Salahaddin University-Erbil
College of Education
Department of Physics
Second Semester

Wave Optics

Student Name :

Name of the Exp.:

Exp. No. :

Date : / / 2023

Group :

OPTICS EXPERIMENTS

Second Semester

Wave Optics

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He-Ne and Laser Diode Safety

The small He-Ne (red and green) and visible (red) diode lasers used in this laboratory pose a potential serious eye risk and must be treated with respect. In using these lasers, the following safety procedures **must** be obeyed.

- Never look down, or close to the unexpanded beam.
- Block all stray beams that leave the immediate work area.
- Remove all unnecessary reflective items from work area, especially unused optical components.
- Avoid optical system layouts that produce vertical beams.
- Remove rings, watches and pendant jewelry, they may result in stray reflections. Do not use an eyepiece, including camera eyepiece, to view laser light.

When viewing an expanding beam, for example in holography, if colour appears to change during viewing it is too bright. Reduce the intensity with neutral density filters or cross polarisers.

Experiment No. (1)

Studying the Phenomenon of Diffraction from a Single Slit

Aim:

The aim of this experiment is to determine the wavelength of a monochromatic light by studying the phenomenon of diffraction from a single slit.

Apparatus:

1) Optical bench
2) A monochromatic light
3) Single slit
4) Screen and plotting paper.

Theory:

Diffraction phenomena can be explained according to Huygens wave theory when a light of a wavelength λ falls onto a slit, each point of the slit acts as a starting point of a new wave. Diffraction can be divided into two main groups namely, Fresnel and Fraunhofer diffraction. In Fresnel diffraction the light source and the screen or both are at finite distance from the aperture or obstacle causing diffraction, while Fraunhofer diffraction the source and the screen both are at infinite distance. In the following, we will consider Fraunhofer diffraction only.

Consider a parallel beam of light is incident on a single slit as shown in figure1. According to Huygens's principle, each portion of the slit acts as a source of light waves. Hence, light from one portion of the slit can interfere with light from another portion, and the resultant light intensity on a viewing screen depends on the direction. To analyze the diffraction pattern, it is convenient to divide the slit into two halves, as shown in figure 1. Keeping in mind that all the waves are in phase as they leave the slit, consider rays 1 and 3. As these two rays travel toward a viewing screen far to the right of the figure, ray 1 travels farther than ray 3 by an amount equal to the path difference $(a/2)\sin(\theta)$, where a is the width of the slit. Similarly, the path difference between rays 2 and 4 is also $(a/2)\sin(\theta)$. If this path difference is exactly a half wavelength (corresponding to a phase difference of 180°) then the two waves cancel each other and destructive interference results. This is true for any two rays that originate at points separated by half the slit width because the phase difference between two such points is 180°. Therefore, waves from the upper half of the slit interfere destructively with waves from the lower half when

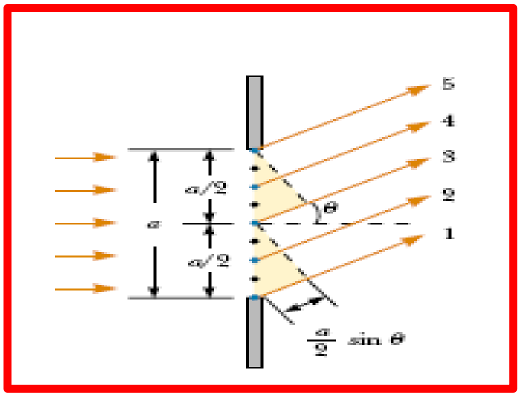


Figure 1: Diffraction of light by a narrow single slit of width **a**.

$$\frac{a}{2}\sin(\theta) = \frac{\lambda}{2}$$

$$\sin(\theta) = \frac{\lambda}{a} \qquad \dots (1)$$

If we divide the slit into four equal parts and use the similar argument, we find that the viewing screen is also dark when

$$\sin(\theta) = \frac{2\lambda}{a} \qquad \dots (2)$$

If we kept dividing, we would have the general condition for destructive interference, see figure 2, which is

$$\sin(\theta_m) = m\frac{\lambda}{a} \qquad \text{where } m = \pm 1, \pm 2, \pm 3, \dots \qquad \dots (3)$$

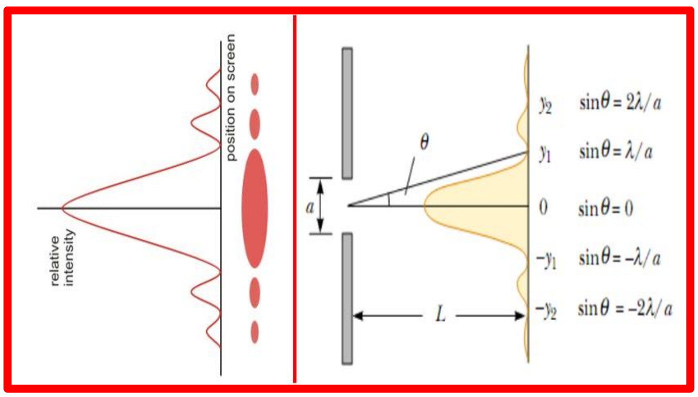


Figure 2: Intensity distribution for a Fraunhofer diffraction pattern from a single slit of a width **a**, showing the positions of two minima on each side.

This equation gives the values of θ for which the diffraction pattern has zero light intensity that is, when a dark fringe is formed. However, it tells us nothing about the variation in light intensity along the screen, which is shown in figure 2.

The intensity distribution for a Fraunhofer diffraction pattern from a single slit of a width a is given by,

$$I = I_{Max}\left(\frac{\sin\left(\pi a \sin(\theta)/\lambda\right)}{\pi a \sin(\theta)/\lambda}\right)^2 \qquad \dots (4)$$

Where $I_{Max}$is the intensity at $\theta = 0$ (the central maxima).

Now, for this result, we see the minima occur when $sin(\pi a$ sin $(\theta)/\lambda)$=0 that is

$$\frac{\pi a \sin(\theta)}{\lambda} = m\pi$$

Or

$$\sin(\theta_m) = m\frac{\lambda}{a} \qquad \text{where } m = \pm 1, \pm 2, \pm 3, \ldots$$

Which the result we have reached in equation 3.

In order to calculate the laser's wavelength using single slit diffraction pattern, we will consider the following: L is the distance on the screen between the slit and the center of the central maximum on the screen and y_1 is the distance on the screen from the center of the central maxima to the first minima, as depicted in figure 2. For this geometry the condition for minimum is, using sin $(\theta) \cong \theta$.

$$\frac{y_m}{L} = m\frac{\lambda}{a} \qquad \ldots (5)$$

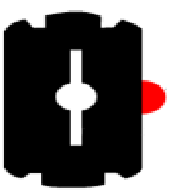
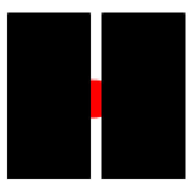
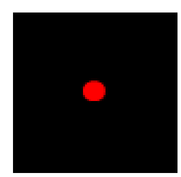
The first intensity minima will be distance y_1, from the center of the central maxima, is given by

$$y_1 = \frac{\lambda L}{a} \qquad \ldots (6)$$

The width of the central maximum $\beta = 2y_1$

$$\beta = \frac{2\lambda L}{a} \qquad \ldots (7)$$

Below are some examples of *diffraction patterns* that are created by certain objects:

Sharp edge (razor blade)	**Slit**	**Wire**	**Circular hole**
			
			

Procedure:

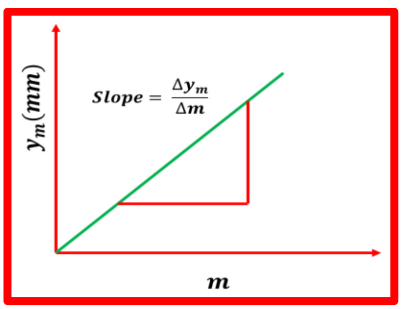
1) Setup the experiment as shown in figure 3.

Fig. 3: Experimental Setup

2) Switch on the laser light.
3) Stick a graphing (plotting) paper to the screen.
4) Align the laser light with the single slit and adjust the screen distance from the single slit until you see a clear diffraction pattern on the screen.
5) Measure the distance (y) between the center of the bright fringe and the center of the first (m) bright fringe.
6) Measure the distance between the center of the bright fringe and the center of the second bright fringe.
7) Repeat the step (6) for the third, fourth, fifth and sixth bright fringes.
8) Record your data in a table as shown below.

m	y_m (mm)

9) Measure the distance (L) between the single slit and the screen.
10) Plot m on x-axis and y_m on y-axis then find the slope of the line.



11) By using the equation below find the wavelength of the light source.

$$\lambda = \frac{a * slope}{L}$$

where d is the slit width and L is the distance between the single slit and the screen.

Assume, $\boldsymbol{a = 0.4\ mm.}$

Questions:

1) How a diffraction occurs by a single slit?
2) How the diffraction pattern spacing changes with the wavelength?
3) What is the relation between fringes spacing and slit width?
4) What is difference between diffraction and interference?
5) What are the main types of diffraction? Explain each one according to the wavelength and slit width.
6) Why we use laser as a light source in this experiment?
7) What is the deference between laser light and other ordinary light?
8) What is monochromatic source of light?
9) What is coherent source?
10) How the fringes width varies with distance from the silt?

