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Preamble for Experiment 5: Laser Beam Divergence

Above three photographs are the images of a laser on the screen kept at increasing distances from the laser. The images become bigger with increasing distance. This is because laser has small divergence. What is divergence of the laser and how can it be measured?

The theoretical foundations of laser were laid down by C.H. Towns, a Nobel laureate

Charles Townes (1915-2015): He was American Nobel prize winning Physicist, who is credited for the construction of first *maser* (Microwave Amplification by Stimulated Emission of Radiation) and laying down the theoretical foundations of laser. He studied at Duke University and obtained Ph.D in California Institute of Technology. He was then appointed as a professor in Columbia University, where he invented the *maser*, the intense microwave radiation. Masers find applications in the high precision atomic clocks and in radio-wave astronomy. In 1958 he proposed that lasing is possible in visible spectrum also. Along with the several awards and honors, he won two Nobel prizes in Physics, one in 1964 for laying down the theoretical foundations of laser and another in 1981 for precision spectroscopy using laser.

The world's first laser was constructed by Theodore H. Maiman

Theodore H. Maiman (1927-2007): He was an American Physicist who is credited for the invention of the world's first ever laser, the Ruby laser. He graduated in University of Colorado and obtained his post graduate degree and Ph.D. in Stanford University. He then joined Hughes Research Laboratories, where he invented the Ruby laser. The idea behind this work was proposed by Charles Towns in 1958 and since then several research groups, including those at IBM, Bell Labs, MIT (Boston) and Columbia University were pursuing the Town's suggestion. However Maiman was the first to realize the idea in practice. Maiman published his invention in 'Nature' and was also awarded a patent for this invention. Later on he earned many patents and won many awards and honors. Time magazine cited Maiman's invention of the laser as among the twenty most important technological developments of the 20th century.

Pledge

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 04: Laser based experiment I: Beam divergence

Aim: To measure the peak power and beam divergence of a given laser beam

Apparatus: He-Ne laser, Optical bench, Laser Beam Analyzer with sensor and micrometer screw arrangement.

Significance of the experiment: *One of the characteristics of laser is high directionality/parallelness. Thus the diameter of the laser at any position should be same. However, laser has a small divergence due to diffraction effects. This experiment provides an easy and accurate method to measure the divergence of a laser*

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 = 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_5 (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.

