Properties of the He-Ne Laser

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Abstract

The properties of the helium-neon laser were determined using a computer controlled experiment. The laser's spatial intensity distribution was found to follow an approximate Gaussian distribution, which indicates TEM_{00} mode. The divergence between the near-field and far-field divergence was observed and the divergence of the laser beam was calculated to be $1.87(6)mrad$. Malus' law was verified experimentally. Brewster's angle was measured and was found to be 0.59 ± 0.08 radians, which corresponds to a refractive index of 1.59.

1 Introduction

The helium-neon laser is one of the most popular types of lasers. It is a gas laser that operates at a variety of wavelengths and produces milliwatts of output power. These wavelengths include green at $543nm$, yellow at $594nm$, orange at $612nm$, red at $633nm$, and infrared at $1523nm$. The laser that was used in the lab operated at $632.8nm$ and was visible in the red portion of the visible spectrum [1]. The laser operates due to the inelastic collision of excited helium atoms with ground state neon atoms. This collision results in the excitation of the neon atoms to upper laser levels [2]. The emitted laser beam has an intensity, which can be measured. Intensity is the flow of energy per unit area per unit time and is proportional to the voltage [3]. This intensity can be fitted with a Gaussian form, which indicates TEM_{00} mode [4]. The Gaussian form is described by the following equation.

$$P(v) = \frac{1}{\sigma\sqrt{2\pi}}(e^{-\frac{1}{2}}(\frac{v-u}{\sigma})^2) \quad (1)$$

Where u represents the replica mean, σ is the square root of the variance, which is also referred to as the standard deviation[5]. This form allow us to see the probability of measuring a certain intensity. While measuring the intensity, we had to ensure that detector saturation was avoided. Detector saturation is when the detector operates at a level where the response is non-linear [6]. What was measured as intensity, was actually the integrated intensity distribution. The integrated intensity distribution was fitted to an error function.

$$\text{erf}(y) = \frac{2}{\sqrt{\pi}}(\int_0^y e^{-x^2}dx) \quad (2)$$

To fit this data with a Gaussian form, its derivative was taken. The divergence of the laser beam is where the beam no longer meets at a single point. To determine this, linear regression was used.

Linearly polarized light is light for which the orientation of the electric field is constant[7]. Its intensity can be described by Malus' law.

$$I = I_0((\cos\theta)^2) \quad (3)$$

Where I_0 is the intensity of the incident polarized light, I is the intensity, and θ is the angle [8]. Since the polarization of the laser can be described by this equation, we can see why the intensity with a polarizer present can be fitted to a sinusoidal curve.

Brewster's angle is the angle where the incident unpolarized light becomes completely polarized upon being reflected[9]. There is an intermediate angle, θ_B, at which the reflected wave is completely extinguished."[10] This happens when

$$sin^2\theta_B = \frac{1-\beta^2}{(n_1/n_2)^2-\beta^2} \quad (4)$$

or approximately,

$$tan^2\theta_B \approx \frac{n_1}{n_2} \quad (5)$$

The light can be polarised to get rid of the light when Brewster's angle is reached; the polarisation angle is obtained experimentally by attaining Brewster's angle, and adjusting the polariser to extinguish the light. Brewster's angle usually involves the reflected intensity and not the transmitted. The transmitted intensity is related to the reflected by the following equation.

$$R + T = 1 \quad (6)$$

where R is the reflected light, and T is the transmitted light[3].

"Divergence is a measure of how much the vector diverges from the point in question."[11] For Gaussian beams, this divergence isn't linear. When near the laser, the divergence angle is very small but when you are far from the laser, it approaches the asymptotic limit. This can be approximated as linear.[12]

2 Experimental Methods

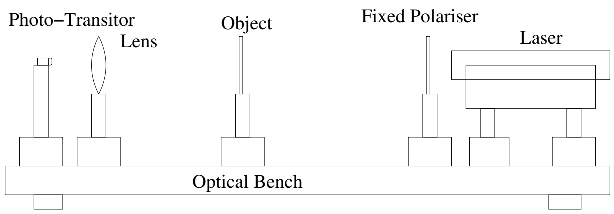

Figure 1: Optical setup used for these measurements.

The 'Object' in Figure 1 is a different object in each of the experiments; for the polariser experiment it's the polariser on a motor, placed with its axis parallel to the laser; for the Brewster's angle experiment, it's the glass slide on a motor, placed with its axis perpendicular to the laser; for the all of the divergence experiments, it's the linear actuator with a razor that cuts into the laser.

The polarising angle was set with the polariser on the laser. Another polariser with a motor that modulated the light that was reaching the photo-diode. The photo-diode outputted to the computer via the ADC (Analog to Digital Converter.)

