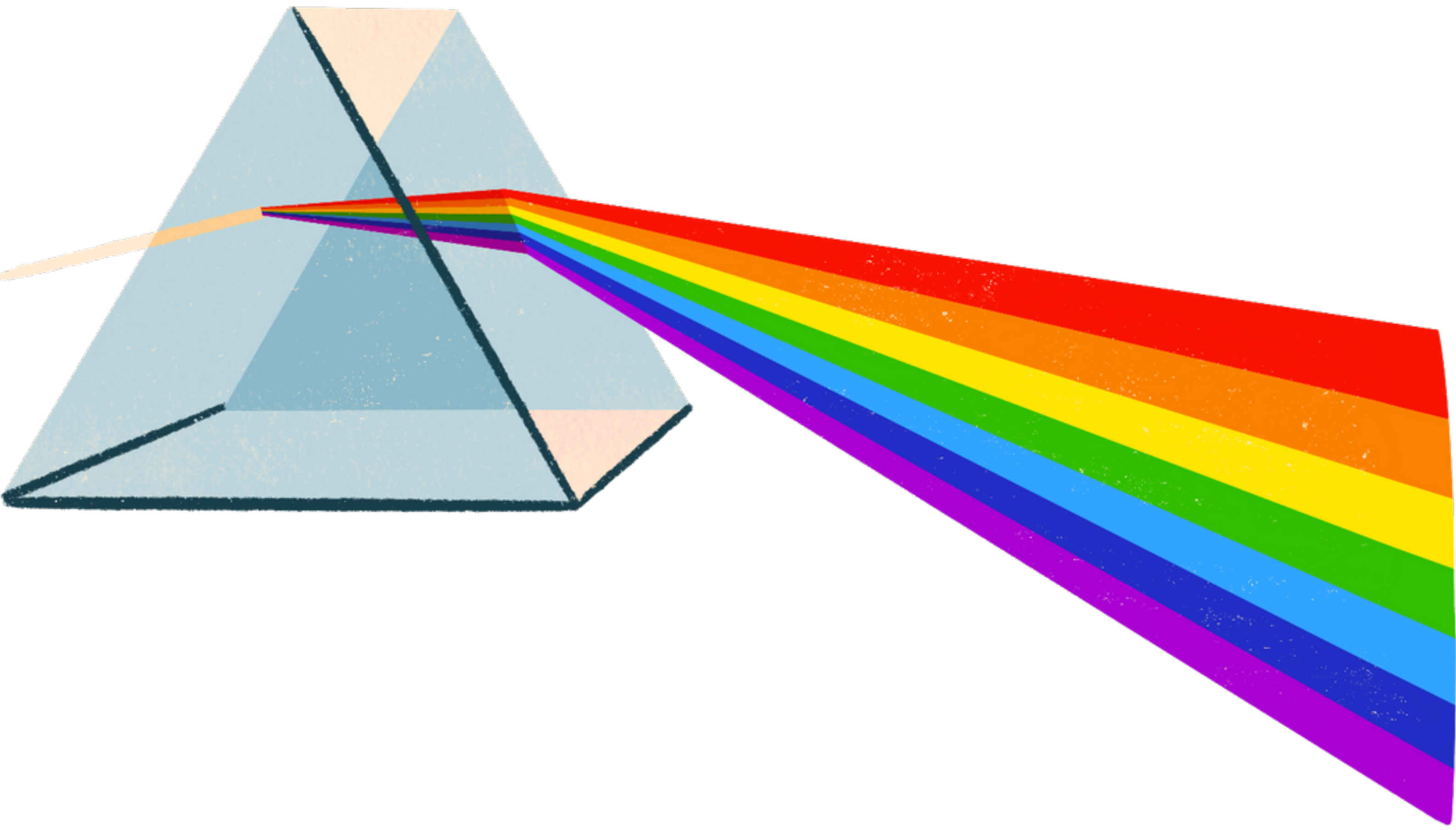
ISTANBUL UNIVERSITY
FACULTY OF SCIENCE
DEPARTMENT OF PHYSICS

OPTICS LABORATORY EXPERIMENTS MANUAL



Optics Laboratory

Name Surname:

Student Number:

Experiment	Date	Sign	Sign
1. a: Malus Law b: Newton's Rings			
2. Fresnel's equations and Reflection Theory			
3. Fresnel's double mirror and biprism			
4. a: Single-slit diffraction b: Single slit diffraction intensity distribution			
5. a: Polarization through lambda-quarter wave plates b: Polarization			
6. Young's double slit experiment			
7. Michelson interferometer			
8. Dispersion			
9. a: Speed of Light b: Absorption			
10. a: Diffraction Grating b: Determination of the wavelength by spectrometer			

Content

Note: This is the first version of the optics laboratory experiments manual, please provide feedback if you see any typing errors or mistakes.

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1A - MALUS' LAW

OBJECTIVES

- To determine the plane of polarization of linearly polarized laser light.
- To measure the intensity of light passing through a polarization filter as a function of the filter's angular position.
- To verify the validity of Malus's Law.

EQUIPMENTS

- He-Ne Laser (1mW, 220 V AC)
- Polarization Filter
- Photocell
- Digital Multimeter

GENERAL INFORMATION

What are the Electromagnetic Theory of Light, Polarization, Polarizer, Analyzer, Brewster's Law, and Malus's Law?

Polarization of light refers to the process by which the oscillations of the electric field vector within an electromagnetic (EM) wave become restricted to a single plane. The plane of polarization is determined by the direction of propagation and the orientation of the electric-field oscillations. Different types of polarization, such as linear, circular, and elliptical, exhibit distinct characteristics and behaviors

1. **Linearly or plane-polarized light**: The oscillations are confined to one plane, and the electric field vector traces a straight line (Figure 1).
2. **Circularly polarized light**: The electric field vector traces a circle.
3. **Elliptically polarized light**: The electric field vector traces an ellipse. This is the most general form of polarized light.

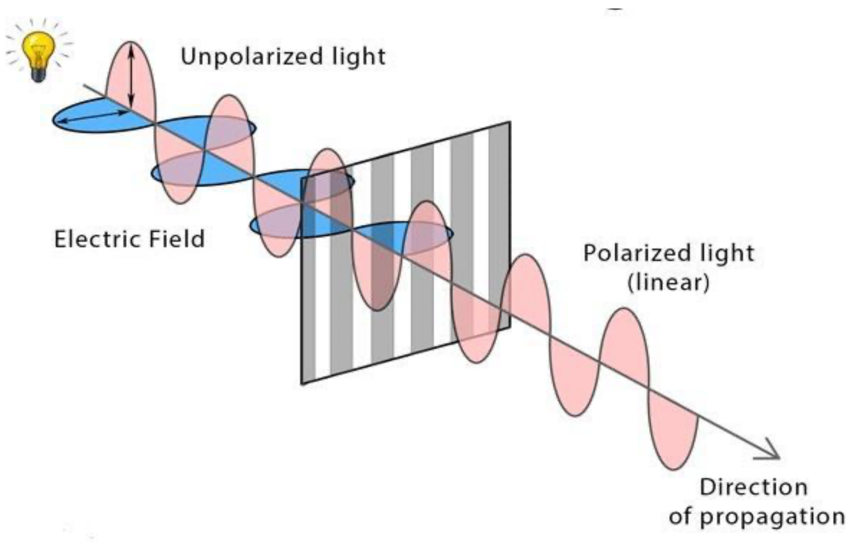

Figure 1: Linearly Polarized Light

All light possesses polarization. Light, commonly termed "unpolarized," lacks organized polarization, instead exhibiting randomized polarization. Randomly polarized light is a type of light in which the electric field vector oscillates in random directions perpendicular to the direction of the light's propagation. Linearly polarized light occurs when the electric field vector oscillates in a single plane perpendicular to the direction of the light's propagation. The direction of polarization is typically denoted as either vertical or horizontal but can be at any angle relative to the viewer. Light can be linearly polarized with a polarizer that selectively transmits light waves in a desired polarization direction while blocking others. Various methods can be employed to generate polarized light, including reflection, refraction, scattering, and absorption.

A polarizer is an optical filter that lets light waves of a specific polarization pass through while blocking light waves of other polarizations. An analyzer is also a polarizer that acts on already polarized light. Let the angle between the analyzer and the polarization angle be θ and the amplitude of the incident waves be E_0.

$$E_0{}' = E_0 cos\theta \qquad (1)$$

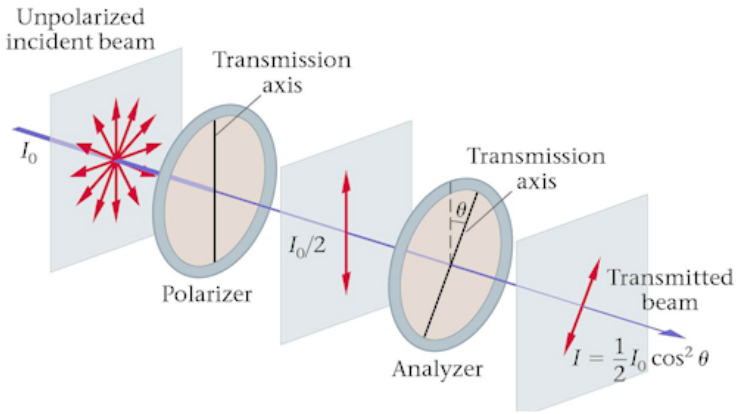

Figure 2: Polarizer-Analyzer System

The intensity of light after it has been through the analyzers proportional to the square of the cosine of the angle θ as described by Malus' Law:

$$I' = I \cos^2\theta \qquad (2)$$

When the two polarizers are positioned perpendicular to each other, no light is observed.

In Figure 3, the photocell current is shown as a function of the angular position of the analyzer's polarization plane after background correction. The intensity peak corresponds to the angular rotation of the emitted laser beam's polarization plane.

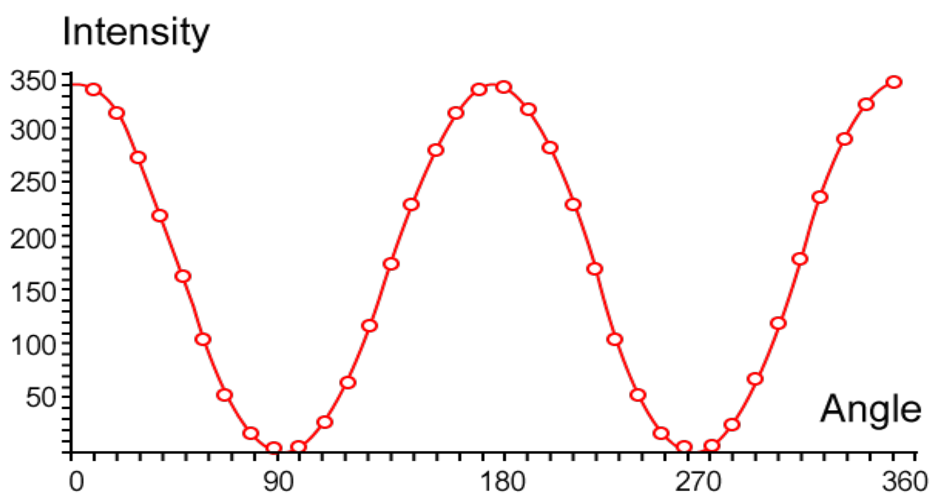

Figure 3: Change in intensity as a function of the analyzer angle

Figure 4 shows the normalized and corrected photocell current as a function of the analyzer's angular position. Malus's Law is verified by the slope of the initial linear section of the graph. (Note: The angular determination of the analyzer for Malus's Law should be done to identify the Malus line in Figure 4).

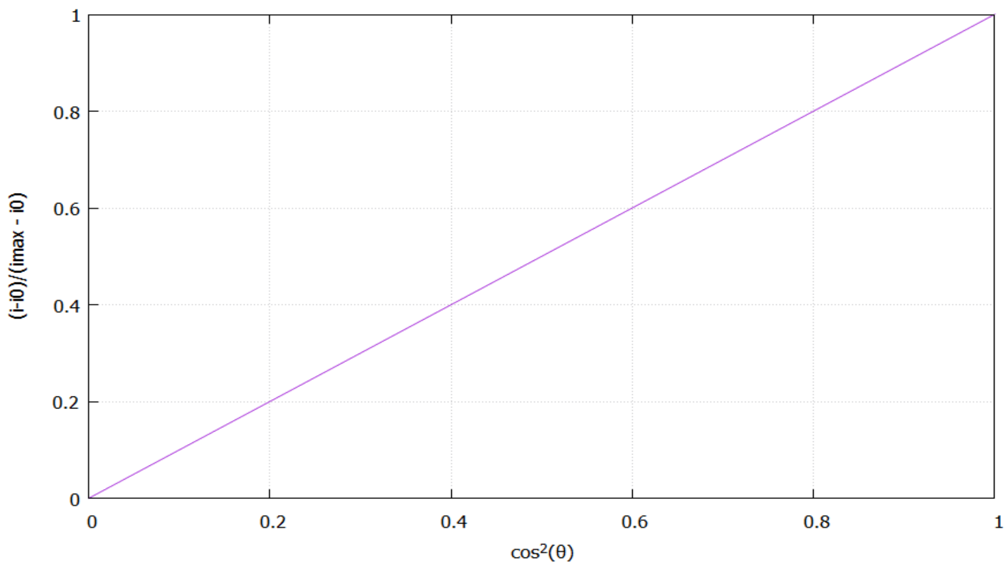

Figure 4: Normalized Photocell Current as a Function of the Analyzer's Angle

EXPERIMENT PROCEDURE

The experiment is set up as shown in Figure 5. Ensure that the polarization filter is correctly positioned so that the photocell is fully illuminated.

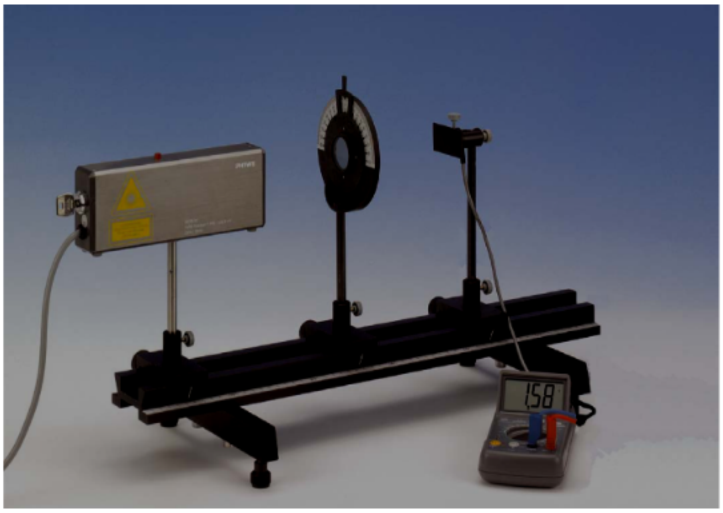

Figure 5: Experimental Setup

If the experiment is conducted in a non-dark environment, background interference current should be measured with the laser off and accounted for during the experiment. Allow the laser to warm up for approximately 30 minutes.

The polarization filter should be rotated at intervals between the positive and negative filter positions, and the corresponding photocell current should be measured using a highly sensitive DC scale on the digital multimeter.

Linearly polarized light passes through a polarization filter. The intensity of the transmitted light is measured as a function of the filter's angular position.

1B - NEWTON's RINGS

OBJECTIVES

- To analyze the interference phenomenon

EQUIPMENTS

- **Newton Ring System**
- **Na Lamp as a Light Source**
- **Viewfinder**
- **A Small Piece of Glass**

GENERAL INFORMATION

The events that confirm the hypothesis that light is an electromagnetic wave are interference and diffraction. Although the interference and diffraction of light appear to be separate events, both are actually similar. Both are special cases of the superposition of waves. Superposition is the ability of two or more waves to exist in the same region of space without affecting each other.

Various setups are viable to observe the phenomenon of interference. In the setup known as Newton's Rings, a plane-convex lens with a large radius of curvature is placed on a flat, parallel glass surface. When the setup is illuminated, the interference pattern appears as concentric rings. The center of these rings is the point where the lens touches the flat parallel surface below it and is dark.

Let the lenses' radius of curvature R, the radius of one of the Newton Rings r and the thickness of the air between the parallel planar glass and the lens be d(r).

$$d = R - R\left[1 - \left(\frac{r}{R}\right)^2\right]^{\frac{1}{2}} \qquad (1)$$

Because $\left(\frac{r}{R}\right) \ll 1$, if the expression is expanded as a series:

$$d = R - R\left[1 - \left(\frac{r}{R}\right)^2 \ \ldots\right] \simeq R - R + \frac{R}{2}\frac{r^2}{R^2} = \frac{r}{2R}^2 \qquad (2)$$

is acquired. Therefore, the optical path difference between the two light rays is:

$$2nd = \left(m + \frac{1}{2}\right)\lambda \quad \text{(max)} \qquad m = 0,1,2,3\ldots$$

$$2nd = m\lambda \qquad \text{(min)} \qquad m = 0,1,2,3\ldots$$

If the refractive index of air is taken as $n = 1$;

$$2d = \left(m + \frac{1}{2}\right)\lambda \qquad \text{(max)} \qquad m = 0,1,2,3\ldots$$

$$2d = m\lambda \qquad \text{(min)} \qquad m = 0,1,2,3\ldots$$

is acquired. If $d = \frac{m\lambda}{2}$ (2) condition is applied

$$\frac{m\lambda}{2} = \frac{r^2}{2R} \Rightarrow r^2 = m\lambda R \qquad (3)$$

is found. The radius of some rings are measured, and a graph is plotted such that r^2 is the y-axis and order is the x-axis. The slope of this graph gives us $R\lambda$, from that;

a. Since the wavelength of used light is known, the lenses' radius of curvature is calculated.
b. If the radius of the lens is known, λ is calculated.

EXPERIMENT PROCEDURE

1. By looking through the viewfinder, the center of the lens is aligned with the crosshair of the viewfinder's eyepiece, i.e., brought to the center of the reticle.
2. The glass plate and sodium lamp are positioned so that the field of view is well illuminated when looking through the viewfinder. The experimental setup is readjusted to make the interference (Newton) rings, formed in the thin air layer between the plane-parallel glass and the plane-convex lens, clearly visible.
3. By looking through the viewfinder, the edge of any m^{th} dark ring is aligned with the center of the reticle. Remembering that the order of the dark ring at the center is $m = 0$, m is determined by counting the dark rings. The radius of the corresponding Newton ring is read from the viewfinder's scale as r_m.
4. The reticle is then aligned with the edge of another dark ring m', and is recorded. The corresponding r_m is read.
5. The same measurements are repeated for different m and m' values. Each measurement is repeated three times, and the average value is taken. By assuming the wavelength of the light used is $\lambda = 5890$ A° and using expression (3), the radius of curvature, R, of the lens is calculated. Then;

$$R_{avg} = \frac{R_1+R_2+R_3+R_4}{4} = \qquad \text{meters}$$

is calculated.

M	r_m	R
1		
2		
3		
4		

From here, the radius of curvature of the lens is found by finding the slope of the previously drawn graph.