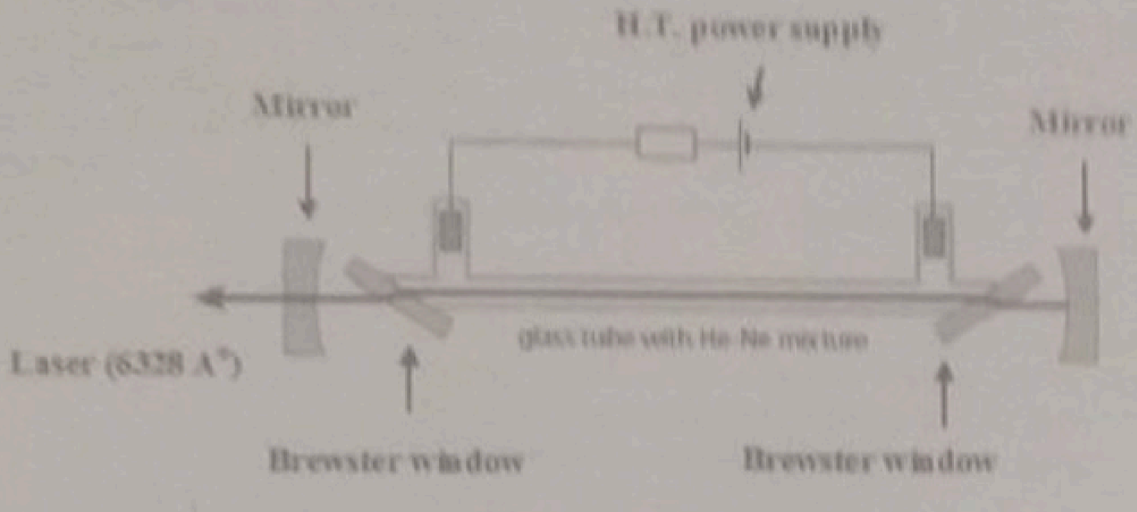

Fig. 4.1: Schematic diagram of He-Ne laser

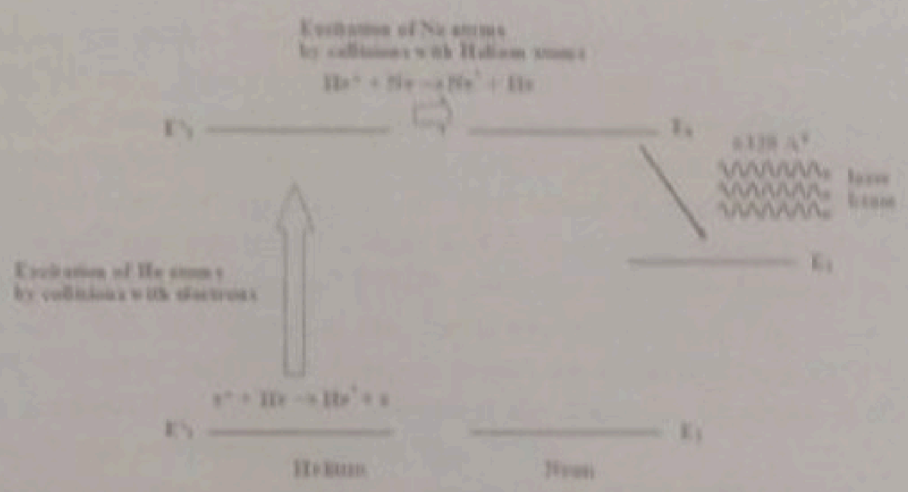

Fig. 4.2: The simplified energy level diagram of He-Ne laser

Procedure:

Make the laser beam ON. **Avoid eye contact**

1. The power in laser beam follows Gaussian distribution with peak value at center.
2. Mount the sensor of LBA on optical bench at a distance relatively closer to laser beam, say 10 cm. Let this distance be d_1. Adjust sensor so that laser is incident exactly on the centre of the window of the sensor. Align the sensor, till LBA reads power closest to 2.0 mW.
3. Now move the sensor laterally so that the beam falls on the edge of the window of the sensor. LBA will now read zero.
4. Using micrometer screw, move the sensor-window gradually across the laser beam. Note the increasing powers in the beam (mW) at various screw positions (mm) as per table

5.1. At certain stage, the power in LBA will reach peak and then will start decreasing, even though the screw is moved in the same direction. Note the decreasing powers at various advanced screw positions. Note that the screw should be moved in only one direction throughout the observations. For measuring the screw positions, use following procedure

$$\text{Screw position} = X = MSR + VSR \times LC \quad mm$$

Where **MSR** is the reading on the main scale, which is closest to the edge of the screw. **VSR** is the vernier scale reading, which is the sequence number of the division on the screw which coincides with the line on main scale.
LC is the least count of micrometer screw gauge

$$LC = \frac{\textit{smallest division on the main scale}}{\textit{number of divisions on the vernier sale}} = \frac{\quad mm}{\quad} = \qquad mm$$

5. Repeat the entire procedure from 2 to 4, by placing the sensor at d_2 cm, sufficiently away from d_1 (say by 50 cm). Record these observations in table 5.2
6. Plot the graph of power (mW) Vs position (mm) for observation table 5.1 (for d_1). Identify the peak power (P_m). Also identify a point on power axis corresponding to $P_m/2$. Draw a horizontal line starting from $P_m/2$. This line will intersect the Gaussian curve at two points having X co-ordinates $X_1\,(mm)$ and $X_2(mm)$. The quantity $D_1\,(mm) = (X_2 - X_1)$ i.e. Full Width at Half Maximum (*FWHM*) gives the effective diameter of laser when the distance between LBA and laser is $d_1$cm. (refer sample graph in Fig. 5.3 a)
7. Plot the graph of power (mW) Vs position (mm) for observation table 2 (for d_2). Repeat the procedure explained in step 6 and calculate the diameter $D_2\,(mm)$ of the laser beam at the position d_2. (refer a widened graph in Fig. 5.3b)
8. The Gaussian distribution at the position d_2 will be slightly wider than that at position d_1. Consequently the diameter D_2 of the laser beam at the position d_2 will be greater than diameter D_1 at the distance d_1. Calculate the divergence of laser beam by using the formula and procedure in 'Calculations'