Experiment No. (2)

Determination the Wavelength of Monochromatic Light Source by using Diffraction Grating.

Aim:

The aims of this experiment are:

1) To study diffraction of light using a diffraction grating spectrometer.
2) To measure the wavelengths of certain lines in the spectrum of the mercury lamp.

Apparatus:

1) Spectrometer
2) Transmission grating (600 lines per mm)
3) Mercury lamp.

Theory:

The phenomenon of diffraction of light is another way to prove the wave properties of light. The Diffraction phenomenon of light was first discovered by Grimaldi in 1665 and its experimental study was done by Newton and Young. Diffraction phenomenon was explained systematically by Augustin Jean Fresnel on the basis of Huygen's wave theory of light in 1815.

The bending of light waves around the sharp edges of opaque obstacle or aperture is defined as diffraction of light. The diffraction phenomenon of light depends on the size of the opening obstacle ("a") and the wavelength of light (λ). Now if we consider a light wave of wavelength (λ) is made to incident on an obstacle of size ("a") then there will be following three possibilities:

(i) If $a <<< \lambda$, then the light waves will undergo reflection not diffraction.

(ii) If $a >>> \lambda$, then the wave will not be diffracted.

(iii) If $a \cong \lambda$ or If $a \leq \lambda$ (about approximately equal) then the waves will deviate from its rectilinear path and form Diffraction of light.

Now to observe the diffraction of light by spectrometer we use diffraction grating in our experiment. The diffraction grating is essentially a multiple-slit device which consists of a large number of fine equidistant, closely-spaced parallel lines of equal width ruled on glass or polished metal by a diamond point (see figure 2). The diffraction grating can be classified into two types, reflective diffraction grating and transmission diffraction grating (we use this type). In transmission gratings glass is used; the lines scatter the incident light and are more or less opaque while the spaces between them transmit light and act as slits.

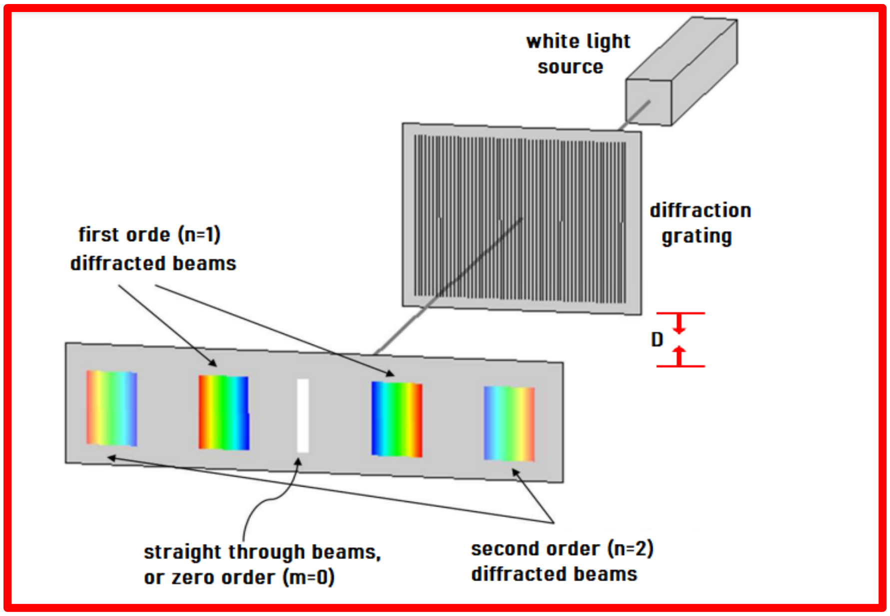


Figure 2: diffraction of white light by diffraction grating.

Diffraction gratings are used to produce spectra and for measuring wavelengths accurately. They have replaced the prism in much modern spectroscopy. Their usefulness arises from the fact that they give very sharp spectra, most of the incident light being concentrated in certain directions.

When light from a bright and small source passes through a diffraction grating, it generates a large number of sources at the grating. The very thin space between every two adjacent lines of the grating becomes an independent source. These sources are coherent sources meaning that they emit in phase waves with the same wavelength. These sources act independently such that each source sends out waves in all directions. As shown in figure 2, on a screen a distance D away, points can be found whose distance differences from these sources are different multiples of λ causing bright fringes. One difference between the interference of many slits (diffraction grating) and double slit experiment is that a diffraction grating makes a number of principle maxima along with lower intensity maxima in between. The principal maxima occur on both sides of the central maximum for which a formula similar to double slit interference holds true which is given by:

$$d * \sin(\theta_n) = n * \lambda \tag{1}$$

In this equation, d is the spacing between every two lines (same as every two sources). If there are N lines per mm of the grating, then d, the space between every two adjacent lines or (every two adjacent sources) is

$$d = \frac{1}{N} \tag{2}$$

Based on equation (1), if the light source has different colors (different wavelengths), shorter wavelength color will have smaller diffraction angle compared to longer wavelength for the same order of principle maximum. Thus, we will see a spectrum in such case. The angular spacing for different colors will increase for higher order maxima.

A spectrometer is a device that measures a continuous, non-discrete physical characteristic by first separating it into a spectrum of its constituent components (see figure 3).

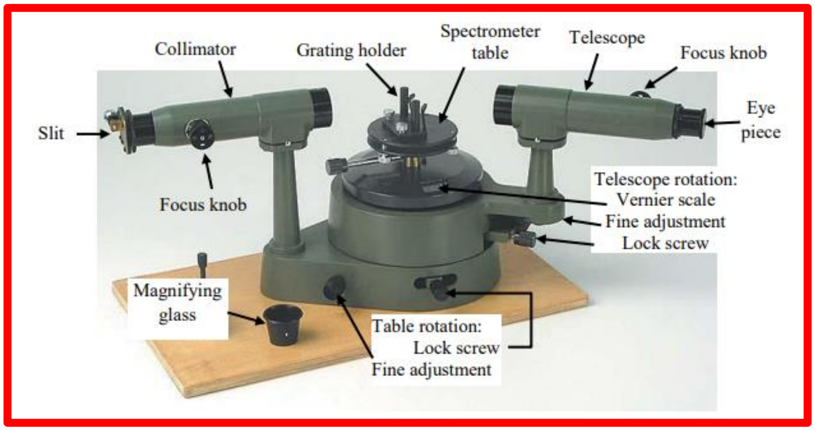


Figure 3: Spectrometer and its components.

Procedure:

1) Setup the experiment as shown in figure 4.

Figure 4: Experimental setup.

2) Adjust the spectrometer as follows:

A) Make sure cross threads are in focus and upright

B) Focus on a distant object to ensure parallel beams

C) Illuminate the slit and focus on slit

D) Adjust the width of the slit to get a narrow beam

E) level the turntable

3) Place the diffraction grating vertically in the holder.

4) Look through the eye-piece which is straight in front of the grating to find the zero-order image. At this stage ensure the vernier scale is zeroed. Hint: The zero number of the vernier scale should be at the collimator side of the spectrometer.

5) Move the telescope to the right and put the cross wire on the violet color of the 1st order image then read the angle (θ_1) of the vernier scale.

6) Move the telescope to the left and put the cross wire on the violet color of the 1st order image then read the angle (θ_2) of the vernier scale.

7) Do step 5 and 6 for other colors and record your data in a table as shown below.

8) Find the wavelength of each color if you know $\left(d = \frac{1}{N}\right)$. where, N is number of grooves.

$n = 1$ and $N =$				
Color	$\theta_1\ (degree)$	$\theta_2\ (degree)$	$\theta = \frac{\theta_2 - \theta_1}{2}$ (degree)	$\lambda = \frac{\sin(\theta)}{N}$
Violet				
Indigo				
Blue				
Green				
Yellow				
Orange				

9) Compare your results with the following wavelengths.

	Color	**Wavelength Interval**
	Red	$\sim 625 - 740\ nm$
	Orange	$\sim 590 - 625\ nm$
	Yellow	$\sim 565 - 590\ nm$
	Green	$\sim 520 - 565\ nm$
	Cyan	$\sim 490 - 520\ nm$
	Blue	$\sim 445 - 490\ nm$
	Indigo	$\sim 425 - 445\ nm$
	Violet	$\sim 380 - 425\ nm$

Questions:

1) Define diffraction of light
2) What is the formula for diffraction grating?
3) What are the applications of diffraction?
4) How many types of grating are there?
5) What factors affect diffraction?
6) What are some examples of diffraction?
7) What are the conditions for diffraction?
8) What is the relationship between diffraction and the wavelength of light?
9) What is grating and what is grating constant?
10) How does a grating work?
11) What do the lines on the diffraction grating represent?
12) What is first order diffraction?
13) How do you work out grating spacing?
14) What are the differences between grating and prism spectrum?
15) Why sodium light is used in spectrometer?
16) Is white light monochromatic?

