SİVAS UNIVERSITY OF SCIENCE AND TECHNOLOGY FACULTY OF ENGINEERING AND NATURAL SCIENCES

ELECTRICAL AND ELECTRONICS ENGINEERING

GEOMETRICAL OPTICS

EXPERIMENTS MANUAL REPORT

Supervisor : **Assoc. Prof. Yusuf DOĞAN**
Prepared by : **Research Asst. İlhan ERDOĞAN**
Research Asst. Berker ÇOLAK

2025

SİVAS

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Experiment-1

Zemax-I- Introduction to OpticStudio, Understanding The Software Interface

Prepared By

Research Asst. İlhan ERDOĞAN

Research Asst. Berker ÇOLAK

2025

Name-Surname	Number	Sign.

Objective:

- To become familiar with the OpticStudio (Zemax) interface and key modules (Sequential and Non-Sequential).
- To understand the basic steps of building an optical system using Lens Data Editor (LDE).
- To simulate ray propagation through a simple optical system (single lens) and analyze layout.

Apparatus Required:

University lab computer with Zemax OpticStudio installed

Theoretical Background:

Zemax OpticStudio is a widely used software for optical design and analysis. It allows simulation of light propagation through lens systems, optimization of optical performance, and visualization of aberrations and ray paths.

There are two main modeling modes:

- Sequential Mode: Light travels in a well-defined path (e.g., imaging systems).
- Non-Sequential Mode: Rays can scatter, split, or reflect arbitrarily (e.g., illumination, laser systems).

Key Interface Components:

- Lens Data Editor (LDE): Define surfaces, thickness, curvatures, and materials.
- System Explorer: Set global parameters such as wavelength, field of view, aperture type.
- Ray Trace & Layout Plots: Visualize system geometry and ray paths.

Prelab:

Students must:

Watch the introductory tutorial (15–20 min) on the Zemax interface.

Review lens terminology: radius of curvature, thickness, refractive index, aperture stop.

Answer short prelab quiz (examples):

- What is the difference between Sequential and Non-Sequential mode?
- What does the paraxial focus tool calculate?

Experimental Procedure for Lab:

1. Launch OpticStudio in Sequential Mode.
2. Define a Simple Optical System:
    - Open Lens Data Editor (LDE).
    - Insert a plano-convex lens (e.g., Surface 1: Radius = 50 mm, Thickness = 5 mm, Material = BK7).
    - Set Image Plane at Surface 3.
3. Set Global Parameters:

- Wavelength = 0.55 µm
- Field = 0°, 0.5°, 1°
- Aperture = Entrance Pupil Diameter = 10 mm

4. Layout and Analysis:
    - Generate 2D Layout and 3D Layout plots.
    - Trace rays and observe focal point location.
5. Save Design File and generate a basic report (ZMX or PDF).

(Optional) Alter curvature or material and observe changes in ray paths.

Safety Precautions

This lab is software-based; however, observe the following:

- Do not alter system files or settings outside the project directory.
- Save frequently to avoid data loss.
- Use lab computers for academic purposes only.

References

1. https://www.ansys.com/products/optics/ansys-zemax-opticstudio
2. https://support.zemax.com/hc/en-us/categories/1500000770122
3. https://en.wikipedia.org/wiki/Zemax

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Geometrical Optics

Experiment-2

Zemax-II- Lens Design

Prepared By

Research Asst. İlhan ERDOĞAN

Research Asst. Berker ÇOLAK

2025

Name-Surname	Number	Sign.

Objective:

- To learn how to design a basic multi-element lens system using Zemax OpticStudio.
- To explore optimization techniques to improve lens performance (minimize aberrations).
- To use the Merit Function Editor and Optimization Wizard effectively.

Apparatus Required:

University Lab Computer with Zemax OpticStudio installed.

Theoretical Background:

Designing lenses involves careful selection of optical materials, curvatures, thicknesses, and spacings to achieve desired imaging performance. Zemax OpticStudio provides tools for:

- Defining Lens Surfaces: Through the Lens Data Editor (LDE).
- Modeling Rays: With paraxial and real ray tracing.
- Optimizing Design: Using built-in algorithms to reduce spot size, coma, astigmatism, etc.
- Merit Function: Quantifies how well the optical system meets design goals (e.g., image quality, field curvature).
- Optimization Wizard: Automates improvement of optical performance by adjusting parameters.

Prelab:

- Watch tutorial: “Introduction to Lens Design and Optimization in Zemax” (15–20 min).
- Review:
- Lens terms: focal length, principal plane, stop surface, edge thickness.
- Optical aberrations: spherical, coma, chromatic.
- Prelab quiz (sample questions):
    - What is the purpose of a Merit Function?
    - How does changing the curvature of a surface affect the focal length?

Experimental Procedure for Lab:

1. Launch Zemax OpticStudio in Sequential Mode.
2. Create a Double-Convex Lens System:
    - Surface 1: Radius = 50 mm, Thickness = 3 mm, Material = BK7
    - Surface 2: Radius = -50 mm, Thickness = 10 mm (to image plane)
    - Surface 3: Image Plane (make this surface "STOP")
3. Set System Parameters in System Explorer:
    - Wavelength: 0.55 µm
    - Field: 0°, 0.7°, 1.5°
    - Aperture: Entrance Pupil Diameter = 10 mm
4. Analyze Initial Design:
    - Generate 2D and 3D Layouts
    - Trace rays and view focal point

- Use Spot Diagram to assess performance
5. Optimize the System:
    - Open Merit Function Editor
    - Use Optimization Wizard to auto-correct spot size
    - Optionally add constraints (e.g., total length ≤ 20 mm)
6. Post-Optimization Analysis:
    - Compare spot diagrams before and after optimization
    - Save ZMX file and export basic analysis report

Report: Please send the following outputs to the relevant research assistants via e-mail.

Safety Precautions

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- Save frequently to avoid data loss.
- Use lab computers for academic purposes only.

References

1. **https://link.springer.com/chapter/10.1007/978-3-031-92584-9_12**
2. Zemax OpticStudio Knowledgebase (https://support.zemax.com)
3. Hecht, E. (2002). Optics, 4th Edition. Addison-Wesley.
4. Zemax LLC. Getting Started with OpticStudio.

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ELECTRICAL AND ELECTRONICS ENGINEERING

Geometrical Optics

Experiment-3

Zemax-III- Spot and MTF Analysis

Prepared By

Research Asst. İlhan ERDOĞAN

Research Asst. Berker ÇOLAK

2025

Name-Surname	Number	Sign.

Objective:

- To analyze the imaging performance of an optical system using Spot Diagrams and Modulation Transfer Function (MTF).
- To understand how aberrations and design parameters affect image quality.
- To gain experience interpreting key analysis outputs in Zemax OpticStudio.

Apparatus Required:

University Lab Computer with Zemax OpticStudio installed.

Theoretical Background:

In optical system evaluation, spot diagrams and MTF curves are critical tools:

- Spot Diagram:

  Shows how rays from a point object are focused. It reveals aberrations like coma, astigmatism, and spherical aberration. Ideally, rays should converge into a small, circular spot.

- MTF (Modulation Transfer Function):

  Describes how well an optical system can reproduce contrast at different spatial frequencies. High MTF values at higher frequencies indicate good resolution performance.

  - Contrast is plotted vs. spatial frequency (usually in cycles/mm).
  - MTF = 1 → perfect contrast, MTF = 0 → no contrast.

Understanding these tools helps evaluate trade-offs in optical design, especially in imaging applications such as cameras, microscopes, and sensors.

Prelab:

- Review:
  - What spot diagrams represent and how to interpret their size and symmetry.
  - Basics of spatial frequency and the role of MTF in imaging.
- Watch a 10–15 minute video: "How to Interpret Spot and MTF Analysis in Zemax".
- Prelab quiz (sample questions):

  1-What is the ideal shape and size of a spot diagram?

  2-What does an MTF value of 0.2 at 50 cycles/mm imply?

Experimental Procedure for Lab:

1. Launch Zemax OpticStudio in Sequential Mode.
2. Load Pre-Designed Lens System:
   - Use the system from Experiment 2, or open provided design.
3. Generate Spot Diagram:
   - Go to Analysis → Spot Diagram.
   - Observe shape and distribution at 0°, 0.5°, and 1.0° fields.
   - Record RMS spot sizes and symmetry.
   - Compare spot patterns across fields.
4. Run MTF Analysis:

- Navigate to Analysis → MTF (Modulation Transfer Function).
- Select spatial frequency range (0 to 100 cycles/mm).
- Choose field points and wavelengths (if applicable).
- Plot Tangential (T) and Sagittal (S) curves.
- Save graph and note at what frequency MTF drops below 0.2.