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ROUGH WORK

Observation table 4.1 Powers at different positions at a distance d_1 = ..20.. cm			Observation table 4.2 Powers at different positions at a distance d_2 = ..20... cm		
Sr. No.	Power in LBA, P (mW)	Position of micrometer X (mm)	Sr. No.	Power in LBA, P (mW)	Position of micrometer X (mm)
1	0	2.2	1	0	1.4
2	0.25	3.2	2	0.25	2.5
3	0.50	4.3	3	0.50	2.8
4	0.75	4.4	4	0.75	3.2
5	1.00	4.5	5	1.00	3.5
6	1.25	4.5	6	1.25	3.7
7	1.50	4.7	7	1.36	4.0
8	1.75	4.8	8	1.25	4.6
9	2.1	5.7	9	1.00	5.0
10	1.75	6.2	10	0.75	5.4
11	1.50	6.3	11	0.50	5.7
12	1.25	6.5	12	0.25	6.5
13	1.00	6.6	13	0	7.8
14	0.75	6.8	14		
15	0.50	7.7	15		
16	0.25	8.5	16		
17	0	9.5			

Calculations:

$$Divergence = \frac{(D_2-D_1)\ mm}{(d_2-d_1)\ cm}$$

$$= \frac{(D_2-D_1)\ cm}{(d_2-d_1)\ cm} \times 10^{-1}$$

$$= \frac{(2.35 - 2.05)}{(80 - 10)} \times 10^{-1}$$

$$= 0.00042\ rad$$

$$= 0.00042\ rad \times \frac{180}{3.14}\frac{deg}{rad}$$

$$= 0.024\ deg$$

$$= 0.024\ deg \times 60\ \frac{min}{deg}$$

$$= 1.44\ min$$

Table 4.3 Results

Sr. No.	Physical quantity	Value	Unit
1	Peak power the laser beam (at d_1 ..... cm)	2.1	mW
2	Divergence of laser beam	1.44	Min

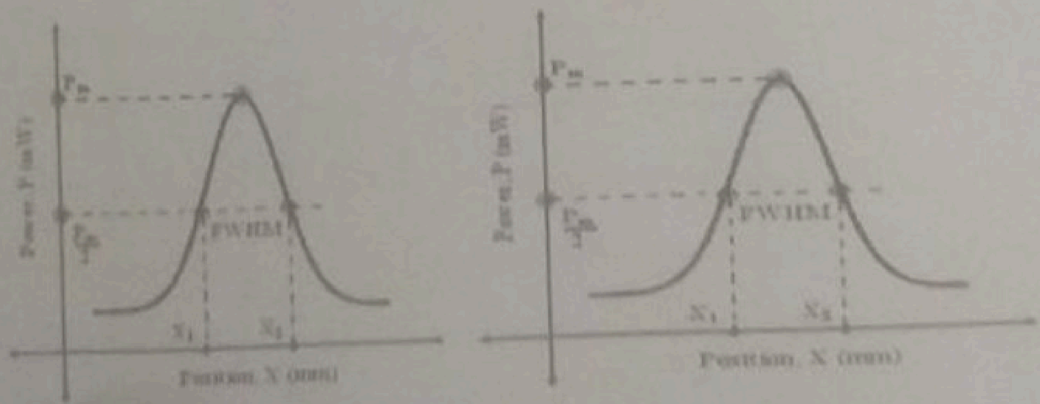

Figure 4.3 Calculation of (a) diameter *D1* at position *d1* (b) diameter *D2* at position *d2*