Experiment No. (3)

Studying the Phenomenon of Interference of Light Waves by Young's Double Slit Experiment

Aim:

In this experiment we treat light beams as wave. Then aims of this experiment are to:

1) Study the inference of light.

2) Determine the wavelength of Sodium Light.

Apparatus:

1) Monochromatic light (sodium Source)
2) Double slit film
3) Optical Bench and Holder
4) Adjustable Single Slit
5) Eye Piece

Theory:

To understand the phenomenon of interference of light waves we should know about the principle of superposition and how does it occur. The principle of superposition states that when two or more waves meet at a point, the resultant wave has a displacement which is the vector sum of the instantaneous amplitudes of the individual light waves. For instance, if we have two waves, the first wave can be represented by $y_1(x,t)$ and the second wave can be represented by $y_2(x,t)$. According to the principle of superposition the resultant wave is equal to $[y = y_1(x,t) + y_2(x,t)]$ as shown in figure (1).

$$y_1(x,t) = A \text{ Sin } (k_1 x - wt)$$

$$y_2(x,t) = A \, Sin(k_2 x - wt)$$

$$y = A \, \text{Sin}(k_1 x - wt) + A \, Sin(k_2 x - wt)$$

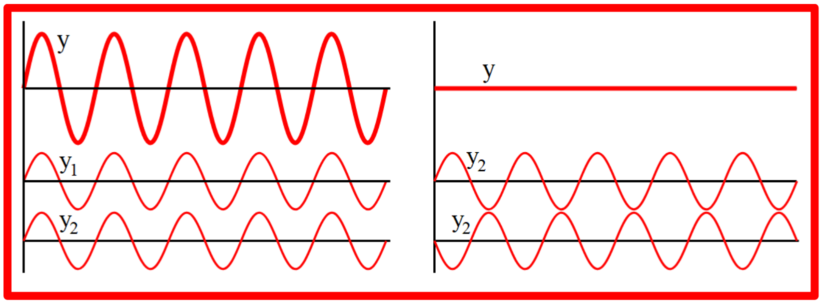


Figure (1) shows the superposition of two light waves.

The interference of light in the region of superposition can be defined as; when two waves of same frequency and constant phase difference travel simultaneously in the same direction, then there is a change in the intensity of the waves due to superposition of two waves. This change in the intensity is said to be interference. Or, the phenomenon of redistribution of light energy due to the superposition of light waves from two or more coherent sources is known as interference. The points where change in intensity is greater than that of the sum of the intensities due to the individual waves are called constructive interference which appears in bright fringes whereas some other points where change in intensities is less than that of the sum of the intensities due to individual waves are called destructive interference which appears in dark fringes.

The British physicist in 1801 was the first one who demonstrated the optical phenomenon of interference of light by a simple double slit experiment. He made two pinholes S_1 and S_2 (very close to each other) on an opaque screen. These were illuminated by another pinholes that was in turn, lit by a bright source. Light waves spread out from S and fall on both S_1 and S_2 (see figure (2 and 3)). S_1 and S_2 then behave like two coherent sources because light waves coming out from S_1 and S_2 are derived from the same original source and any abrupt phase change in S will manifest in exactly similar phase changes in the light coming out from S_1 and S_2. Thus, the two sources S_1 and S_2 will be locked in phase; i.e., they will be coherent. This means two sources are said to be coherent source if these two have constant phase difference between them and have same frequency.

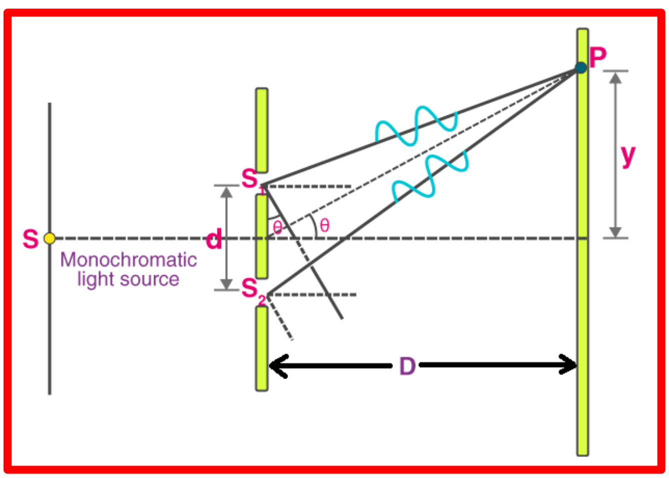


Figure (2) illustrates two monochromatic sources

To derive young's double slit experiments, consider a monochromatic light source 'S' kept at a considerable distance from two slits S_1 and S_2. S is equidistant from S_1 and S_2. S_1 and S_2 behave as two coherent sources as both are derived from S. The light passes through these slits and falls on a screen which is at a distance 'D' from the position of slits S_1 and S_2. 'd' is the separation between two slits. If S_1 is open and S_2 is closed, the screen opposite to S_1 is closed, only the screen opposite to S_2 is illuminated. The interference patterns appear only when both slits S_1 and S_2 are open.

When the slit separation (d) and the screen distance (D) are kept unchanged, to reach P the light waves from S_1 and S_2 must travel different distances. It implies that there is a path difference in Young's double slit experiment between the two light waves from S_1 and S_2. Two approximations should be considered to in the experiment:

A) $\boldsymbol{D \gg d}$**:** Since D > > d, the two light rays are assumed to be parallel.

B) $\boldsymbol{d/\lambda \gg 1}$**:** Often, d is a fraction of a millimeter and λ is a fraction of a micrometer for visible light.

Under these conditions θ is small, thus we can use the approximation $Sin(\theta) = \tan(\theta) = \theta = \lambda/d$.

So, the path difference $\Delta = \lambda/d$. This is the path difference between two waves meeting at a point on the screen. Due to this path difference in Young's double-slit experiment, some points on the screen are bright and some points are dark.

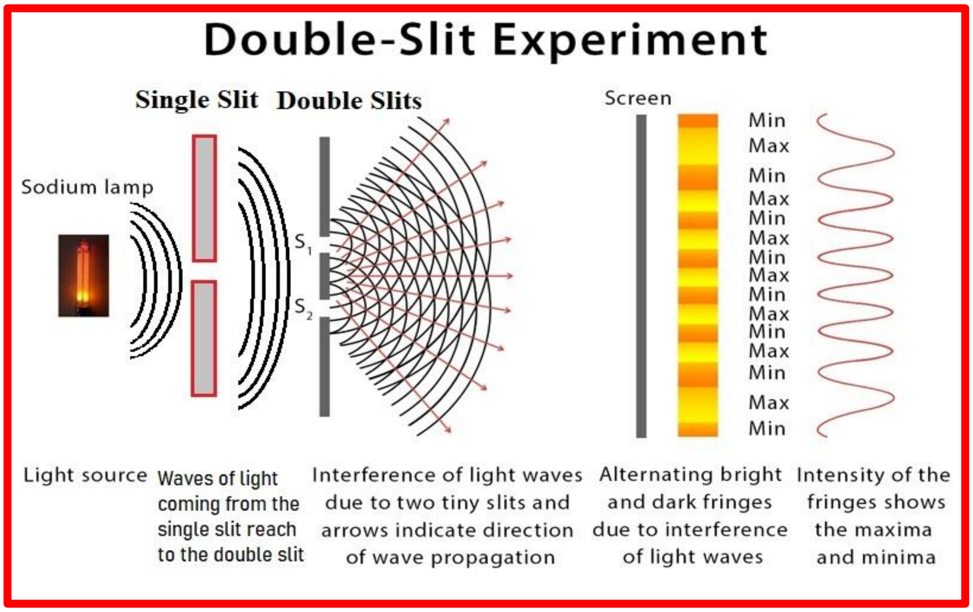


Figure (3) shows double slit experiment

The characteristics of young's double-slit experiment mathematically can be summarized as follows:

1) Path difference (Δ):

$$\Delta = S_2P - S_1P = d\,Sin(\theta) = \frac{d * y}{D}$$

Maxima path difference: $\Delta = d\,Sin(\theta) = n\lambda = \frac{d*y}{D}$ where $n = 0, \pm1, \pm2, \pm3, \ldots$

Minima path difference: $\Delta = d\,Sin(\theta) = (2n-1)\frac{\lambda}{2}$ where $n = \pm1, \pm2, \pm3, \ldots$

2) Position of n^{th} bright fringes (constructive interference) from central maxima:

$$(y_n)_{Bright} = \frac{n * D * \lambda}{d}$$

where $n = \pm 1, \pm 2, \pm 3, \ldots$

3) Position of n^{th} dark fringes (Destructive Interference) from the central maxima:

$$(y_n)_{Dark} = \frac{(2n - 1) * D * \lambda}{2d}$$

where $n = \pm 1, \pm 2, \pm 3, \ldots$

4) Fringe width (β): It is the separation between two consecutive bright or dark fringes.

$$\beta = y_{n+1} - y_n = \frac{D * \lambda}{d}$$

5) Wavelength of light (λ):

$$\lambda = \frac{\beta * d}{D}$$

6) Phase Difference (δ):

$$\delta = k * \Delta$$

Where $k = 2\pi/\lambda$ is the wave number.

