Properties of the HeNe Laser

Tim Marquez

Physics Department, University of California, Santa Barbara

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Abstract

We were assigned the task of exploring the properties of a Helium-Neon laser with several different instruments and techniques. Furthermore, we discovered that the polarization angle was $57.06° \pm 2.29°$; the beam diameter was found to be 0.070472 cm $\pm$ 0.0059 cm; and the beam divergence angle to be $1.08mrad \pm 0.18mrad$. We were able to compare these values to theoretical calculations and discuss where we found errors in both experiments and in calculations.

INTRODUCTION

The LASER (or "Light Amplification through Simulated Emission of Radiation") is a special form of light emission in the sense that its coherence allow it to have unique properties unlike other ordinary light sources, like a light bulb. Angel Torres and Tim Marquez explore a few of these properties, such as the polarization angle, the diameter of the beam, and the beam divergence angle. A red monochromatic Helium-Neon laser, a power meter and detector, a linear polarizer, and a mounted blade were utilized in different parts of the lab in order to discover these properties of the laser. Furthermore, we found that a measurement of its power output was a main proponent of the discovery of such properties.

METHOD

This lab consisted of three different experiments, all three of which utilized different pieces of equipment and/or different usages.

Before doing all this, however, we had to calibrate the laser and align each component that was placed on the rail for each stage. The laser itself took around 30 minutes to warm up before we could even begin. To calibrate the laser, we started by maintaining the laser's apparatus height at a constant height above the rail. This was defined as $19.51 \pm 0.1cm$. The next step was to align the laser with the spectrum analyzer retroreflector along the direction of propagation. To do this, we adjusted the laser apparatus and the retroreflector until the reflection of the laser was projected onto the bottom corner underneath the exit aperture. To confirm that the laser was aligned correctly, we adjusted the instruments until the oscilloscope measuring the output of the retroreflector was reading pairs of peaks at a finite (and readable) height. These peaks would slowly change in height, only to eventually cycle back to their original height after a certain amount of time. This was due to the laser's constantly-changing longitudinal modes. The spacing between these peaks was suggested at 8 divisions apart, with the following oscilloscope settings:

CH 1:

Coupling: AC

BW Limit: OFF

Volts/Div: COARSE

Probe: 1X

Volts/Div: 1 V

Polarization Angle

The polarization angle was discovered using the laser apparatus, the power detector and meter, and the polaroid linear polarizer. To find this angle, one must measure the power output of the laser as it passes through the filter at several angles, i.e. $P(\theta)$ vs. θ. The polarizer was placed at a constant distance from the laser at $70cm$. Then, we allowed the laser to pass through the polarizer, and utilized its rotating outer wheel to measure the angle of polarization in increments of a range of 10° to 20° at the given time of laser passage for a total of 32 measurements. We then typed the power output corresponding to the angle measured. With these measurements, we were able to find the polarization angle ρ given by:

$$\rho = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \tag{1}$$

A diagram of the setup used is presented below in **FIG. 1**.

We noticed that the power readings were directly affected by the peak readings on the oscilloscope, and that the longest lasting peak mode was when the pairs of peaks were at their maximum heights. Therefore, to mitigate infrequent power readings and to produce accurate data, we only measured the power outputs at varying angles during the maximum voltage peaks.

Beam Diameter

The diameter of the beam for a TEM_{00} mode of a laser is when the electric field of the cross-section of the beam has decreased to $1/e$ of its maximum value. We also found that the electric field is related to power in electromagnetic propagation, which is directly related to intensity as a function of $r = \sqrt{x^2 + y^2}$, namely

$$I(x,y) = \frac{P}{\pi r^2} = \frac{\varepsilon_0 E^2}{2\pi(x^2 + y^2)} \tag{2}$$

Therefore, the beam diameter can be defined as the diameter where the intensity drops off $1/e^2$ of its maximum value. By defining the beam propagation direction as $\hat{z}$, the cross-sectional plane of the laser would then be on the $x - y$ plane, so we could measure the power output of the laser as a function of x by keeping y constant (the laser sits at a constant height). To do so, we required the use of our mounted knife edge to block the laser in constant increments of $x = 0.5mm$ until the power output reading was $0\mu W$. The knife edge was located 1 cm away from the laser. Therefore, we were able to measure the power output at each increment, and plot a graph of $P(x)$ vs. x (**FIG 2. and 3.**) to show where the intensity decreased by $1/e^2$, and thus find the diameter of the beam. Our best fit line turned out to be the derivative of the $1/e^{x^2}$, shown in **FIG. 3**, which was used to find the value of the corresponding intensity.