5. Optional Exploration:
    - Vary lens curvature or spacing slightly.
    - Observe resulting changes in spot size and MTF.
6. Save your updated optical system and export a PDF report including:
    - Spot Diagrams
    - MTF Plots
    - Summary of interpretation

Report: Please send the following outputs to the relevant research assistants via e-mail.

Safety Precautions

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- Save frequently to avoid data loss.
- Use lab computers for academic purposes only.

References

1. Zemax Knowledgebase – Spot Diagram and MTF Analysis Tools
2. Smith, W. J. (2007). Modern Lens Design: A Resource Manual.
3. Hecht, E. – Optics, 4th Edition, Addison-Wesley.

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Geometrical Optics

Experiment-4

Zemax-IV- Complex Optical System Design and Understanding

Prepared By

Research Asst. İlhan ERDOĞAN

Research Asst. Berker ÇOLAK

2025

Name-Surname	Number	Sign.

Objective-1:

- To design and model a multi-element complex optical system using Zemax OpticStudio.
- To understand the importance of surface spacing, glass choice, stop location, and system symmetry in performance.
- To analyze ray propagation, system geometry, and imaging behavior in a multi-surface design.

Apparatus Required:

University Lab Computer with Zemax OpticStudio installed.

Theoretical Background:

Complex optical systems (e.g., telescopes, microscopes, cameras) consist of multiple lenses and precise alignment to control imaging quality, field of view, and aberrations.

Key design elements include:

- Surface Arrangement: Sequence and spacing of elements influence focal length and image location.
- Stop Surface Positioning: Impacts field angle, depth of field, and vignetting.
- Glass Selection: Different materials (e.g., BK7, F2, SF11) have varying dispersion properties affecting chromatic aberration.
- System Explorer Settings: Essential for defining wavelength range, fields, pupil size, and configuration.

Zemax enables step-by-step creation and analysis of such systems with visual feedback and optimization tools.

Prelab:

Students must:

- Review basic lens combinations: collimating + focusing, achromatic doublets, relay systems
- Read about system stops, principal planes, and effective focal length
- Watch video: "Designing Multi-Element Systems in Zemax" (10–15 min)
- Prelab quiz examples:

  1- What is the effect of shifting the aperture stop in a multi-lens system?

  2- How does glass material choice affect chromatic aberration?

Experimental Procedure for Lab:

1. Open Zemax in Sequential Mode
2. Begin a New Lens System Design
    - Surface 1: Plano-convex lens (Radius = 40 mm, Thickness = 3 mm, BK7)
    - Surface 2: Air gap (5 mm)
    - Surface 3: Bi-convex lens (R1 = 60 mm, R2 = −60 mm, Thickness = 4 mm, F2)
    - Surface 4: Air gap (10 mm)

- Surface 5: Plano-concave lens (Radius = −40 mm, Thickness = 3 mm, SF11)
- Surface 6: Image Plane (STOP surface)

3. Set Global Parameters in System Explorer:
   - Wavelength: 0.486 µm, 0.588 µm, 0.656 µm (for chromatic analysis)
   - Field of View: 0°, 0.7°, 1.4°
   - Entrance Pupil Diameter: 8 mm
4. Analysis:
   - Generate 2D and 3D Layout
   - Use Ray Fan and Wavefront Map tools to examine aberrations
   - Create Spot Diagrams and Field Curvature / Distortion Plots
   - Evaluate Effective Focal Length (EFL) using Paraxial Analysis
5. Optimization (Optional but recommended):
   - Use Merit Function Editor to minimize spot size or correct field curvature
   - Adjust element spacing or radius values
   - Monitor RMS spot radius and distortion across fields
6. Save Project and Export Design Report (PDF or ZMX)

Report: Please send the following outputs to the relevant research assistants via e-mail.

Safety Precautions

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- Save frequently to avoid data loss.
- Use lab computers for academic purposes only.

References

1. Zemax Knowledgebase – Spot Diagram and MTF Analysis Tools
2. Smith, W. J. (2007). Modern Lens Design: A Resource Manual.
3. Hecht, E. – Optics, 4th Edition, Addison-Wesley.

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ELECTRICAL AND ELECTRONICS ENGINEERING

Geometrical Optics

Experiment-5

Fundamental Optical Components

Prepared By

Research Asst. İlhan ERDOĞAN

Research Asst. Berker ÇOLAK

2025

Name-Surname	Number	Sign.

Objective: To understand the working principles of basic optical components, including lenses, mirrors, prisms, and light sources.

Apparatus:

- Optical Bench with sliding mounts and measurement scale
- White Light Source (e.g., halogen lamp with diffuser)
- Laser Pointer (Class II or low-power Class III, for ray path demonstrations)
- Triangular Glass Prism (e.g., 60° crown glass prism)
- Plane Mirror
- Concave and Convex Mirrors (with known focal lengths)
- Convex Lenses (e.g., +100 mm and +200 mm focal length)
- Concave Lenses (e.g., −100 mm focal length)
- Ray Box or Slit Aperture (to create narrow beams)
- Projection Screen or white paper for image observation
- Rulers and Protractors (for measuring angles and distances)
- Color Filters (red, green, blue)
- Retort Stand and Clamps (for stable mounting)

Theoretical Background:

Snell's law

Snell's law of refraction states that the ratio of the sines of the angles of incidence and refraction at the boundary between two media equals the ratio of their refractive indices. Named after the 17th-century Dutch astronomer Willebrord Snell, this principle allows us to predict the path of a refracted ray when the refractive indices of the two materials and the incident angle are known. A formula for Snell's law, along with a supporting diagram, is presented in Figure 5.1

Snell's Law

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

I is the angle of incidence

r is the angle of refraction

n_i is the index in the incident medium

n_r is the index in the refracting medium

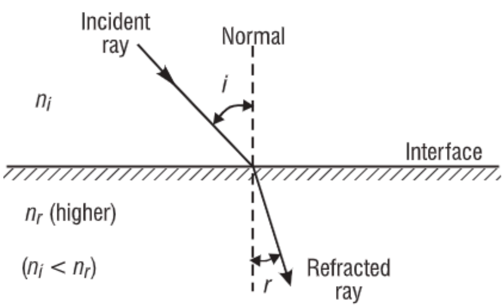

Figure 5.1: Snell's law

For convenience, Snell's law is commonly expressed as

$$n_i \sin i = n_r \sin r$$

Critical angle and total internal reflection

When light passes from a material with a higher refractive index into one with a lower index, several distinct behaviours occur. As illustrated in Figure 5.2, four separate rays leave point O in the denser medium and strike the boundary at different incident angles. Ray 1 strikes normally (90° to the surface) and therefore experiences no refraction.

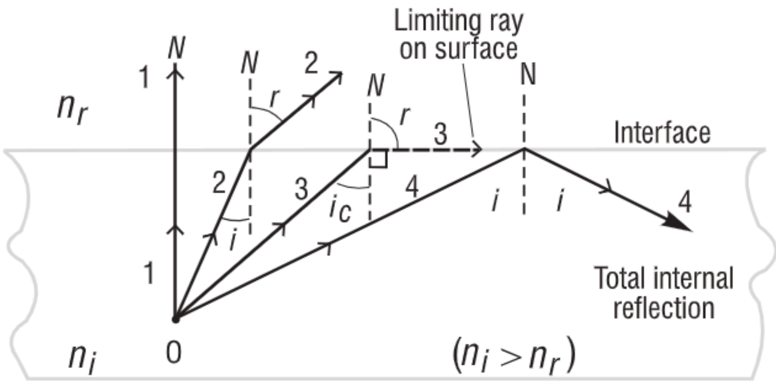

Figure.5.2 : Critical angle and total internal reflection

The critical angle for any two optical media—when light travels from the higher-index to the lower-index medium—can be found with Snell's law. For Ray 3 in Figure 5.2 and Snell's law from below Eq.,

$$n_i \sin i_c = n_r \sin 90°$$

where n_i is the refractive index of the incident (higher-index) medium, i_c is the critical angle, n_r is the index of the lower-index medium, and $r = 90°$ is the angle of refraction at the critical condition. Because sin90◦=1, we can solve directly for the critical angle.

$$i_c = \sin^{-1}\left(\frac{n_r}{n_i}\right)$$

When light travels from one medium to another—such as from air into glass—it changes direction. This phenomenon is known as refraction, and it occurs because the speed of light varies depending on the optical density of the material. The degree to which light bends is determined by a property called the index of refraction. In basic explanations, refraction is often considered for a single color (or wavelength) of light. However, in reality, the index of refraction varies with wavelength. Light with shorter wavelengths, such as blue or violet, bends more sharply than light with longer wavelengths, like red. This behavior is known as dispersion. As a result, when white light, which consists of all visible wavelengths, passes through a prism, each color is refracted at a slightly different angle. Blue light bends the most, while red light bends the least, causing the beam to spread out into a continuous spectrum of colors, much like a rainbow. This is why a prism can separate white light into its individual components.