The Brewster's angle saw a glass polariser placed with its axis vertical. A motor turned the polariser so that we could measure the intensity of the light as a function of its angle. The angle of the slide with respect to the polariser was set by finding Brewster's angle manually and adjusting the angle until the reflected beam vanishes. The angle was started off perpendicular to the laser so it was near aligned. Then we took the lines of zero slope calculated with a simple mid-point rule for derivatives, Figure 4. We got four such lines, folded at $\frac{\pi}{2}$, performing error-analysis to get one value.

The divergence was measured with a razor blade cutting into the laser at various intervals along it. We used a disk drive to set up a linear actuator perpendicular to the laser. Measurements were taken as the actuator swept across the laser at very fine steps. Thirty-two replicas were made and condensed into one value per angle. The vibrations were a problem, and the source of most of our systematic error. We adjusted the stepping rate of the actuator, and we found that $30ms$ gave us the best results; $1ms$ was too fast, and the vibrations were noticeable; $100ms$ set up a resonance that was equally as bad. We took photos with a tripod of one-hundred and twenty-eight steps of the motor and the sinusoid of the angle; this allowed us to get the step size of $93.75(1)\mu m$.

3 Results and Discussion

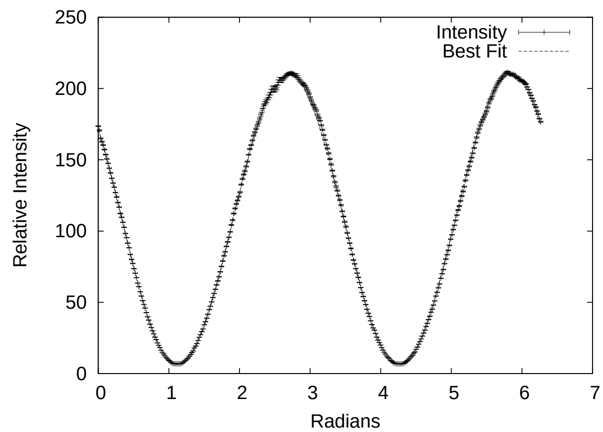

Figure 2: Angle of polarisation of the laser beam.

Figure 2 shows the intensity of the light transmitted through the fixed polariser and then the rotating polariser. Ambient light caused an offset. The reduced-χ^2 is large, 28; this was caused by imperfections in the rotating polariser. These imperfections caused a decrease in the amount of light passing through the lens. This resulted in an asymmetric distribution of errors hence the large reduced χ^2 value. This experimentally agrees with Malus' law.

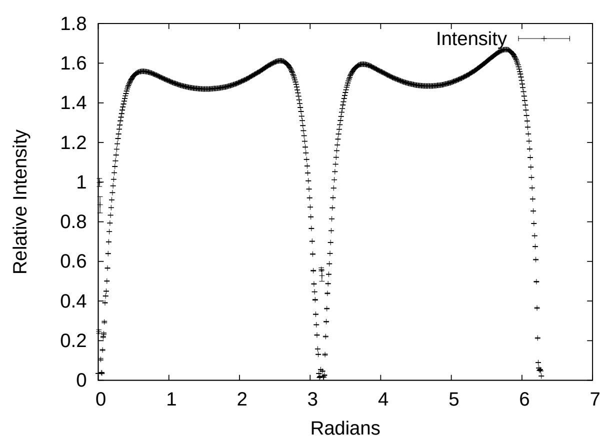

Figure 3: Intensity of the light transmitted through a glass slide as a function of the angle of rotation.

To find the maxima in the data it was differentiated and the regions close to the zero crossing were fitted using linear regression.

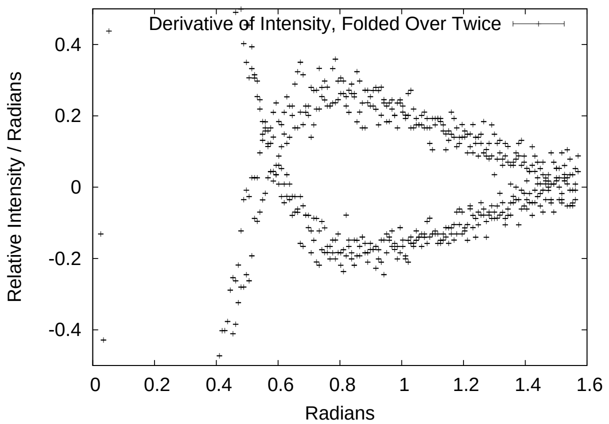

Figure 4: Derivative of the intensity of the laser beam as a function of the angle of rotation using the midpoint rule.

The zeros occur at 0.59 ± 0.08 radians. This is the minima and Brewster's angle. The measured light was the transmitted light but when discussing Brewster's angle, one refers to the reflected light. This value for Brewster's angle corresponds to an index of refractive of 1.59. Since our transmitted medium is glass, with a refractive index of 1.5, this supports our measured Brewster's angle.