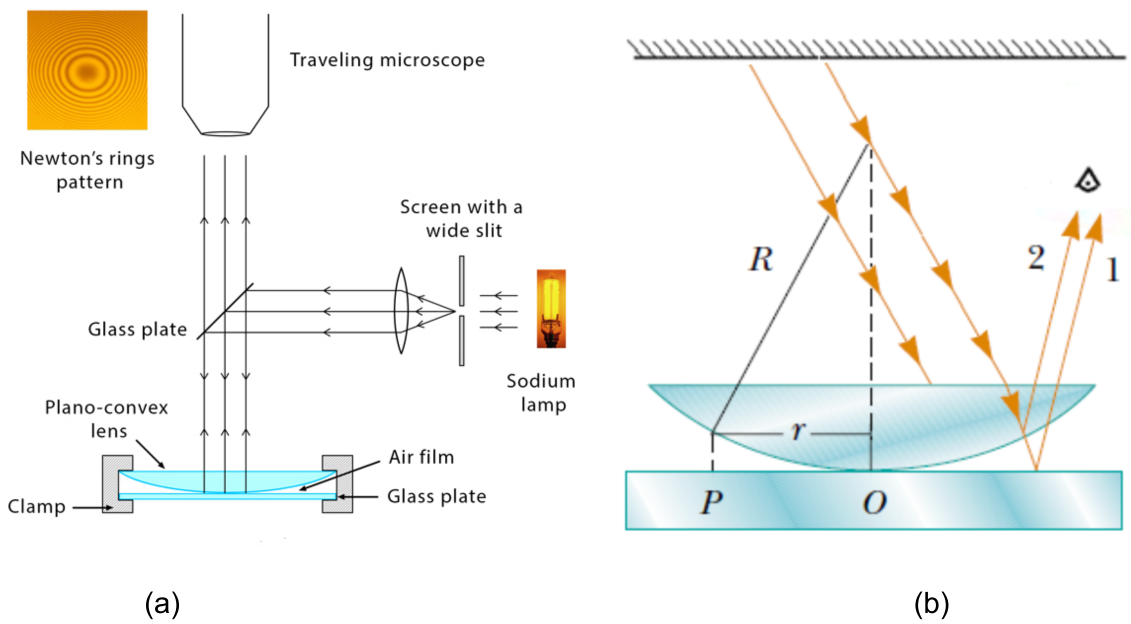

Figure 1: (a) Newton's Rings experiment setup (b) Close-up of the lens and planar glass

2 - FRESNEL EQUATIONS - REFLECTION THEORY

Objectives

- Planar-polarized light is reflected off a glass surface. The rotation of the plane of polarization and the intensity of the reflected light are determined and compared with the Fresnel formula for reflection.

Equipments

- He-Ne Laser(1,0 mW, 230 VAC)
- Polarization Filter
- Prism(60°, $h = 36mm$)
- Prism Holder
- Si-Photodetector Amplifier and Control Unit
- Digital Multimeter
- Connection Cables
- Protractor
- Scaled Jointed Radial Holder

General Information

What are the electromagnetic theory of light, reflection coefficient, reflection factor, Brewster's law, law of refraction, polarization, and level of polarization?

According to electromagnetic theory, light consists of two components: the electric field vector E and the magnetic field vector B. These components oscillate in directions perpendicular to both the direction of propagation of the electromagnetic wave and to each other, and they oscillate in the same phase. The correlation between them can be expressed as:

$$|B| = n|E| \qquad (1)$$

Where n is the refractive index. The Poynting vector that carries the energy in the direction of propagation is determined by the following:

$$S \sim E \times B \quad \text{and} \quad |S| \sim |E|^2 \qquad (2)$$

If light strikes the boundary surface of an isotropic medium with a refractive index of n at an angle of α, part of the incoming light is reflected at the same angle of α, while the remaining part propagates through the isotropic medium at an angle of refraction β.

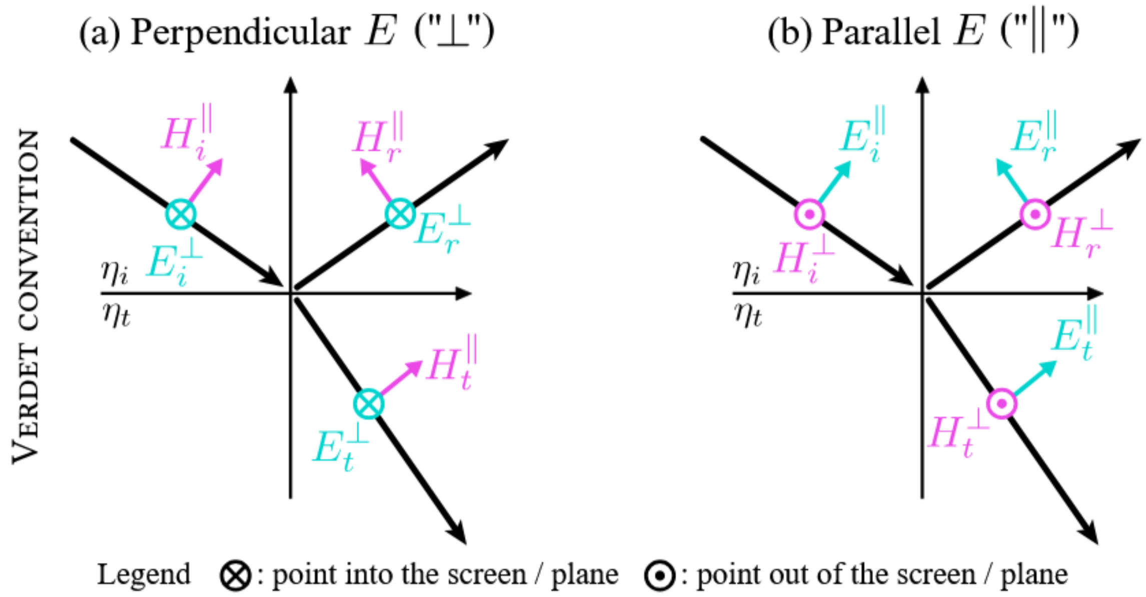

Figure 1: (a) Perpendicular (b) Parallel Polarization

In Figure 1(a), according to expression (2), the electric field vector $E_i^{\perp}$ of the incoming light is polarized perpendicular to the plane of incidence, while the magnetic field vector $H_i^{||}$ is polarized parallel to it. Based on the continuity of the tangential components and considering the direction of the light, the following expressions are obtained:

$$E_i^{\perp} + E_r^{\perp} = E_t^{\perp}; \qquad \left(H_i^{||} - H_r^{||}\right)cos\alpha = H_t^{||}cos\beta \tag{3}$$

Where α is the angle between the incident ray and the normal and β is the angle between the transmitted ray and the normal.

Using expressions (1) and (3);

$$(E_i^{\perp} - E_r^{\perp})cos\alpha = n(E_i^{\perp} + E_r^{\perp})cos\beta \tag{4}$$

is obtained. Taking reflection law into consideration, the magnitude of electric fields of reflected and incident rays' ratio, which is also known as reflective coefficient, is as follows:

$$\zeta^{\perp} = \frac{E_r^{\perp}}{E_i^{\perp}} = \frac{cos\alpha - n\,cos\beta}{cos\alpha + n\,cos\beta} = -\frac{sin(\alpha-\beta)}{sin(\alpha+\beta)} \tag{5}$$

Figure 1(b) shows an incoming light wave with an electric field vector $E_i^{||}$ oscillating parallel to the plane of incidence. Similar to expression (3):

$$H_i^{\perp} + H_r^{\perp} = H_t^{\perp}; \qquad \left(E_i^{||} - E_r^{||}\right)cos\alpha = E_t^{||}cos\beta \tag{6}$$

Using expressions (1) and (6):

$$\left(E_i^{||} - E_r^{||}\right)cos\alpha = \frac{1}{n}\left(E_i^{||} - E_r^{||}\right)cos\beta \qquad (7)$$

is obtained. Similar to (5) the magnitude of electric fields of reflected and incident rays ratio is as follows:

$$\zeta^{||} = \frac{E_r^{||}}{E_i^{||}} = \frac{n\,cos\alpha - cos\beta}{n\,cos\alpha + cos\beta} = -\frac{tan(\alpha-\beta)}{tan(\alpha+\beta)} \qquad (8)$$

By using Snell's law of refraction, if the angle of refraction β is eliminated, Fresnel's formulas (5) and (8) can be expressed in a different form.

$$\zeta^{\perp} = \frac{E_r^{\perp}}{E_i^{\perp}} = -\frac{\left(\sqrt{n^2 - sin^2\alpha} - cos\alpha\right)^2}{n^2-1} \qquad (9a)$$

$$\zeta^{||} = \frac{E_r^{||}}{E_i^{||}} = \frac{n^2cos\alpha - \sqrt{n^2-sin^2\alpha}}{n^2cos\alpha + \sqrt{n^2-sin^2\alpha}} \qquad (9b)$$

$$tan\alpha_p = n \qquad (\alpha_p = \text{Brewster's angle})$$

For all incident rays between angles 0 and $\pi/2$, $\zeta^{\perp} \geq \zeta^{||}$ is valid.

For special cases:

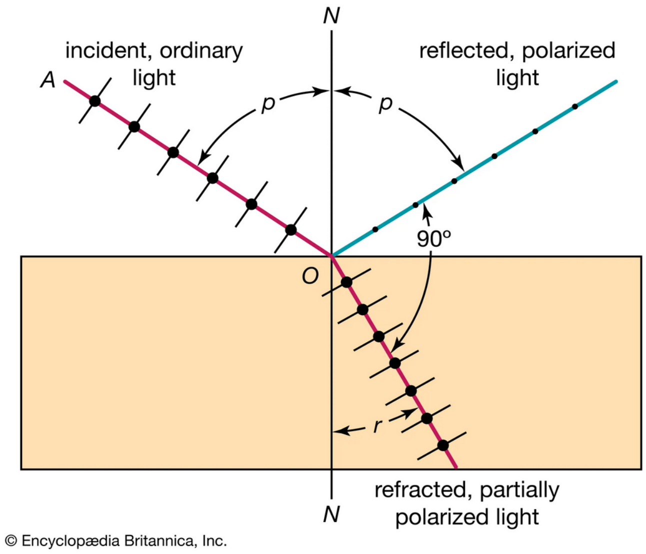

Figure 2: Brewster's Law

1. For a perpendicular incident angle $(\alpha = \beta = 0)$;

$$\zeta^{\perp} = \zeta^{||} = \left|\frac{n-1}{n+1}\right| \qquad (10)$$

2. For incident angle $\alpha = \frac{\pi}{2}$;

$$\zeta^{\perp} = \zeta^{||} = 1 \qquad (11)$$

3. If the reflected and transmitted angles are perpendicular to each other $\alpha + \beta = \frac{\pi}{2}$ (see Figure 2), due to expression (8);

$$\zeta^{||} = 0 \qquad (12)$$

which means the reflected light is completely polarized.In this case, only the electric vector oscillates in the normal plane of incidence. Using Snell's Law:

$$sin\alpha = n\ sin\beta = n\ sin\left(\frac{\pi}{2} - \alpha\right) = n\ cos\alpha \qquad (13)$$

is acquired. In this special case, for the incident angle:

$$tan\ \alpha_p = n$$

is acquired.

Table 1: Current values $i_r^{\perp}$ and $i_r^{||}$ as a function of angle α

α Degr.	i'_µA (235 µA)	ζ" = E'_t / E'_0	i'_µA (230 µA)	ζ" = E'_⊥ / E'_0	√(i' / i'_0)
10.0	11.5	0.221	13.5	0.243	0.243
15.0	11.0	0.216	15.0	0.255	0.255
20.0	10.5	0.211	16.5	0.268	0.268
25.0	10.0	0.206	18.5	0.282	0.282
30.0	9.0	0.2	21.0	0.298	0.298
35.0	8.0	0.187	24.5	0.316	0.316
40.0	7.1	0.187	29.0	0.338	0.338
45.0	6.0	0.16	35.0	0.365	0.365
50.0	5.6	0.149	41.0	0.39	0.39
52.5	5.4	0.144	41.0	0.422	0.422
55.0	5.2	0.138	49.0	0.462	0.462
60.0	4.7	0.123	72.0	0.55	0.55
62.5	4.5	0.117	100.0	0.661	0.661
65.0	4.0	0.105	135.0	0.765	0.765
70.0	3.0	0.08	165.0	0.846	0.846
75.0	2.0	0.058	200.0	0.935	0.935
80.0	1.0	0.032	230.0	1.0	1.0
85.0	0.8	0.027	260.0	1.07	1.07

Tab. 1 contains the i_r current values measured with a photocell for the intensity of light reflected at an angle α. According to expression (2), the current is directly proportional to the intensity of light, which is proportional to the square of the magnitude of the electric (or magnetic) field.

Figure 3 shows the experimentally determined curves for $\zeta_r^{||}$ and $\zeta_r^{\perp}$ as functions of the angle of incidence. The curve for $\zeta^{||}$ shows a distinct minimum at $\alpha_p = 58.5°$. Using this value and the point where the ζ curves intersect via extrapolation, the refractive index $n = 1.63$ is obtained from expressions (13) and (10).

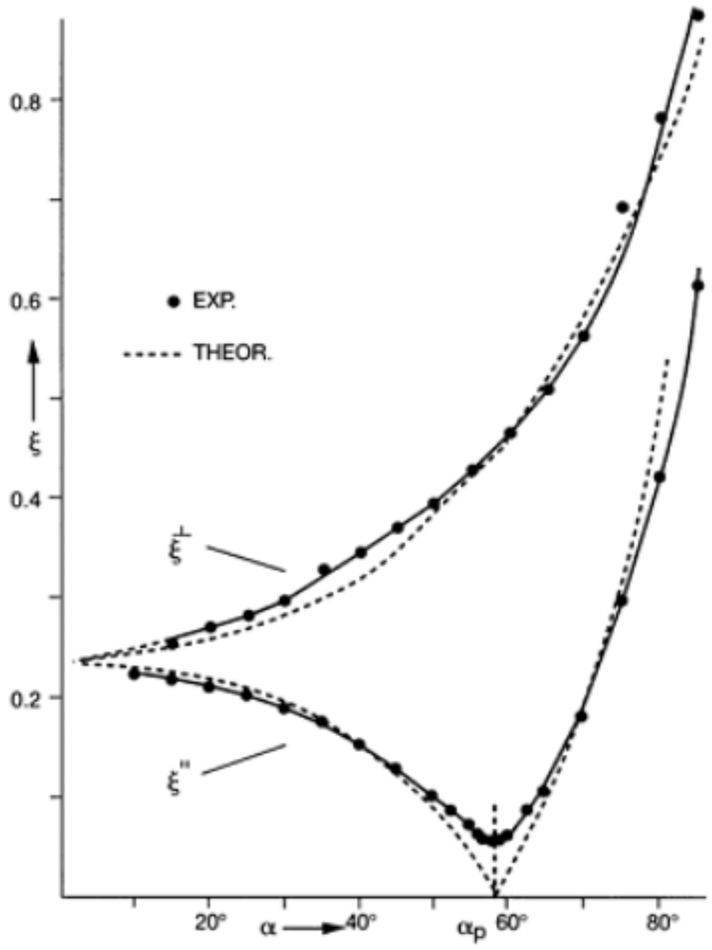

Figure 3: $\zeta_r^{||}$ and $\zeta_r^{\perp}$ as a function of incident angle and experimental values

If reflection components of (9a) and (9b) are squared and summed up reflective factor is:

$$R = \frac{(E_r^{\perp})^2 + (E_r^{||})^2}{(E_0^{\perp})^2 + (E_0^{||})^2} = \left(\frac{n-1}{n+1}\right)^2 \qquad (14)$$

In this experiment, the reflection factor(R) is calculated to be $n = 1.63$ for the prism.

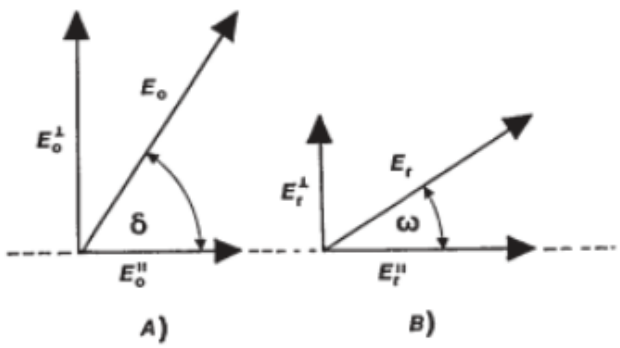

Figure 4: Change in polarization direction by reflection

Another method for verifying Fresnel's formulas is described below:

Plane-polarized light is directed onto glass at a fixed δ angle relative to the plane of incidence. The rotation of the plane of polarization for the reflected light is determined as a function of the angle of incidence. In Figure 4, the paper plane represents the reflective surface.