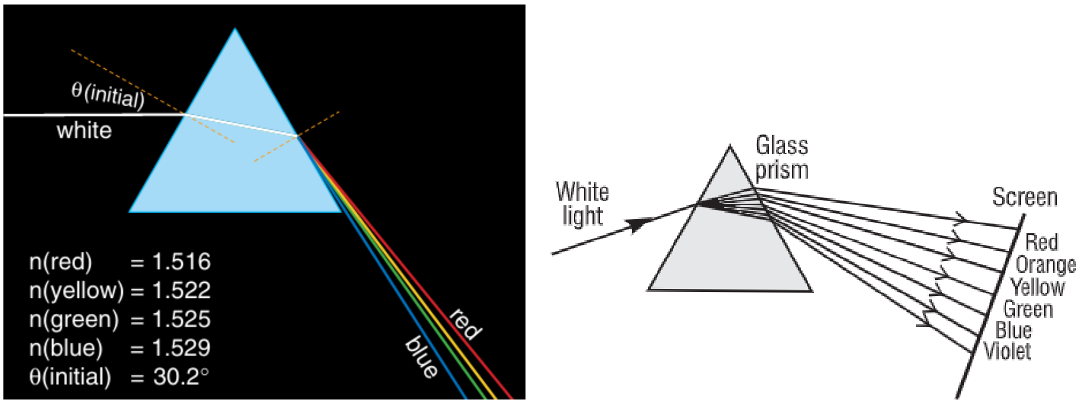

Figure 5.3: Dispersion of White Light Through a Prism

Mirrors

Mirrors reflect light according to the law of reflection, which states that the angle of incidence equals the angle of reflection. A plane mirror produces upright virtual images, while a concave mirror can form real or virtual images depending on the position of the object. Parallel rays striking a concave mirror converge at a point known as the focal point.

Lenses

Geometrical optics plays a crucial role in everyday technologies such as microscopes, telescopes, eyeglasses, and even human vision. The behavior of lenses—central components in these systems—is governed by the principles of refraction, as described by Snell's law, which determines how light bends when it passes between materials of different refractive indices. Lenses are generally classified into two types: convex (converging) and concave (diverging). A convex lens focuses parallel rays to a single focal point, while a concave lens causes them to diverge as if they originated from a virtual point behind the lens. The focusing power of a lens depends on both its surface curvature and the refractive index of the material, a relationship expressed mathematically by the lensmaker's equation. Figure 5.4 shows a Nikon zoom lens alongside its internal optical design, illustrating the complex arrangement of multiple lens elements required for variable focal length and image correction.

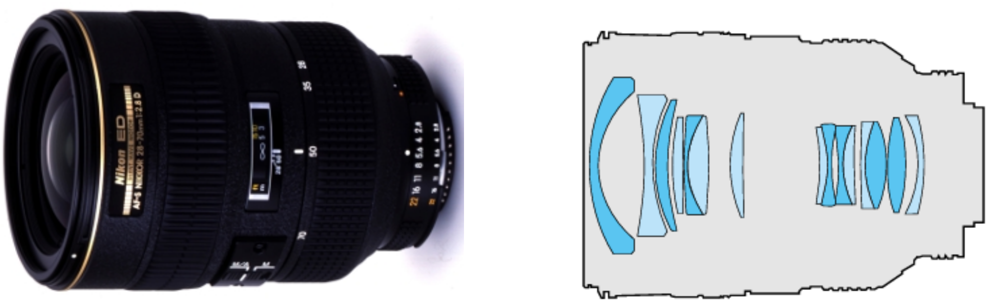

Figure 5.4 : Nikon zoom lens

a. Function of a lens

A lens is composed of a transparent material—typically glass—that bends light as it passes through. Its front and back surfaces are usually spherical in shape. When a light ray strikes the front surface of the lens, it bends according to Snell's law, then travels through the lens material and bends again upon exiting the rear surface. Figure 5.5 illustrates how a relatively thick lens bends light rays coming from an object **OP**, forming an image at **O'P'**. The methods we use to trace these rays and apply lens equations are based on the principles of Gaussian optics, similar to those used for analyzing mirrors.

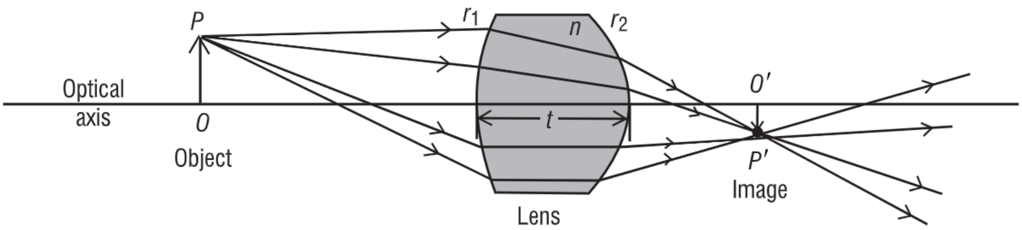

Figure 5.5: Refraction of light rays by a lens

When a lens has a very small axial thickness compared to the curvature radii of its surfaces, it is considered a thin lens. In such cases, the ray-tracing methods and lens equations are relatively straightforward. However, if the lens thickness is significant relative to the surface curvatures, it must be classified as a thick lens, requiring more complex analysis. As illustrated in *Figure 5.6*, various common shapes of thin lenses are presented. Although the diagrams show some physical thickness, thin lens theory assumes that light rays refract at the front and back surfaces without accounting for the actual path within the lens material. The first three lens types are thicker at the center than at the edges and are referred to as converging or positive lenses. These lenses bend incoming parallel rays inward, causing them to meet at a point, which corresponds to a positive focal length. The last three lens types are thinner in the center than at the edges and are known as diverging or negative lenses. Unlike converging lenses, diverging lenses cause parallel rays to spread outward after passing through, resulting in a negative focal length. The names of these lens shapes are labeled in *Figure 5.6*

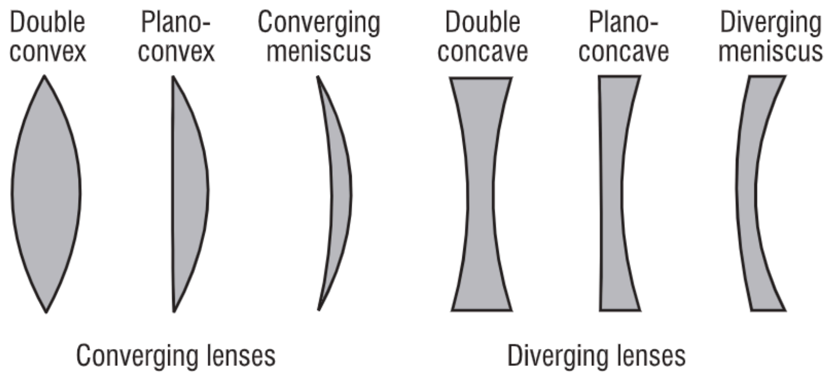

Figure 5.6 : Shapes of common thin lenses

Prelab:

- Snell's law
- Understand the two main types of thin lenses: converging (positive) and diverging (negative).
- Know how parallel rays behave in each type (converging rays vs. diverging rays).
- Learn the sign convention for focal lengths (+ for converging, − for diverging).
- Practice drawing basic ray diagrams to predict image formation.

- Recognize the difference between thin and thick lenses.
- Understand why paraxial rays are used in geometrical optics.

Experimental Procedure for Lab:

Experiment 1

1. Place the semicircular acrylic block with its flat face on a protractor sheet that shows a normal (0°) and 10° divisions.
2. Aim the laser along the normal; mark the undeviated exit point to verify alignment as in Figure 5.7.
3. Rotate the laser to an incident angle of 10° (±0.5°); mark the refracted beam's exit point and read the refracted angle on the protractor twice, then record the average.
4. Repeat step 3 for incident angles 20°, 30°, 40°, 50°, 60°, 70° and 80°.
5. Calculate sin i and sin r for each data pair.
6. Plot sin i (vertical axis) versus sin r (horizontal axis) and draw the best-fit line.
7. Determine the slope of the line; the slope equals n_2 / n_1. If $n_1 \approx 1.00$ (air), the slope gives the refractive index of the block.
8. Compile a table of all angles, the plot, the computed refractive index, an error estimate, and a short discussion of uncertainties (alignment, reading precision, beam width).