FAIR WORK

Observation table 4.1 Powers at different positions at a distance d_f= .... cm		
Sr. No.	Power in LBA, P (mW)	Position of micrometer X (mm)
1	0	2.2
2	0.25	3.2
3	0.50	4.3
4	0.75	4.4
5	1.00	4.5
6	1.25	4.5
7	1.50	4.7
8	1.75	4.8
9	2.1	5.7
10	1.75	6.2
11	1.50	6.3
12	1.25	6.5
13	1.00	6.6
14	0.75	6.8
15	0.50	7.7
16	0.25	8.5
17	0	9.5

Observation table 4.2 Powers at different positions at a distance d_f= .... cm		
Sr. No.	Power in LBA, P (mW)	Position of micrometer X (mm)
1	0	1.4
2	0.25	2.5
3	0.50	2.8
4	0.75	3.2
5	1.00	3.5
6	1.25	3.7
7	1.36	4.0
8	1.25	4.6
9	1.00	5.0
10	0.75	5.4
11	0.50	5.7
12	0.25	6.5
13	0	7.8
14		
15		
16		

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Calculations:

$$Divergence = \frac{(D_2 - D_1)\,mm}{(d_2 - d_1)\,cm}$$

$$= \frac{(D_2 - D_1)\,cm}{(d_2 - d_1)\,cm} \times 10^{-1}$$

$$= \frac{2.35 - 2.05}{(80 - 10)} \times 10^{-1}$$

$$= 0.00042\,rad$$

$$= 0.00042\,rad \times \frac{180}{3.14}\frac{deg}{rad}$$

$$= 0.024\,deg$$

$$= 0.024\,deg \times 60\,\frac{min}{deg}$$

$$= 1.44\,min$$

Table 4.3 Results

Sr. No.	Physical quantity	Value	Unit
1	Peak power the laser beam (at d_1 .... cm)	2.1	mW
2	Divergence of laser beam	1.44	min

