Pledge 116048/SHASHANK

I solemnly affirm that I am presenting this journal based on my own experimental work. I have neither copied the observations, calculations, graphs and results from others nor given it to others for copying.

Signature of the student

Experiment 5: Laser based experiment II: Measuring width of an ultra-thin slit, diameter of an ultra-thin wire and counting number of slits in diffraction grating using He Ne laser

Aim:

Using He-Ne laser to

1. Measure width of a narrow slit
2. Measure diameter of a thin wire
3. Counting the number of slits in a diffraction grating.

Apparatus: He-Ne laser, a narrow slit, thin wire, and diffraction grating, optical bench with stands to mount slit, wire and grating, screen, scale etc.

Significance of the experiment: *This experiment demonstrates three out of several applications of laser. The conventional techniques for measuring the width of narrow slits and thin wires are tedious and error prone. Laser provides an easy and accurate method to measure these quantities. Secondly, counting enormously large number of slits in the grating using any other method is almost impossible, however, laser makes it possible*

Theory: Laser is an extremely coherent, monochromatic, directional, focusable, polarized and powerful light. These extraordinary features make it greatly applicable in day-to-day life, science and technology. A few notable applications of laser include medical diagnosis and treatments, fiber optic communications, CD-ROMS, CD players, laser printers, defense, cutting, welding, drilling, surveying, aligning etc.

Laser is produced due to stimulated radiation; a process where a resonating photon stimulates the de-excitation of an excited atom. This results in to emission of two coherent photons, which are identical in all respects. These photons further stimulate the de-excitation of other excited atoms and this continues to generate an avalanche of coherent photons. For stimulated emission to take over spontaneous emission and stimulated absorption, a few conditions are necessary. These are availability of metastable state (life time $\approx 10^{-3}$ sec), population inversion (greater number of atoms in metastable state than in lower energy state) and enough number of photons in the cavity (mirrors).

He-Ne laser

He-Ne laser is a low power, continuous gas laser, which is used in supermarket scanners, student laboratories and holography. The active system is neon, which is pumped electronically via helium in a resonant cavity made of discharge tube (Fig. 5.1) . The main lasing occurs in neon between the levels E_6 (metastable) and E_3 which produces an intense coherent beam of red color (wavelength 6328°). (refer Fig 5.2). The population of photons necessary for stimulated emission is maintained by mirrors (one is semitransparent) on both sides. Brewseter windows are used to polarize the laser light.

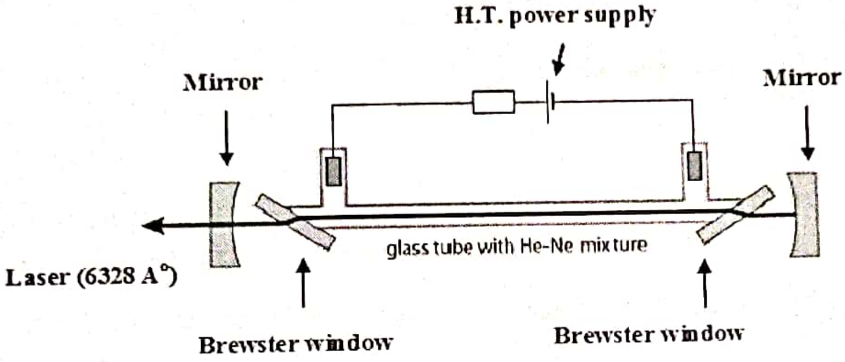

Fig. 5.1: Schematic diagram of He-Ne laser

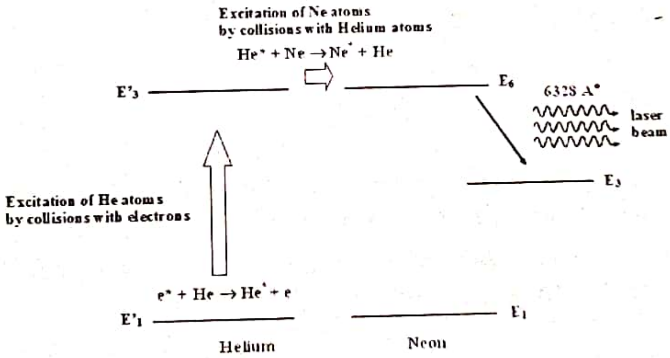

Fig. 5.2. The simplified energy level diagram of He-Ne laser

1. Measuring width of a narrow slit:

Consider a narrow slit of width a exposed to a laser of wavelengthλ. The laser is diffracted through the slit and a diffraction pattern, as shown in Fig 6.1 is produced. It consists of central maximum, minima and secondary maxima. According to theory of single slit diffraction, the angular position, θ of the m^{th} minimum is given by