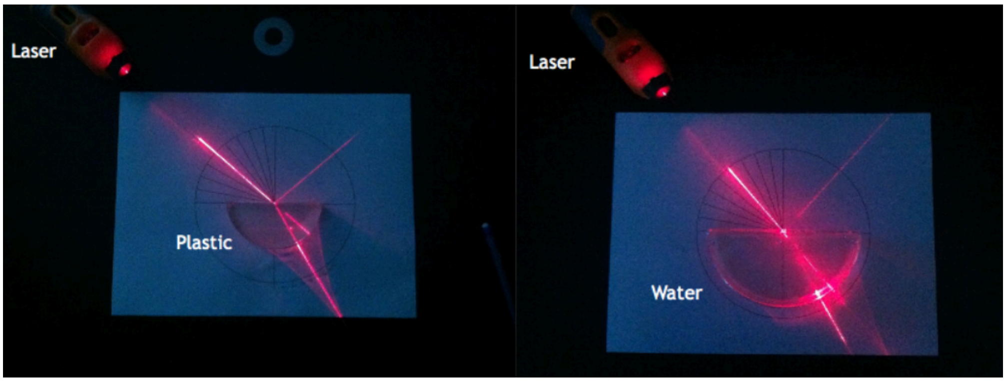

Figure 5.7: Experimental setup for Snell's law

Experiment 2

1. Arrange the laser pointer, equilateral prism, and white cardboard screen on a flat tabletop as shown in Figure 5.8. Center the prism over a sheet of white paper. Fasten down the white paper, cardboard screen, and laser with tape.
2. As you 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 OPQB 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 spot D will then be more exaggerated.)
3. When you have achieved the minimum angle for δ, carefully tape the prism in place. Trace the prism edges on the paper, the straight segments OP and QB along the original direction, and the segment CD. (Note: Location of laser spots Q, C on the exit face of the prism and B, D on the screen are needed 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. 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

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

to calculate the index of refraction n.

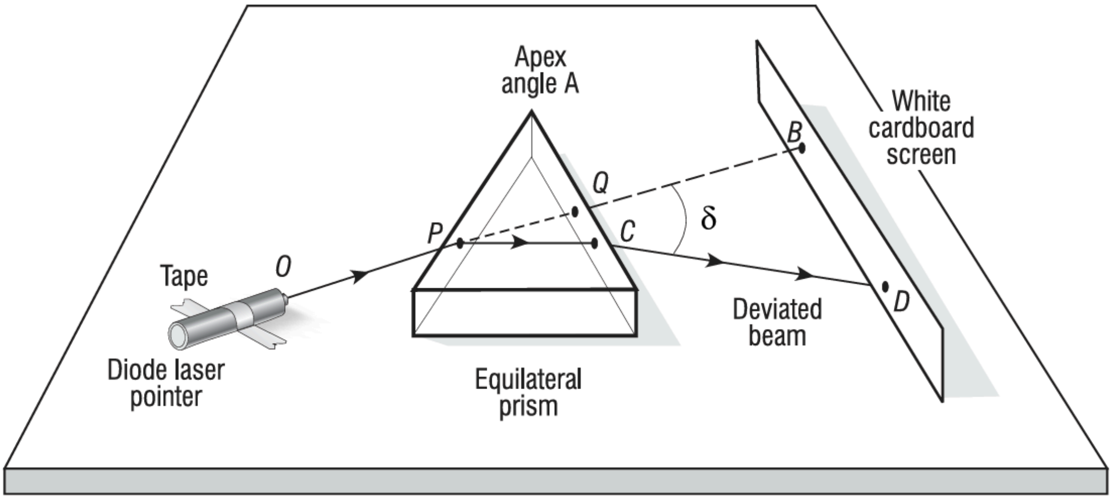

Figure 5.8. Prism Experimental Setup

Report: Please send the following outputs to the relevant research assistants via e-mail.

Safety Precautions

1. Avoid contact of the laser with the body and eyes
2. Never look directly into a laser beam.
3. Ensure the laser is securely fixed or handheld with care.
4. Work in a dim or darkened environment, but maintain general visibility for safety.

References

1. https://www.claytonschools.net/cms/lib/MO01000419/Centricity/Domain/266/AP%20Physics%20Files/15%20-%20AP%20Light/2012%20Geometric%20Optics%20Presentations/SnellsLaw-Ali%20Appi%20Zach.pdf
2. Fowles, G. R. (1989). Introduction to modern optics. Courier Corporation.

ELECTRICAL AND ELECTRONICS ENGINEERING

Geometrical Optics

Experiment-6

Optical Interference and Polarization Experiments

Prepared By

Research Asst. İlhan ERDOĞAN

Research Asst. Berker ÇOLAK

2025

Name-Surname	Number	Sign.

Objective:

- To understand and demonstrate fundamental optical phenomena using simple experimental setups.
- To observe and analyze diffraction and interference patterns formed by single and double slit arrangements.
- To explore basic principles of collimation, polarization, and focusing using hands-on optical components.

Apparatus Required:

- Laser pointer
- White paper or card stock
- Razor blade / sharp knife / scissors
- Pencil lead (0.7 mm or similar)
- Transparent tape
- Ruler, markers
- Linear polarizing filters (x2)
- Plano-convex lens (focal length ~5–10 cm)
- Optical bench (optional)
- Screen or wall for projection

Theoretical Background:

Focusing: When a converging lens (e.g., plano-convex) is placed in the path of a diverging laser beam, it focuses the rays toward a common point called the focal point. The focal length of the lens determines how far from the lens the rays converge.

Interference: When monochromatic light (such as a laser) passes through a narrow slit, it undergoes diffraction, spreading out instead of traveling in a straight line. The resulting pattern on a screen displays a central bright fringe flanked by dimmer secondary fringes, whose spacing depends on wavelength (λ), slit width (a), and distance to the screen (L).

For double slit interference, two closely spaced slits act as coherent light sources, creating a superimposed pattern of constructive and destructive interference. The bright and dark fringes result from differences in optical path length between the two waves. The intensity maxima occur at angles where the path difference equals an integer multiple of the wavelength:

$d \cdot sin(\theta) = m \cdot \lambda$, $(m = 0, \pm 1, \pm 2, \ldots)$

Where:

d = distance between slits

λ = wavelength of light

θ = angle of the m-th fringe

Polarization describes the orientation of oscillations in the plane perpendicular to the direction of wave propagation. This concept is fundamental in various scientific and technological fields involving wave behavior, such as optics, seismology, and space communications. Unpolarized light consists of oscillations in all directions perpendicular to the direction of propagation. A polarizer filters this light, allowing oscillations in only one direction to pass through. When two polarizers are placed at 90° to each other (cross-polarization), all light is blocked, illustrating Malus's Law.

Prelab:

- Review concepts of wave interference, Huygens' principle, and Young's double slit experiment.
- Watch video: "Laser Diffraction Basics" (approx. 10 min).
- Calculate expected fringe spacing for a known wavelength and slit separation.

Sample Questions:

1. How can you tell if a laser beam is collimated?
2. What happens when two polarizers are rotated 90° with respect to each other?
3. What condition produces the central maximum in single slit diffraction?

Experimental Procedure for Lab:

Experiment 1

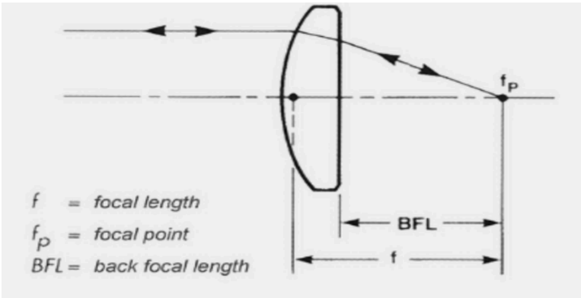

Figure 6.1. Focus point illustration of plano-convex lenses

1. Shine the laser beam through a plano-convex lens as in Figure 6.1.
2. Move a piece of white paper or screen along the beam path.
3. Identify and mark the sharpest, smallest spot – this is the focal point.
4. Measure the focal length (distance from lens to focal point).
5. Reverse the lens to observe focal behavior difference (if any).