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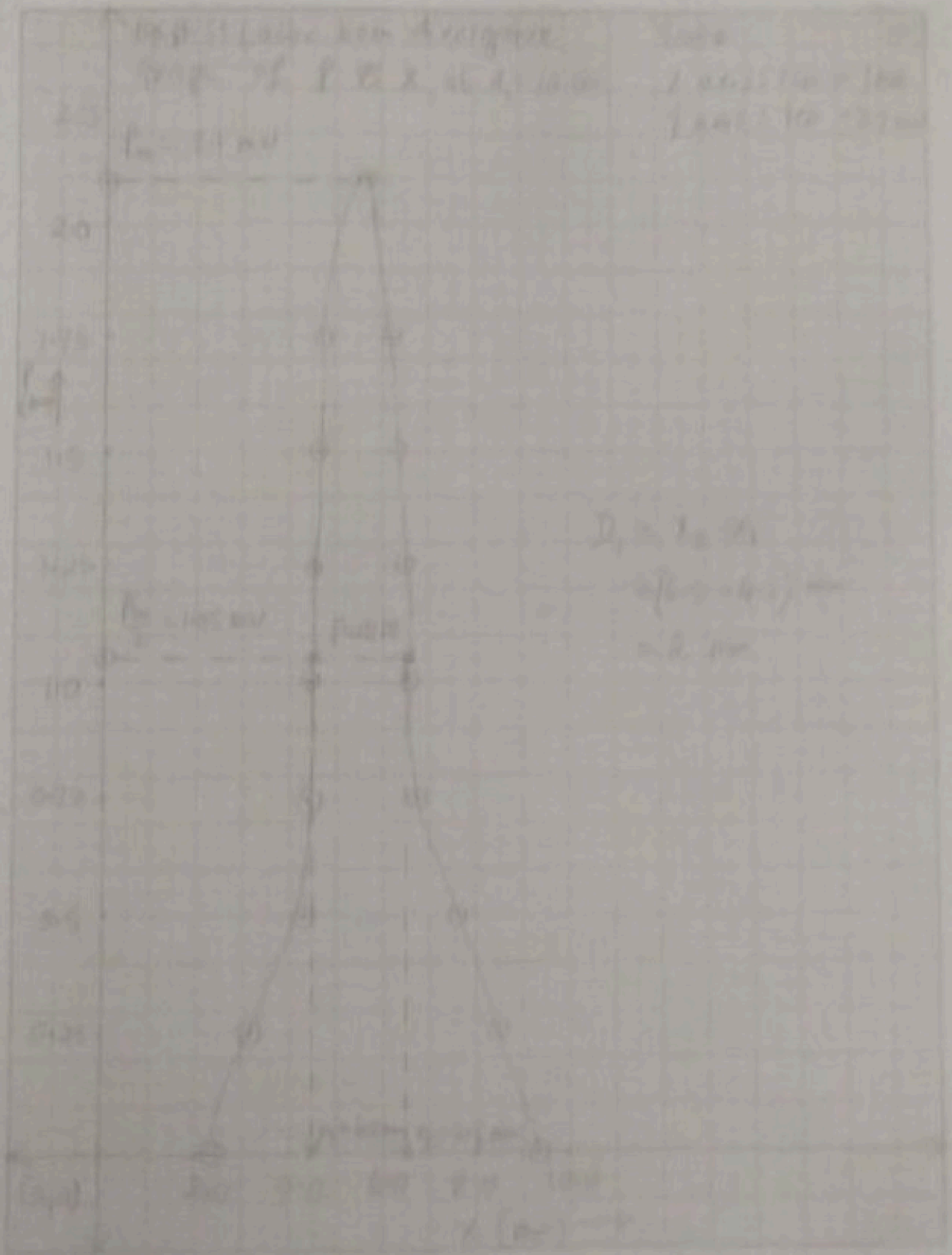
