incidence) so there is no bending as it moves into the lower-index medium.

Ray ② is incident at angle i_2 and refracts (bends away from the normal *N*) at angle r_2.

Ray ③ is incident at the so-called *critical angle* i_c, large enough to cause the refracted ray bending away from the normal to bend by 90°, at angle r_c, thereby traveling *along the interface* between the two media.

Ray ④ is incident on the interface at an angle *greater than* the critical angle and is *totally reflected* into the same medium from which it came. Ray ④ obeys the *law of reflection* so that its angle of reflection r_4 is exactly equal to its angle of incidence i_4.

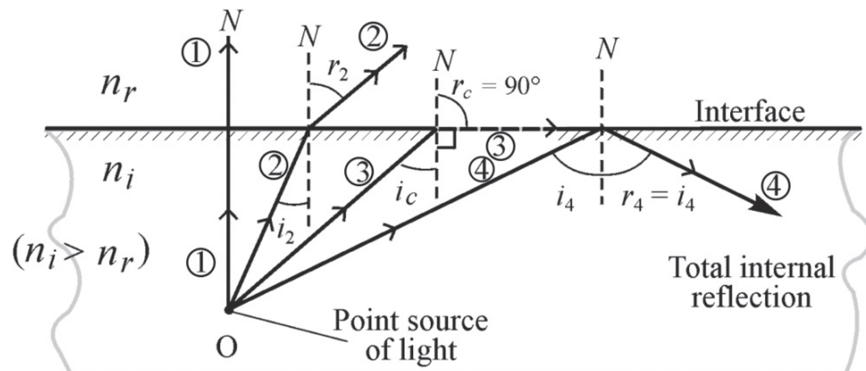


Figure 9 *Critical angle i_c and total internal reflection*

APPENDIX A: EQUIPMENT LIST

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