Experiment 2

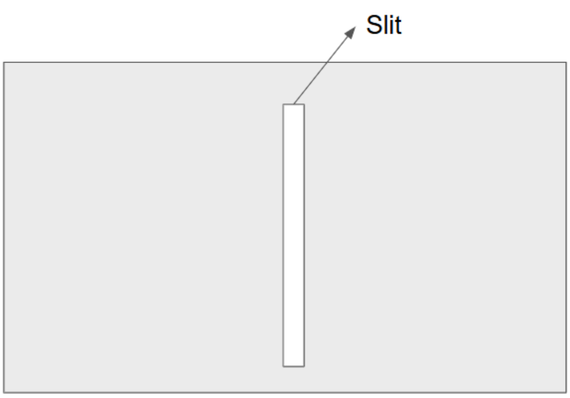

Figure 6.2. Experimental setup for single slit

Part A: Single Slit Diffraction

1. Take a piece of dark-colored cardstock or paper.
2. Using a razor blade, carefully cut a narrow (approx. 1mm) vertical slit in the center (see Figure 6.2).
3. Mount the paper upright on a stable surface.
4. Direct a laser pointer at the slit in a dark room.
5. Observe and sketch the diffraction pattern projected onto a screen or wall.

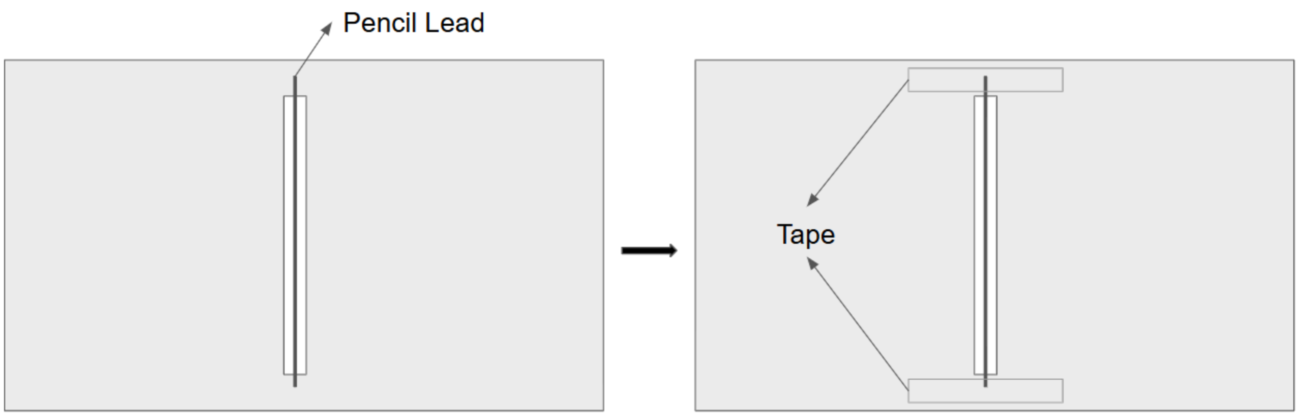

Figure 6.3. Experimental setup for double slit

Part B: Double Slit Interference

1. Take a piece of paper and tape a thin pencil lead (e.g., 0.7 mm) vertically at the center.
2. Secure the pencil lead on both ends using transparent tape, leaving space between two lead strands as in Figure 6.3 .
3. Shine the laser light between the two leads.
4. Observe the interference fringes on a screen positioned several meters away.
5. Record fringe spacing and pattern symmetry.

Experiment 3

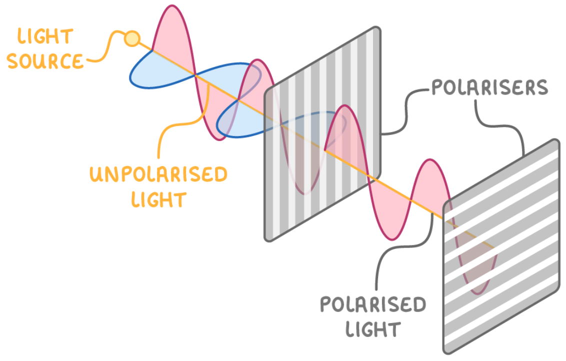

Figure 6.4. Demonstration of the working principle of the polarization experiment

1. Pass laser or ambient light through a linear polarizer as in Figure 6.4.
2. Observe the beam through a second polarizer:
3. When aligned: light passes
4. When rotated 90°: light is blocked

5. Rotate one filter from 0° to 90° in steps.

Report: Please send the following outputs to the relevant research assistants via e-mail.

Safety Precautions

- Never look directly into a laser beam.
- Ensure the laser is securely fixed or handheld with care.
- Work in a dim or darkened environment, but maintain general visibility for safety.
- Be cautious when using blades or sharp tools to prepare slits.

References

1. Hecht, E. – Optics, 4th Edition
2. Young's Double Slit Experiment – Physics Open Resources
3. Practical Physics – Diffraction and Interference with Lasers (IOP)

SİVAS UNIVERSITY OF SCIENCE AND TECHNOLOGY

ELECTRICAL AND ELECTRONICS ENGINEERING

Geometrical Optics

Experiment-7

Fundamentals of Optical Fibers

Prepared By

Research Asst. İlhan ERDOĞAN

Research Asst. Berker ÇOLAK

2025

Name-Surname	Number	Sign.

Objective: Understand the classification of optical fibers (single-mode vs. multi-mode), gain hands-on experience with proper fiber handling techniques, and learn to perform basic fiber preparation steps including stripping, cleaving, and fusion splicing.

Apparatus Required:

- Single-mode and multi-mode fiber optic cables
- Fiber splicing device
- Fiber clever device

Theoretical Background:

An **optical fiber** is a thin, flexible strand made of glass or plastic that transmits light signals over long distances with minimal loss. It operates on the principle of **total internal reflection**, where light is confined within the fiber core by reflecting repeatedly off the core–cladding boundary.

A standard optical fiber consists of four main layers in Figure 7.1 shows;

1. **Core**: The innermost part where light travels. It is made of high-purity glass and has a higher refractive index than the cladding.
2. **Cladding**: A surrounding glass layer with a slightly lower refractive index. It ensures that light is reflected back into the core, keeping the signal confined.
3. **Coating or Buffer Layer**: A protective polymer layer that shields the fiber from moisture, mechanical damage, and environmental factors.
4. **Outer Jacket:** The outermost protective layer, typically made of durable plastic (like PVC or polyethylene), which shields the fiber from physical, chemical, and environmental damage such as moisture, abrasion, and UV exposure.

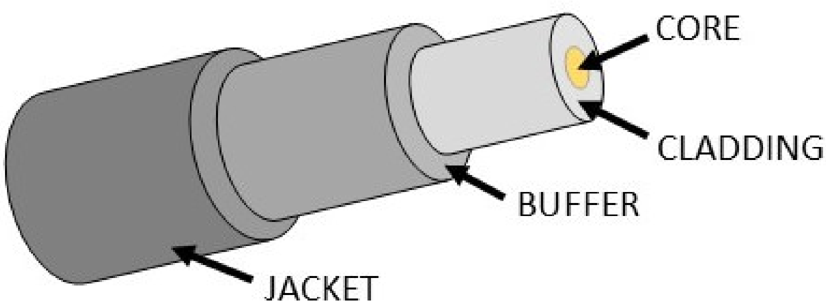

Figure 7.1 : Optical Fiber Construction

Optical fibers are widely used in telecommunications, internet infrastructure, sensing technologies, and medical devices due to their high bandwidth, low attenuation, immunity to electromagnetic interference, and small physical size. Fiber optics offer several key advantages over copper wires, including significantly higher bandwidth (up to >10 GHz·km for single-mode fibers), immunity to electromagnetic interference, and lower signal loss, which allows for longer transmission distances. They are also lighter, more cost-effective, and safer—posing no risk of sparks, electrical shorts, or grounding issues—making them ideal for secure and electrically isolated communication, especially in hazardous environments.

A Step-Index Fiber is an optical fiber characterized by a uniform core refractive index that changes abruptly at the core–cladding boundary, creating a sharp contrast between the core (n_1) and cladding (n_2) where $n_1 > n_2$. Light is guided through the core by total internal reflection, following a zigzag path along the fiber. Step-index fibers are categorized as single-mode (with a very small core supporting only the fundamental mode) and multi-mode (with a larger core allowing multiple propagation modes). Single-mode fibers (SMFs), typically with core diameters of 8–10 µm, eliminate modal dispersion and support higher bandwidth and longer transmission distances. In contrast, Multi-Mode Fibers (MMFs), with core diameters of 50 or 62.5 µm, allow multiple light paths, which causes modal dispersion and limits transmission range, though they are more cost-effective and easier to align for short-distance applications. A Graded-Index (GRIN) Fiber, a type of multi-mode fiber, gradually decreases its core refractive index from center to edge. This design bends light rays into smooth sinusoidal paths, minimizing modal dispersion by allowing outer rays to travel faster and thus improving signal synchronization and performance. Figure 7.2 shows step index and graded index fiber profiles.

