Properties of Helium-Neon Laser, Kenji Kemp

Abstract:

The assumption of the properties of a He-Ne laser is are well known and taken for granted in basic physics, however, this report will show that the accurate observation of these properties experimentally is taken for granted. For this laser we found these key results: the average polarization to be 0.8908 ± 20%, beam divergence 0.206 mRad ±30%. Inserting a Fabry-Perot interferometer confirmed previous suspicions that the polarizer was not calibrated at zero correctly, and from the interferometer we could calculate the mode spacing to be 2 x10⁻³ m.

Introduction:

The properties of a He-Ne lasers (Light amplification by stimulated emission of radiation) are well known. There is a great understanding in the mechanism of the laser in terms of basic quantum and atomic physics. The excitation of a molecule from an initial state to a higher energy state by the absorption of a photon with frequency 'v,' is proportional to the energy separation between two states. The subsequent decay from this excited state to its original state emits a photon of the same frequency, v. The onset of excitation can occur in two ways, stimulated emission and spontaneous emission.

Stimulated emission-This is the process by which molecules collide with a photon of frequency, $hv=I_m-I_n$, emitting a second photon. These two photons leaving the molecule have identical phase, polarization, frequencies and direction.

In Spontaneous Emission, the molecule is not induced into decay but this happens on its own.

Lasers are almost monochromatic, this laser has a wavelength λ of 632.8nm. The

light in lasers has a temporal decoherence, by which the light oscillates like a sine wave but over time loses its coherence. The point over a distance, x, this happens is called the coherence length, L_c For our laser we calculated this to be 0.4m.

This experiment is going to observe some of the known properties of lasers in the lab and see how our results confirm these.

Method:

The initial part of the experiment was purely theoretical, using our knowledge of statistical mechanics, atomic and quantum theory we calculate a number of key physical values.

(i) $E = \frac{1}{2}k_BT$, $E = \frac{1}{2}mv^2$ and hence $\frac{v}{c} = 1.36 \times 10^{-6}$

(ii)
$$v = v_0 \left(1 + \frac{v}{c}\right), F = \frac{v}{\lambda}$$
, and hence $v_n = 4.74 \times 10^{14} Hz$ and using a similar method, $F = 0.6 \text{GHz}$.

The number of modes of oscillation can be found using $v_n = \frac{nc}{2L}$, n= 634113.71

Polarization of light

(iii)
$$\rho = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

The polarization of light using a sheet of Polaroid linear polarizer, passing the laser through this, then measuring the intensity using a pyro-electric laser power meter. The intensity of the laser was recorded as a function of θ . To get a broad view on how the change θ we did this in increment of 15° from 0° to 180°. We ensured that the meter and polarizer are within the coherence length calculated earlier and recorded intensities at three points along the x-axis to see how this varies within the coherence length of the laser.

Beam Diameter

To measure the beam diameter of the laser we used a knife edge to measure the cross-sectional intensity of the laser. Using the power meter we measured the beam profile. Some analysis was necessary to calculate the intensity.

(iv)
$$I(r) = I_0 e^{-\frac{r^2}{w^2}}$$

(v) $I = I_0 \int_0^\infty e^{\frac{-r^2}{w^2}} r \, dr \, \int_0^{2\pi} d\theta$, where $r = \sqrt{x^2 + y^2}$, we get:

(vi)
$$I = 2\pi I_0 \sqrt{\pi w^2}$$

Beam Waist

Using a lens with known focal length, 17cm, the beam laser was focused to a certain minimum diameter, 'd' (beam waist). This occurs understandably at a length 'L.' Both these can be found theoretically using equations (vii) and (viii), or experimentally, by using a razoredge to cut the cross section of the laser. We have done this with increments of 0.0025m. Doing this along the z-axis at position 8cm, 10cm and 13cm.

(vii)
$$d = \left(\frac{4\lambda}{\pi}\right) \left(\frac{f}{D_0}\right)$$
 ,(viii) $L = 2 \left(\frac{4\lambda}{\pi}\right) \left(\frac{f}{D_0}\right)^2$

Beam Divergence

The beam divergence is due to Fraunhofer diffraction caused by the circular aperture at the end of the laser, occuring only where the aperture the laser passes through changes only the size of the aperture. It occurs only in the far-field of the laser, so is necessary to record the beam diameter a large distance from the laser. However due to restraints in our apparatus the maximum distance we could do this was at 1.5m. We used a the razor edge again to measure the change in intensity along the cross section of the laser, from this finding the beam diameter. The divergence is defined as the full angle $2\Delta\theta$. The geometry of this theory we know that