If the electric field vector oscillates at an angle ω after reflection, a rotation of the plane of polarization occurs as it passes through the angle $\psi = \delta - \omega$. For the parallel and normal components to the plane of incidence:

$$E_r^{||} = E_r cos\ \omega \quad ; \qquad E_r^{\perp} = E_r sin\ \omega \qquad (15)$$

or

$$tan\ \omega = \frac{E_r^{\perp}}{E_r^{||}} = \frac{E_r^{\perp} \times E_0^{||} \times E_0^{\perp}}{E_0^{\perp} \times E_r^{||} \times E_0^{||}} \qquad (16)$$

is acquired. Using expressions (5) and (8), expression (16) is:

$$tan\ \omega = -\frac{sin(\alpha-\beta)}{sin(\alpha+\beta)} \cdot \frac{tan(\alpha-\beta)}{tan(\alpha+\beta)} \cdot tan\ \delta \qquad (17)$$

In the special case of $\delta = \frac{\pi}{4}$:

$$tan\ \psi = tan\left(\frac{\pi}{4} - \omega\right) = \frac{1-tan\ \omega}{1+tan\ \omega} \qquad (18)$$

is acquired. If $tan\ \omega$ from (17) is put in its place in (18) and some adjustments are made the expression becomes:

$$tan\psi = \frac{cos(\alpha+\beta)+cos(\alpha-\beta)}{cos(\alpha+\beta)-cos(\alpha-\beta)} = -\frac{cos\ \alpha\sqrt{1-sin^2\beta}}{sin\alpha \cdot sin\beta} \qquad (19)$$

By using Snell's law of refraction, if the angle of refraction β is eliminated, expression (19) can be expressed as:

$$\psi = arctan\left(\frac{cos\alpha\sqrt{n^2 - sin^2\alpha}}{sin^2\alpha}\right) \qquad (20)$$

If the polarization plane has rotated $\psi = \frac{\pi}{4}$, Brewster's Law is acquired from expression (20):

$$tan\alpha_p = n$$

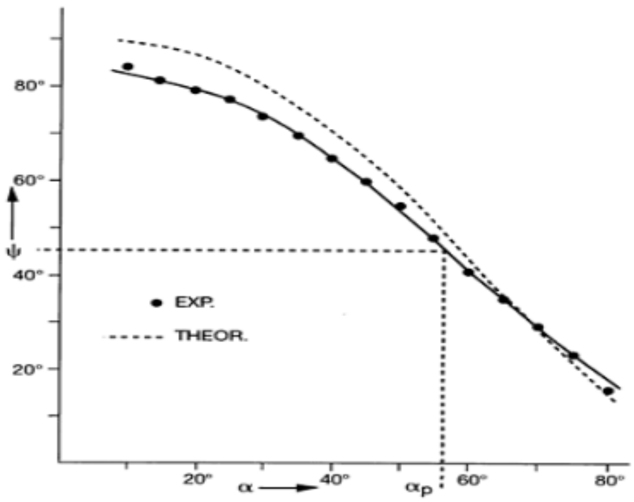

Figure 5: The calculated and measured variations for the rotation of the oscillation direction as a function of the angle of incidence at 45°

Experiment Procedure

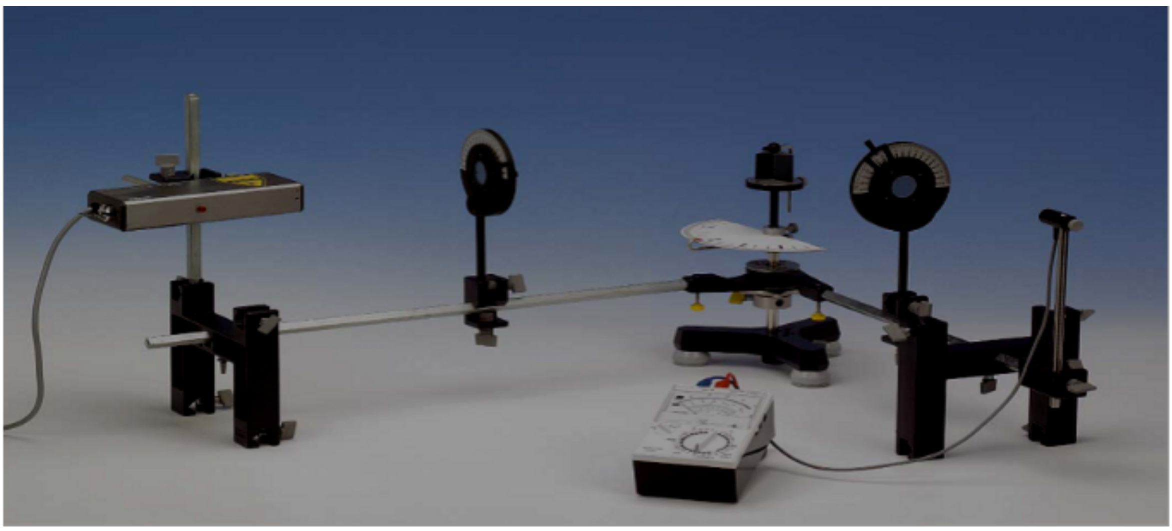

Figure 6: Experiment Setup

1. The experimental setup is shown in Figure 6.

2. The laser should be allowed to heat for approximately 15 minutes before starting the procedures.

3. The laser beam should be positioned over the center of the prism table to find the zero position.

4. The intensity $i_0^{||}$ of the light polarized parallel to the plane of incidence is measured.

5. The protractor scale is set to zero to determine the $\alpha = 0$ angle of incidence.

6. The prism is placed on the table so that it reflects the incoming light back along its path (Figure 7).

7. The angle of incidence α should be changed in 5° increments starting from $\alpha \leq 10°$, and in 1° increments near the Brewster angle region.

8. The photocell is rotated to obtain the maximum current for determining the intensity $i_r^{||}$.

9. First, the intensity $i_0^{\perp}$ is re-measured. Then the angle of incidence is changed in 5° increments, and the intensity corresponding to the reflected light is measured.

10. The laser is readjusted to its normal position to determine the degree of rotation of the plane of polarization due to reflection.

11. The photocell is placed in the path of the beam without the prism.
12. To precisely determine the oscillation plane, a polarization filter is attached in front of the laser, and the filter is rotated until the recorded intensity reaches a minimum.

13. Once the filter is rotated by 45°, the prism is placed in position using a known method.

14. The degree of rotation of the plane of polarization for the reflected beam is found using a second polarization filter placed between the prism and the detector.

15. The angle of incidence is changed in 5° increments.

16. The rotation angle of the plane of polarization is the average of multiple measurements.

17. The reflection coefficients for polarized light perpendicular and parallel to the plane of incidence will be determined as a function of the angle of incidence and represented graphically.

18. The refractive index of the crystal prism will be determined.

19. The reflection coefficients will be calculated using Fresnel's formulas and compared with the measured curves.

20. The reflection factor for the glass prism will be calculated.

21. The rotation of the plane of polarization of plane-polarized light upon reflection will be determined as a function of the angle of incidence and will be presented graphically.

22. Later, the values calculated using Fresnel’s equations should be compared.

3 - FRESNEL DOUBLE MIRROR AND DOUBLE PRISM

OBJECTIVES

- To analyze the interference phenomenon by using Fresnel's Double Mirror and Double Prism

EQUIPMENTS

- **White Light Source**
- **Green and Red Filters**
- **Fresnel's Double Mirror and Double Prism**
- **Viewfinder**

GENERAL INFORMATION

Fresnel's Double Mirror is made of two mirrors that have almost 180° between them.

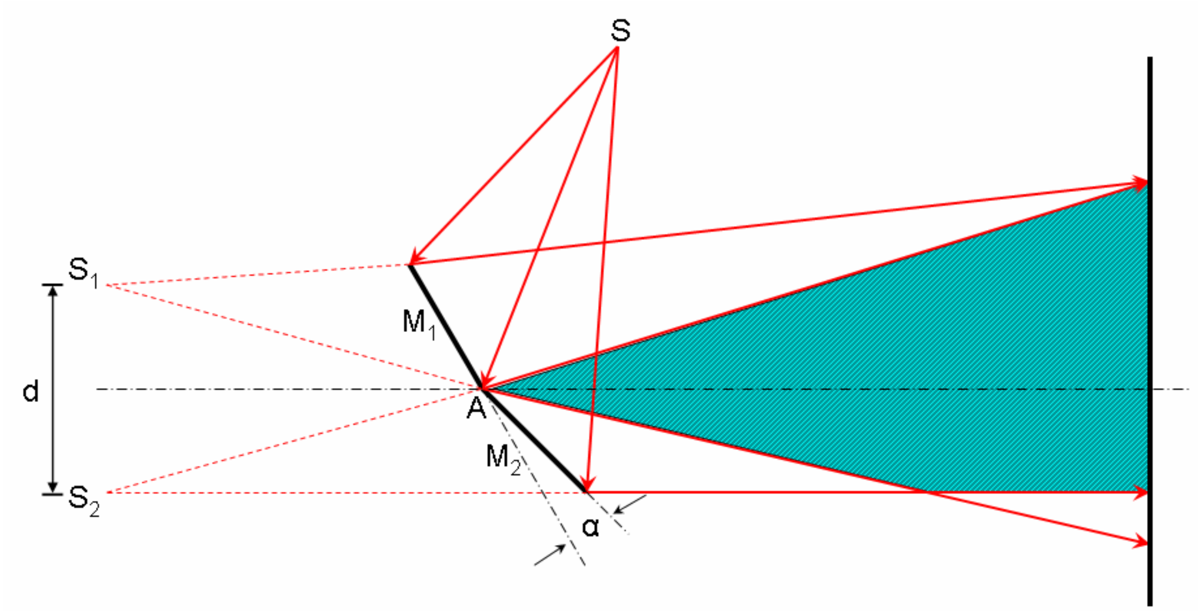

Figure 1: Fresnel Double Mirror

The wavefront of light from a point source S is reflected by mirrors and splits into two beams. Thus, the images of the light source S on mirrors 1 and 2 (S_1 and S_2) appear on the screen. The S_1 and S_2 image sources are synchronized. If they are brought close enough to each other, it will be sufficient for the light waves from these sources to be coherent in order to observe interference.

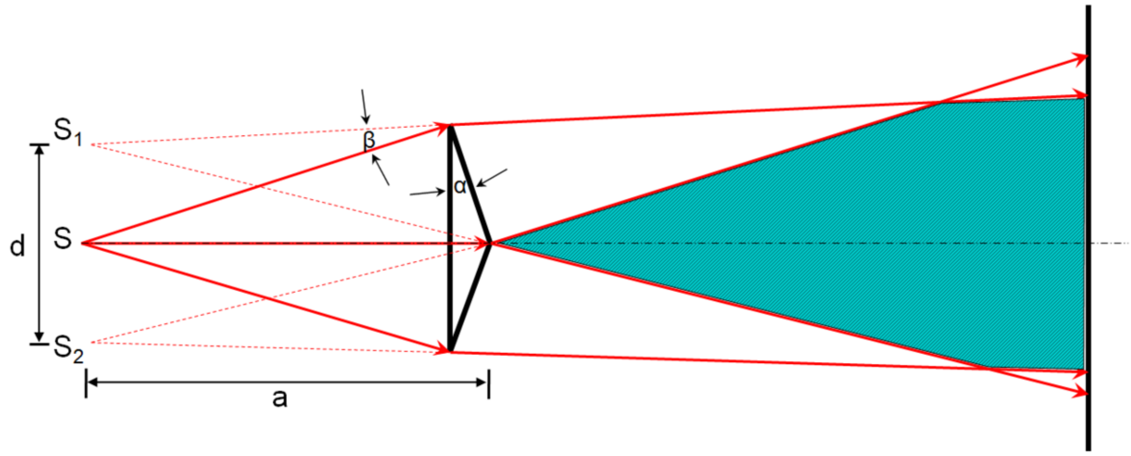

Figure 2: Fresnel Double Prism

The Fresnel Biprism is a system made up of two prisms that are very small at their apex and share a common base, each shaped like a right triangle (Figure 2). After the wavefront of light from source S is split into two parts by the biprism, the two beams overlap in a specific region on the screen, creating interference.

EXPERIMENT PROCEDURE

After the necessary conditions are met, the rays of light from the point source S either reflect off mirrors A_1 and A_2 or pass through the biprism system, creating a pattern of illumination on the viewport.

1. First, the Fresnel biprism experimental setup is arranged as shown in Figure 3 to observe the interference pattern. The rays of light that reach the viewport with a path difference equal to an integer multiple of the wavelength create regions of maximum intensity, while those with a path difference equal to a half-integer multiple of the wavelength create regions of minimum intensity. In the interference pattern, the distance between successive fringes is denoted as Δx.

$$\Delta x = \lambda \frac{L}{d}$$

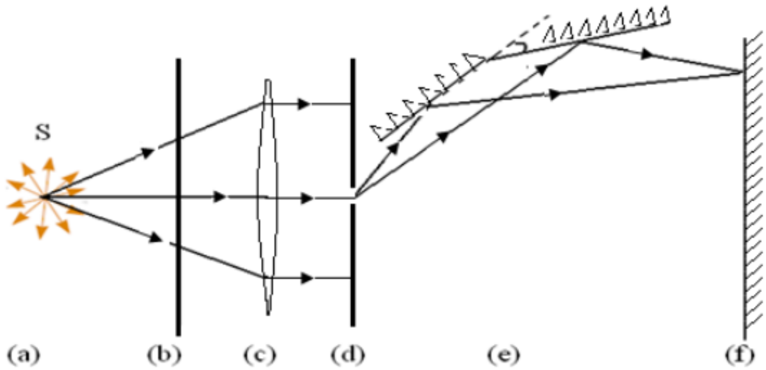

Figure 3: Experiment setup for double mirror (a)Light Source, (b)Filter, (c)Lens, (d)Coherency Slit, (e)Fresnel Double Mirror, (f)Screen

Here, λ is the wavelength of the light used, L is the distance between the viewport and the mirror or prism system, and d is the distance between the synchronized sources obtained using the biprism or double mirror. Given the wavelength of the light, the distance Δx between fringes is read from the viewport, and the length L is measured with a ruler. By substituting these values into the above formula, the distance between synchronized sources d is determined. The obtained values are then entered into Table 1.

Table 1: Results from Fresnel Double Mirror using red and green filters

$\lambda_{green} = 5592\ A°$	$\lambda_{red} = 6040\ A°$
$L =$.............................	$L =$.............................
$\Delta x_{min} =$....................................	$\Delta x_{min} =$....................................
$\Delta x_{max} =$....................................	$\Delta x_{max} =$....................................
$d =$.....................................	$d =$.....................................

2. First, the experiment is conducted using a red filter. Then, the experiment is repeated using a green filter. The differences in the resulting illumination patterns are discussed.

3. In the second stage of the experiment, the Fresnel double-prism experimental setup, as shown in Figure 4, is assembled, and the interference illumination pattern is observed.

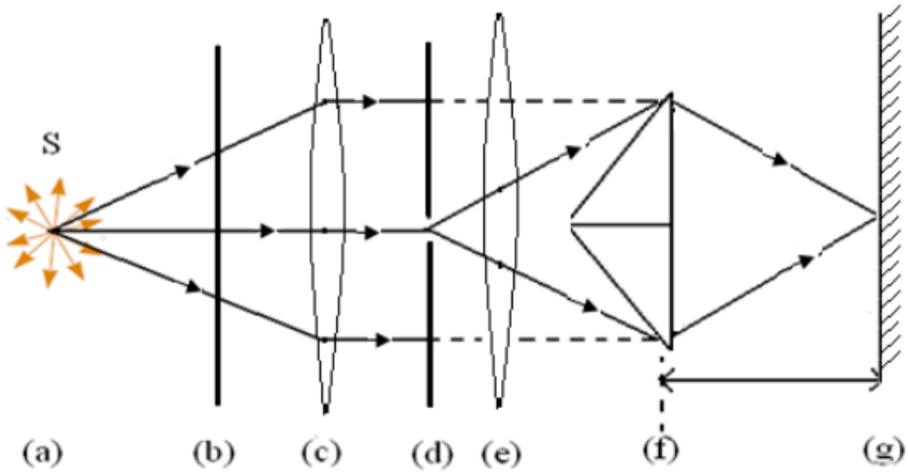

Figure 4: Experiment setup for double prism(a)Light Source, (b)Filter, (c)Lens, (d)Coherency Slit, (e)Fresnel Double Prism, (f)Screen

4. Similar to double mirror, the experiment is done and values are collected and put into Table 2.

Table 2: Results from Fresnel Double Prism using red and green filters

λ_{green}	λ_{red}
$L =$..............................	$L =$..............................
$\Delta x_{min} =$....................................	$\Delta x_{min} =$....................................
$\Delta x_{max} =$....................................	$\Delta x_{max} =$....................................
$d =$......................................	$d =$......................................

4A - SINGLE SLIT DIFFRACTION

OBJECTIVE

- Investigation of Single-Slit Diffraction

EQUIPMENTS

- **White light source**
- **Filter**
- **Coherence slit**
- **Diffraction slit**
- **Viewer**

GENERAL INFORMATION

The intensity distribution is in the illumination pattern obtained from a single slit with an aperture width a when it is illuminated with light of wavelength λ.

$$I_s = I_0 \left[\frac{\sin\alpha}{\alpha}\right]^2 \qquad (1)$$

I_0 is the intensity of the central maximum. Additionally, θ is the observation angle.

$$\alpha = \pi a \,\frac{\sin\theta}{\lambda} \qquad (2)$$

At $\theta = 0$, the illumination pattern has a maximum. When the path difference is

$$m\lambda = a \sin\theta \,; \qquad m = 1,2,3\ldots \qquad (3)$$

intensity is at minimum.

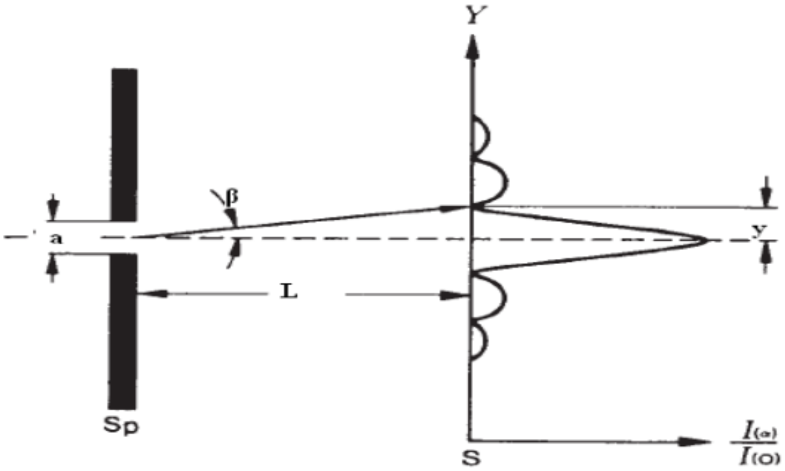

Figure 1: Definition of angles and distances for single-slit diffraction measurements**.**

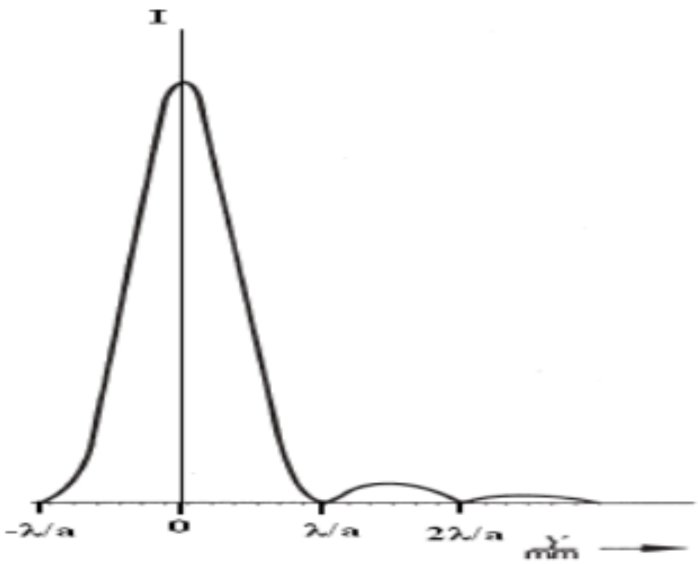

Figure 2: Intensity distribution of single-slit diffraction

$$sin\theta \approx tan\theta = a\frac{y}{L} \qquad (4)$$

Here, y is the distance from the central maximum to the first-order minimum. When expressions (3) and (4) are used, it is observed that the distance between successive minima is the same. This distance is given by:

$$y = \frac{\lambda L}{a} \qquad (5)$$

EXPERIMENT PROCEDURE

1. A single-slit system is illuminated by a white light source, considered as a point source (S). Coherence is achieved using a filter and a coherence slit (Figure 3), and the diffraction pattern is observed on the screen.