Beam Divergence

Finding the divergence, Θ, of the beam required taking simpler measurements, since the divergence was dependent on the definition of the beam diameter:

$$\Theta = 2arctan(\frac{D_1 - D_0}{l}) \tag{3}$$

where D_1 is the diameter of the beam at a very far distance, l, from the laser, and D_0 is the beam diameter calculated in the previous experiment. Our value of l was $148.4 \pm 0.25cm$.

We then compared this value with the manufacturer's listed divergence angle and the angle of Fraunhofer Diffraction, i.e.

$$\Theta = 2.44(\frac{\lambda}{D_0})$$

where $\lambda = 632.8nm$.

RESULTS

Polarization Angle

The polarization angle found was $0.996 rad$, or $57.06°$. Our error was $\pm 0.04 rad$, or $\pm 2.29°$. This error was found by taking into account of multiple systematic uncertainties, such as the fluctuating laser modes which caused destabilization of the power readings over time, and the measurement readings of the polarizer's angles.

Beam Diameter

The beam diameter, defined as $1/e^2$ of the maximum intensity of the beam, was found to be $d_{beam} = 0.070472 cm$ with an error of $\pm 0.0059 cm$, or 8.3 %. Compared to the manufacturer's value of $d_{beam} = 0.08 cm$, our measured value contained a 11.9% difference. Moreover, d_{beam} was found to be the corresponding diameter at the $1/e^2$ maximum intensity, or $114.9 \mu W$, and after centering the modelled curve at $0.003229 cm$. The errors were systematic as well, and were found with the fluctuations of the power meter and the detector.

Beam Divergence

By using equation (3), $D_\circ = d_{beam}$, and $D_1 = 0.231 \pm 0.019 cm$, we found the divergence of the beam to be

$$\Theta = 1.08 \pm 0.18 mrad$$

which is an 8% difference from the manufactuer's value of $1.0 mrad$.

From the Fraunhofer diffraction equation, we calculated that our theoretical value of the beam divergence should have been $\Theta = 2.19 \pm 0.18 mrad$. This is over a 50% error, which could have been caused by an incorrect calculation.

CONCLUSION

We investigated the properties of the Helium-Neon laser with several different instruments and techniques. Furthermore, we found that the polarization angle was $57.06° \pm 2.29°$; the beam diameter was found to be 0.070472 cm $\pm$ 0.0059 cm; and the beam divergence angle to be $1.08mrad \pm 0.18mrad$. These results make sense, as the spatial coherence property allow us to easily measure a small beam radius and a small divergence angle from the exit aperture.

Future Improvements

There were several systematic errors that could easily be improved. First, aligning each piece of equipment took up a good amount of time and was not the same each time. Because the laser covers a small cross-sectional space, it is easy for the laser to be measured incorrectly if the alignment is off by even a fraction of the laser diameter. So, it could be easiest to assist alignment calibration if it was easier to see the laser in a much darker environment. Also, having a more stable mounting system for each instrument after adjustment would be more reliable in providing accurate measurements.

Another major issue was the constant switching laser modes. Although this is a property of the laser apparatus itself, it would greatly mitigate the measurement errors, especially those related to the power output. The maximum power would always fluctuate over time, and that was related to the laser's modes switching.