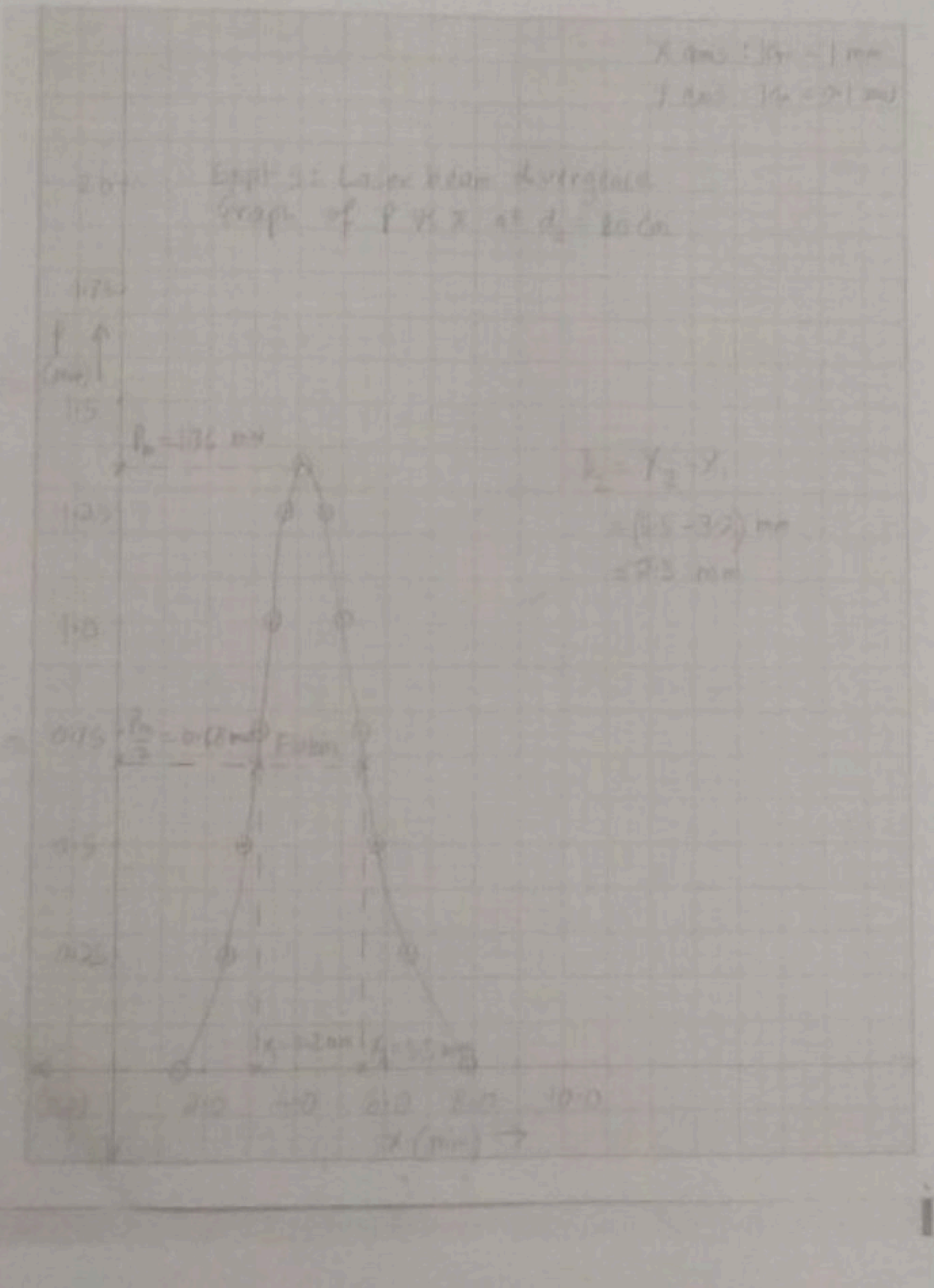
Model Graph-I for Expt. 4, Laser Beam Divergence