Conditions for Interference of Light:

A) Conditions for sustained interference:

1) The two light sources must be coherent *i.e.*, they should emit continuous light waves of same frequency or wavelength and they must have phase difference between them either zero or constant with respect to time.
2) The polarization state of both waves must be same.
3) The two coherent light waves must be travel in same direction.

B) Conditions for good observation:

1) The separation between two coherent sources must be very small.

2) The screen must be placed quite far from the two coherent sources.
3) The two coherent sources should be strong with least back ground.

C) Conditions for good contrast:

1) The amplitudes of waves from two coherent sources should preferably be equal.
2) The coherent sources should be point sources or narrow sources.
3) The two coherent sources preferably be monochromatic.
4) The two coherent light waves should have their vibration in same direction.

Procedure:

1) Set up the experiment as shown in figure (4).

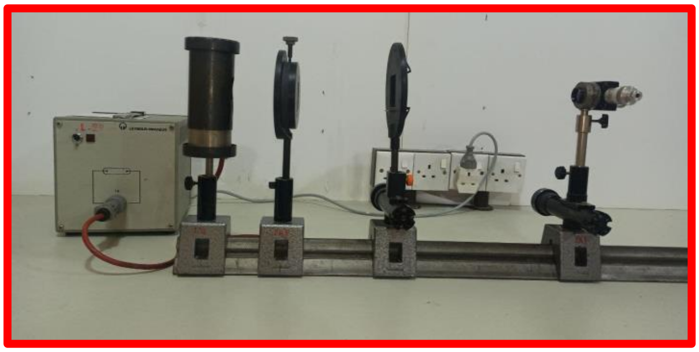


Fig. 4: Experimental Setup

2) Switch on the power supply and wait for a few minutes until a stable bright light is achieved.
3) By aligning the incoming light with single slit, double slit and the eyepiece you will be able to see the fringes.
4) The fringes are in dark (black) and bright (yellow) color as shown in figure 5.

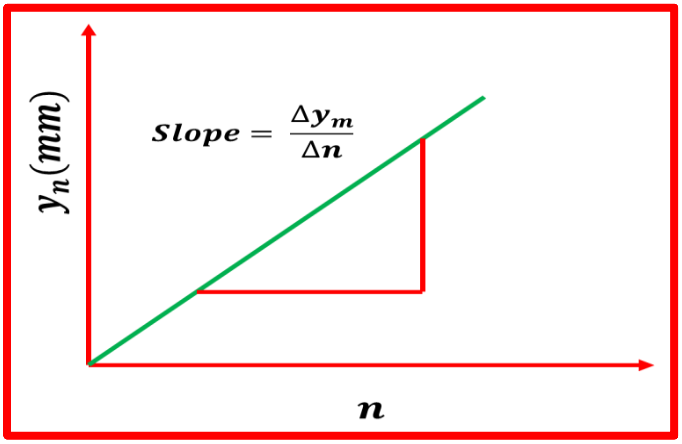
Figure 5: dark (black) and bright (yellow) fringes.

5) At the right side of the fringes put the cross wire of the eyepiece on the first bright fringe (n) then read the micrometer (vernier) scale in millimeter.
6) Move the cross wire on the second bright fringe then measure its distance (y) from the first bright fringe.
7) Repeat step (6) for third, fourth, fifth and sixth bright fringes and record your data in a table as shown below.

n	$y_n\ (mm)$

8) Measure the distance (D) between the double slit and the eyepiece.

9) Plot n on x-axis and y_n (mm) on y-axis the find the slope of the line.



10) By using the equation below find the wavelength of the light source.

$$\lambda = \frac{d * slope}{D}$$

where d is the slit width and D is the distance between the double slit and the eyepiece.

Assume, $\boldsymbol{d = 0.2\ mm.}$

Questions:

1) What does Young's experiment prove?
2) Why is it important that monochromatic light be used in Young's interference experiment?
3) What do you mean by interference?
4) What is light interference?
5) What are interference fringes?
6) What is an example of interference of light?
7) What are the main types of interference?
8) What is an example of constructive interference?
9) What are different types of interference?
10) How does interference happen?
11) What is the concept of interference?
12) What kinds of waves can show interference?
13) What are coherent sources of light?
14) Write an equation for each of the dark and bright fringes.
15) How the distance between fringes varies with the slit width?
16) Explain the relation between wavelength and the slit width.
17) What is fringe width?

Experiment No. (4)

Determination the Wavelength of Color Filter by Using Newton's Rings

Aim:

The aim of this experiment is to determine the wavelengths a color filter by using Newton's rings.

Apparatus:

No.	Material	No.	Material
1	1 Newton rings apparatus	**8**	2 Lens holder
2	1 Lens, mounted, f = +50 mm	**9**	4 Slide mount f. opt. pr.-bench, h = 30 mm
3	1 Interference filters, set of 3	**10**	1 Slide mount f. opt. pr.-bench, h = 80 mm
4	1 Screen, translucent, 250 x 250 mm	**11**	1 Optical profile-bench, l = 1000 mm
5	1 Lamp, f. 50 W Hg high press. lamp	**12**	2 Base f. opt. profile-bench, adjust.
6	1 Power supply for Hg CS/50 W lamp	**13**	1 Rule, plastic, l = 200 mm
7	1 Double condenser, f = 60 mm		

Theory:

Newton's rings are a phenomenon in which an interference pattern is created by the reflection of light between two surfaces, typically a spherical surface and an adjacent touching flat surface. Interference occurs when two coherent light beams overlap after travelling different paths. Newton's ring apparatus consists of a plano-convex lens of long focal length on a glass plate. Interference occurs through thin air film enclosed between the lower surface of the lens and the upper surface of the plate. Here, the interference due to the reflected beams will be considered where the interference of transmitted beam is complementary to it.

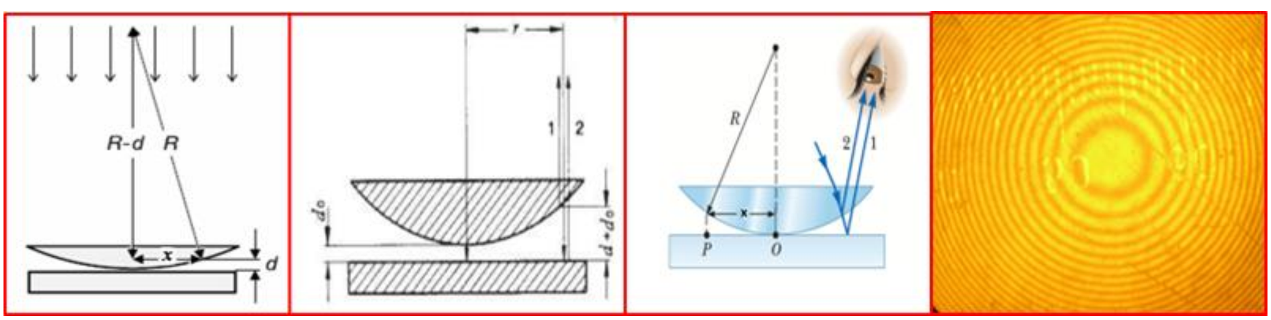


Figure 1: Plano-convex lens with radius of curvature R in contact with glass plate

Suppose the radius of curvature of the lens is R and the thickness of the air film at a distance (x) from the contact point between the lens and the plate is $d(x) = d + d_o$, figure 1, d_o can be positive if there is dust between the lens and the glass plate, and it can be negative if the lens compressed at the touching point. In figure 1, Ray 1 reflected at the lower surface of the lens will interfere Ray 2 reflected at the top of the glass plate with path difference given by,

$$Path\ difference = 2(d + d_o)$$

The factor 2 appears as ray 1 travels twice the air film. A phase shift π is experienced by the ray 2 due to travelling between optically thinner and denser medium. Then the path difference between the interfering rays become

$$\delta = 2(d + d_o) + \frac{\lambda}{2} \qquad \ldots (1)$$

As the condition for maximum cancellation between the two interfering beams is

$$\delta = \left(n + \frac{1}{2}\right)\lambda \qquad \ldots (2)$$

then from equation (1) and (2)

$$2(d + d_o) + \frac{\lambda}{2} = \left(n + \frac{1}{2}\right)\lambda$$

After rearranging this equation gives,

$$2(d + d_o) = n\lambda \qquad \ldots (3)$$

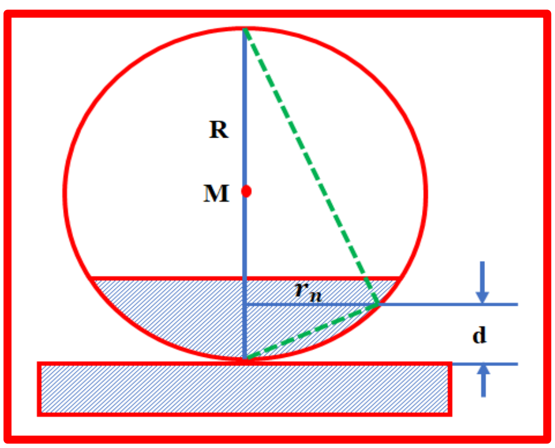


Figure 2. Geometry used to determine the thickness d.