$$a sin\theta = m\lambda \ldots \quad \ldots(5.1)$$

The central maximum is the principle image of the slit and it is bounded by 1st minima on both the sides. Therefore taking $m = 1$ and rearranging for a, Eqn 6.1 becomes

$$a = \frac{\lambda}{sin\theta} \qquad ...(5.2)$$

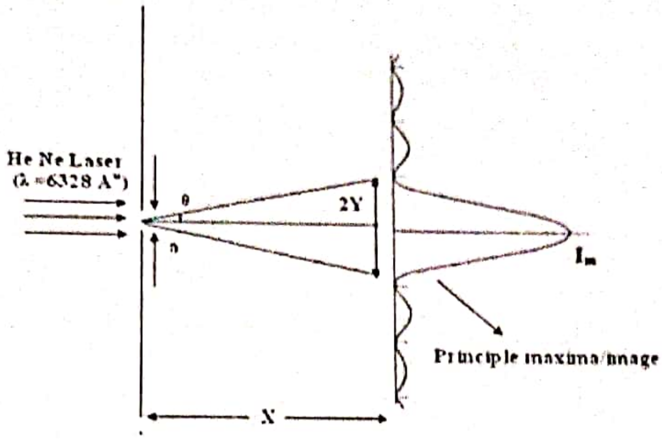

Figure 5.3: Diffraction pattern of single slit. Linear width of a central maximum (principle image of the silt) is quite wider than the slit itself.

Thus, the width of the slit can be measured if λ is known and θ is measured. The geometry of the Fig 6.1 suggests that

$$tan\theta = \frac{Y}{X} \qquad ...(5.3)$$

Where $Y = \frac{2Y}{2}$, (2Y = full linear width of the central maximum) and
X = distance between the slit and the screen

Equations 5.1, 5.2 and 5.3 collectively indicate that narrower the slit, greater is the value of θ, thus greater is the value of *2Y*. *2Y* i.e. the principle image of the slit is considerably larger than the slit itself. The relatively large value of *2Y* makes its measurement easy. As against this, the conventional techniques, which are based on direct measurements, find it more difficult to measure the width of the slit if it is narrower.

2. Measuring the diameter of a thin wire:

Consider a thin wire having diameter *d* exposed to a laser of wavelength λ. The wire diffracts the light and a diffraction pattern similar to as shown in the Fig 6.2 is observed. The diffraction pattern consists of a central maximum surrounded by maxima of almost same intensity on the upper and lower side. These three distinct maxima are surrounded by several secondary maxima and minima. If x is the distance between the first maximum on upper side and the first maximum on the lower side of the central maximum and if D is the distance between wire and screen, then it can be shown that

$$d = \frac{\lambda \times D}{x} \qquad ...(5.4)$$

Thus if λ is known, and if x and D are measured then the diameter of the thin wire can be calculated. It can be noted from Eqn 6.4 that the dependence of x on d is inverse. Thus if the wire is thinner, then x is large and thus can be measured more conveniently. Thus laser technique is particularly advantageous for thinner wires. On the contrary, thinner the wire, more it is difficult to measure its diameter by using conventional techniques.