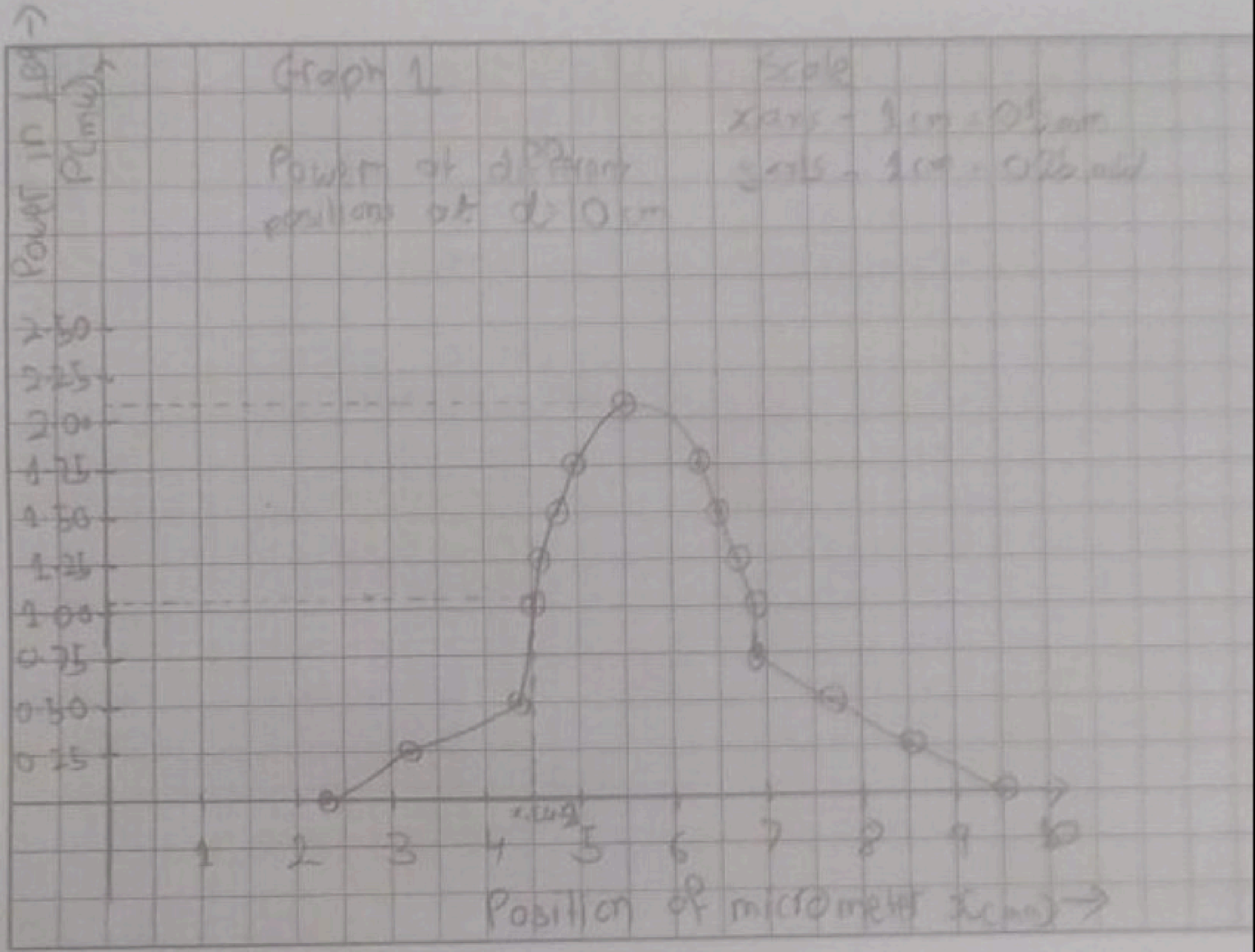
This Model Graph is only for cross-checking your graph with its nature and style of presentation. As such, your Graph must be based on your own observations and calculations. Only formatting and presentation needs to be as per the Model Graph.