From Figure 1 and 2, it is clear that

$$r_n^2 = d(2R - d)$$

but as the lens in Newton's apparatus is slightly bend then $(2R \gg d)$, so we can assume

$$r_n^2 = 2dR \qquad \ldots (4)$$

Substituting for d from equation 3 into equation 4

$r_n^2 = nR\lambda + 2d_oR$

d_o can be approximated to zero then

$$r_n^2 = nR\lambda \quad \dots (5)$$

Where r_n is the nth dark ring in the interference pattern. In the case of the transmitted beam, the substitution is complementary to that of the reflected light studied above. Where in the interference of the transmitted beams the middle of the set of the interference rings is bright ring not a dark one and $r_n^2 = nR\lambda$ is the radius of the bright nth ring of the Newton's rings. The experiment is going to be carried out for the transmitted beam, as it is simpler, and the radii of the bright interference rings, the relationship

$r_n^2 = (n-1)R\lambda + 2Rd_o$

Procedure:

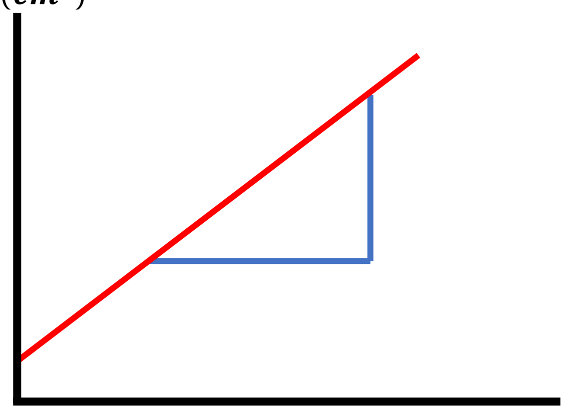
1) Setup the experiment as shown in figure 4.

Fig. 4: Experimental setup.

2) Switch on the power supply and adjust the three screws on newton's ring apparatus until interference ring can be observed.
3) Adjust the lens and the color filter until clear you see clear rings.
4) Stick a plotting paper to the screen then measure the diameter of the first bright ring (D_1).
5) Now, measure the diameter of the second (D_2), third (D_3), fourth (D_4), fifth (D_5), and sixth (D_6) rings.

6) Tabulate your data as below:

n	$D\ (cm)$	$r = \frac{D}{2}\ (cm)$	$r^2(cm^2)$
1			
2			
3			
4			
5			
6			



7) Plot $\boldsymbol{n}$ on x-axis and $\boldsymbol{r^2(cm^2)}$on y-axis then find the slope of the line.

8) Use the below equation to find the wavelength of the color filter.

$$\lambda = \frac{slope}{R}$$

where $R = 1.13\ m$

Questions:

1) How Newton's rings are formed?
2) Why do the rings get closer as the order of the rings increases?
3) Why is the central spot dark in Newton's rings?
4) Why monochromatic light is used in Newton ring?
5) Where are the Newton's rings formed?
6) What is the use of Newton rings?
7) Which lens is used in Newton's rings experiment? Why?
8) What will happen if white light is used in Newton's ring experiment?
9) What is principle of Newton's ring?
10) Why are circular fringes formed in Newton rings?
11) On what factors does the diameter of ring depend?

Experiment No. (5)

Determination the Wavelength of the He-Ne Laser by Using Michelson Interferometer

Aim:

The aims of this experiment are to:

1) understand the interference phenomenon by using Michelson-Morley interferometer.

2) determine the wavelength of He-Ne laser.

Apparatus:

1) Michelson interferometer
2) He-Ne Laser (1 mW, 220 V AC)
3) Lens, mounted $f = +20\, mm$
4) Supported base
5) Screen

Theory:

If two waves of the same wavelength different amplitudes and phase impinge on one point at the same time interference occurs. If the displacement of the two wanes given by

$$y_1 = a_1 \sin\,(wt - \alpha_1) \qquad \dots (1)$$

$$y_2 = a_2 \sin\,(wt - \alpha_2) \qquad \dots (2)$$

Where a_1, a_2 are the amplitudes, and α_1, α_2 are the initial phase angles, the resultant amplitude wave is

$$y = A \sin\,(\mathrm{wt} - \alpha) \qquad \dots (3)$$

where,

$$A^2 = a_1^2 a_2^2 + 2a_1 a_2 \cos\,(\delta) \qquad \dots (4)$$

$$\delta = \alpha_1 - \alpha_2 \qquad \dots (5)$$

So, the intensity distribution I for the case $(a_1 = a_2 = a)$ is given by:

$$I \approx A^2 \approx 4a^2 cos\left(\frac{\delta}{2}\right) \qquad \dots (6)$$

Michelson interferometer consists of two polished mirrors M_1 and M_2 set perpendicular on each other. A beam splitter (BS) which is a half-silvered glass plate at an angle 45 degree is set in the way of the laser beam. So, one half of the light coming out of the laser source S is reflected by BS to the mirror M1 while the outer half is transmitted toward the mirror M_2. The two beams will return to the BS after being reflected by the mirrors and impinge on the screen (see figure 1). The two points of light on the screen can made coincide by tweaking the fine adjustment screws fitted to the mirror M_2. Interference pattern can be noticed if a lens inserted in between the laser source and the BS. Note that the compensating plate is inserted between the mirror M_2 and BS to compensate the distance traveled in glass between the two Michelson arms.

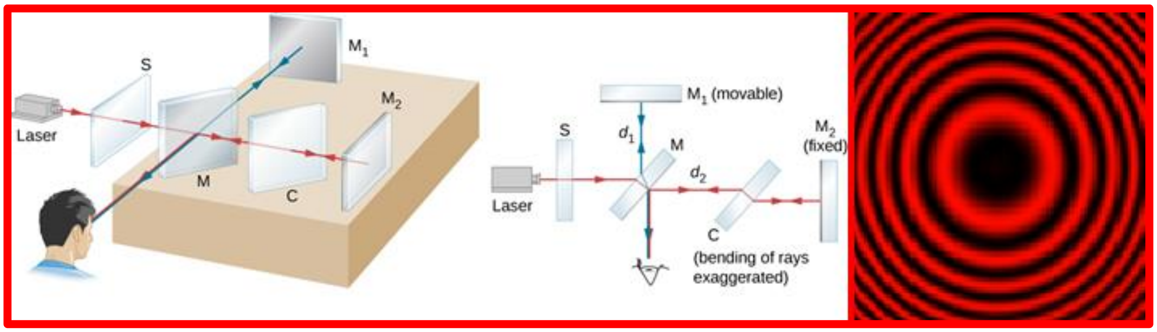


Figure 1: Michelson interferometer

If the path difference between the mirror M_1 and the virtual Mirror M_2', the virtual image of the mirror M_2 formed by the plate BS, is d then the distance between the virtual image $S_1$and S_2' , formed by M_1 and M_2' for the source S, will be $2d$ (see figure 2 for details). The path difference between the two beams will be $2d$ cos (θ), where θ is the inclination angle.

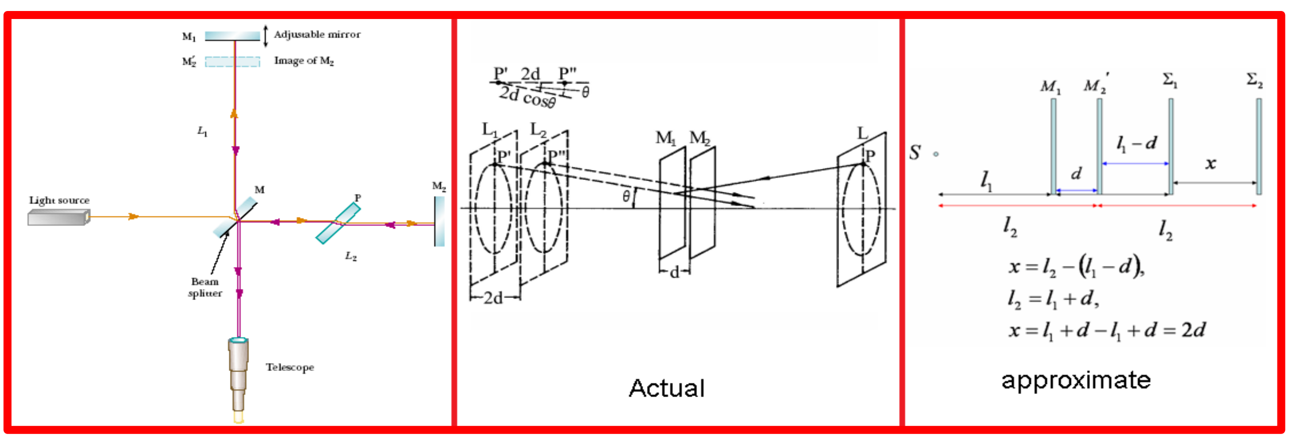


Figure 2: the separation distance between virtual sources

The phase difference $\delta = \frac{2\pi}{\lambda} * path\ difference$

$$\delta = \frac{2\pi}{\lambda} * 2d\cos(\theta) \qquad \dots (7)$$

By Substituting equation (7) into equation (6) we get:

$$I = 4a^2 cos\left(\frac{\pi}{\lambda} * 2d\cos(\theta)\right)$$

Maxima occurs if

$$2d\cos(\theta) = m\lambda \qquad m = 1,2,3, \dots \qquad \dots (8)$$

Thus, for constant θ , fixed inclination angle, by slowly moving the mirror a measured distance d, and counting m, the number of times the fringe pattern is restored to its original state, the wavelength of the light (λ) can be calculated as

$$\lambda = \frac{2\Delta d}{\Delta m} \qquad \dots (9)$$

Procedure:

1) Set up the experiment as shown in figure 3.