2. By looking through the viewer, the reticle is aligned with a specific minimum, and a reading is taken from the scale:

$$y_1^{red} = \ldots\ldots\ldots.$$

Then, by turning the scale, the reticle is aligned with the next minimum and another reading is taken:

$$y_2^{red} = \ldots\ldots..$$

The difference between them gives the distance between successive minima:

$$\Delta y^{red} = \ldots\ldots\ldots\ldots$$

The distance between the slit and the screen is determined and recorded from the ruler on the optical rail:

$$L = \ldots\ldots\ldots..$$

If the wavelength of the red filter used is known, the slit width can be calculated using equation (5):

$$a = \ldots\ldots\ldots\ldots\ldots\, mm$$

3. The experiment is repeated using a green filter.

$$y_1^{green} = \ldots\ldots\ldots\ldots.. ; \qquad y_2^{green} = \ldots\ldots\ldots\ldots.. ;$$

$$\Delta y^{green} = \ldots\ldots\ldots\ldots.. ; \qquad L = \ldots\ldots\ldots\ldots ;$$

$$a = \ldots\ldots\ldots\ldots\ldots\, mm$$

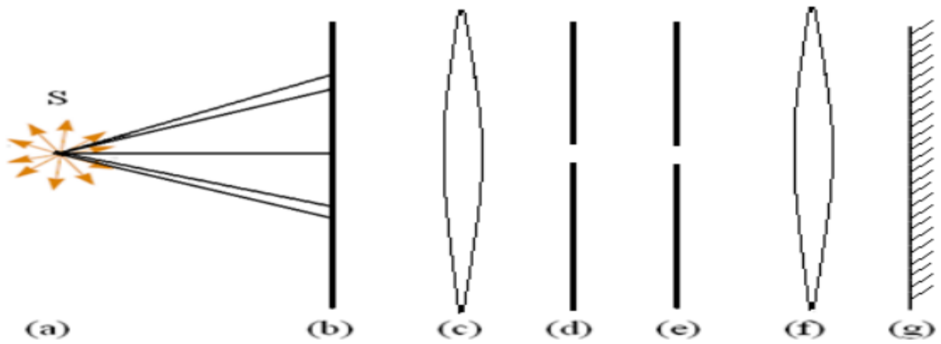

Figure 3: Experimental setup for single-slit Fraunhofer diffraction. (a) Light source, (b) Filter, (c) Thin lens, (d) Coherence slit, (e) Diffraction slit, (f) Thin lens, (g) Screen

4. This time, place other single-slit options with known slit widths onto the plate one by one and observe the illumination pattern. Specifically, observe how the illumination pattern changes as the single-slit width is altered. Additionally, examine the illumination pattern by changing the distance of the slit from the light source and the screen.

5. Evaluate the results obtained from both stages of the experiment together.

Results for Slit A:

Slit Width, a	
Distance Between Slit and Screen	
Average Distance Between Successive Minima	
$\lambda = a\,\frac{y}{L}$	

Results for Slit B:

Slit Width, a	
Distance Between Slit and Screen	
Average Distance Between Successive Minima	
$\lambda = a\,\frac{y}{L}$	

Results for Slit C:

Slit Width, a	
Distance Between Slit and Screen	
Average Distance Between Successive Minima	
$\lambda = a\,\frac{y}{L}$	

Question 1: How and why does the distance between successive fringes change when red and green filters are used?

Question 2: How does the illumination pattern change as the slit width increases? Why?

Question 3: How and why does the illumination pattern change when the distance between the slit and the light source or screen is altered?

4B - DETERMINATION OF ILLUMINATION INTENSITY WITH A SINGLE SLIT

OBJECTIVE

- To determine the intensity distribution of the illumination pattern obtained using a single-slit system.

EQUIPMENTS

- Laser
- Lens
- Slit systems on a plate
- Photodiode
- Photocell measurement amplifier.

GENERAL INFORMATION

In this experiment, the goal is to analyze and determine the intensity distribution of the diffraction pattern produced by a single-slit when illuminated by a coherent light source, such as a laser. The setup includes a laser, lenses to focus the beam, and a single-slit apparatus mounted on a plate. The diffraction pattern is observed on a screen or detected using a photodiode and photocell measurement amplifier.

EXPERIMENT PROCEDURE

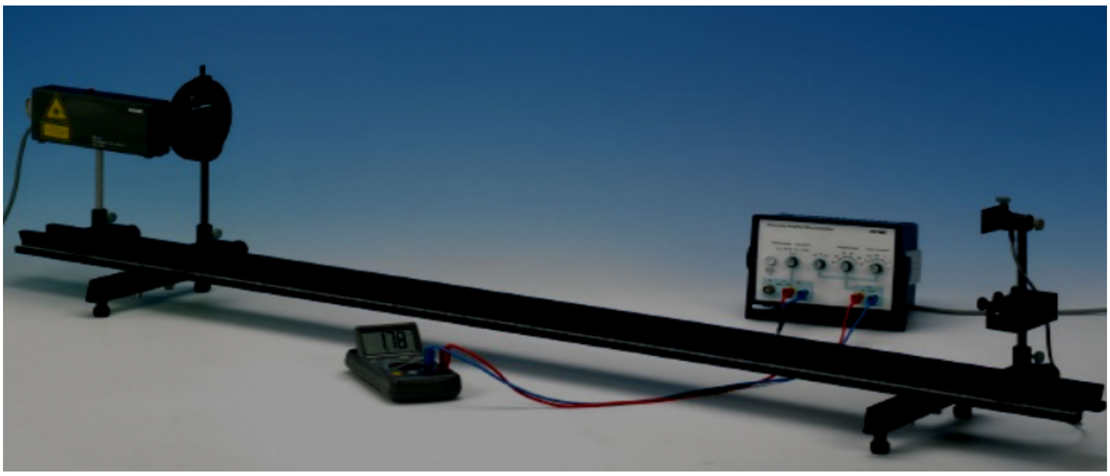

Figure 1: Experiment Setup

1. The experimental setup is arranged as shown in Figure 1. The components are positioned and fixed on the optical rail to achieve the best illumination pattern: Laser = 2.5 cm; f = +20 mm lens = 14.5 cm; f = +100 mm lens = 27.5 cm; plate with slit systems = 33 cm; photodiode = 147.5 cm. The wavelength of the laser used is λ =632.8 nm.

2. An expanded laser beam is created with the help of the lenses. This laser beam is directed through a single slit onto the photodiode. The plate is
positioned with a holder. Ensure that the slit systems are perpendicular to the holder and are adequately illuminated.

3. To prevent unwanted intensity fluctuations, the laser and measurement amplifier should be turned on approximately 15 minutes before starting the measurements. The photocell measurement amplifier (with an amplifier factor of (10^3–10^5) ×10^4 ohms) is connected to the input. When changing the amplifier factor, the zero point of the measurement amplifier should be checked with the photocell covered and adjusted if necessary.

4. For the single-slit systems, the light intensity values are measured at steps of 0.1 mm to 0.2 mm using the photocell.

5.The single-slit system is positioned as described above. The wavelength of the laser used is λ=632.8 nm. In the resulting diffraction pattern, the width of the central diffraction maximum, i.e., the distance between two minima, is read as $2\Delta x$ using a micrometer.

6. The distance between the photocell and the single slit is measured with a ruler, and the slit width a is determined from the formula. These measurements are made for orders, m=1,2, and 3. The measurements and calculations are recorded in Table 1.

$$sin\varphi_{dif} = m_{dif}\frac{\lambda}{a} \qquad m = 1,2,3 \ldots$$

Table 1: Determination of the Slit Width for the Single-Slit System

m	Δx	$sin\varphi_{dif} = \frac{\Delta x}{L}$	$a(mm)$
1			
2			
3			
$\lambda = 632.8nm = \ldots\ldots\ldots\ldots\ldots\ldots mm$ $L = \ldots\ldots\ldots\ldots\ldots cm$ $a_{avg}(mm)$			

5A - POLARIZATION OF LIGHT IN QUARTER-WAVE PLATES

OBJECTIVE

- Measure the intensity of plane-polarized light as a function of the analyzer's position.
- Measure the light intensity behind the analyzer as a function of the angle between the optical axis of the quarter-wave plate and the analyzer.
- Repeat the experiment using two quarter-wave plates

EQUIPMENTS

- Lens (f=+100f = +100f=+100 mm)
- Power Supply
- Interference Filter (Yellow, 578 nm)
- Polarizing Filter
- Digital Multimeter
- Connection Wires (Red and Blue, 750 mm)

GENERAL INFORMATION

The speed of light traveling along the optical axis of a birefringence crystal is the same, regardless of the orientation of the plane of polarization, and is denoted by c_0. When light propagates at right angles to the optical axis, the polarized light (called the ordinary ray when the electric vector of the incident light is perpendicular to the optical axis, as shown in Figure 1) has the same speed c_0. If the electric field component of the light is parallel to the optical axis, the speed of light (called the extraordinary ray) is different.

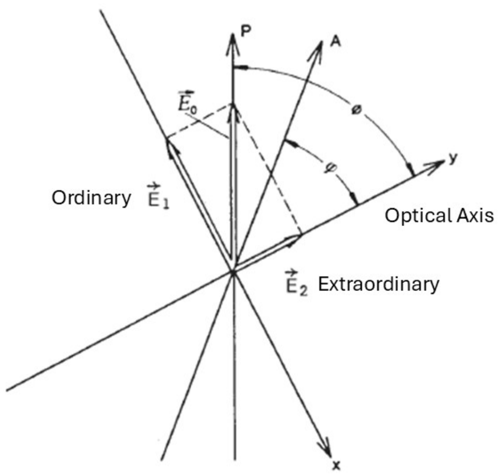

Figure 1: Separation of polarized light into its components in a birefringence crystal (A: Analyzer, P: Polarizer).

E_0 is the amplitude of the electric field vector passing through a polarizer, and θ is the angle between the optical axis fringence crystal and the direction of polarization P. From Figure 1, the following expressions for the amplitudes of the ordinary and extraordinary rays can be derived:

$$E_1(t) = E_0(t) \cdot sin\ \phi$$
$$E_2(t) = E_0(t) \cdot cos\ \phi \qquad (1)$$

The oscillation state of the two rays at the time t on the crystal surface

$$E_1(t) = E_0(t) \cdot sin\ \phi \cdot sin\ \omega t$$
$$E_2(t) = E_0(t) \cdot cos\ \phi \cdot cos\ \omega t \qquad (2)$$

Thickness in Birefringence Crystals (Quarter-Wave Plates):

$$d_{\lambda 4} = \frac{\lambda}{4} \frac{1}{n_0 - n_{a0}} \qquad (3)$$

Here, n_0 is the refractive index for the ordinary ray, and n_{a0} is the refractive index for the extraordinary ray. When the ordinary and extraordinary rays are considered as a composite beam emerging from the crystal, they create a path difference of $\lambda/4$ (resulting in a phase difference). From expression (2):

$$E_x = E_1 = E_0 sin\ \phi \cdot sin\ \omega t$$
$$E_y = E_2 = E_0 cos\ \phi \cdot cos\ \omega t \qquad (4)$$

The expressions are obtained. Expression (4) is a parametric representation of a E vector rotating in the direction of propagation on a fixed axis (perpendicular to the x and y axes).

ϕ=0° and ϕ=90° The intensity of plane-polarized light for these angles

$$I = I_0 \sim E_0^2 \qquad (5)$$

for ϕ=45° and $sin\ \phi = cos\ \phi = \frac{1}{\sqrt{2}}$ The magnitude of the rotating electric field vector, E;

$$E = \sqrt{E_x^2 + E_y^2} = \frac{E_0}{\sqrt{2}} \qquad (6)$$

The light becomes circularly polarized, and its intensity is;

$$I = \frac{I_0}{2} \sim \frac{E_0^2}{2} \qquad (7)$$

It passes through without any loss of intensity at all analyzer positions. At angles other than 0°, 90°, and 45°, the transmitted light becomes elliptically polarized. The tip of an E electric field vector rotating around an axis parallel to the direction of propagation describes an ellipse with semi-major and semi-minor axes.

$$E_a = E_0 sin\ \phi \ \text{(x-direction)}$$
$$E_b = E_0 cos\ \phi \ \text{(y-direction)} \qquad (8)$$

For the intensity of light passing through the analyzer in every direction

$$I_a \sim E_a^2 = E_0^2 sin^2\phi$$
$$I_b \sim E_b^2 = E_0^2 cos^2\phi \qquad (9)$$

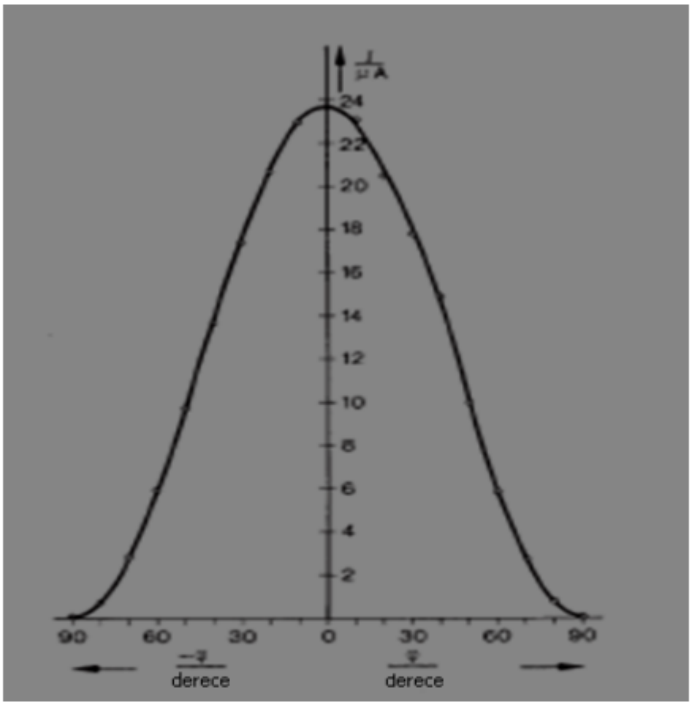

Figure 2: Variation of the intensity of plane-polarized light as a function of the analyzer's position

With the rotation of the analyzer, the ratio of the transmitted light intensity for maximum and minimum values is;

$$\frac{I_a}{I_b} = \frac{E_a^2}{E_b^2} = \frac{sin^2\phi}{cos^2\phi} = tan^2\phi \qquad (10)$$

or any angle φ between the analyzer and the optical axis of the quarter-wave plate;

$$I \sim E_0^2 cos^2\phi \, cos^2\varphi + E_0^2 \, sin^2\phi \, sin^2\varphi \qquad (11)$$

Without the $\lambda/4$ plate in the path of the rays, the entire intensity distribution of plane-polarized light is measured as a function of the analyzer's position (Figure 2).

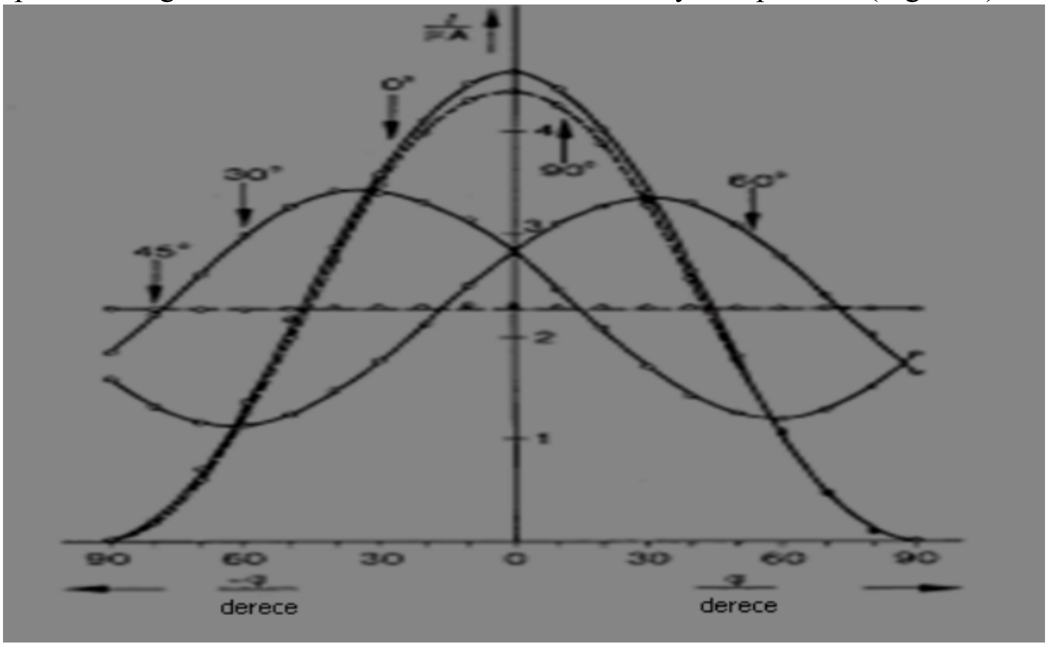

Figure 3: Variation of the intensity of polarized light as a function of the analyzer's transmission axis (with λ/4 plates at different angles)

The type of polarization of the transmitted light is determined based on the light intensity values obtained at different angles between the optical axis of the plate and the direction of the analyzer (Figure 3). If two quarter-wave plates are placed consecutively, the light polarized by the plate will be produced regardless of the angle between the resulting half-wave plate and the optical axis (Figure 4).

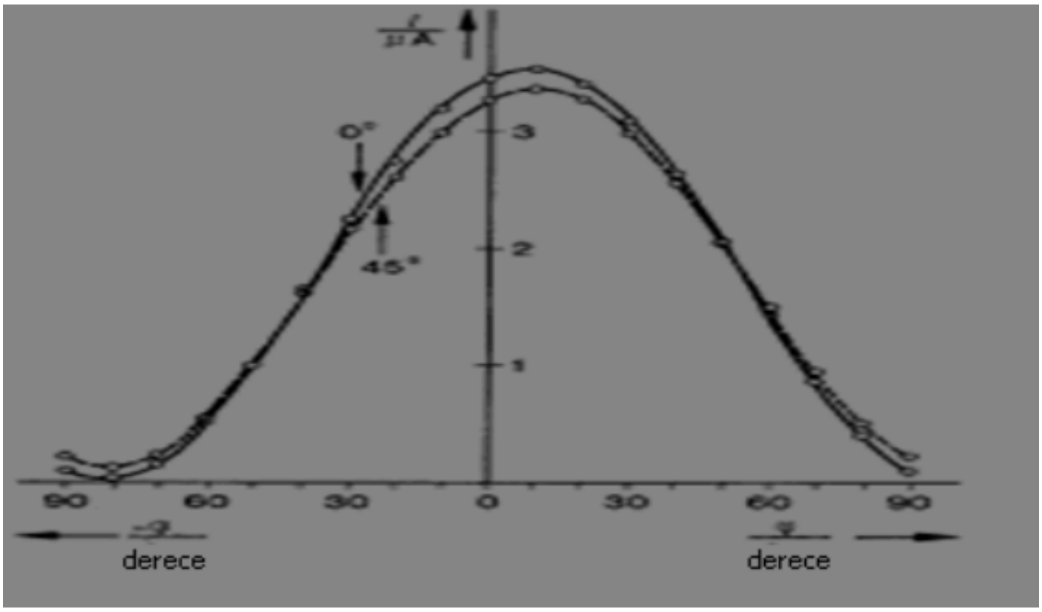

Figure 4: Variation of the intensity of polarized light with the presence of a half-wave plate at different angles.

