15. Is there any phase change on reflection ?

Ans. If the wave is reflected from a denser medium ($\theta > \theta_2$) then $\left(\frac{E_{10}}{E_0}\right)_\perp$ is negative. This indicates that the reflected wave suffers a phase change of π.

On the other hand if the wave is reflected from a rarer medium ($\theta < \theta_2$) then $\left(\frac{E_{10}}{E_0}\right)_\perp$ is positive. This means that there is no phase change on reflection in this case.

[Also see the Oral Question on spectrometer (Art. 5.5 & Expt. 5.6)]

9.2 To measure the wavelength of laser radiation by studying its diffraction through a single slit :

• **Theory :** If a laser beam of light of wavelength λ falls normally on a narrow slit of width 'a' then the angular interval (θ) between any two successive dark bands is given by the relation, $a \sin\theta = \lambda$. As θ is small, we can write $\sin\theta \approx \theta$. Therefore,

$$\lambda = a\theta \qquad \text{... (9.2-1)}$$

Now, if d be the linear distance between two successive dark bands on a screen placed at a distance D from the slit then $\theta \approx d/D$. Thus

$$\lambda = ad/D \qquad \text{... (9.2-2)}$$

This relation may be employed to find λ.

• **Apparatus :** *(i)* An adjustable narrow slit, *(ii)* travelling microscope, *(iii)* Diode or *He-Ne* laser source, *(iv)* screen, metre scale, etc.

• **Procedure :** *(i)* Place the frame containing the single slit on a horizontal support with the slit vertical, at a distance of about 10 cm from the laser. Place the screen a few metres away from the slit.

(ii) Switch on the laser and allow the laser beam to fall *normally* on the slit. Adjust the width of the slit and also the distance of the screen from the slit such that the fringes formed on the screen are distinct and sufficiently apart for measurement with reasonable accuracy.

(iii) Take the reading of the metre-scale (may be fixed horizontally on the screen) corresponding to the centre of the extreme left distinct dark band. Note the order of this dark band with respect to the *central bright band of zero order*. Continue this process of noting the scale reading and order number for all the dark bands upto the extreme distinct right dark band (of the same highest order as that at the extreme left at the start).

(iv) Repeat the process *(iii)* of noting scale reading and order number by strating from extreme right and ending in the extreme left.

(v) Take the mean of two readings obtained for each dark band. Calculate the differences (x) of the mean scale reading between 5 (or 6) dark bands and from these find the mean distance between two consecutive dark bands ($d = x/5$ or $x/6$).

(vi) Measure the distance D of the screen from the slit with the help of a thread and a metre scale.

(vii) Measure the width 'a' of the slit with the help of a travelling microscope. Calculate λ from the relation (9.2-2).

(viii) Repeat the whole operation for a different slit width.

• **Experimental data :**

(A) *Width of diffraction dark bands :*

TABLE I

Serial number of the dark fringes from left	Order no. of the dark fringes with respect to central bright band of zero order	Readings of the scale (S) in cm			Diff. of scale readings (R) between 5 dark bands in cm (x)	Mean x in cm	Value of d is $d = x/5$ in cm
		From left to right R'	From right to left R''	Mean $= R = \frac{R' + R''}{2}$			
1.	4			... $= R_1$	$R_6 \sim R_1 =$ ...		
2.	3	...	...	... $= R_2$			
3.	2	...	...	... $= R_3$	$R_7 \sim R_2 =$ ...		
4.	1	...	...	... $= R_4$			
5.	(0 central) bright band)	...	...	...		...	...
6.	1	...	...	... $= R_6$	$R_8 \sim R_3 =$ ...		
7.	2	...	...	... $= R_7$			
8.	3	...	...	... $= R_8$	$R_9 \sim R_4 =$ ...		
9.	4	...	...	... $= R_9$			

(B) ***Slit width measurement by microscope :***

Vernier constant (v.c.) of microscope : Calculate in the usual manner.

No. of obs.	Microscope reading for Left edge: Scale (S) in cm	Left edge: Vernier (v.r.)	Left edge: Total in cm $R_1 = S + v.r. \times v.c.$	Right edge: Scale (S) in cm	Right edge: Vernier (v.r.)	Right edge: Total in cm $R_2 = S + v.r. \times v.c.$	Slit width $a = R_1 \sim R_2$ in cm	Mean a in cm
1.	...	...	...	...	...	...	...	
2.	...	...	...	...	...	...	...	...
3.	...	...	...	...	...	...	...	