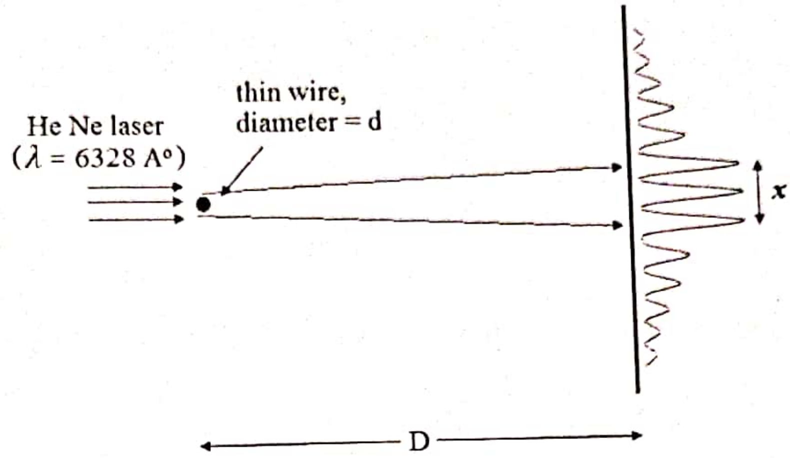

Figure 5.2: Measuring diameter of a thin wire using laser. Smaller the d, larger is the x

We know that diffraction is prohibited when the obstacle is smaller than the wavelength of light. Thus laser cannot be used for measuring the dimensions of the slits and wires having dimensions smaller than the wavelength of the laser. It may also be noted that if the dimensions of the obstacle is considerably larger than the wavelength of the light then diffraction effects are feeble. Thus the dimensions of slits and wires having size considerably larger than the wavelength of laser cannot be measured using laser.

3. Counting the number of slits in the diffraction grating:

Diffraction grating is a device consisting of very large number of parallel slits of equal width and equal spacing. It uses principle of diffraction to disperse the white light in to a colored spectrum. The resolving power and dispersive power of grating are considerably large as compared to prism. These qualities depend upon number of slits. The number of slits in the grating are typically 15000 to 20000 per inch. Counting these slits directly is almost impossible.

Consider a monochromatic light of wavelength λ incident on a grating having grating element d (spacing between the slits). The light is diffracted and a diffraction pattern as shown in Fig (6.3) is produced. According to theory of diffraction grating, the angle of diffraction θ of a principle maxima of order m is given by

$$d\sin\theta = m\lambda \qquad \text{...(5.5)}$$

The first order maxima is most intense, hence m = 1. Thus

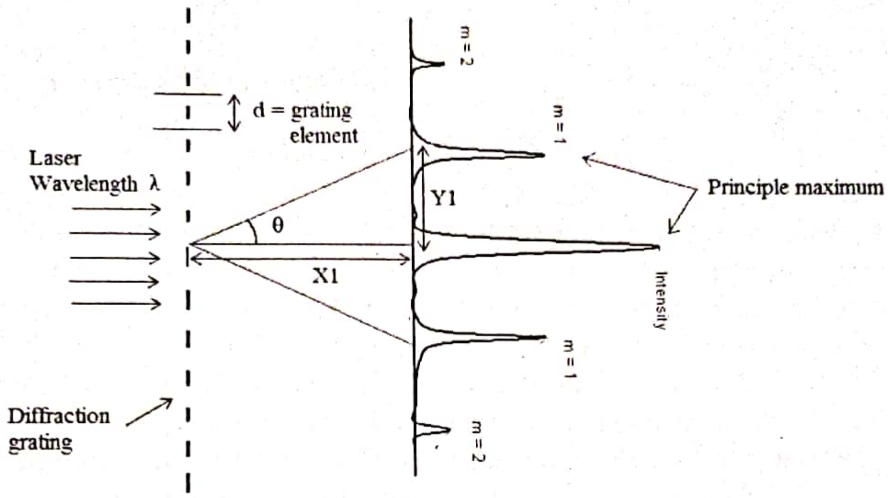

Figure (5.3). Diffraction grating and it's diffraction pattern

$$d = \frac{\lambda}{\sin\theta} \qquad \ldots (5.6)$$

As seen in Fig 5.3, θ can be calculated using following relation

$$\tan\theta = \frac{Y_1}{X_1} \qquad \ldots (5.7)$$

Where Y_1= the distance between the central maximum and the first maximum and
X_1= distance between the grating and the screen

Thus according to eqn (5.6) if λ and θ are substituted, then the grating element d can be calculated.

