9.

To determine the wavelength of laser light using single slit diffraction pattern.

9.1 Apparatus:

Helium-Neon laser or diode laser, a single slit with adjustable aperture width, optical detector and power meter

9.2 Theory:

It is generally assumed that light travels in a straight line but it suffers some deviation from its straight path in passing close to edges of opaque obstacles and narrow slits. Some of the light does bend into the region of geometrical shadow and its intensity falls off rapidly. This bending of light which is not due to reflection/refraction is called as DIFFRACTION:

Two main classes of diffraction are:
i) Fresnel diffraction: In this case, the source of light or the

screen or both are at a finite distance from obstacle. Here no lenses are employed for rendering the rays parallel or convergent. Therefore the incident wave front is spherical or cylindrical instead of being plane.

ii) Fraunhoffer diffraction: In this case, the source of light and the screen are effectively at infinite distance from the obstacle (or aperture) causing diffraction. This means that the wave front incident on the obstacle is plane and all the secondary wavelets at every point of aperture are in phase. This can be achieved by placing the source on the focal plane of a convex lens and placing the screen on the focal plane of another convex lens. Alternatively, using a laser, this can be achieved by placing the obstacle/aperture in the parallel beam and observing the pattern on a screen placed at sufficiently large distance($D >> \frac{d^2}{\lambda}$, where D is the distance between the screen and the aperture, d is the slit width and λ is the wavelength of light used).

Fraunhoffer diffraction due to single slit:

Let AE represents a long narrow slit of width d as shown in fig.9.1. A plane wave front WW of monochromatic light of wavelength λ propagating normally to the slit is incident on it. To calculate diffraction pattern due to this slit, it is assumed that the slit consist of a large number of equally spaced point sources and that each point on the slit is a source of Huygen's secondary wavelets which interfere with the wavelets emanating from other points. The resultant field amplitude produced by these N sources at some arbitrary point P on the screen is given

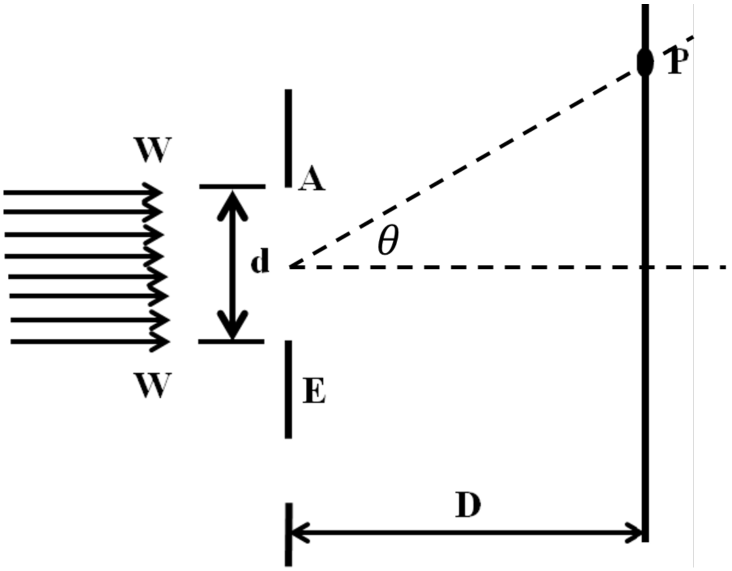

Figure 9.1: Geometry of the single slit diffraction setup.

by

$$R = a[\frac{\sin\left(\frac{N\pi}{N-1}\frac{d\sin\theta}{\lambda}\right)}{\sin\left(\frac{\pi}{N-1}\frac{d\sin\theta}{\lambda}\right)}]$$

Here θ is the angle made by the line joining center of the slit and observation point P with the direction of incident beam. In the limiting case of N tending to infinity and distance between two consecutive points on the slit tends to zero then we have

$$R = a[\frac{\sin\left(\frac{\pi d\sin\theta}{\lambda}\right)}{\left(\frac{\pi d\sin\theta}{N\lambda}\right)}] \tag{9.1}$$

Rewriting eqn.9.1

$$R = A(\frac{sin\alpha}{\alpha}) \tag{9.2}$$

Where $A = Na$ and $\alpha = \frac{\pi d sin\theta}{\lambda}$.
Since the intensity at P, being proportional to square of ampli-

tude can be given by

$$\begin{aligned} I &= \frac{A^2 sin^2\alpha}{\alpha^2} \\ I &= I_0\frac{sin^2\alpha}{\alpha^2} \end{aligned} \tag{9.3}$$

Where $I_0 = A^2$, is the intensity at $\theta = 0$.

Central maximum intensity position:

For $\alpha = 0$, $\frac{sin\alpha}{\alpha} = 1$ and $I = I_0$, which corresponds to the maximum intensity. Therefore $\alpha = 0$ i.e. $\theta = 0$ is the central maximum position.

Minimum intensity positions:

In the diffraction pattern the intensity will fall to zero where $sin\alpha = 0$, which means $\alpha = \pm m\pi$ or

$$d\ sin\theta_m = \pm m\lambda \tag{9.4}$$

The value of $m = 0$ does not correspond to a minimum since $m = 0 \Rightarrow \theta = 0$, which is the central maximum.