EXPERIMENT PROCEDURE

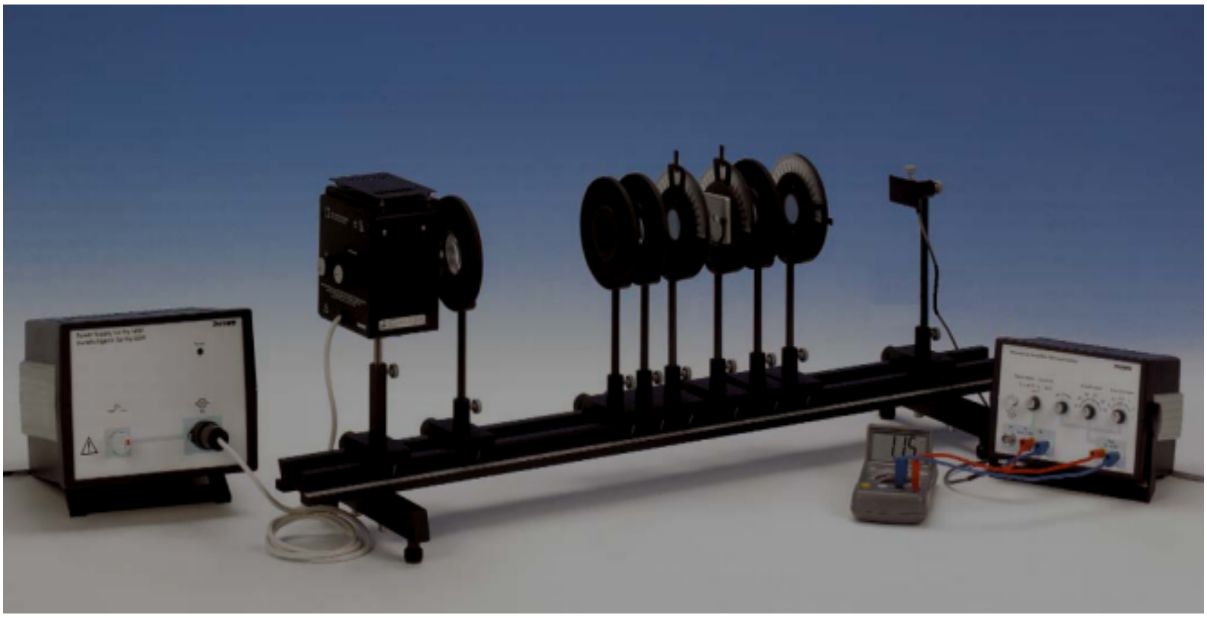

Figure 5: Experiment Setup

1. The path of the light is adjusted without the quarter-wave plates. This adjustment ensures that the photodetector is well illuminated.

2.The analyzer is rotated until the light transmission through the polarizer is minimized when it is in the “0” position. Table 1 is then created.

3.The λ/4 plate is installed. The plate is rotated until the minimum value is obtained again at the analyzer. The polarization plane of the light emerging from the polarizer makes an angle of 0° (or "90°)with the optical axis of the λ/4 quarter-wave plate. Table 2 is then created.

4.Light intensity, interval between -90° to 90° It is analyzed as a function of the analyzer's position at angles of 0°, 30°, 45°, 60°, and 90°.

5.The adjustable resistor is connected in parallel to the amplifier's input.

6.The current intensity of the photodetector is proportional to the intensity of the incoming light.

7.The experiment is repeated with two quarter-wave plates, and table 3 is created.

8.Graphs of tables 1, 2 and 3 are plotted.

Table 1

$\varphi\ (degrees)$	-90	-80	-70	-60	-50	-40	-30	-20	-10	0
$I(\mu A)$										
$\varphi\ (degrees)$	90	80	70	60	50	40	30	20	10	0
$I(\mu A)$										

Table 2

$\varphi\ (degrees)$	-90	-80	-70	-60	-50	-40	-30	-20	-10	0
$I(\mu A)$										
$\varphi\ (degrees)$	90	80	70	60	50	40	30	20	10	0
$I(\mu A)$										

Table 3

φ $(degrees)$	-90	-80	-70	-60	-50	-40	-30	-20	-10	0
$I(\mu A)$										
φ $(degrees)$	90	80	70	60	50	40	30	20	10	0
$I(\mu A)$										

5B - POLARIZATION

OBJECTIVES

- To study the phenomenon of polarization.
- To determine the percentage amount of optically active substances in a solution.

EQUIPMENTS

- **Na light source**
- **Polarimeter**
- **Visor**

GENERAL INFORMATION

Polarization of light refers to the process by which the oscillations of the electric field vector within an electromagnetic (EM) wave become restricted to a single plane. The plane of polarization is determined by the direction of propagation and the orientation of the electric-field oscillations. Different types of polarization, such as linear, circular, and elliptical, exhibit distinct characteristics and behaviors.

1. **Linearly or plane-polarized light**: The oscillations are confined to one plane, and the electric field vector traces a straight line (Figure 1).
2. **Circularly polarized light**: The electric field vector traces a circle.
3. **Elliptically polarized light**: The electric field vector traces an ellipse. This is the most general form of polarized light.

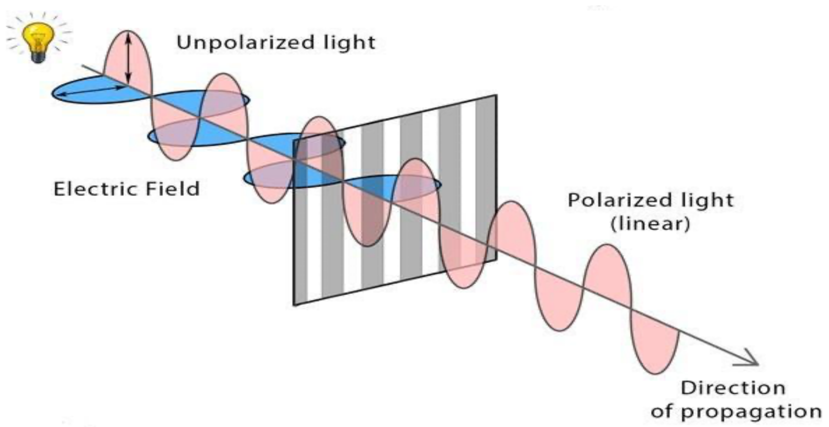

Figure 1: Linearly Polarized Light

All light possesses polarization. Light, commonly termed "unpolarized," lacks organized polarization, instead exhibiting randomized polarization. Randomly polarized light is a type of light in which the electric field vector oscillates in random directions perpendicular to the direction of the light's propagation. Linearly polarized light occurs when the electric field vector oscillates in a single plane perpendicular to the direction of the light's propagation. The direction of polarization is typically denoted as either vertical or horizontal but can be at any angle relative to the viewer. Light can be linearly polarized with a polarizer that selectively transmits light waves in a desired polarization direction while blocking others. Various methods can be employed to generate polarized light, including reflection, refraction, scattering, and absorption.

A polarizer is an optical filter that lets light waves of a specific polarization pass through while blocking light waves of other polarizations. An analyzer is also a polarizer that acts on already polarized light. Let the angle between the analyzer and the polarization angle be θ and the amplitude of the incident waves be E_0.

$$E_0{}' = E_0 cos\theta \qquad (1)$$

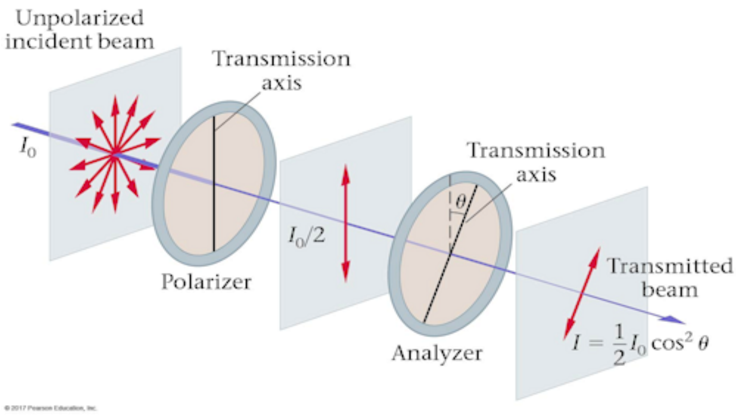

Figure 2: Polarizer-Analyzer System

The intensity of light after it has been through the analyzer is proportional to the square of the cosine of the angle θ as described by Malus' Law:

$$I' = I\, cos^2\theta \qquad (2)$$

When the two polarizers are positioned perpendicular to each other, no light is observed.

Objects that rotate the plane of vibration of linearly polarized light are called *optically active* substances. When plane-polarized light passes through quartz plates or substances containing asymmetric carbon atoms, the waves obtained are still plane-polarized; however, the plane of polarization of the transmitted light is rotated by an angle α relative to the plane of polarization of the incident light. Polarimeters are instruments used to measure how much the plane of vibration of polarized light is rotated (the angle of rotation) by an optically active substance. The specific rotation angle φ_0 is defined as the amount of rotation in a solution with 1 gram of active substance per cm³ in a tube 10 cm long. For sugar, the specific rotation angle is $\varphi_0 = 66°54'$.

EXPERIMENT PROCEDURE

1. The polarizer is illuminated with sodium light

2. When there is no tube between the polarizer and the analyzer, the circular scale is adjusted to zero. For this, the polarizer is rotated until the upper and lower parts of the visual field in the visor appear equally bright. At this point, the angle values on both sides of the circular vernier scale are read:

$$\varphi_1^{top} = \ldots\ldots\ldots\ldots,\ \varphi_1^{bottom} = \ldots\ldots\ldots\ldots$$

There may be a slight difference between these readings. To eliminate any potential error from this, the average of the two values is taken.

$$\varphi_1^{avg} = \ldots\ldots\ldots\ldots$$

3. The vernier is continuously turned in the same direction, and the situation described above is observed four times until it returns to the initial position. The obtained values are recorded in a table. This process is repeated two more times, and their averages are taken. The starting value is determined from the obtained averages. That value is $\underline{\varphi_1}$. This value stays constant.

Table 1. Results when there is no tube in the system

	φ_1^{top}	φ_1^{bottom}	φ_1^{avg}
1st Dark State			
2nd Dark State			
3rd Dark State			
4th Dark State			

(repeated measurement)

	φ_1^{top}	φ_1^{bottom}	φ_1^{avg}
1st Dark State			
2nd Dark State			
3rd Dark State			
4th Dark State			

4. When the instrument is in the zero position, place the tube of length L containing the optically active sugar solution between the polarizer and the analyzer. Rotate the scale again to achieve the previously described alignment. Read and record the scale value in this initial condition. Repeat the experiment four times, recording the obtained values in Table 2. Calculate the average angle.

$$\underline{\varphi_2} = \ldots\ldots\ldots\ldots$$

Table 2: Results when the tube in the system

	φ_2^{top}	φ_2^{bottom}	φ_2^{avg}
1st Dark State			
2nd Dark State			
3rd Dark State			
4th Dark State			

5.The deviation angle is found, and from these values:

$$\varphi = \underline{\varphi_2} - \underline{\varphi_1} = \ldots\ldots\ldots\ldots\ldots\ldots$$

6. The specific rotation angle for sugar, ϕ0=66∘54′. If the rotation angle for a sugar-water solution of length L is ϕ, then the concentration q of the optically active solution, i.e., the amount of sugar (in grams) in 100 cm³ of the solution, is calculated using the formula.

$$q = \frac{\varphi 110}{\varphi_0 L} = 1.503\frac{\varphi}{L} = \ldots\ldots\ldots$$

6 - DOUBLE-SLIT DIFFRACTION

OBJECTIVE

- To investigate the phenomenon of diffraction using a double slit.

EQUIPMENTS

- **White Light Source,**
- **Laser**
- **Filter**
- **Coherence Slit**
- **Lens**
- **Photodiode**
- **Double Slit**
- **Viewfinder**

GENERAL INFORMATION

We know that the intensity distribution of the interference pattern obtained with a double slit system, where the slit width is a and the distance between the slits is d, is given by the equation:

$$I = 4I_s cos^2\beta \qquad (1)$$

Here, θ is the observation angle and, where

$$\beta = \left(\frac{\pi b}{\lambda}\right) sin\theta \qquad (2)$$

Here, it is assumed that the intensity Is from each slit is constant. For a single slit system with slit width a, the intensity distribution of the diffraction pattern is given by $\alpha = \pi\ a\ \frac{sin\,\theta}{\lambda}$, where:

$$I_s = I_0 \left[\frac{sin\alpha}{\alpha}\right]^2 \qquad (3)$$

In a double-slit system, since both interference and diffraction effects can be observed simultaneously, the intensity distribution of the resulting illumination pattern is given by the product of the interference term $cos^2\beta$ and the diffraction term $\left[\frac{sin\alpha}{\alpha}\right]^2$, where:

$$I = 4I_s\left[\frac{sin\alpha}{\alpha}\right]^2 cos^2\beta \qquad (4)$$

In the expression above, the diffraction factor, as shown in Figure 1, determines the envelope curve of the interference fringes.

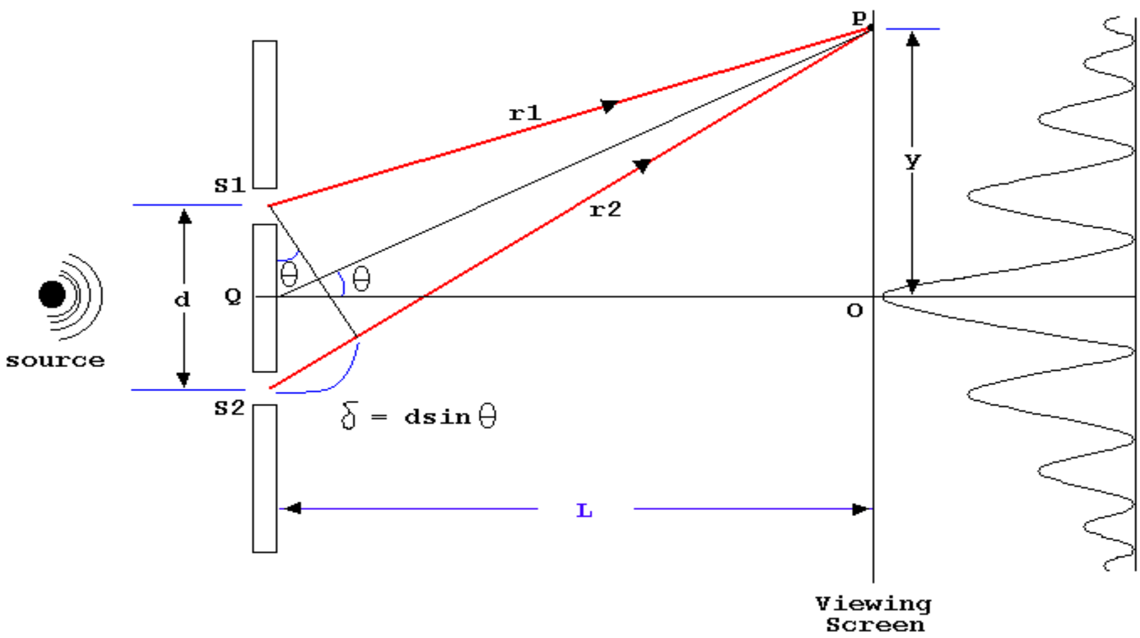

Figure 1: Double-Slit Diffraction

Interference minimum:

$$\beta = \left(m + \tfrac{1}{2}\right)\pi \qquad m = 0,1,2,3... \qquad (4)$$

Interference maxima :

$$\beta = m\pi \qquad m = 0,1,2,3... \qquad (5)$$

If the distance between the slits and the screen, L, is much larger than the distance between the slits, b, then for θ approximately:

$$sin\theta \approx tan\theta = \frac{y}{L} \qquad (6)$$

The distance between all consecutive maxima and minima is given by

$$y' = \lambda \frac{L}{d}$$

EXPERIMENT PROCEDURE

The experiment is conducted in two stages:

1. **First Stage:** A white light source is used. Conditions are set with the appropriate elements to observe the illumination pattern of the double-slit system.
2. **Second Stage:** A laser light source is used to obtain the illumination pattern of the double-slit diffraction and to determine the intensity distribution.

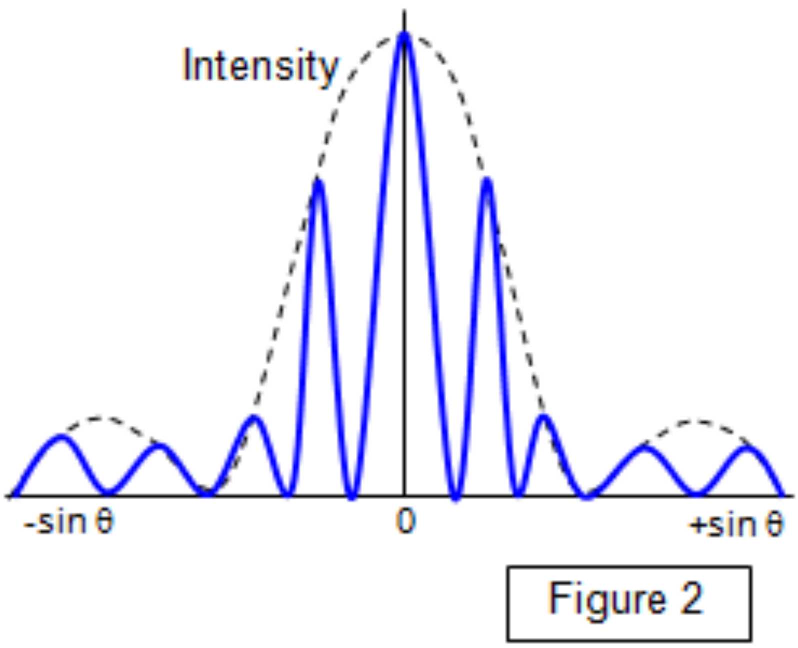

Figure 2: Intensity distribution of double-slit diffraction.