If a grating consists of N number slits per unit length, then it consists of N number of grating elements (d) per unit length. Thus

$$d = \frac{1}{N} \Rightarrow N = \frac{1}{d} \qquad \ldots (5.8)$$

If d is expressed in A°, then

$$N\ (number\ of\ slits\ per\ A^o) = \frac{1}{d(A^o)}, \Rightarrow N\ (number\ of\ slits\ per\ inch) = \frac{2.54\times10^8}{d(A^o)} \qquad \ldots (5.9)$$

Eqn (5.9) enables us to count the number of slits in the grating even though it is very large

Procedure:

Part A. Measuring width of a narrow slit:

1. Make laser ON. **Avoid eye contact.**
2. Place the screen in front of the optical bench at sufficiently large distance.
3. Mount the slit on the optical bench such that the laser is incident exactly on the slit. Align it properly so that a well-defined and distinct diffraction pattern consisting of central maximum surrounded by minima and secondary maxima is observed on the screen
4. Measure the full width of the central maximum. This is $2Y$ (cm). Calculate Y (cm).
5. Measure the distance between the slit and the screen. Let this be X (cm)
6. Calculate θ and the width of the slit a_e (mm) by using the procedure in table 6.1.
7. Compare a_e with standard width of the slit (a_s) and calculate the percentage deviation.
8. Tabulate all observations, calculations and results as per table 5.1

Part B: Measuring diameter of a thin wire

1. Fix the wire on a suitable mount. Clamp the mount on the stand. Fix the stand on the optical bench.
2. Illuminate this wire by laser. Use trial and error method the expose the wire completely to the laser, so that a well-defined diffraction is observed on the screen. As shown in Fig (6.2), the pattern should consist of a central maximum surrounded by 1^{st} maxima of almost similar intensity on upper as well as lower side. These three maxima are surrounded by several secondary maxima and minima on both the sides.
3. Measure the distance between the first maxima on the upper side and first maxima on the lower side of the central maximum. Let this be x (mm)
4. Measure the distance between the screen and the wire. Let this be D (mm).
5. Calculate the diameter of the wire d_e (mm) by using the procedure in table 5.2.
6. Compare d_e with standard d_s. Calculate the percentage deviation.
7. Express all observations, calculations and results as per table 5.2.

Part C: Counting the number of slits of a grating

1. Mount the diffraction grating on a stand. Clamp the stand on the optical bench
2. Place laser behind the diffraction grating. Align the diffraction grating such that the laser is incident exactly perpendicularly on the grating.
3. Place a screen in front of the grating. A well-defined diffraction pattern similar to as shown in Fig (6.3) will be observed. Only principle maxima will be observed. Secondary maxima are too weak to be observable. If the grating is sufficiently close to the screen, then central maximum, first maximum as well as second maximum will be observed.
4. As shown in Fig (6.3), measure the distance between the first maximum and the central maximum (Y_1) and the distance between screen and the grating (X_1).
5. Calculate θ, d (A^0) and N_e as per the procedure given in table 5.3.
6. Compare N_e with standard N_s. Calculate the percentage deviation
7. Express the observations, calculations and results as per table 5.3

ROUGH WORK:

Table 5.1: Measuring the width of the slit

Sr. No.	Parameter	Symbol	Value	Unit
1	Full linear width of the central maximum	$2Y$	4	Cm
2	Half linear width of the central maximum	$Y = \frac{2Y}{2}$	2	Cm
3	Distance between the screen and the slit	X	184	Cm
4	Angular position of the first minimum	$\theta = tan^{-1}\frac{Y}{X}$	0.6227	Deg
5	Width of the slit	$a_e = \frac{\lambda}{sin\theta}$ Where $\lambda = wavelength of\ He\ Ne\ laser = 6328 \times 10^{-7} mm$	0.058	Mm
6	Standard width of the slit	a_s	0.0~~8~~7	Mm
7	Percentage deviation	$\%\ deviation\ = \left\lvert\frac{a_e - a_s}{a_s}\right\rvert \times 100\%$	17.14	%