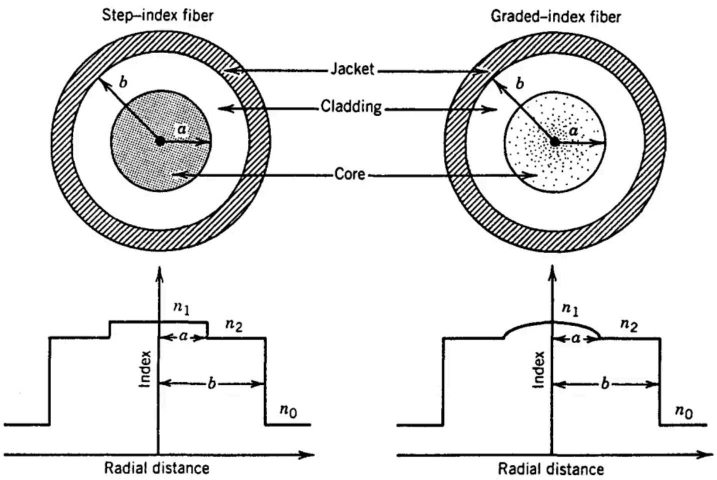

Figure 7.2. Cross section and refractive-index profile for step-index and graded-index fibers.

Prelab:

1. What is an optical fiber? What are the types of optical fibers?(Single mode, multi mode, step index, graded index etc.)
2. What is fiber handling? What is fiber cleaving and splicing? How are optical fibers cleaved and spliced?

Experimental Procedure for Lab:

A. <u>Fiber cleaver</u>

1. Prepare the Fiber

   a. Ensure the fiber is properly stripped using a fiber stripper (typically 125 µm bare fiber after coating is removed).

   b. Clean the stripped fiber with lint-free wipes soaked in isopropyl alcohol to remove any debris or oil.

2. Open the Cleaver Lid

   a. Lift the cleaver's protective lid and slide mechanism to expose the fiber placement area.

3. **Position the Fiber**
    a. Place the cleaned, stripped fiber into the fiber holder or guide, aligning the tip to the cleaving length (usually marked on the cleaver or pre-set by the holder).
4. **Secure the Fiber**
    a. Gently close the fiber clamp or lid to fix the fiber in place without stressing or bending it.
    b. Ensure the fiber is lying flat and straight for an accurate cleave.
5. **Perform the Cleave**
    a. Press the cleaver blade button or slide the cleaving mechanism.
    b. The blade scores the fiber and the device automatically applies a small tension to snap it cleanly.
6. **Remove the Cleaved Fiber**
    a. Lift the lid and carefully remove the front (cleaved) fiber end.
    b. Avoid touching the cleaved surface as it is delicate and crucial for low-loss splicing.

Figure 7.3: Fujikura Fiber cleaver device

B. Fiber splicing

1. **Strip the Fibers**
    a. Carefully remove the outer jacket of the fiber optic cable.
    b. Strip the buffer and coating layers using a precision fiber stripper, exposing the bare glass fiber.
    c. Ensure the fiber is not scratched or damaged during this process.
2. **Clean the Fibers**
    a. Use lint-free wipes soaked in 99% isopropyl alcohol to thoroughly clean the bare fiber ends.
    b. This step removes dust, oil, and residues that may affect the splice quality.
3. **Cleave the Fibers**
    a. Place the cleaned fibers into a precision cleaver and perform a perpendicular cleave (approximately 90°).
    b. A smooth, flat end face is essential for a low-loss splice.
4. **Insert the Fibers into the Splicer**
    a. Carefully place the cleaved fiber ends into the holders of the Fujikura splicer.
    b. Make sure the fiber ends are properly aligned and positioned as guided by the device.
5. **Auto Alignment and Fusion**
    a. The Fujikura splicer automatically aligns the fiber cores using core alignment technology.

    b. Once aligned, the device initiates an electric arc that melts and fuses the fiber ends together in a few seconds.

6. **Check the Splice Result**

    a. After splicing, the machine displays the estimated splice loss (e.g., 0.01–0.05 dB).
    b. The splicer provides a visual inspection of the splice zone to confirm the connection quality.

Figure 7.4: Fujikura Fiber splicing device

Report: Please send the following outputs to the relevant research assistants via e-mail.

Safety Precautions

- Wear Safety Glasses:
- Keep the Work Area Clean
- Dispose of Waste Properly
- Electrical Safety
- Follow Instructor's Guidance

References

1. Mitschke, F., & Mitschke, F. (2016). Fiber optics (Vol. 2). Berlin, Germany:: Springer.
2. Ientilucci, E. (1993). Fundamentals of Fiber Optics. Rochester Institute of Technology.
3. https://www.fibersystems.com/pdf/whitepapers/Basics-of-Fiber-Optics.pdf
4. https://www.fiberoptics4sale.com/blogs/wave-optics/step-index-optical-fibers?srsltid=AfmBOorjx-nuMZglCHdofArDLtDS7BxUEORLzubhBxkS1oJxovewB-dF
5. https://booksite.elsevier.com/samplechapters/9780240804866/9780240804866.PDF

ELECTRICAL AND ELECTRONICS ENGINEERING

Geometrical Optics

Experiment-8

Fiber Optic Sensing and Optical Spectrum Analyzer

Prepared By

Research Asst. İlhan ERDOĞAN

Research Asst. Berker ÇOLAK

2025

Name-Surname	Number	Sign.

Objective:

- To understand the working principle of an Optical Spectrum Analyzer (OSA).
- To perform spectral measurements of light sources and fiber-optic signals.
- To explore basic fiber optic sensing principles using wavelength-based analysis.

Apparatus Required:

- Optical Spectrum Analyzer (OSA) (e.g., Anritsu)
- Broadband Light Source (e.g., SLED or ASE)
- Fiber-optic patch cords (SMF or MMF)
- Fiber coupler or splitter
- Optical attenuators, connectors, adapters

Theoretical Background:

An Optical Spectrum Analyzer (OSA) is a crucial instrument in modern optics and photonics laboratories, used to measure the spectral power distribution of optical signals across a given wavelength range. Unlike time-domain instruments such as oscilloscopes, the OSA operates in the wavelength domain, allowing users to visualize and analyze the spectral characteristics of lasers, LEDs, fiber-optic systems, and other light sources. The working principle of an OSA is based on wavelength-selective dispersion, typically using diffraction gratings and photodetectors to scan and record the intensity of light at each wavelength with high resolution and sensitivity. Key performance parameters include resolution bandwidth (RBW), wavelength range, and dynamic range, all of which influence the accuracy and clarity of spectral measurements. Figure 8.1 illustrates the OSA in our lab.

Figure 8.1. Optical Spectrum Analyzer Setup

In addition to source characterization, OSAs are extensively used in fiber optic sensing applications. One widely studied technique involves Fiber Bragg Gratings (FBGs), which are periodic variations of the refractive index within an optical fiber core. These gratings reflect specific wavelengths of light and transmit others. When external factors such as temperature or strain are applied, the Bragg reflection wavelength shifts proportionally, making FBGs ideal for real-time sensing applications. The OSA can detect these shifts with sub-nanometer accuracy, enabling precise monitoring of environmental changes. In experimental setups, combining OSAs with passive or active fiber components allows for the evaluation of insertion loss, filter response, and wavelength stability in communication and sensing systems.

Prelab:

- Review:
  - Principles of diffraction and grating-based wavelength separation
  - Wavelength vs. frequency relationship: $\lambda = \frac{c}{f}$
  - What "insertion loss" and "reflection spectrum" mean in fiber optics
- Watch a short video: "How an Optical Spectrum Analyzer Works" (10 min)

Prelab Quiz Example Questions:

1. What information can be extracted from an OSA plot?
2. How can OSA be used to measure temperature in an FBG-based sensor?
3. Why is dynamic range important in spectral measurements?

Experimental Procedure for Lab:

Part A: OSA Familiarization

1. Turn on the OSA and allow warm-up.
2. Connect a broadband light source via a fiber patch cord.
3. Set scan parameters:
   - Wavelength range: 1250–1650 nm
   - RBW: 0.1 nm
   - Sweep mode: Single or Continuous
4. Observe and save the output spectrum.

Part B: Insertion Loss and Peak Measurement

1. Insert an inline fiber component (e.g., coupler or filter).
2. Measure:
   - Peak wavelength
   - Peak power (dBm)
   - 3 dB bandwidth
3. Calculate insertion loss if applicable.