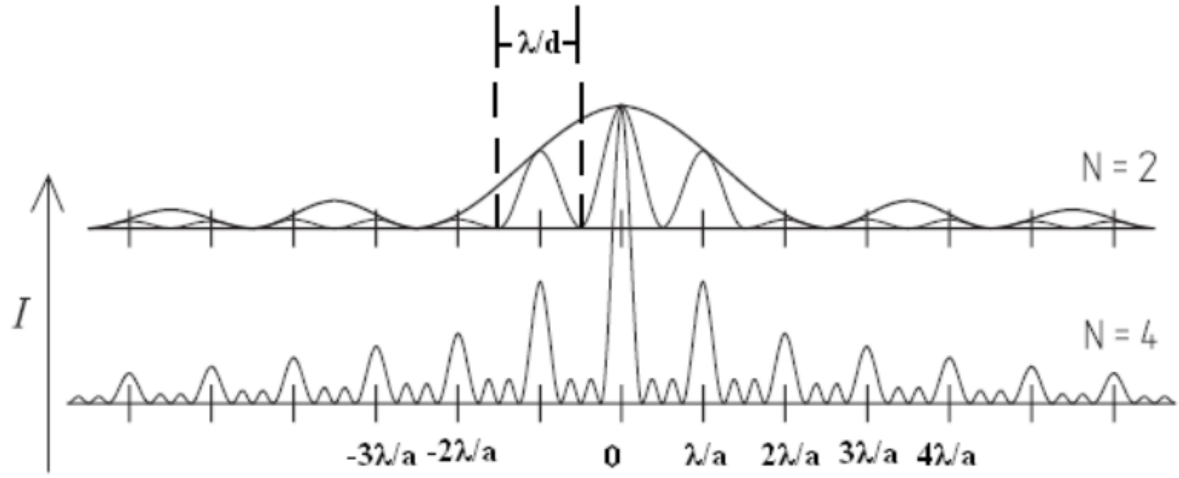

Figure 3: Variation of the intensity distribution of double-slit diffraction with the number of slits in the barrier.

At this stage, light rays from a point source, a white light source S, are passed through a single slit and a filter to ensure coherence of the light before being directed onto the double-slit system. To observe the diffraction and interference pattern on the screen, the most suitable slit width and slit-to-screen distance are determined. In the first phase of the experiment, no measurements will be taken; only the illumination pattern will be observed.

Phase 1:

Light rays emitted from a point source, S, undergo diffraction at the diffraction slit when the elements are arranged appropriately, creating an illumination pattern on the screen (Figure 4)

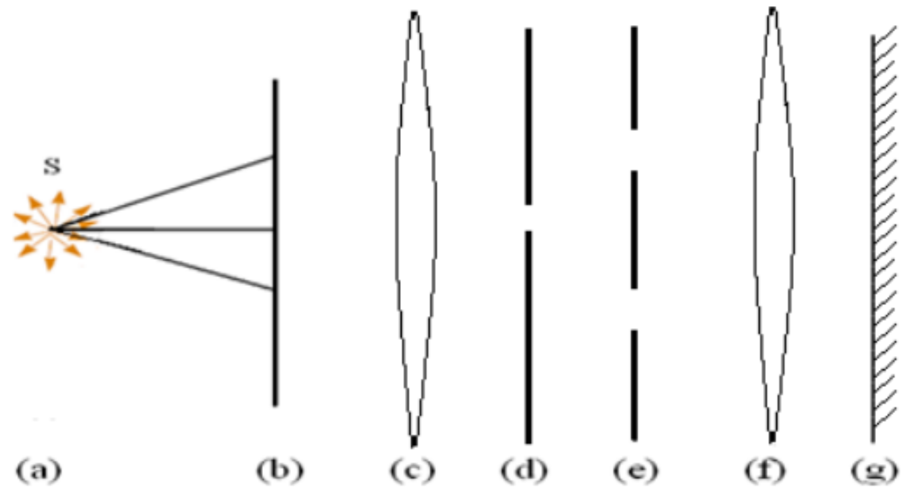

Figure 4: Double slit experimental setup. (a) Light source, (b) Filter, (c) Thin-edged lens, (d) Coherence slit, (e) Diffraction slit, (f) Thin-edged lens, (g) Screen.

Phase 2:

1. The experimental setup is arranged as shown in Figure 4. The components are placed and fixed in the optical path to achieve the best illumination pattern: Laser = 2.5 cm; f = +20 mm; lens = 14.5 cm; f = +100 mm; lens = 27.5 cm; plate with the slit systems = 33 cm, photodiode = 147.5 cm. The wavelength of the laser source used is λ = 632.8 nm.

2. An expanded laser beam is created with the help of lenses. This laser beam is directed onto the photodiode through a single slit. The plate is placed with a holder. Ensure that the slits being examined are perpendicular to the holder and that they are properly illuminated.

3. To prevent unwanted variations in intensity (such as fluctuations), the laser and measurement amplifier should be warmed up approximately 15 minutes before starting the measurements. Connect the photodiode to the measurement amplifier (amplifier factor (10^3 - 10^5) x 10^4 ohms). When changing the amplifier factor, check and, if necessary, adjust the zero point of the measurement amplifier with the photodiode covered.

4. Light intensity values are measured with the photodiode in 0.1 mm to 0.2 mm steps for the double slit systems.

5. The illumination pattern for the double-slit system is observed. Minima in the interference pattern, where diffraction maxima are observed, occur under the conditions specified in the following expression:

$$sin\varphi_m = \left(m + \frac{1}{2}\right)\frac{\lambda}{d}; \qquad m = 0,1,2,3\ldots$$

The d values for minima at different orders, i.e., different mmm values, are found and averaged. The measurements and calculations are recorded in Table 1.

Table 1: Results of the Double-Slit Diffraction Experiment

<table>
<tr><th></th><th>Δx</th><th>$\sin \varphi_m = \frac{\Delta x}{L}$</th><th>$d(mm)$</th></tr>
<tr><td>1</td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">$d_{avg} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots mm$</td></tr>
<tr><td colspan="4">$\lambda = 632.8\ nm = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots mm$ $L = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots cm$</td></tr>
</table>

7 - MICHELSON INTERFEROMETER

OBJECTIVE

- Determination of the wavelength of the laser light source used in interference.

EQUIPMENTS

- **Michelson interferometer,**
- **Laser (He-Ne 1.0 mW, 230 VAC)**
- **Lenses (f = +20 mm and +5 mm)**
- **Screen**

GENERAL INFORMATION

What are the physics of interference, wavelength, refractive index, speed of light and phase?

The superposition of two waves with the same frequency ω, different amplitudes, and different initial phases,

$$y = a_1 sin(\omega t - \alpha_1) + a_2 sin(\omega t - \alpha_2)$$

The resultant of the combined wave can be described as follows:

$$y = A\, sin(\omega t - \alpha)$$

Amplitude:

$$A^2 = {a_1}^2 + {a_2}^2 + 2a_1 a_2\, cos\delta \qquad (1)$$

Phase difference:

$$\delta = a_1 - a_2$$

In a Michelson interferometer, light is split by a partially silvered glass plate into two beams, which are reflected by two mirrors and then pass through the glass plate again to produce an interference pattern. A lens is placed between the light source and the glass plate to focus the light at the focal point of the light source.

Based on different light paths, the phase difference is:

$$\frac{Phase\ difference\ (\delta)}{2\pi} = \frac{Path\ difference\ (d\ sin\theta)}{\lambda}$$

Using the relationship:

$$\delta = \frac{2\pi}{\lambda} 2d\ cos\theta \qquad (2)$$

Here, λ is the wavelength of the light used in the experiment. For a1=a2=a, the intensity distribution is as follows:

$$I \approx A^2 = 4a^2\ cos^2\frac{\delta}{2} \qquad (3)$$

If δ is a multiple of 2π, maxima occurs.

$$2d\ cos\theta = m\lambda\ ; \qquad m = 1, 2, 3\ldots \qquad (4)$$

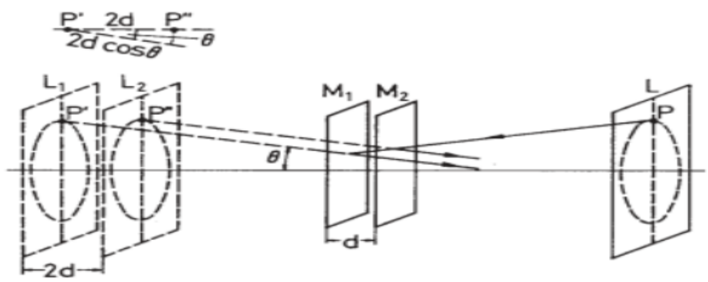

Figure 1: Circular Interference Pattern

If the position of the movable mirror is changed, according to equation (4), d decreases, and the diameter of the ring will also decrease because mmm is constant for this ring. Each time the d value is reduced by a certain amount, one ring disappears. When d=0, no rings are visible. If M1 and M2 are not parallel, curved fringes are obtained, which turn into straight fringes when d=0. To measure the wavelength of light, the rings are counted. The displacement of the mirror (158 μm) is measured. Using this data, the wavelength is calculated.

$$\lambda = 632nm$$

EXPERIMENT PROCEDURE

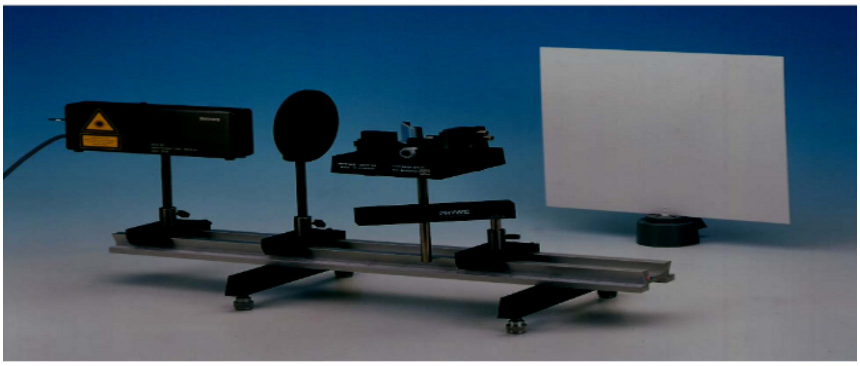

Figure 2: Experiment Setup

1. The experimental setup is shown in Figure 2.

2. In the Michelson arrangement, interference will be created using two mirrors (Figure 3). To achieve the maximum number of interference fringes, the two mirrors of the interferometer must be adjusted. To do this, the lenses should be removed.

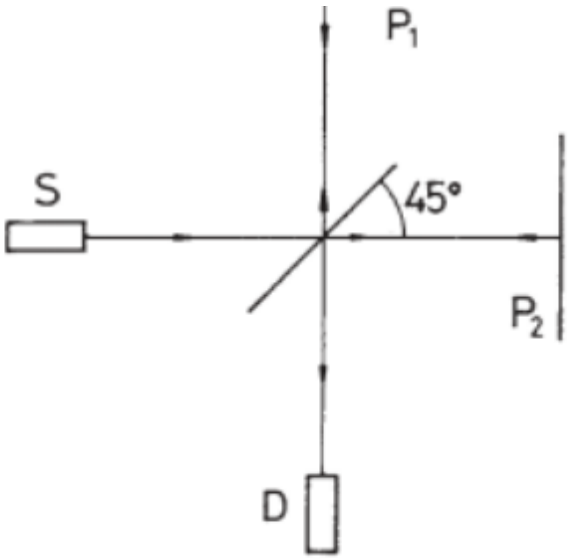

Figure 3: Michelson interferometer experiment setup

3. The laser beam strikes the half-silvered mirror and splits into two beams: one that reflects at an angle and another that refracts. These two beams are reflected by the mirrors and projected onto the screen.
4. The two light spots are made to converge at the same point using two adjustable screws fixed to one of the mirrors. The interference pattern is observed on the screen using a lens.
5. To measure the wavelength, the micrometer screw is rotated to any initial position where the center of the circular pattern is dark.

6. The micrometer screws are turned in the same direction, counting the repetitions of bright and dark at the center.

7. The distance moved by the mirror is read from the micrometer screw and divided by ten (since the lever reduction is 1:10).

8. The wavelength of the laser light is determined using the formula $d = m\lambda/2$, where d is the path difference, m is the number of fringes, and λ is the laser wavelength.

9. The process of determining the wavelength of laser light is repeated five times and recorded in the table.

	d(μm)	m	λ (nm)
1)			
2)			
3)			
4)			
5)			

8 - DISPERSION

OBJECTIVES

- To measure the angle of deviation of light passed through a prism by using a goniometer.
- To study the phenomenon of dispersion by determining the angle of refraction of the prism for different wavelengths.

EQUIPMENTS

- **Goniometer.**
- **He, Ne and H_2 spectral lamps.**

GENERAL INFORMATION

A *goniometer* is an optical instrument that creates and analyzes a spectrum. It is shown schematically in Figure1. It consists of four main parts: collimator, prism table, prism, and telescope.

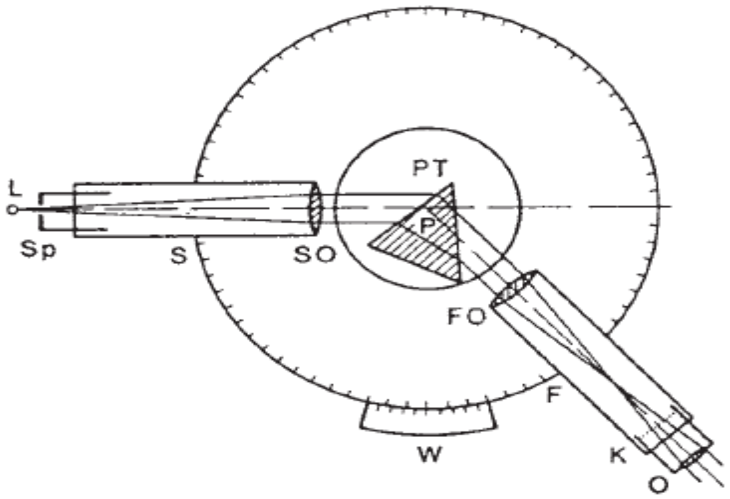

Figure 1: Schematic drawing of a goniometer.

A Goniometer setup consists of four parts:

1 - Collimator: It is a tube with an adjustable slit at one end and a converging lens at the other end. The rays of light coming from the light source enter through the slit and exit parallel to the axis of the collimator.

2 - Prism Table: A small prism stand, used to place the prism, is positioned on the table so that it is coaxial with it. The parallel rays coming from the collimator are directed onto the prism placed on the goniometer table.

3 - Telescope: An instrument that can rotate around the prism axis and is used to examine the light that comes directly or passes through the prism.

4 - Prism: It refracts and disperses the different wavelengths of light from the light source. The set of parallel rays emerging from the prism (one set for each wavelength) enters the telescope, and when viewed through the telescope, distinct lines are observed in the shape of the collimator slit.

In this experiment, the refractive index of the material from which the prism is made will first be determined. Transparent objects with a triangular cross-section are called optical prisms (see Figure 2). The angle between the intersecting planes is called the apex angle (or refracting angle) of the prism. A ray of light that hits one of the lateral surfaces emerges from the other lateral surface in a direction different from it's initial direction due to refraction. The angle between the direction of incidence of the light on the prism and the direction of its exit is called the angle of deviation, denoted by δ.

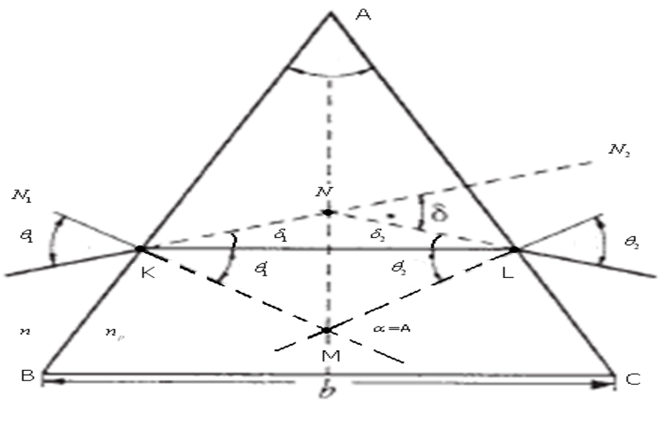

Figure 2: Determination of the deviation angle of the prism.

If we consider that a light ray coming from a medium with a refractive index n enters the prism with a refractive index of n_p at point K and exits the prism at point L, Snell's Law applies to the refractions at points K and L in the following form:

$$nsin\theta_1 = n_p sin\theta_1 \qquad (1)$$

$$n_p sin\theta_2 = nsin\theta_2 \qquad (2)$$

The exterior angle δ of triangle *KLN* is equal to the sum of the two non-adjacent interior angles δ_1 and δ_2.

$$\delta = \delta_1 + \delta_2 \qquad (3)$$

$$\delta = (\theta_1 - \theta_1') + (\theta_2 - \theta_2') \qquad (4)$$

$$\delta = (\theta_1 + \theta_2) - (\theta_1' + \theta_2') \qquad (5)$$

Since the arms of the exterior angle α at vertex *M* of triangle *KLM* are perpendicular to the arms of the refracting angle *A* of the prism, $A = a$. At the same time, in triangle *KLM*, $\alpha = \theta_1' + \theta_2'$, so: $\delta = \theta_1 + \theta_2 - A$

- **Minimum Deviation**

The angle of deviation varies according to the angle at which the light ray strikes the surface of the prism. The smallest value of the angle of deviation is called the minimum deviation. In this case:

$$\theta_1 = \theta_2 , \theta_1' = \theta_2' , A = 2\theta_1' \qquad (6)$$

Hence the angle of minimum deviation is given by:

$$\delta_{min} = 2\theta_1 - A \qquad (7)$$

When the angle of deviation is at it's minimum, the refractive index of the prism can be found using a simple relationship. To derive this relationship, Snell's law is applied at the surface where the light enters the prism. Following figure 2:

$$n sin\theta_1 = n_p sin\theta_1' \qquad (8)$$

can be obtained. In the case of the minimum deviation:

$$\theta_1 = \frac{(\delta_{min} + A)}{2} \text{ and } \theta_1' = \frac{A}{2} \qquad (9)$$

When these values of θ_1 and θ_1' are placed in the Snell's equation and solved for n_p:

$$n_p = \frac{sin\left(\frac{\delta_{min} + A}{2}\right)}{sin\left(\frac{A}{2}\right)}$$ is obtained (For this experiment, n =1). (10)

The graph of the refractive index as a function of wavelength is called the dispersion curve. The experimentally obtained curve can be analytically expressed using the empirical Cauchy formula in the form:

$$n = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \dots \qquad (11)$$

A, B, and C are known as the Cauchy constants. Often, it is sufficient to take only the first two terms.

In this experiment, the refractive index of the material from which the prism is made will be determined for several different wavelengths, and the Cauchy constants will be obtained.

EXPERIMENTAL PROCEDURES

1 - Before the prism is placed on the table, the telescope's focus is adjusted and is not changed until the end of the experiment.

2 - The collimator is adjusted to obtain parallel light. Once adjusted, the collimator's setting is not changed.

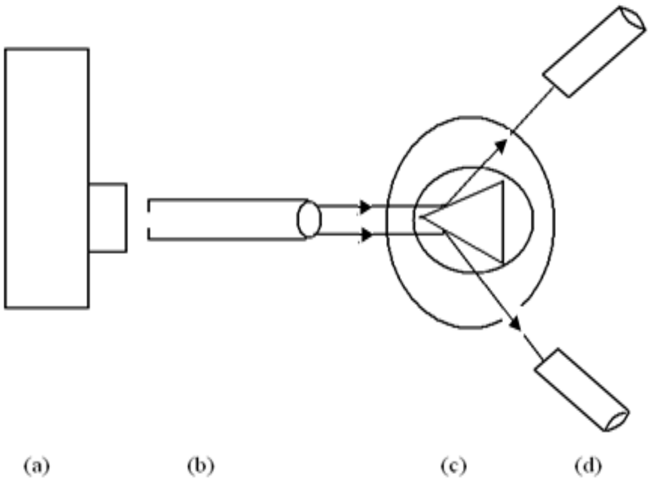

Figure 3: Measuring the apex angle of the prism. (a) Light source. (b) Collimator. (c) Prism and the prism table. (d) Telescope.