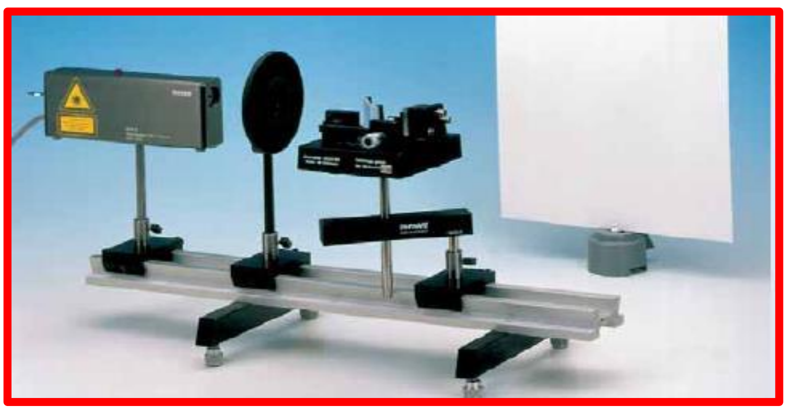


Fig. 3: Experimental setup.

2) Switch on the laser source.
3) Remove the lens and make sure that the laser beam strikes the center of the half-slivered plate at an angle 45∘ .

4) Make the resulting two light points impinge the screen completely overlap using the fine adjustment screws fitted on M_1.

5) Insert the lens $f = 50\ mm$ in the laser beam to enlarge it. Adjust the vertical and the horizontal position to ensure that the beam still strikes the mirrors equally and centrally.

6) Turns the micrometer to any initial position at which the center of the pattern is bright and the micrometer cylinder points to zero.

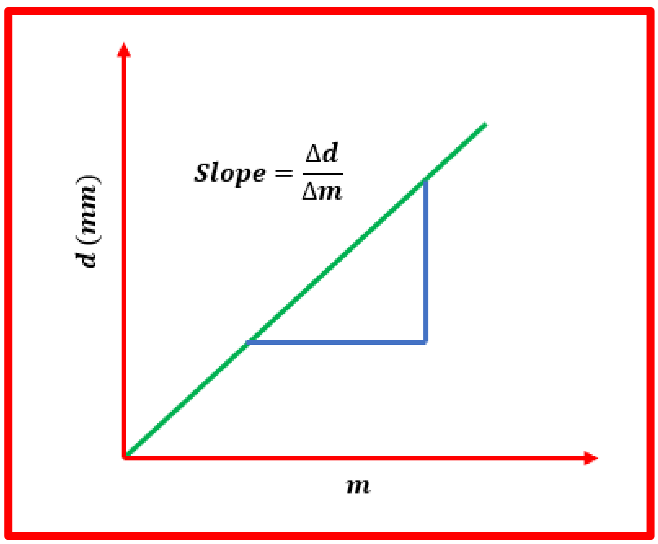
7) Turn the micrometer several times slowly, and at the same time count the intensity maxima growing in the interference pattern (10 times).

8) Read off the distance traveled (d), by the micrometer. You have to notice that the distance travelled by the micrometer must be divided by ten because of the mirror lever reduction.

9) Repeat steps 7 and 8 for several times in each time read different number of maxima's.

10) Record your data in a table as shown below.

m	$d\ (mm)$
10	
20	
30	
40	
50	
60	
70	
80	
90	
100	



11) Plot m on x-axis and $d\ (mm)$ on y-axis then find slope.

12) Find the wavelength of He-Ne laser by using the equation below.

$$\lambda = \frac{2 * slope}{10}$$

<u>Hint:</u> The slope is divided by ten (10) because you counted the intensity maxima growing of the interference pattern (10 times) for each measurement.

Questions:

1) What is the Michelson interferometer used for?
2) How does a Michelson interferometer work?
3) Why do we get circular fringes in Michelson interferometer?
4) Can two lasers interfere?
5) What is it called when two waves overlap?
6) What is interference? What are the types of interference of light?
7) Why is the glass plate inclined at 45 degrees?
8) How the phase deference is adjusted in the Michelson interferometer?
9) What is the equation for finding the wavelength in this experiment?

Experiment No. (6)

Studying Linear Polarization of Light and Verification of Malus's Law

Aim:

The aims of this experiment are:

1) to study linear polarization of light.
2) to verify Malus's law.

Apparatus:

1) Laser, He-Ne 1.0 mW, 220 V AC
2) Optical profile bench, l = 60 cm
3) Base for optical profile bench, adjustable
4) Slide mount f. opt. pr.-bench, h = 30 mm
5) Polarizing filter on stem
6) Photocell, silicon on stem
7) Digital multimeter

Theory:

Polarization means alignment. It can be alignment of molecular of molecular or atomic dipoles in case of dielectric or alignment molecular magnets as in case of magnetic hysteresis, etc. In case of plane polarized light, it is the alignment of the plane of oscillations of electric field components. Actually, Interference and diffraction phenomenon of light only states that the waves nature of light but there is no information available about whether the given light waves are longitudinal or transverse or whether the vibrations are linear, circular, elliptical or torsional. Polarization of light phenomena constitute such types of information.

The phenomena of polarization of light can be explained from electromagnetic theory of light which is given by James Clerk Maxwell in 1864. According to this light is an which has its transverse nature in which electric and magnetic components varying sinusoidally mutually perpendicular to each other and also perpendicular to the direction of wave propagation.

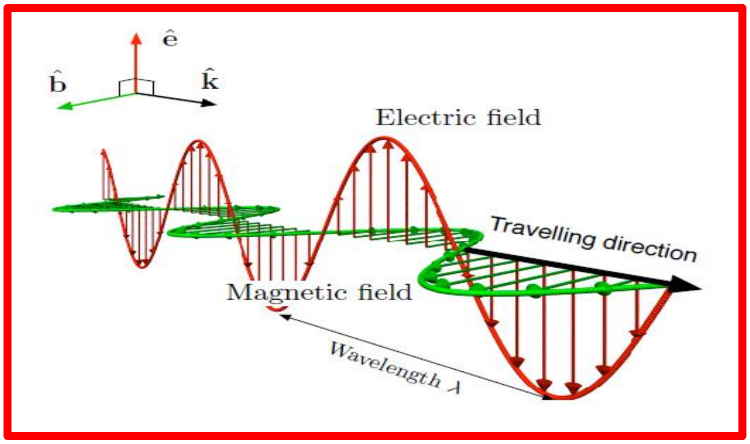


Figure 1: electromagnetic nature of light.

The light in which the vibration of electric vectors are limited or restricted in only any one particular direction in a plane perpendicular the direction of propagation of light is known as polarized light and this phenomena is known as polarization. The types of polarization are:

A) Linear (Plane) Polarization Light (P.P.L):

In linear polarization, the electric field of light is limited to a single plane along the direction of propagation.

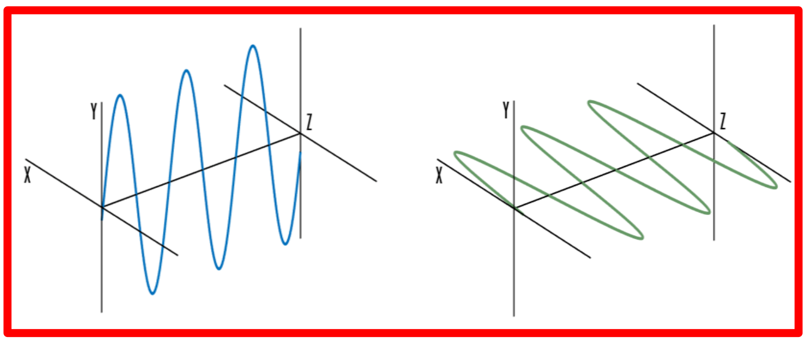


Figure 2: The electric field of linearly polarized light is confined to the y-z plane (left) and the x-z plane (right), along the direction of propagation.

B) Circularly Polarization Light (C.P.L):

There are two linear components in the electric field of light that are perpendicular to each other such that their amplitudes are equal, but the phase difference is $(\frac{\pi}{2})$. The propagation of the occurring electric field will be in a circular motion.