Report: Please send the following outputs to the relevant research assistants via e-mail.

Table.x. Data Recording Template

Measurement	**Value**
Peak Wavelength (nm)	
Peak Power (dBm)	
3 dB Bandwidth (nm)	
Insertion Loss (dB)	

Safety Precautions

- Never look into fiber ends, especially when using active light sources.

- Use angled connectors (APC) if available to reduce back reflections.
- Handle fibers carefully; they can cause skin punctures or breakage.
- Avoid bending fibers below their minimum bend radius.

References

1. https://www.anritsu.com/en-us/test-measurement/products/ms9740b
2. https://www.sciencedirect.com/topics/engineering/optical-spectrum-analyzer

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ELECTRICAL AND ELECTRONICS ENGINEERING

Geometrical Optics

Experiment-9

Lasers and Working Principles

Prepared By

Research Asst. İlhan ERDOĞAN

Research Asst. Berker ÇOLAK

2025

Name-Surname	Number	Sign.

Objective:

- To understand the working principle of a CO_2 laser system.
- To identify and describe the optical components in a typical laser cavity (mirrors, lenses, gas tube, cooling system).
- To safely operate or observe the alignment and beam path of a CO_2 gas laser.

Apparatus Required:

- Coherent CO2 laser machine
- Fibers
- Other substrates

Theoretical Background:

The CO_2 laser is a gas discharge laser that emits strongly in the infrared spectrum at 10.6 µm. It operates via electrical excitation of a gas mixture (usually CO_2, N_2, He) inside a sealed glass or ceramic tube. Excited CO_2 molecules undergo population inversion and stimulated emission.

Key components of the system include:

- Laser tube: where the gas discharge occurs
- Resonator mirrors: one fully reflective, one partially reflective for output coupling
- ZnSe focusing lens: transparent to 10.6 µm IR; focuses the beam for cutting or marking
- Cooling: essential to avoid overheating due to high power dissipation

CO_2 lasers are commonly used in cutting, engraving, IR spectroscopy, and medical surgery, due to their high efficiency and relatively low cost.

Application Areas:

1. Materials Processing:
   - Cutting, engraving, welding, and drilling of non-metallic materials such as plastics, wood, glass, ceramics, and acrylic.
   - Micropatterning on polymer surfaces (e.g., plastic optical fibers).
   - Surface texturing and marking.
2. Medical Applications:
   - Surgical procedures including dermatology, gynecology, and dentistry.
   - Used in laser ablation, skin resurfacing, and removal of lesions or scars.
3. Scientific Research:
   - Precise micromachining for sensor fabrication.
   - Grating fabrication on optical fibers and waveguides.
   - Infrared spectroscopy and photonics experiments.
4. Communication and Photonics:
   - Used to inscribe fiber Bragg gratings (FBGs) or surface relief gratings on polymer or silica fibers for sensing applications.

    - Component marking in optical device manufacturing.
5. Electronics and PCB Industry:
    - Micro-drilling via holes in printed circuit boards (PCBs).
    - Thin-film removal or etching on flexible electronics.
6. Textile and Packaging:
    - Marking of fabrics, leather, and flexible packaging materials.

Prelab:

- CO_2 laser review, working principle, application areas
- Examine the related article (*CO2 laser-induced long-period fiber grating in the dispersion turning point*) https://doi.org/10.1016/j.yofte.2023.103342, note the key points

Experimental Procedure for Lab:

⚠️**Due to the high-power and infrared nature of the CO_2 laser, this experiment is potentially hazardous. Students are not permitted to operate the laser system directly. Instead, please observe the following steps as performed by the lab supervisor or research assistant, and take detailed notes on each stage.**

1. **Cut the POF to 20 cm length.**
   A plastic optical fiber segment of approximately 20 cm is carefully cut using a precision fiber cutter or sharp blade to ensure clean, perpendicular end faces.
2. **Fix the fiber tightly between two optical holders.**
   The POF is mounted horizontally and stretched slightly between two adjustable fiber clamps or V-groove holders to maintain a stable and flat working surface.
3. **Turn on the CO_2 laser system.**
   Power is supplied to the Coherent CO_2 laser unit, and system initialization is completed following standard operating procedures.
4. **Set the laser power from the control interface.**
   Using the laser software interface, the output power is carefully adjusted to a safe level that avoids melting or damaging the POF. (Typical range: 1–5 W depending on the fiber material.)
5. **Draw the grating pattern in the interface and start the process.**
   A periodic grating design is drawn within the laser software (e.g., parallel lines with specific pitch and width), and the **"Run"** command is executed to begin patterning.
6. **Direct the CO_2 laser beam perpendicularly (90°) onto the fiber.**
   The laser beam is aligned to strike the top surface of the POF at a 90-degree angle using mirror-guided optics and focusing lenses to ensure uniform energy delivery across the fiber surface.
7. **Inspect the POF gratings under a camera or microscope.**
   Once the patterning is complete, the grating structures on the POF surface are examined under an optical microscope or digital inspection camera to verify pattern accuracy, depth, and continuity.
8. **Turn off the CO_2 laser system.**
   After the process and inspection are completed, the laser power is safely turned off, and the system is shut down according to laser lab safety protocols. Figure 9.1 shows the experimental setup for CO_2 laser system.

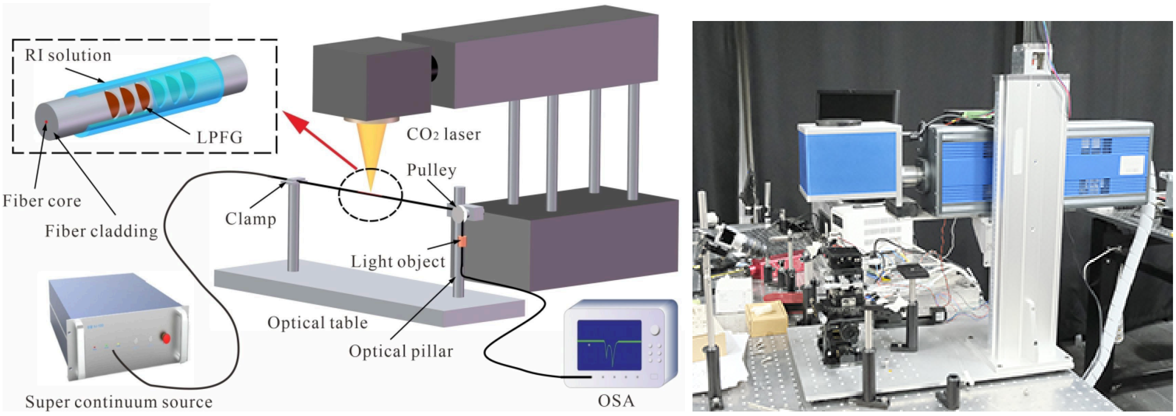

Figure 9.1: Experimental setup for CO_2 laser system

Report:

- Record the purpose of each step performed, note the experimental parameters and interpret the results.

Please send the following outputs to the relevant research assistants via e-mail.

Safety Precautions

- CO_2 lasers are Class IV: direct and diffuse reflections can cause permanent eye and skin damage.
- Always wear IR-rated goggles (OD ≥ 6 at 10.6 μm).
- Never align the beam while the laser is powered.
- Use proper beam stops and enclosures.
- Operate in a controlled, supervised environment only.

References

1. Silfvast, W. T. (2004). Laser fundamentals. Cambridge university press.
2. Du, C., Zhao, S., Wang, Q., Jia, B., Zhang, L., Cui, L., & Deng, X. (2023). CO2 laser-induced long-period fiber grating in the dispersion turning point. Optical Fiber Technology, 79, 103342. https://doi.org/10.1016/j.yofte.2023.103342
3. https://www.intechopen.com/chapters/47952

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ELECTRICAL AND ELECTRONICS ENGINEERING

Geometrical Optics

Experiment-10

Understanding The Optical Manufacturing and Thin Film Coatings - OPMAM Technical Visit

Prepared By

Research Asst. İlhan ERDOĞAN

Research Asst. Berker ÇOLAK

2025

Name-Surname	Number	Sign.

Objective:

- To observe advanced processes in optical fabrication and coating technologies.
- To gain insight into DLC (Diamond-Like Carbon) coating via PECVD.
- To gain exposure to modern equipment such as SPDT, PECVD, E-beam PVD, and high-precision metrology systems.
- To understand how surface quality, film thickness, and optical performance are measured and controlled using laser interferometry, WLI, and FTIR.