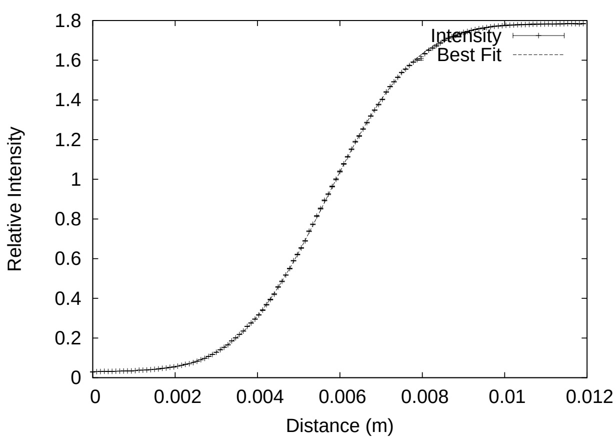

Figure 5: The integrated intensity distribution of the razor that is $0.509 \pm .003m$ away from the laser.

The beam width is defined as being two standard deviations of the Gaussian profile. Figure 7 shows the beam width as a function of distance from the laser. An interesting feature of this is the flat region from approximately 0 to 10 cm. This agrees with the near-field divergence. This explains why we fit to exclude the points from 0 to 10 cm and calculate the divergence from the remaining points, as seen in Figure 8.

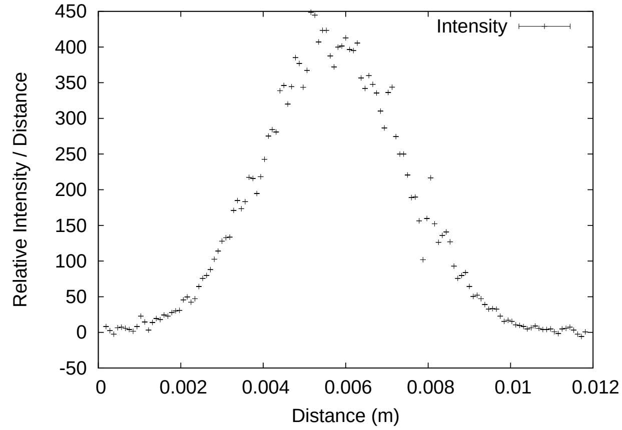

Figure 6: Beam profile at 50.9 cm from the laser

Figure 6 data shows the Gaussian distribution of the intensity profile, which indicates TEM_{00} mode.

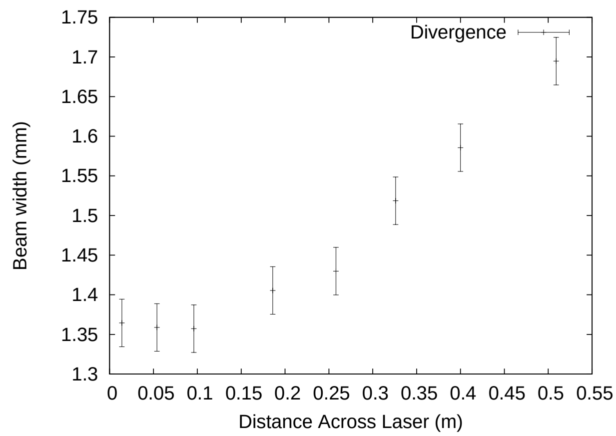

Figure 7: The beam width as a function of the distance from the laser

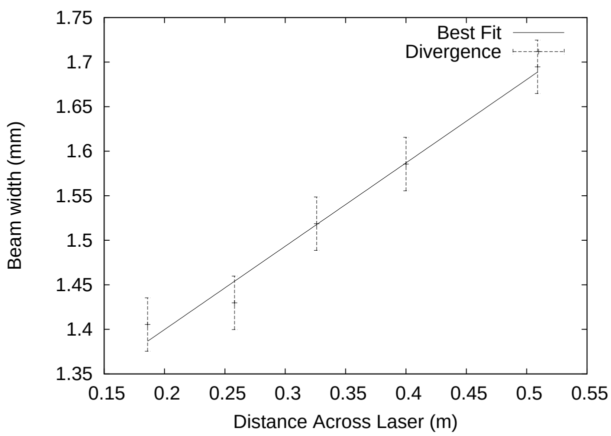

Figure 8: This is the divergence without the first three points.

These excluded points could be representative of the non-linear relationship near the laser because this is where the divergence is really small and isn't approaching the asymptotic value.

Divergence is $2\sigma = 1.87(6) mrad$

4 Conclusion

The polarisation of the laser beam was found to be governed by Malus' law and could easily be fitted to a sinusoidal curve. Brewster's angle was determined to be 0.59 ± 0.08 radians, which corresponds to a refractive index for the transmitted medium of 1.59. The transmitted refractive index value confirms the experimental value of Brewster's angle because the actual transmitted medium, glass, has a refractive index of 1.5. The integrated intensity profile was fitted to the error function and its derivative could be approximated by a Gaussian distribution. This confirms that the laser is operating in TEM_{00} mode. The divergence was calculated by using the values greater than 10 cm and was found to be 1.87(6) mrad.

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