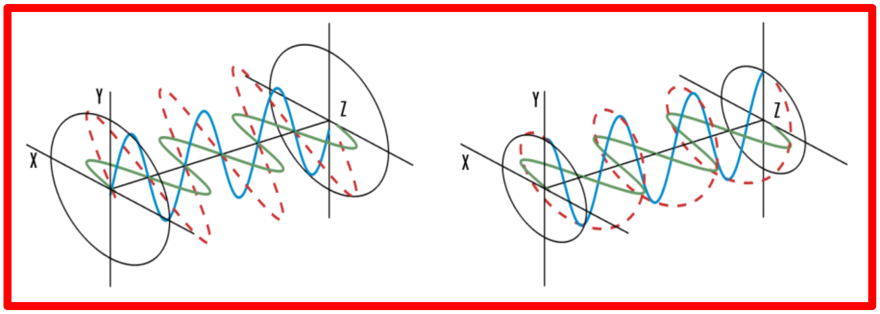


Figure 3: The electric field of linearly polarized light (left) consists of two perpendicular, equal in amplitude, linear components that have no phase difference. The resultant electric field wave propagates along the y = x plane. The electric field of circularly polarized light (right) consists of two perpendicular, equal in amplitude, linear components that have a phase difference of $(\frac{\pi}{2})$. The resultant electric field wave propagates circularly.

C) Elliptically Polarized Light (E.P.L):

The electric field of light follows an elliptical propagation. The amplitude and phase difference between the two linear components are not equal.

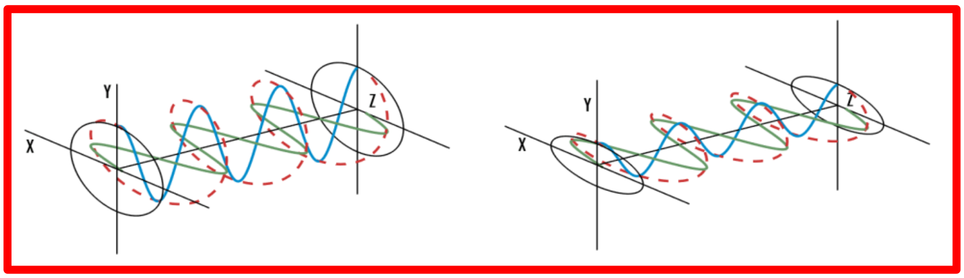


Figure 4: The circular electric field (left) has two components which are of equal amplitude and have a $\pi/2$ or 90° phase difference. If the two components however, have differing amplitudes, or if there is a phase difference other than $\pi/2$, then then they will create elliptically polarized light (right).

There are five methods to produce a polarized light which they are:

A) Polarized by reflection of light.
B) Polarized by refraction of light.
C) Polarized by scattering of light.
D) Polarized by selective absorption or polaroids.
E) Polarized by double refraction phenomenon of light

The most common technique for producing polarized light is to use a material that transmits waves whose electric fields vibrate in a plane parallel to a certain direction and that absorbs waves whose electric fields vibrate in all other directions. In 1938, Edwin Herbert Land (1909–1991) discovered a material, which he called Polaroid that polarizes light through selective absorption by oriented molecules.

It is common to refer to the direction perpendicular to the molecular chains as the transmission axis, optic axes. In an ideal polarizer, all light with E parallel to the transmission axis is transmitted, and all light with E perpendicular to the transmission axis is absorbed. Figure 3 represents an unpolarized light beam incident on a first polarizing sheet, called the polarizer. Because the transmission axis is oriented vertically in the figure, the light transmitted through this sheet is polarized vertically. A second polarizing sheet, called the analyzer, intercepts the beam.

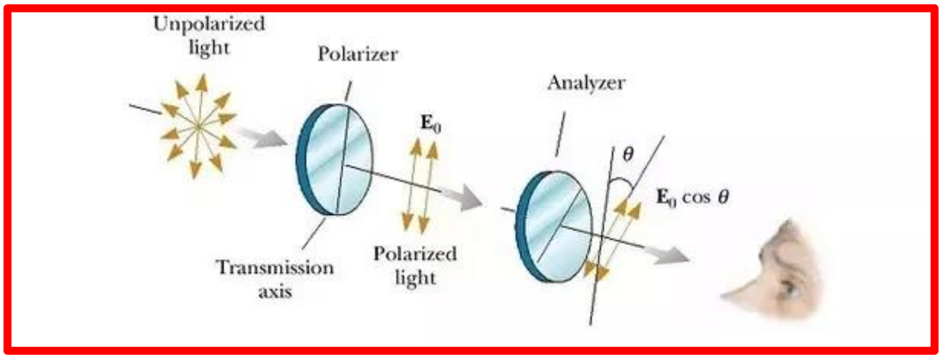


Figure 5: Two polarizing sheets whose transmission axis make angle θ with each other. Notice that, only fraction of the polarized light incident on the analyzer is transmitted through it

In figure 5, the analyzer transmission axis is set at an angle θ to the polarizer axis. We call the electric field vector of the transmitted beam E_o. The component of E_o perpendicular to the analyzer axis is completely absorbed. The component of E_o parallel to the analyzer axis, which is allowed through by the analyzer, is $E_o Cos(\theta)$ because the intensity of the transmitted beam varies as the square of its magnitude, we conclude that the intensity of the (polarized) beam transmitted through the analyzer varies as

$$I = I_{Max} Cos^2(\theta) \qquad \dots (1)$$

Where I_{Max} is the intensity of the polarized beam incident on the analyzer. This expression is known as Malus's law. The Malus law states that, ʽThe intensity of the polarized light transmitted through the analyzer varies as the square of the cosine of the angle between the plane of refraction of the analyzer and the plane of the polarizer'.

Procedure:

1) Set up the experiment as shown in figure 6.

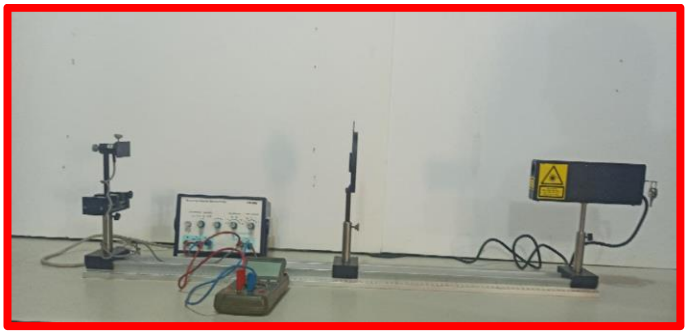
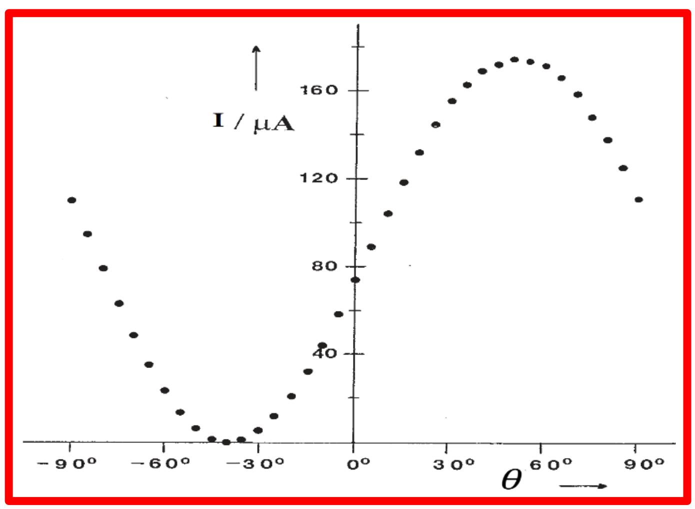


Fig. 6: Experimental setup.

2) Switch on the laser light source.
3) Make sure the polarizer angle is on zero degree and perpendicular to the incoming laser light then adjust the photocell until maximum reading of the multimeter is achieved. Record this value as $I_{Max.}$
4) Change the angle between polarized and the incoming light 10 degrees then record the current via multimeter.
5) Next, change the angle to 20 degrees then read the multimeter again.
6) Repeat step (5) until you reach 90 degrees.
7) Now, set the polarizer angle on -10 degrees then read the multimeter.
8) Repeat step (7) until you reach -90 degrees. Record your data in a table as shown below.

$\theta\ (degree)$	$I\ (\mu A)$	$Cos^2(\theta)$
10 20 : 90		
-10 -20 : -90		



9) Plot $\theta(degree)$ on x-axis and $I\ (\mu A)$ on Y-axis.

Questions:

1) What is Malus law polarization?
2) What is Malus law formula?
3) What is an example of polarization?
4) Define a polarized light.
5) Is sunlight polarized?
6) How does polarization occur?
7) What do you mean by wave polarization?
8) What is the definition of polarization in physics?
9) What are the types of polarization?
10) What are the methods for producing polarization?

Experiment No. (7)

Studying Linear Absorption Coefficient

Aim:

The aims of this experiment are to:

1) verify the absorption law of Light radiation.
2) determine linear absorption coefficient (μ) and mass absorption coefficient (μ_m).
3) determine the half value thickness of the absorbing material ($x_{1/2}$).