• **Calculation of λ :** Distance of the screen from the slit is

$$D = \frac{...+...+...}{3} = ...\text{cm}$$

$$\therefore \quad \lambda = \frac{ad}{D} = ...\text{cm} = ...\text{nm}$$

• **Precautions and Discussions :** (*i*) The distance D between the slit and the screen should be large otherwise the distance between successive dark bands will be small for measurement by a metre-scale.

(*ii*) The slit should be narrow and placed vertically very near to the source in the path of the laser beam.

(*iii*) The dark bands, and not the bright bands, are equally spaced and hence the dark bands only should be used for measurements, otherwise the formula employed will not hold good.

(*iv*) One should not look at directly towards the laser source. It may be harmful to the eye.

(*v*) **Instead of the metre scale a millimeter graph paper may be pasted on the screen and ink dots may be put on the graph paper at the positions of the dark bands. Then the fringe width can be easily calculated.**

• **Maximum proportional error :** Wavelength $\lambda = \frac{ad}{D} = \frac{xa}{nD}$

where x is the distance between n dark bands.

Therefore, $\left.\frac{\delta\lambda}{\lambda}\right|_{max} = \frac{\delta x}{x} + \frac{\delta a}{a}$

As D is large $\delta D/D$ is insignificant.

δx = 2 divisions of the metre scale = 0.2 cm

δa = 2 × *v.c.* of the microscope.

Now using a typical set of values of x and a, we can calculate the maximum percentage in λ as $\left(\frac{\delta\lambda}{\lambda}\right)_{max} \times 100\%$.

□ Oral Questions and Answers □

1. What is laser?

Ans. The word laser is an acronym for 'Light Amplification by Stimulated Emission of Radiation'. Unlike the ordinary light the beam of light emitted from a laser is highly monochromatic, directional and coherent.

2. What type of diffraction is being used in this experiment?

Ans. Fraunhofer type. This requires that the source and the screen should be effectively at infinite distance from the slit. As the laser beam is highly directional and can propagate without much divergence we can consider the light incident on and diffracted by the slit to be essentially parallel.

3. Why do you use the dark bands and not the bright bands?

Ans. See Precautions (*iii*).

4. What would you do to increase the separation between successive dark bands?

Ans. The slit width should be made small and the distance of the screen from the slit large.

5. What do you mean by population inversion?

Ans. If in a system the population of the upper state is made greater than that of the lower state, the system is said to possess population inversion.

6. What is pumping?

Ans. The method by which population inversion is achieved in a system is called pumping.

7. What is a metastable state?

Ans. A state having comparatively long life time than the normal mean life time ($\sim 10^{-8}$s).

Experiment 6

Diffraction at a Single and Double slit (LASER)

Aim: To determine slit width of single and double slit by using He-Ne Laser.

Apparatus: He-Ne laser, Single Slit, Double Slit, Screen, Scale, tape etc.

Theory: If the waves have the same sign (are *in phase*), then the two waves constructively interfere, the net amplitude is large and the light intensity is strong at that point. If they have opposite signs, however, they are *out of phase* and the two waves destructively interfere: the net amplitude is small and the light intensity is weak. It is these areas of strong and weak intensity, which make up the interference patterns we will observe in this experiment. Interference can be seen when light from a single source arrives at a point on a viewing screen by more than one path. Because the number of oscillations of the electric field (wavelengths) differs for paths of different lengths, the electromagnetic waves can arrive at the viewing screen with a *phase difference* between their electromagnetic fields. If the Electric fields have the same sign then they add *constructively* and increase the intensity of light, if the Electric fields have opposite signs they add *destructively* and the light intensity decreases.

Diffraction at single slit can be observed whe
is usually a vertical *slit*) whose width, *a*, is sm
width of the slit will take paths of different len
1). When the light interferes destructively, inte
1 shows such a diffraction pattern, where the in

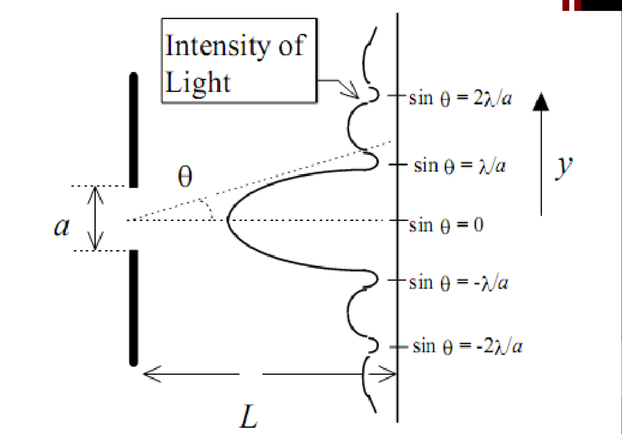

Figure 1: Diffraction by a slit of width *a*. Graph shows intensity of light on a screen.

is shown as a graph placed along the screen.