Table 5.2: Measuring the diameter of the thin wire

Sr. No.	Parameter	Symbol	Value	Unit
1	Distance between the first maximum on the upper side and first maximum on lower side	X	5	Mm
2	The distance between the screen and the wire	D	1820	Mm
3	Diameter of the wire	$d_e = \frac{\lambda \times D}{x}$ Where $\lambda = wavelength of\ He\ Ne\ laser = 6328 \times 10^{-7} mm$	0.23	Mm
6	Standard diameter of the wire	d_s	0.25	Mm
7	Percentage deviation	$\%\ deviation\ = \left\lvert\frac{d_s - d_e}{d_s}\right\rvert \times 100\%$	8	%

Table 5.3: counting the number of slits in the grating

Sr. No.	Parameter	Symbol/formula	Value	Unit
1	Distance between the first maximum and the central maximum	Y_1	7.7	Cm
2	Distance between screen and the grating	X_1	14	Cm
3	Angle of diffraction of the first minimum	$\theta = tan^{-1}\frac{Y_1}{X_1}$	28.81	deg
4	Grating element	$d = \frac{\lambda}{sin\theta}$ Where $\lambda = wavelength of laser = 6328A^o$	13131.17	A°
5	Number of slits per inch in the grating	$N_e = \frac{2.54 \times 10^8}{d(A^o)}$ Where d = grating element as calculated in (step 4), to be taken in A°	19343	Per inch
6	Standard value of the number of slits in the grating	N_s	~~15000~~ 20000	Per inch
7	Percentage deviation	$\% \ Deviation = \left\lvert\frac{N_e - N_s}{N_s}\right\rvert$	3.285	%

FAIR WORK:

Table 5.1: Measuring the width of the slit

Sr. No.	Parameter	Symbol	Value	Unit
1	Full linear width of the central maximum	$2Y$	4	Cm
2	Half linear width of the central maximum	$Y = \frac{2Y}{2}$	2	Cm
3	Distance between the screen and the slit	X	184	Cm
4	Angular position of the first minimum	$\theta = tan^{-1}\frac{Y}{X}$	0.6227	Deg
5	Width of the slit	$a_e = \frac{\lambda}{sin\theta}$ Where $\lambda = wavelength of\ He\ Ne\ laser = 6328 \times 10^{-7} mm$	0.058	Mm
6	Standard width of the slit	a_s	0.07	Mm
7	Percentage deviation	$\% \ deviation = \left\lvert\frac{a_e - a_s}{a_s}\right\rvert \times 100\%$	17.14	%

Table 5.2: Measuring the diameter of the thin wire

Sr. No.	Parameter	Symbol	Value	Unit
1	Distance between the first maximum on the upper side and first maximum on lower side	X	5	Mm
2	The distance between the screen and the wire	D	1820	Mm
3	Diameter of the wire	$d_e = \frac{\lambda \times D}{x}$ Where $\lambda = wavelength of\ He\ Ne\ laser = 6328 \times 10^{-7} mm$	0.23	Mm
6	Standard diameter of the wire	d_s	0.25	Mm
7	Percentage deviation	$\%\ deviation = \left\lvert\frac{d_s - d_e}{d_s}\right\rvert \times 100\%$	8	%

Table 5.3: counting the number of slits in the grating

Sr. No.	Parameter	Symbol/formula	Value	Unit
1	Distance between the first maximum and the central maximum	Y_l	7.7	Cm
2	Distance between screen and the grating	X_l	14	Cm
3	Angle of diffraction of the first minimum	$\theta = tan^{-1}\frac{Y_1}{X_1}$	28.81	deg
4	Grating element	$d = \frac{\lambda}{sin\theta}$ Where $\lambda = wavelength of laser = 6328 A^o$	13131.17	A^o
5	Number of slits per inch in the grating	$N_e = \frac{2.54 \times 10^8}{d(A^o)}$ Where d = grating element as calculated in (step 4), to be taken in A^o	19343	Per inch
6	Standard value of the number of slits in the grating	N_s	~~15000~~ 20000	Per inch
7	Percentage deviation	$\%\ Deviation = \left\lvert\frac{N_e - N_s}{N_s}\right\rvert$	3.285	%

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My understanding to this experiment

⇒ This experiment helps us to understand some applications of laser. For this experiment, in all the three perrameters we used He-Ne laser. Also the intensity of a laser beam is maximum at its center and gradually decreases side ways.