Apparatus:

1) Optical bench
2) Light source
3) Glass slabs
4) Light detector
5) Luxmeter

Theory:

When light radiation passes through matter such as a glass, it undergoes absorption primarily by Compton, photoelectric and pair production interactions. The intensity of the radiation is thus decreased as a function of thickness of the absorbing material (see figure 1). The absorption coefficient defines how far light of a particular wavelength can penetrate into a material before being absorbed. In a material with a low absorption coefficient, light is only poorly absorbed, and if the material is thin enough, it will appear transparent to that wavelength. The absorption coefficient depends on the material and also on the wavelength of light which is being absorbed. Accordingly, Lambert's law can be stated as "when a beam of light is allowed to pass through a transparent medium, the rate of decrease of intensity with the thickness of medium is directly proportional to the intensity of light." Mathematically, the Lambert's law may be expressed as follows.

$$I = I_o e^{-\mu x} \qquad \dots (1)$$

Where $I_o$is the original intensity of the beam, I is the intensity transmission through an absorber to thickness x and μ is the linear absorption coefficient for the absorbing material. The unit of μ is cm^{-1}.

If we rearrange eq. (1) and take the logarithm of both sides, the expression becomes:

$$ln\left(\frac{I_o}{I}\right) = \mu x \qquad \dots (2)$$

The half value layer (HVL) of the absorbing material is defined as that thickness $(x_{1/2})$ which will cut the initial intensity in half, that is $\left(I = \frac{I_o}{2}\right)$. If we substitute this into equation (2) we get:

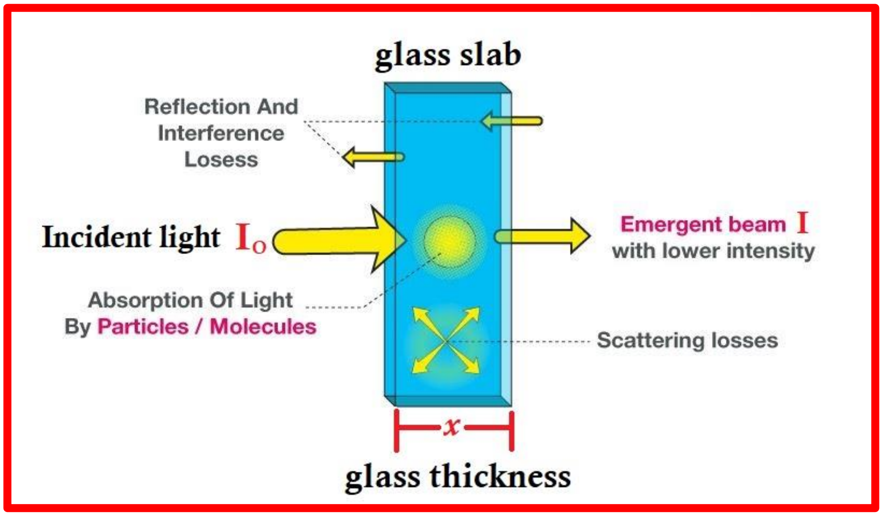


Figure 1: The intensity of light is decreased due to the absorption mechanism by the material.

$$ln(2) = \mu x_{1/2} \qquad \dots (3)$$

Putting in numerical values and rearranging Eq.(3) becomes,

$$x_{1/2} = \frac{0.693}{\mu} \qquad \dots (4)$$

The mass absorption (attenuation) coefficient (μ_m) is defined as the ratio of the linear attenuation coefficient and absorber density.

$$\mu_m = \frac{\mu}{\rho} \qquad \dots (5)$$

where (ρ) is the density of the material. The unit of (μ_m) is (cm^2/kg). The values of mass attenuation coefficients, based on proper values of photon cross section, are dependent upon the absorption and scattering of the incident radiation caused by several different mechanisms such as Rayleigh scattering (coherent scattering); Compton scattering (incoherent scattering); photoelectric absorption and pair production.

Procedure:

1) Setup the experiment as shown in figure 2.

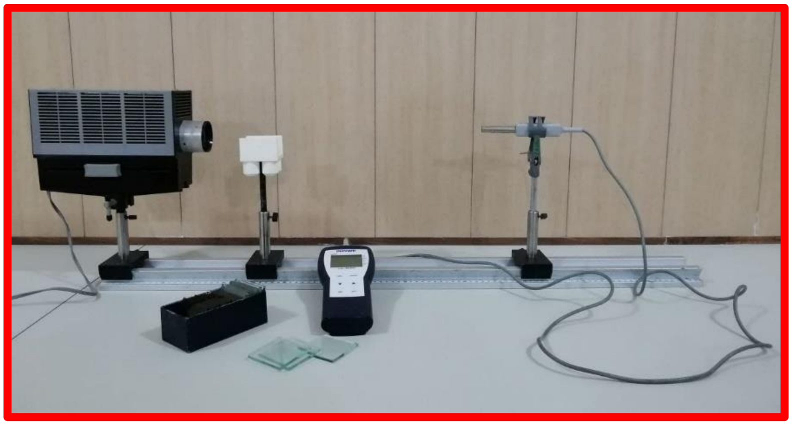


Fig. 2: Experimental setup.

2) Switch on the light source then read the intensity of light via luxmeter. Name this value as (I_o).

3) Measure the thickness *(x / cm)* of the glass slab (1) then put it on a holder which is located between the light source and the light detector. Next, read the intensity of light via luxmeter and name it as (I_1).

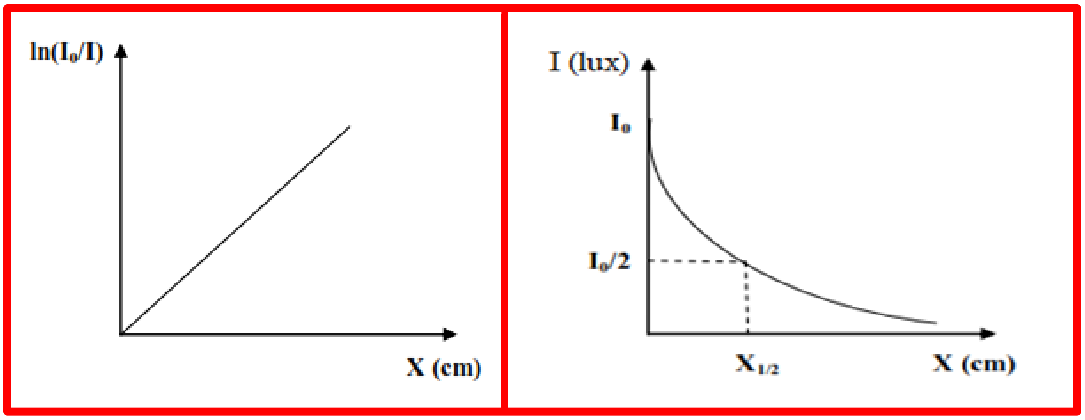
4) Repeat the step (3) for the glass slabs (2,3,4,5 and 6).

5) Now, remove the last glass slab then read the intensity of light via luxmeter name it as (I_2).

6) Repeat step (5) for the glass slabs (5,4,3 and 2), then record your data in a table as shown below.

$I_o =$					
Glass slab No.	$x\ (cm)$	$I_1\ (lux)$	$I_2 (lux)$	$I = \frac{I_1 + I_2}{2}\ (lux)$	$\ln\left(\frac{I_o}{I}\right)$
1					
2					
3					
4					
5					
6					

7) Plot (x/cm) on X- axis and $(I\ /lux)$ on Y-axis.



8) Determine the $(x_{1/2})$ on the graph then put in into equation (4) to find the linear absorption coefficient (μ).
9) Use equation (5) to find the value of mass absorption coefficient (μ_m).

<u>**Note:**</u> The density of soda lime glass slabs is $(\rho = 2.5 \ gm/cm^3)$.

10) Plot $x \ (cm)$ on x-axis and ln $\left(\frac{I_o}{I}\right)$ on y-axis. Then, find the slope of the line which is equal to the linear absorption coefficient (μ).
11) Compare you're the result of step (10) with the result of step (8).

Questions:

1) Define linear absorption coefficient.
2) How light behave when it interacts with matter?
3) How do you find the absorption coefficient?
4) Explain the main process that probably occur when a beam of light incident on a piece of glass.
5) What are the main parameters that absorption coefficient depends on?
6) Write a mathematical expression for finding the absorption coefficient.
7) How the intensity of light varies with the thickness of a glass? Why?
8) How can we find the half thickness experimentally and theoretically?
9) How the absorption varies with the density?
10) What is the units of absorption coefficient?
11) What is mass absorption coefficient?
12) On what factors does mass absorption coefficient depend?

References:

[1] Subrahmanyam, N., 2004. *A textbook of Optics*. S. Chand Publishing.

[2] Chandra, P.S., 2010. *Course In Physics 3: Waves, Optics And Thermodynamics*. Pearson Education India.

[3] Hecht, E., 2002. *Optics, 5e*. Pearson Education India.

[4] Edmundoptics.com. 2022. *Introduction to Polarization | Edmund Optics*. [online] Available at: <https://www.edmundoptics.com/knowledge-center/application-notes/optics/introduction-to-polarization/> [Accessed 10 February 2022].