For a rectangular slit it can be shown that the minima in the intensity pattern fit the formula

$$a\sin\theta = m\lambda$$

where m is an integer (±1, ±2, ±3…..), a is the width of the slit, λ is the wavelength of the light and θ is the angle to the position on the screen. The m^{th} spot on the screen is called

the m^{th} order minimum. Diffraction patterns for other shapes of holes are more complex but also result from the same principles of interference.

Two-slit Diffraction: When laser light shines through two closely spaced parallel slits (Figure 2) each slit produces a diffraction pattern. When these patterns overlap, they also interfere with each other. We can predict whether the interference will be constructive (a bright spot) or destructive (a dark spot) by determining the path difference in traveling from each slit to a given spot on the screen.

Intensity maxima occur when the light arrives *in phase* with an integer number of wavelength differences for the two paths: $d\sin\theta = m\lambda$ where m = ±0, ±1, ±2,… …and the interference will be destructive if the path difference is a half-integer number of wavelengths so that the waves from each slit arrive *out of phase* with opposite signs for the electric field.

$$d\sin\theta = \left[m + \frac{1}{2}\right]\lambda$$ where m = ±0, ±1, ±2,… …

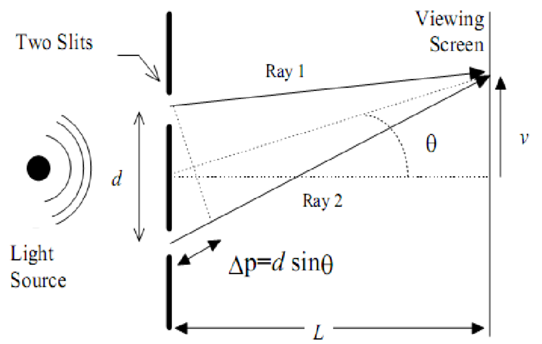

Figure 2: Interference of light from two slits. A maximum occurs when $\Delta p = m\lambda$ and a minimum when $\Delta p = (m+1/2)\lambda$, where m=0,1,2,…

Small Angle Approximation: The formulae given above are derived using the *small angle approximation*. For small angles θ (given in *radians)* it is a good approximation to say that $\theta \approx \sin\theta \approx \tan\theta$ (for θ in radians). For the figures shown above this means that $\theta \approx \sin\theta \approx \tan\theta = \frac{y}{L}$

Procedure:

Part A: Diffraction at single slit

The diffraction plate has slits etched on it of different widths and separations. For this part use the area where there is only a single slit.

For two sizes of slits, examine the patterns formed by single slits. Set up the slit in front of the laser. Record the distance from the slit to the screen, *L*. For each of the slits, measure and record a value for *y* on the viewing screen corresponding to the center of a dark region. Record as many distances, *y*, for different values of *m* as you can. Use the largest two or three values for *m* which you are able to observe to find a value for *a*. The He-Ne laser has a wavelength of 633 nm.

Part B: Two-slit Diffraction

Using the two-slit templates, observe the patterns projected on the viewing screen.
Observe how the pattern changes with changing slit width and/or spacing.
For each set of slits, determine the spacing between the slits by measuring the distances between minima on the screen. (The smaller spacings give are from the two slits patterns interfering, if they get too small to measure accurately, just make your best estimate.) You will need to record distances on the screen *y* and the distance from the slits to the screen, *L*.

Precautions: Look through the slit (holding it very close to your eye). See if you can see the effects of diffraction. Set the laser on the table and aim it at the viewing screen.
DO NOT LOOK DIRECTLY INTO THE LASER OR AIM IT AT ANYONE! DO NOT LET REFLECTIONS BOUNCE AROUND THE ROOM.
Pull a hair from your head. Mount it vertically in front of the laser using a piece of tape. Place the hair in front of the laser and observe the diffraction around the hair. Use the formula above to estimate the thickness of the hair, *a*. (The hair is not a slit but light

diffracts around its edges in a similar fashion.) Repeat with observations of your lab partners' hair.

Observations:

Table 1: Single slit

L = …….

λ = ………..

Diffraction Order, m	Distance, y	y/L	Angle θ in *radians*	$\sin\theta$	a $\left(=\dfrac{m\lambda}{\sin\theta}\right)$

Result : Slit width = …….

Table 2: Double slit

L = …….

λ = ………..

Diffraction Order, m	Distance, y	y/L	Angle θ in *radians*	$\sin\theta$	a $\left(=\frac{m\lambda}{\sin\theta}\right)$

Result : Slit width = …….

Experiment 7

Time Constant of RC Circuit