FIGURES

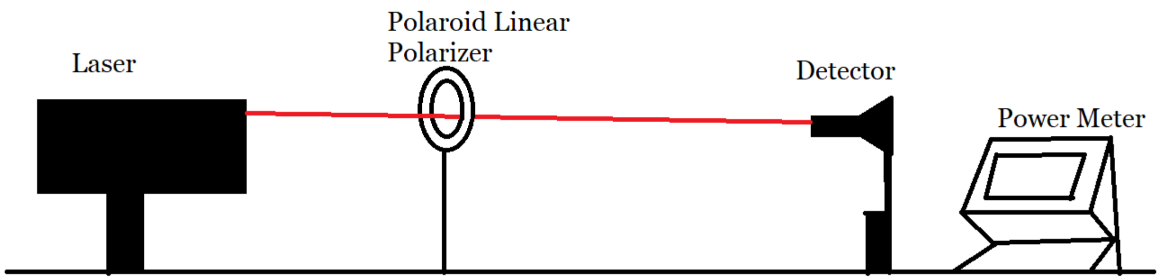

FIG. 1. Setup to find the laser's polarization angle.

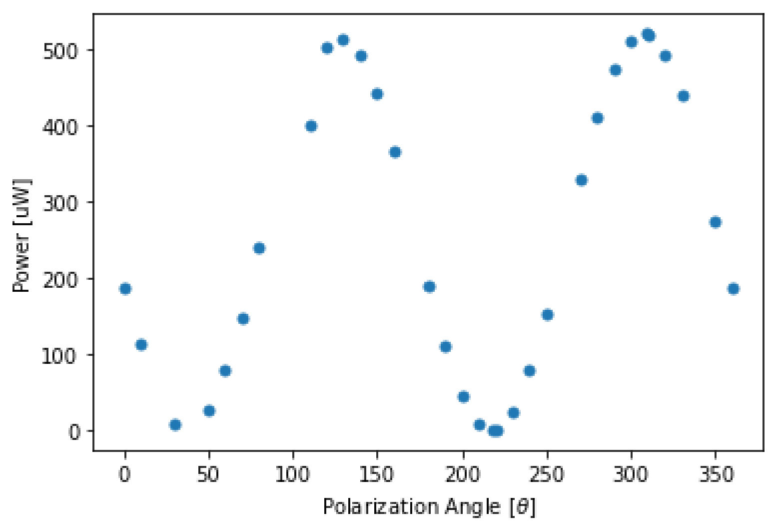

FIG. 2. A plot of Power vs. Polarization Angle

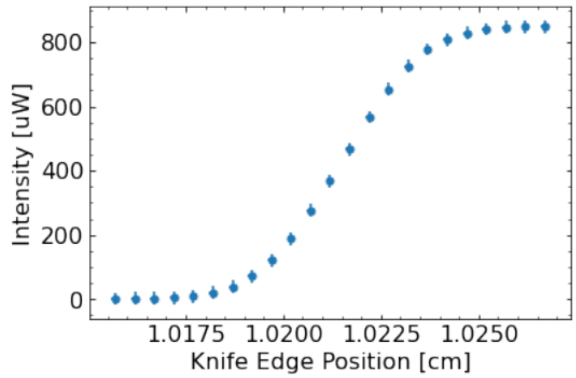

FIG. 3. Plot of Intensity vs. Knife Edge Position with error

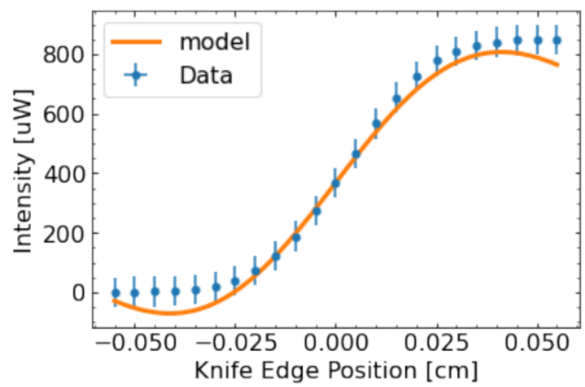

FIG. 4. A modelled line of best fit

FIG. 5. Plots of laser Intensity vs. knife edge position

TABLES

TABLE I. Table depicting beam divergence and their standard deviations.

Quantity	**SD**	**SD(%)**
l = 148.4 cm	0.25 cm	0.2
D_1 = 2.31mm	0.02mm	0.9
Θ = 1.08 mrad	0.18mrad	17