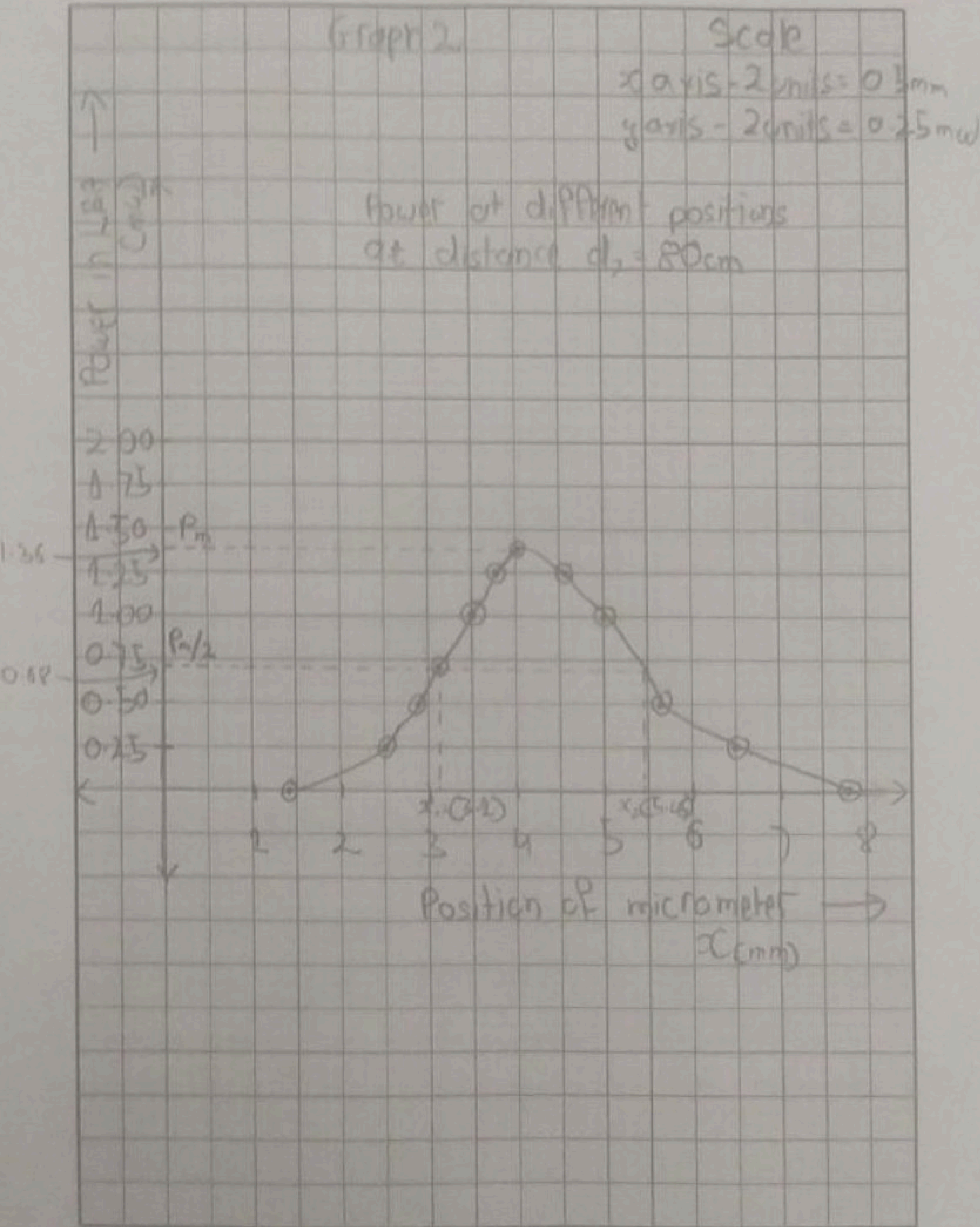


Model Graph-II for Expt. 4, Laser Beam Divergence

This Model Graph is only for cross-checking your graph with its nature and style of presentation. As such, your Graph must be based on your own observations and calculations. Only formatting and presentation needs to be as per the Model Graph.




Graph 1
Power at different positions at d = 0 cm
Scale
Power in log P(mW)
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
1
2
3
4
5
6
7
8
9
10
Position of micrometer x(mm)



Graph 2
Scale
x axis - 2 units = 0.5 mm
y axis - 2 units = 0.25 mW
Power at different positions
at distance d_2 = 80cm
Power in (mW)
2.00
1.75
1.50
P_m
1.36
1.25
1.00
0.75
$P_m/2$
0.68
0.50
0.25
x_1 (3.2)
x_2 (5.46)
1
2
3
4
5
6
7
8
Position of micrometer
x (mm)

Viva voce

1. Define following terms

    a. Stimulated emission
    b. Spontaneous emission
    c. Stimulated/resonance absorption
    d. Metastable state
    e. Population inversion
    f. Pumping
    g. Active system
    h. Resonant cavity
    i. Lasing
    j. Brewster window

2. What is the role of He in the action of He-Ne laser?
3. What is the role of Ne in the action of He-Ne laser?
4. Is He-Ne laser a continues laser or pulsed laser?
5. Ideally laser is supposed to move as a parallel beam. Why does it diverge then?
6. Which element is responsible for red light of He-Ne laser? He? Or Ne?
7. Does He-Ne laser emit only 6328 A° Or other wavelengths also? If, yes then what are these wavelengths?
8. What are the advantages of He-Ne laser?
9. What are the disadvantages of He-Ne laser?
10. What are the applications of He-Ne laser?
11. Why He atoms are at quite a higher percentage and quite a high pressure than Ne atoms?
12. Why does He-Ne laser require heavy and high tension power supply?

My Understanding of the Experiment

(Not exceeding 5 to 6 lines)

In the above expperiment we measured peak power and beam divergance of a He-Ne Lazer. Diffraction of Lazer beam is what caused this diversion in the lazer. we find the divergance with the help of lazer beam analyzer and a micrometre screw.