3 - The prism is properly placed on the goniometer table as shown in Figure 3.

4 - By moving the telescope, the angular position of the light reflected from one face of the prism is read (telescope position 1).

5 - The obtained value is recorded in its corresponding place in Table 1.

6 - The telescope is rotated to observe the light reflected from the other face of the prism. In this case, the angular position of the telescope is read (telescope position 2), and the obtained value is again recorded in its corresponding place in Table 1.

- ## Measuring the angle of minimum deviation

1 - The prism is removed. Through the telescope, a fine line in the center, called the slit, is observed.

2 - The position of the telescope is read (telescope position 1) and recorded in its corresponding place in Table 2.

3 - The prism is placed as shown in Figure 4. The rays coming from the collimator are refracted and exit through the other face of the prism. The telescope is adjusted to observe this image. Keeping the telescope fixed, the table is slowly moved, and the turning point of the image is found. The angular position of the telescope in this situation is read (telescope position 2) and recorded in its corresponding place in Table 2. This process is repeated several times until the turning point is clearly determined.

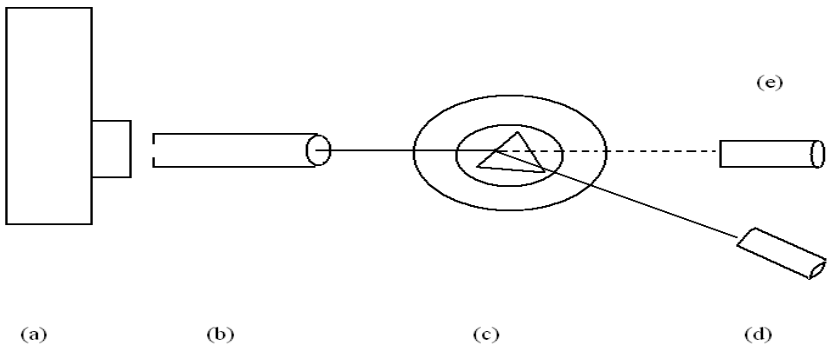

Figure 4: Determining the angle of minimum deviation. (a) Light source. (b) Collimator. (c) Prism and prism table. (d) Telescope at position 1. (e) Telescope at position 2.

This process is repeated for lines of different wavelengths. For each wavelength, the refractive index is calculated using. A graph is then plotted with the refractive index on the vertical axis and the wavelength on the horizontal axis.

Experimental points are plotted on graph paper. Assuming that the relationship between n and λ is given by the Cauchy formula, the least squares line is determined for the expression:

$$n - 1 / \lambda^2$$

The values of the constants *A* and *B* are obtained from this line.

Table 1: Values required for determining the apex angle.

	Case 1	Case 2	*A*
1)			
2)			
3)			

Table 2: Values for refraction index corresponding to the wavelength.

	λ	Case 1	Case 2	δ_{min}	*n*
1)					
2)					
3)					
4)					
5)					
6)					
7)					

9A - MEASURING THE SPEED OF LIGHT

OBJECTIVES

- Measuring the speed of light in air and calculating the refractive index.
- Measuring the speed of light in water and synthetic resin.
- Determining the refractive indices of water and synthetic resin.

EQUIPMENTS

- **Oscilloscope.**
- **Speed of light calculation unit.**
- **Synthetic resin block.**

GENERAL INFORMATION

What are the refractive index, wavelength, frequency, phase, modulation, permittivity constant, and permeability constant?

- ### Speed of light

The speed of light and other electromagnetic waves in a vacuum is given by Maxwell's equations:

$$c = \frac{1}{\sqrt{(\varepsilon_0 \mu_0)}} \qquad (1)$$

and its value in a vacuum is 299,792,458 m/s.

The value of μ will vary depending on the material (water, glass, resin, etc.). In Latin, speed is written as 'celeritas,' which is why it is represented by the letter c. Here, the permittivity constant of the vacuum is $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m; the permeability constant of the vacuum is $\mu_0 = 1.257 \times 10^{-6}$ H/m. If the speed of light in a material medium is v, it is described by:

$$v = \frac{1}{\sqrt{(\varepsilon \mu)}} \qquad (2)$$

Here, ε is the permittivity constant of the material medium, and μ is the permeability constant of the material medium. The refractive index of the medium is equal to the ratio of the speed of light in a vacuum to the speed of light in the medium:

$$n = \frac{c}{c}{}' = \sqrt{\varepsilon_b \mu_b} \qquad (3)$$

- **Measuring the speed of light**

The speed of light is calculated based on the relations between phase, modulation frequency, and changes along the path of light.

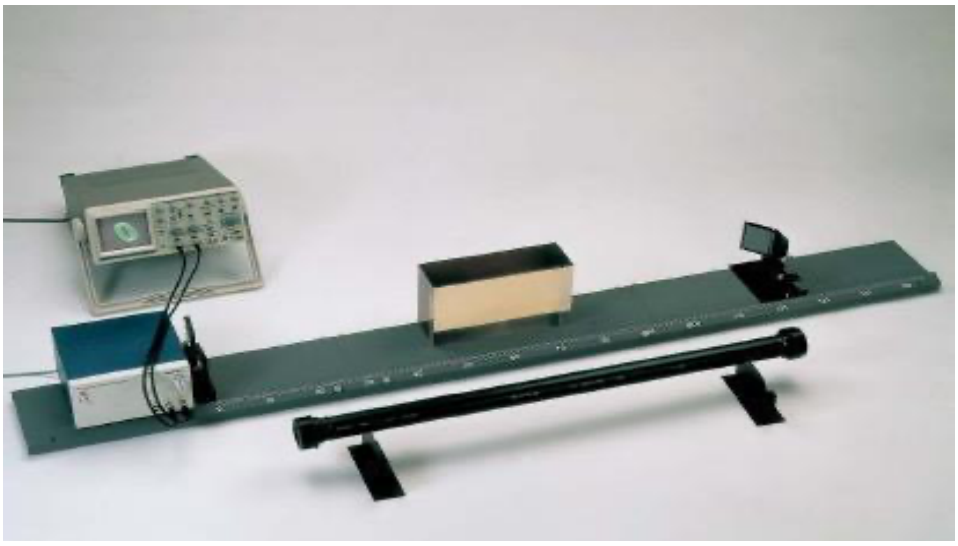

Figure 1: Setup for calculating the speed of light.

With the experimental setup shown in Figure 1, the speed of light in air or different mediums can be measured. This setup consists of a light speed measurement unit placed on an optical plane with a ruler, an oscilloscope, a movable mirror, and lenses. The light speed measurement unit includes a light-emitting diode (LED) and a light-receiving diode (photodiode).

Through the use of a movable mirror and lenses, the light rays emitted from the light-emitting diode are directed to fall onto the photodiode after traveling a certain path. The phase difference between the emitted signal and the received signal depends on the path traveled by the light. By measuring this path, the speed of light can be calculated. Using an oscilloscope, the resulting phase difference can be observed as a Lissajous figure. When the figure is a straight line, the phase difference is 0 (zero) for a positively sloped line and π for a negatively sloped line.

To calculate the speed of light in air, the path taken by the light in increased by an amount:

$$\Delta l = 2\Delta x \tag{4}$$

The amount of time taken by the light to travel the path difference given in the equation above to create a path difference of π is:

$$\Delta t = \frac{1}{2f} \tag{5}$$

Hence, the speed of light in air can be calculated using:

$$c_{air} = \frac{\Delta l}{\Delta t} = 4f\Delta x \tag{6}$$

Here, f is the modulation frequency of the light source used. The actual calculated value of the speed of light in air is 3 x 10^8 m/s.

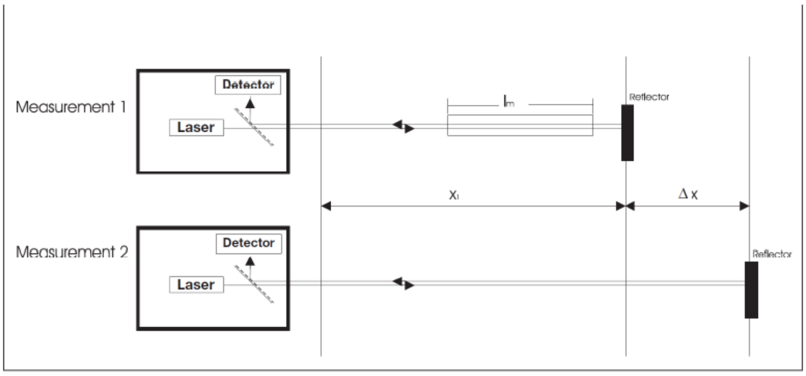

Figure 2: Setup for measuring the speed of light in air or in a different medium.

The speed of light in water and synthetic resin can be determined by comparing it with its speed in air. In the first measurement, the amount of time it takes for the light to travel the distance of $l_1 = 2x_1$ is given as:

$$t_1 = \frac{l_1 - l_m}{c_{air}} + \frac{l_m}{c_m} \tag{7}$$

In the second measurement, the amount of time it takes for the light to travel the distance of $l_2 = l_1 + 2\Delta x$ is given as:

$$t_2 = \frac{l_1 + 2\Delta x}{c_{air}} \tag{8}$$

For both cases, the phase difference between the signal emitter and receiver is the same:

$$t_1 = t_2 + \frac{k}{f}\ ;\ k = 0,1,2\ldots \tag{9}$$

Thus, the index of refraction can be found as the following:

$$n = \frac{c_{air}}{c_m} = \frac{2\Delta x}{l_m} + 1 + \frac{kc_{air}}{fl_m} \tag{10}$$

The speed of light in water and synthetic resin is known to be 2.248×10^8 m/s and 1.87×10^8 m/s, respectively. Additionally, the refractive index of water is 1.333, and the refractive index of synthetic resin is 1.597.

EXPERIMENTAL PROCEDURES

1. The experimental setup shown in Figure 1 is arranged for measuring the speed of light in air. Using a movable mirror and lenses, the incoming and reflected light beams are adjusted to be parallel to the horizontal plane, ensuring that the maximum signal reaches the photodiode.

2. The speed of light measurement unit has a red light-emitting diode (LED). To make the receiver and transmitter signals observable on the oscilloscope, the modulation frequency of the lamp is reduced from approximately 50.1 MHz to around 50 kHz.

3. The movable mirror is placed as close as possible to the light speed measurement unit (at the 0 point of the optical plane).

4. The phase difference between the light-emitting signal and the receiving signal is observed on the oscilloscope in XY mode as a Lissajous figure.

5. The phase adjustment knob of the light speed measurement unit is used to make the Lissajous figure appear as a straight line.

6.The movable mirror is slid along the optical plane until the phase difference reaches π, and the displacement Δx of the mirror is measured (see Figure 2). The measurements are repeated, and Δx is recorded in Table 1.

7. The speed of light in air is calculated. For red light, the modulation frequency is f = 50.1 MHz.

8. The relative error is calculated using the actual value of the speed of light in air and recorded in Table 1.

9. To determine the speed of light in water, a 1-meter-long cylindrical tube filled with water is placed horizontally in the path of the reflected light beams. This ensures that the light passes parallel through the tube, which has glass windows at both ends.

10. The movable mirror is placed right behind the cylindrical tube.

11. Using the phase adjustment knob of the light speed measurement unit, a straight line is again obtained on the oscilloscope screen.

12. The tube placed in the path of the light is removed, and the mirror is shifted until the Lissajous figure again shows the same phase difference.

13. The displacement Δx of the mirror is measured several times, and the results are recorded in Table 2.

14. The speed of light in water and the refractive index of water are calculated for the case where k=0.

15. The relative error is calculated, and the results are recorded in Table 2

16. To determine the speed of light in synthetic resin, a 30 cm long piece of synthetic resin with its effective surfaces perpendicular to the path is placed.

17. Steps 10-15 of the experiment are repeated. The speed of light in the resin and the refractive index of the resin are calculated, and the results are recorded in Table 3.

Question 1: What factors affect the speed of light? Please explain.
Question 2: How is a Lissajous figure formed? Please explain.
Question 3: Draw the Lissajous figure for phase differences of 0 (zero), π, and any other case.
Question 4: How can the speed of light be changed? Please explain.

Table 1

Δx *(air) (cm)*	c_{air} *(m/s)*	Relative error ($\lvert\Delta c\rvert / c_{real}$)
$\Delta x_{average}$ =		

Table 2

Δx *(cm)* *(water)*	c_{water} *(m/s)*	Relative error ($\lvert\Delta c\rvert$ / c_{real})	n_{water}	Relative error ($\lvert\Delta n\rvert$ / n_{real})
$\Delta x_{average}$ =				

Table 3

Δx *(cm)* *(resin)*	c_{resin} *(m/s)*	Relative error ($\lvert\Delta c\rvert$ / c_{real})	n_{resin}	Relative error ($\lvert\Delta n\rvert$ / n_{real})
$\Delta x_{average}$ =				

9B - ABSORPTION

OBJECTIVES

- Determine the absorption coefficient of semi-permeable plates and examine the absorption phenomenon.
- Determine the permeability value.

EQUIPMENT

- **Luxmeter.**
- **Light source.**
- **Semi-permeable plates of various thicknesses.**
- **Ampermeter**

GENERAL INFORMATION

As a light beam passes through a semipermeable plate with a thickness of *d*, it's intensity decreases according to the relation:

$$I = I_0 10^{-kx} \qquad (1)$$

Here, I_0 is the intensity of the incoming light, I is the intensity of the light exiting the plate, d is the thickness of the plate, and k is the absorption coefficient of the plate. The coefficient k is a constant that depends on the type of medium and the wavelength of the incoming light.

The permeability of the medium, T, is defined as the ratio of the intensity of the transmitted light to the intensity of the incoming light. It can be found using the relation:

$$T = \frac{I}{I_0} = 10^{-kx} \qquad (2)$$

By taking the logarithm of both sides:

$$logT = -kx$$

The slope of the graph plotted between $logT$ and x gives us k.

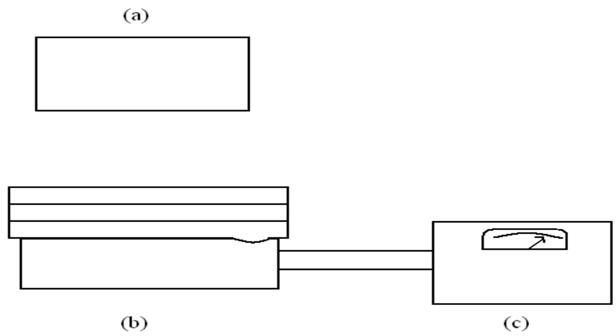

Figure 1: Setup for the experiment. (a) Light source. (b) Luxmeter. (c) Ammeter.

EXPERIMENTAL PROCEDURES

1. The luxmeter is placed directly under the light source so that it reaches full scale deflection, and it is kept stationary there.

2. First, with no plate in front of the source, the maximum intensity value is read from the light meter (I_0) and recorded in the table.

3. By placing a plate of known thickness on the light meter, the transmitted light intensity, I, is read and recorded in the table. Then, other plates of known thickness are sequentially stacked on top of each other, and the intensity is measured for the total thickness.

(We want to draw attention to one point: equation (1) is derived for a continuous medium made of the same material. However, in the experiment, plates of different thicknesses are stacked to perform the measurements. We assume that the error caused by the air layer between the plates remains within the acceptable error limits of the experiment.)

4. The permeability values *T* are calculated, and their logarithms are taken and recorded in the table provided below.

5. A graph of permeability as a function of thickness, i.e., the change in permeability *T* with respect to thickness *d*, is plotted.

6. A graph of *logT* versus thickness *d* is plotted, and the absorption coefficient *k* is determined from the slope of the line.

$$k = tg\alpha = \ldots mm^{-1}$$

$d(mm)$	I_0 (lux)	I (lux)	$T = I / I_0$	log T

10A - DIFFRACTION GRATING

OBJECTIVES

- Using a spectrometer, determine the grating constant of a given diffraction grating.
- Use this to calculate the wavelength of one of the double lines of sodium.

EQUIPMENTS

- **Sodium lamp.**
- **Spectrometer.**
- **Diffraction grating**.

GENERAL INFORMATION

Imagine placing an opaque object in front of a light source and a screen behind it. You would expect the area on the screen behind the object to be dark while the rest is illuminated. However, a pattern of illumination has been observed in the area that should be dark. This pattern is known as diffraction.

Diffraction is classified in two ways: Fraunhofer and Fresnel diffraction. In Fresnel diffraction, the image is formed at infinity. We aim to observe diffraction in a laboratory setting, which is known as Fraunhofer diffraction. By using an appropriate lens, we can make the image form at a finite distance. On the screen, a wide bright region is observed at the center, bordered by darkness. This pattern of illumination continues with secondary maxima.

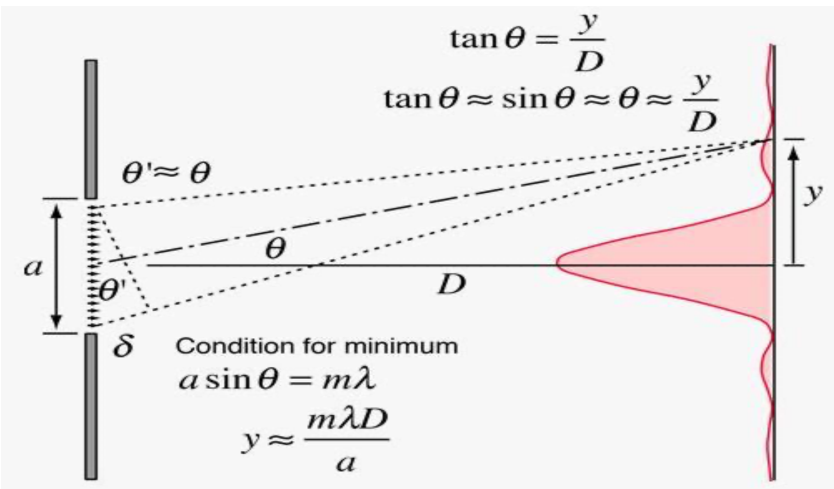

Figure 1: Fraunhofer diffraction.