Angular separation between consecutive minima:

From eqn.9.4,if θ is small, the angular separation between two consecutive minima is

$$\Delta\theta = \frac{\lambda}{d} \tag{9.5}$$

Thus by measuring the angular separation between two consecutive minima and the width of the slit one can find out the wavelength of light.

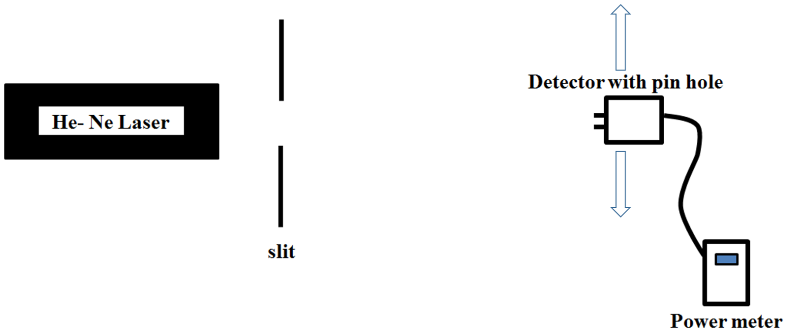

Figure 9.2: Schematic of experimental setup

9.3 Procedure:

The laser, slit and an optical detector with a pinhole are placed on an optical bench as shown in fig.9.2. It should be made sure that the distance between the slit and the detector should be sufficiently large ($>> \frac{d^2}{\lambda}$) to meet the Fraunhoffer diffraction condition. The light from the laser is allowed to fall on the slit and the diffraction pattern can be seen behind the slit. This diffraction pattern is made to fall on optical detector by laterally moving the position of the slit and the laser. Starting from one end of the diffraction pattern, the intensity is scanned by moving the pinhole detector along the entire length of the pattern. You need to measure the intensity profile up to 2 minima on either side of the central maximum. The corresponding power shown in the power mater at appropriate intervals is noted down. The plot between the position of detector and the power gives the diffraction pattern of the slit as shown in Fig.3. The position of the slit and that of the detector is also noted down; the difference between them gives the distance D. The slit is now observed

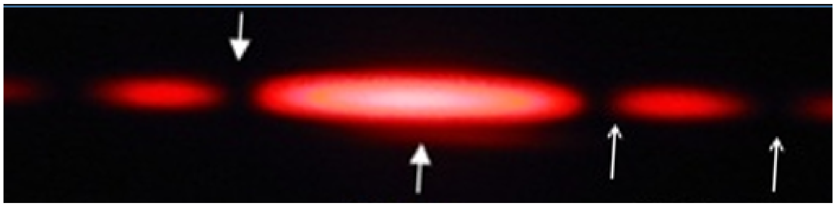

Figure 9.3: Typical single slit diffraction pattern observed on a screen. The arrows indicate positions of maxima and minima to be measured.

under a traveling microscope and the width of the slit d is found out.

Now from the plot of observed intensity vs. detector position, the distance 2L between the first minimum on the left and the first minimum on the right is measured. The angular separation $\Delta\theta_{\pm}$ between them can be calculated as follows (under the condition θ is very small)

$$\Delta\theta_{\pm 1} = \frac{2L}{D} \tag{9.6}$$

From eqn.9.4 the angular separation between +1 and -1 order minima can be given by

$$\Delta\theta_{\pm 1} = \theta_1 - \theta_{-1} = \frac{2\lambda}{d} \tag{9.7}$$

Using eqs.9.6 and 9.7 the wavelength of light can be determined.

9.4 Observations:

(a)Measurement of Intensity distribution of the Diffraction pattern

S. No.	Position of the detector (mm)	Power (mW)
1.		
2.		
3.		
. .		

(b) Measurement of the width of the slit

S. No.	Reading for right edge (a)	Reading for left edge (b)	d=$\|a-b\|$
1.			
2.			
3.			
. .			

Important Note: Never look into the laser beam directly, because it will damage your eyes permanently!

The main characteristics of a laser which distinguishes it from normal source like lamp, candle e.t.c are:

1) Directionality.
2) Monochromaticity.
3) High intensity and power.
4) High degree of coherence.

EFFECT OF LASER ON HUMAN BODY

The structures which are most affected by laser light are retina, cornea and skin. The retina can be damaged by light from visible (0.4-0.7 μ m) and near infrared (0.7-1.4 μ m) laser. The light from UV ($< 0.4\mu$ m) and far infrared ($< 1.4\mu$ m) lasers does not reach retina, but can harm cornea. Skin can be affected by lasers of any wavelength.

CLASSIFICATION OF LASERS BASED ON POWER:

1) CLASS-I: The emission of power accessible to human exposure is below levels at which harmful effects are known to occur.

2) CLASS-II: Low power visible lasers belongs to this class, its subclass II-A is for laser for which exposure for period less than 1000 sec should not be hazardous but exposure for period greater than this could be hazardous.

3) CLASS-III: Medium power lasers such that exposure to direct beam can be harmful but for which diffuse reflection are not harmful belong to this class.

4) CLASS-IV: High power lasers that can emit at levels such that harmful effects from diffuse reflections could occur belong to this class.