Location:

OPMAM- Optical Excellence Research and Application Center (Optik Mükemmeliyet Uygulama ve Araştırma Merkezi)

Theoretical Background:

Modern optical manufacturing integrates both mechanical precision shaping and nanometer-scale thin film engineering. Below are key systems and techniques students will encounter:

Fabrication Technologies

SPDT – Single Point Diamond Turning

Figure 10.1. Single Point Diamond Turning Setup

- Ultra-precision machining method for optical surfaces, often on metals and infrared materials.
- Capable of producing aspheric and freeform surfaces.
- Resolution down to sub-micron level.

Thin Film Coating Technologies

E-beam PVD – Electron Beam Physical Vapor Deposition

Figure 10.2. Electron Beam Physical Vapor Deposition Setup

- Uses an electron beam to vaporize target materials inside a vacuum chamber.
- Enables high-purity, high-density thin films.
- Used for multilayer dielectric and metallic coatings.

PECVD – Plasma Enhanced Chemical Vapor Deposition

Figure 10.3. Plasma Enhanced Chemical Vapor Deposition Setup

- PECVD in this lab is configured specifically for DLC (Diamond-Like Carbon) deposition.
- DLC is an amorphous carbon film combining the hardness of diamond with the smoothness of graphite.

Measurement and Characterization Systems

Laser Interferometry

Figure 10.4. Laser Interferometry Setup

- Measures surface flatness and wavefront error with nanometer accuracy.
- Common types: Fizeau and Twyman-Green.

WLI – White Light Interferometry

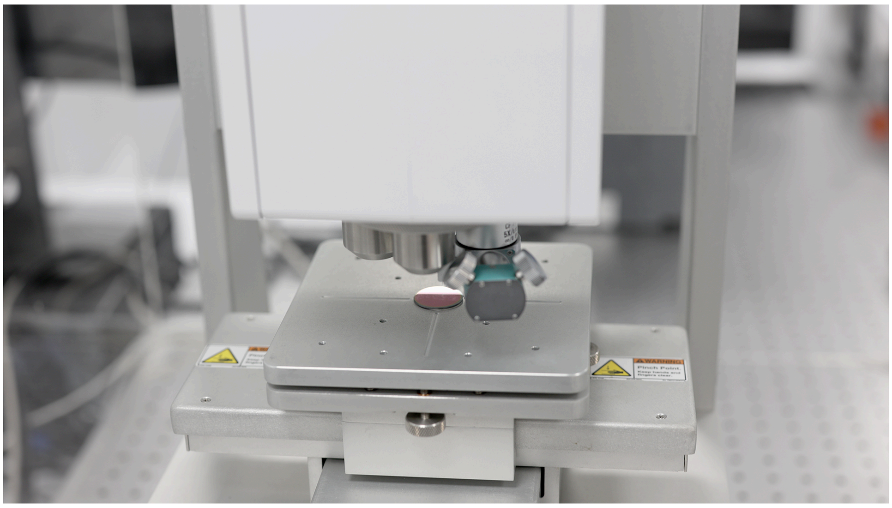

Figure 10.5. White Light Interferometry Setup

- Provides 3D surface profiles with vertical resolution down to nanometers.
- Non-contact technique ideal for coating thickness and roughness evaluation.

Taylor Hobson Contact Profileometer

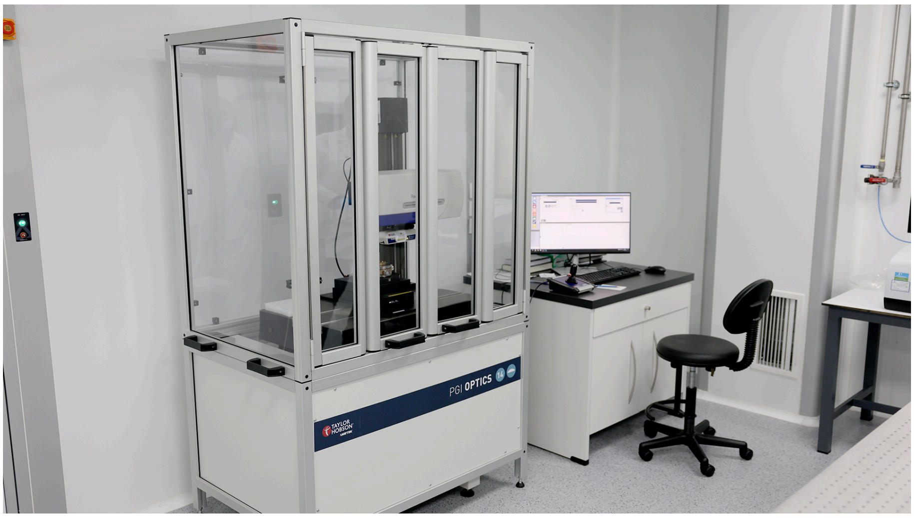

Figure 10.6. Taylor Hobson Contact Profileometer Setup

- Stylus-based surface profilometer that physically traces the surface.
- Used especially where coatings (e.g., DLC) must be verified for mechanical uniformity.
- Provides cross-check with non-contact WLI data.

FTIR – Fourier Transform Infrared Spectroscopy

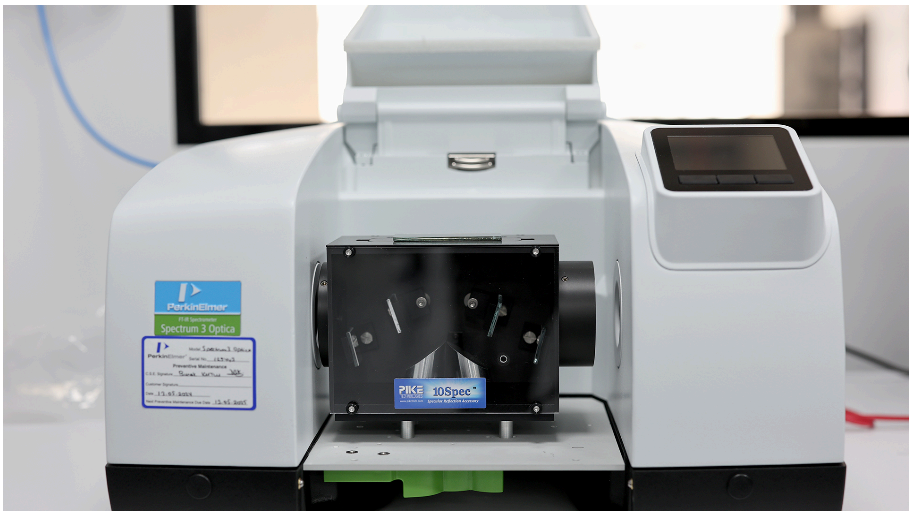

Figure 10.7. Fourier Transform Infrared Spectroscopy Setup

- Measures spectral absorption/transmission of optical coatings.
- Useful in identifying material composition and coating performance across IR range.

Pre-Visit Preparation:

Students must:

- Review how each tool contributes to surface preparation, coating, or testing.
- Watch short tutorial: "Thin Film Deposition and Optical Metrology Overview"
- Research key terms: reflectance, spectral bandwidth, surface roughness, RMS wavefront error.

Sample Pre-Visit Questions:

1. What is the difference between PECVD and E-beam PVD in terms of deposition method?
2. What does laser interferometry measure in an optical surface?
3. What is the advantage of using both WLI and contact profilometry?

Visit Procedure:

1. Welcome Briefing
    - Introduction to facility layout, safety rules, equipment overview.
2. Live Demonstration Stations
    - SPDT Machine: Observe diamond cutting of a precision optic.
    - E-beam PVD Chamber: Learn about coating material loading, vacuum preparation, and layer control.
    - PECVD Reactor: Understand gas flow, plasma generation, and film growth parameters.
    - Laser Interferometer: See how optical surfaces are analyzed for flatness and wavefront error.
    - WLI Station: Visualize 3D topographic surface maps of coated optics.
    - FTIR System: Examine transmission spectrum of coated samples.
3. Interactive Q&A Session
    - Students engage with lab engineers and ask detailed questions.
4. Documentation
    - Students take structured notes and collect data for post-visit analysis.

Post-Visit Assignment:

- Submit a 2-page report including:
- Purpose and principle of each system visited (SPDT, PECVD, E-Beam PVD, metrology tools)
- Observations on manufacturing workflow
- Comparison of deposition techniques
- Relevance to lens design and system performance

Please send the following outputs to the relevant research assistants via e-mail.

Safety Precautions

- Follow cleanroom or lab dress codes if applicable (lab coats, shoe covers, gloves, etc.)
- Do not touch machinery or coated optics.
- Ask for permission before taking notes/photos.
- Keep clear of laser paths and vacuum equipment in operation.

References

1. https://optik.sivas.edu.tr/