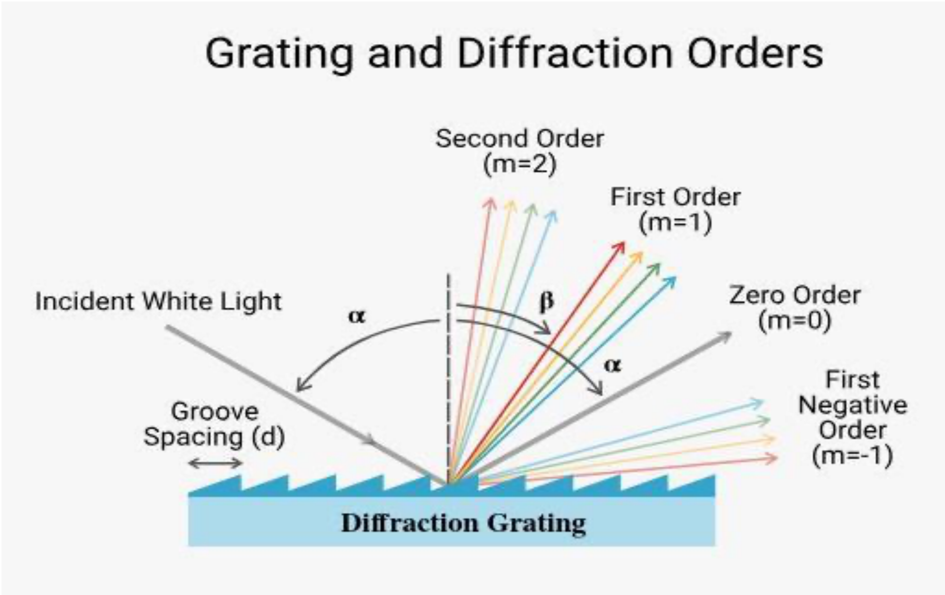

Figure 2: Reflection directions of the diffracted white light.

A diffraction grating, which is a very useful device in the analysis of light sources, consists of a large number of equally spaced slits. The regions between the lines are transparent to light, thus behaving like separate slits. The distance between two slits is defined as the 'grating constant' a. The diffraction grating used in the experiment is a transmission grating. In this case, the light path shown in Figure 3 applies. For inclined incidence on the diffraction grating (Figure 3), the following expression is valid for bright spots.

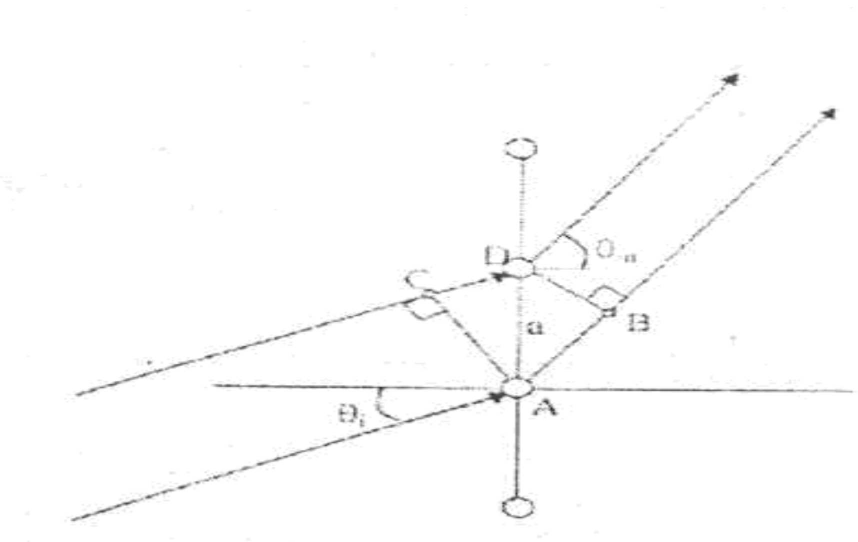

Figure 3: Incidence at an angle on a transmission grating.

$$AB - CD = a(\sin\theta_m - \sin\theta_i) \qquad (1)$$

$$m\lambda = a(\sin\theta_m - \sin\theta_i)$$

Here, $\underline{AB} - \underline{CD}$ is the optical path difference, m is the order of the diffraction grating, λ is the wavelength of the incoming light, and a is the grating constant.

In the case where the incident light is perpendicular to the grating:

$$m\lambda = a sin\theta_m \qquad (2)$$

Here, θ_m is the diffraction angle. For m = 0, the central bright spot will be formed, and for m = 1, the first-order bright spot will be formed.

In the case where the optical path difference is an exact multiple of $\lambda/2$, the resulting interference is destructive:

$$(2m - 1)\frac{\lambda}{2} = a sin\theta_m \qquad (3)$$

In a diffraction grating, the more slits there are, the more destructive interferences occur, making the bright spots narrower and clearer. If two plane waves with very close wavelengths fall on the diffraction grating, each wave will produce diffraction maxima at different angles according to their wavelengths. The maxima of a given order for all wavelengths form a spectrum. Here, the long-wavelength light is the most deflected, meaning that red light is deflected more than violet light. This is the opposite of the dispersion of light in a prism. The dispersion of the diffraction grating, 'D,' is given by the following expression.

$$D = \frac{d\theta}{d\lambda} = \frac{m}{a cos\theta m} \qquad (4)$$

The resolving power of a given diffraction grating is given as:

$$R = mN = \frac{\lambda}{\Delta\lambda_{min}} \qquad (5)$$

$$R = \frac{aN(sin\theta_m - sin\theta_i)}{\lambda} \qquad (6)$$

Here, $(\Delta\lambda)_{min}$ is the minimum wavelength range that the spectrometer can resolve, and N is the total number of slits in the diffraction grating. Diffraction grating spectrometers are used to achieve spectral separation of light with multiple wavelengths and to determine each wavelength. The maximum value of R occurs when both θ_i and θ_m are on the same side of the normal. In this case:

$$R = \frac{2aNsin\theta_i}{\lambda} \quad (7)$$

EXPERIMENTAL PROCEDURES

A spectrometer essentially consists of four main parts: the collimator, the angular scale table, the table on which the diffraction grating is placed, and the telescope. The collimator has an adjustable slit (slit width). The angular scale table consists of two concentric circular parts. The K2 table, marked with angles up to 360°, can easily rotate around a vertical axis with the telescope. The K1 circle has two vernier scales with 180° intervals. The full degree is the value in front of the zero line of the vernier. The vernier division that aligns with the lower degree divisions gives the minutes to be added to the full degree.

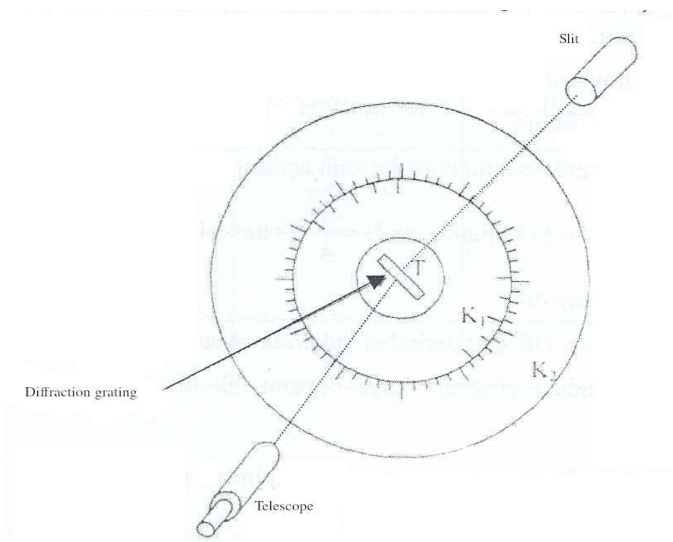

Figure 4: Spectrometer.

1. Turn on the sodium lamp.

2. Adjust the table so that the light is incident perpendicularly onto the diffraction grating.

3. Look through the telescope to see the zero-order bright line and read the angle in this case.

4. Turn the telescope to the left and read the θ_m values for the possible values of m.

5. Considering the zero-order angle you read in step-3, calculate the diffraction angles θ_m and record them into Table-1.

Note: From the first order onwards, you will see that the sodium lines are split into two. These are two bright lines with wavelengths of 589.592 nm and 588.995 nm. When measuring the angles, be careful to read the same line each time.

6. For each value of m, calculate the average of the diffraction angles found on the left and right sides.

7. For each value, determine the diffraction grating constant a and calculate $N = 1/a$.

8. Calculate the average value of a (a_{average}).

9. Using this a value, calculate the wavelength of the line outside the sodium doublet with a wavelength of 589.592 nm for a single m value.

10. Plot the graph of $\sin\theta_m = f(m)$. Use the slope of the line you obtain to find a value for a and compare it with the previously found a_{average}.

11. Calculate the expected dispersion value for sodium with a wavelength of $\lambda = 589.592$ nm at the 1st and 2nd orders.

Question 1: What is the expected resolving power of this diffraction grating at the 1st and 2nd orders?
Question 2: What is the minimum wavelength range that can be resolved at the 1st and 2nd orders?
Question 3: Why does the distance between lines, or the resolving power, increase as the order increases? Provide an explanation.

Table 1: Spectral values obtained for the sodium line with a wavelength of $\lambda = 589.592$ nm (bright yellow line)

m	θ_k (left)	θ_k (right)	θ_{left} ($\theta_{k,left} - \theta_0$)	θ_{right} ($\theta_{k,right} - \theta_0$)	$\theta_{average}$	$\sin\theta_{average}$	a (mm)	N
0								
1								
2								

Table 2: Spectrometer measurements obtained for the Sodium line other than the yellow line.

$a_{average}$	m	$\theta_{k,left}$	$\theta_{k,right}$	θ_{left}	θ_{right}	$\theta_{average}$	$\sin\theta_{average}$	λ (nm)

Table 3: Other spectral information (for the line with a wavelength of λ = 589.592 nm).

m	D (dispersion)	R (resolving power)	Smallest resolvable wavelength range
1			
2			

10B - ANALYZING THE WAVELENGTH WITH A SPECTROMETER

OBJECTIVES

- Understanding the spectrometer and obtaining the calibration curve.
- Determining the Rydberg constant using the Balmer series of Hydrogen.

EQUIPMENTS

- **Goniometer.**
- **He, Ne and H_2 spectral lamps.**

GENERAL INFORMATION

What are diffraction, interference, wavefront, spectrometer-goniometer, index, wavelength, frequency, and spectrum?

Since the refractive index is a function of wavelength and decreases as the wavelength increases, white light passing through a prism gives a spectrum, meaning it separates into its constituent primary rays. Short-wavelength violet rays deviate the most, while long-wavelength red rays deviate the least. Considering this fact, the wavelength of light can be determined using a prism spectrometer.

Using light sources with known wavelengths, the corresponding scale values are read, and a graph, known as the calibration curve, is plotted. The position of the spectral lines of the light from an unknown wavelength source is observed, and the corresponding wavelength is found on the calibration curve.

A spectrometer is an instrument used to measure the angle of deviation caused by the reflection, refraction, and diffraction of light. It is shown in Figure 1.

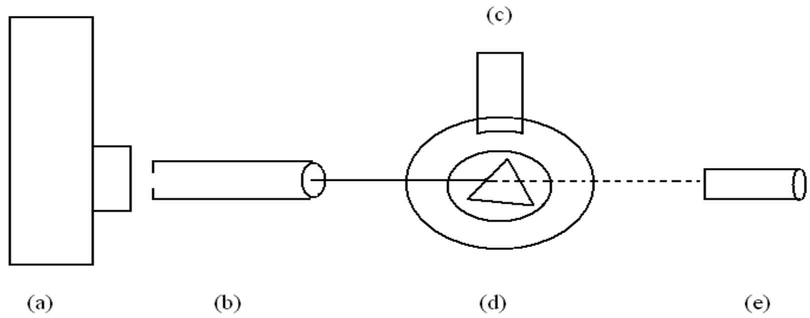

Figure 1: Scheme of the spectrometer. (a) Light source, (b) Collimator, (c) Lamp, (d) Prism and prism table, (e) Telescope.

The *collimator* ensures that the light rays from the light source reach the prism parallel. At one end of the tube, there is a converging lens, and at the other end, there is a slit. The slit plane is adjusted to be at the focal plane of the lens.

The *telescope* is used to determine the position of the deviated rays coming from the prism. The rays that fall on the converging lens in the telescope are focused at the focal point and observed through the eyepiece.

The scale tube is a tube with a converging lens at one end and a millimetric scale at the focal point of the lens. This scale is illuminated by an external lamp. The rays emerging parallel from the lens reflect off the prism and form an image of the millimetric scale at the focal point of the telescope. When looking through the eyepiece, this scale and the slit illuminated by the dispersed light from the prism can be observed.

• Determining the Rydberg constant using the Balmer series of Hydrogen

Energy levels for the Hydrogen atom are given as:

$$E_n = \frac{me^4}{8\varepsilon_0 h^2}\frac{1}{n^2} \qquad (1)$$

The quantum number n is referred to as the principal quantum number. These energy levels are shown in Figure 2. The lowest energy level, E_1 is called the atom's ground state energy. The higher levels (E_2 ,E_3 ,…) are referred to as the atom's excited state energies. As the principal quantum number n increases, the absolute values of the corresponding E_n energies decrease. However, due to the presence of the '–' sign, the E_n value approaches E_∞ =0 as n approaches infinity. This means the electron has transitioned to a free state.

When an electron transitions from a higher energy level to a lower energy level, the energy difference between these levels is released due to the conservation of energy. This released energy packet is called a photon.

Einstein, when explaining the photoelectric effect for which he won the Nobel Prize, assumed that the relationship between the energy of a photon and its frequency is given by $E = h\nu$, and this assumption was confirmed by the photoelectric effect itself. Accordingly, for a photon emitted when an electron in a hydrogen atom transitions from a higher level to a lower level:

$$h\nu = E_{initial} - E_{final} \qquad (2)$$

Using this definition:

$$\nu = \frac{1}{\lambda} = R\left(\frac{1}{n_{initial}^2} - \frac{1}{n_{final}^2}\right) \qquad (3)$$

In the above relation, all constants are combined and represented by R. This constant is called the *Rydberg constant*, and its value is calculated to be 1.0968×10^5 cm^{-1}.

This relation implies that the emission that occurs when a hydrogen atom is excited can only occur at specific wavelengths. The relations obtained for the first three series in the hydrogen atom's spectrum are as follows:

$$n_{initial} = 1, \frac{1}{\lambda} = R\left(\frac{1}{1} - \frac{1}{n_{final}^2}\right), n_{final} = 2, 3, 4 \ldots \textit{Lyman Series}$$

$$n_{initial} = 2, \frac{1}{\lambda} = R\left(\frac{1}{2} - \frac{1}{n_{final}^2}\right), n_{final} = 3, 4, 5 \ldots \textit{Balmer Series}$$

$$n_{initial} = 3, \frac{1}{\lambda} = R\left(\frac{1}{3} - \frac{1}{n_{final}^2}\right), n_{final} = 4, 5, 6 \ldots \textit{Paschen Series}$$

Among these spectral series, the Lyman series falls in the ultraviolet region, the Balmer series in the visible region, and the Paschen series in the infrared and longer wavelength regions. The spectral series of hydrogen in terms of wavelengths are plotted in Figure 3. Accordingly, for the red line in the Balmer series of the hydrogen spectrum, $n_{\text{final}} = 3$; for the green line, $n_{\text{final}} = 4$; and for the violet line, $n_{\text{final}} = 5$.
The wavelengths of these lines are determined as follows: The 'scale values' are read from the spectrometer's scale. The corresponding λ values are then determined from the calibration curve

for these 'scale values.' The determined wavelength values are substituted into the above formula, using cm in place of Å.
Thus, the values obtained are calculated as:

R_1 = _______, R_2 = _______, R_3 = _______

From the Rydberg constants, the average R is calculated as $R_{average}$ = _______ cm^{-1}.

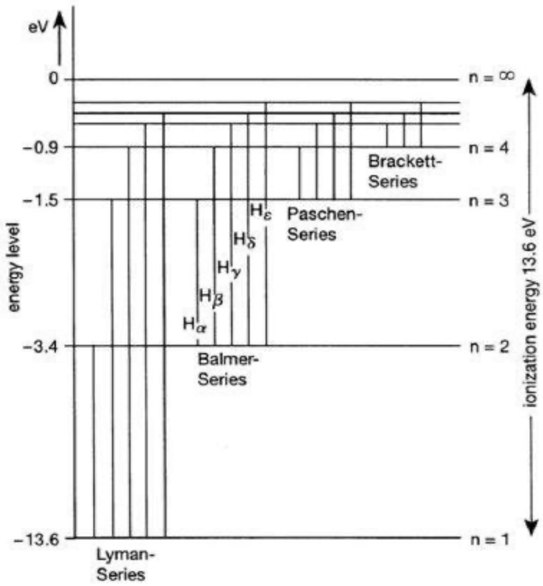

Figure 2: Spectrum for hydrogen.

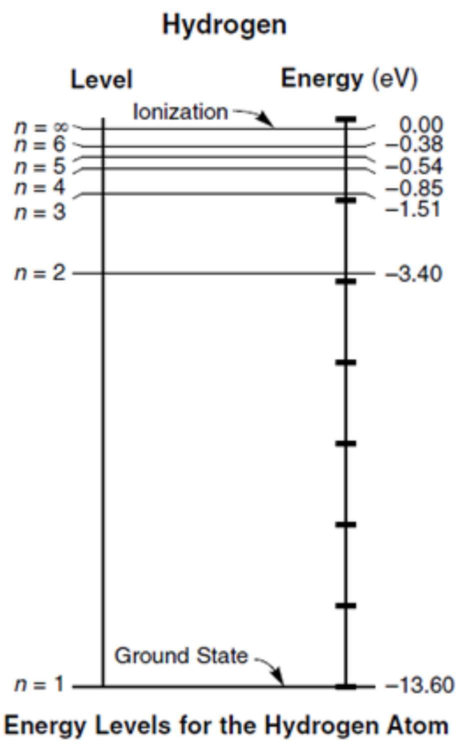

Figure 3: Energy levels of the hydrogen atom.

EXPERIMENTAL PROCEDURES

1. After the spectrometer is prepared for the experiment, the millimeter scale in the R tube is illuminated from the outside. By rotating the telescope around the axis of the table, the illuminated scale is made visible inside the telescope.

2. A helium tube is placed vertically in front of the slit in the collimator. The characteristic lines and wavelengths in the spectrum are shown in Table 1.

3. The *n* scale values corresponding to the helium wavelengths are read and recorded in Table 1, and a calibration curve is plotted.

4. The helium tube is removed and replaced with a hydrogen tube. The *n* scale values corresponding to some lines of the hydrogen spectrum given in Table 2 are read and recorded in Table 2.

5. Using the calibration curve obtained for helium, wavelengths that are corresponding to the *n* scale values obtained from the hydrogen are found.

Table 1: For the helium source, the observed spectrum's color and wavelength

Color of the line	**λ (wavelength) (Å)**	***n* (scale)**
Red	7065	
Burgundy red	6678	
Yellow	5875	
Green	5015	
Pine green	4921	
Blue	4713	
Violet 1	4471	
Violet 2	4387	
Violet 3	4144	
Violet 4	4120	

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Table 2: For the hydrogen source, the observed spectrum's color and wavelength.

Color of the line	**λ (wavelength) (Å)**	***n* (scale)**
Red	7065	
Burgundy red	6678	
Yellow	5875	