(ix)
$$\tan \theta = \frac{D_{final} - D_{initial}}{L}$$
,

(where D=diameter)

we can calculate $\theta = 1.22 \frac{\lambda}{D}$ to be 0.96mRad

The Fabry Perot Interferometer

This interferometer makes use of two mirrors to amplify the wave frequency. If the incident waves are in phase and add constructively the detector generates a voltage proportional to the intensity of the light striking it. Our apparatus has been set up to be seen on an oscilloscope, via an output on the interferometer. The image on the oscilloscope is periodic because of the separation of the mirrors 'x'. If the wavelength has an 'n' integer value of , then the frequency increases dramatically so we have a periodic function as the x-value changes. The interferometer allows us to be able to calculate various laser properties. We used it to estimate the mode spacing, mode polarization. The mode stability could be observed for a laser as it warms up however as we were using a He-Ne laser that was fully warmed this was not observed.

Safety Points:

The laser has the potential to blind or damage the eyes of those working or in the same room as the laser. We ensured safety goggles were worn when the laser was being used, keeping the safety card at the end of the apparatus up at all times and keeping the laser cover close when not in use.

Reducing Experimental Error:

In order to try to reduce systematic error it was necessary to ensure some key points of our experiment be kept consistent throughout.

Being careful not to lean on the table when results were being taken, as it may interfere with alignment of the laser. Ensuring that the same person read the polarization angles as square on as possible. The same person for reading the intensity meter, and always reading the lowest value if when fluctuations occur.

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Keeping the laser as squared off_onto the meter or interferometer as possible.

<u>Results</u>

Polarization:











M 250.05

Ext / -56.0mV





Beam Waist:



Figure 4

Mode Spacing:





Discussion

Our average degree of polarization was calculated to be 0.8908±0.167

Figure 1 represents our three values taken at different values of Xcm from the laser edge. we can see there is a consistent 'dip' at 15 degrees polarization, and peak at 105°, not giving a perfect curve. This

indicates that the polarizer is not zeroed on the 0° point. When finding to mode polarization this was also a consistent factor. Doing this again I would use a polarizer with smaller increment, of 5 degrees to get a nicer smother curve. Also using a number of different polarizer's will have given a very good average degree of polarization of the laser and to see if there was any specific 'character' to this laser. The uncertainty was calculated by adding the errors of the intensity of I_{max} and I_{min} in quadrature, and taking the square root. I calculated the error this way as in the equation (iii) there are only these terms. The similarity of the points at different Xcm values indidcates that within L_c there is little change of the degree of polarization. This assumption would be made more accurate with more sets of data taken.

The graphs for beam diameter are half of a Gaussian curve, as expected by the cross-section of a laser profile. However getting curve with enough point to see the exponential growth was fiddly and required very small changes of the razor position. Here it became clear the fragility and constant changing of the system. Trying to put two sets of data together within a graph, they did not match leaving us a graph with two turning points. (Figure 2) These two sets of data were taken directly after each other, yet this small change in time had caused a large difference in our graph. Our best curve is shown in Figure 3, indicated the beam diameter can be estimated to be about 0.0024m ±30%. Uncertainty being calculated using the quadrature method

again. There was no perfectly smooth curve, but it gives us a good indication of the of the way the intensity varies within a laser. Doing this again, obtaining an average would be essential, and also seeing how the cross section varies right at z=0 and Z_{max} would be interesting.

Figure 4 shows a plot of our laser crosssection after being passed through a lens. From the graph I estimate the beam waist to be of order 1 magnitude from the calculated value, 1.7×10^{-4} m. We had a jump in data (circled) which happened in two of our three trials. This is most likely due to human error, as it was not consistent throughout our experiment. Further collection of data would make it clear if this is a consistent result. The anomalies may be due to the laser being moved, or background light. Doing the experiment again I would do it in a darkroom, measure background light and use this as a control for the experiment.

Our beam divergence value was found to be 0.206mRad. This is very different, from the estimated value of 0.96mRad calculated and the manual value of 1.0mRad. There are a number of reasons why this may be, however, it is probably due to the distance we measured the intensity at. The far field for this laser is greater than 2 meters, we conducted our experiment at 1.5m due to apparatus constraints. Hence our calculated value for the divergence is going to be smaller than the literature and calculated values.

The Fabry-Perot interferometer gave us an indication of how the mode polarization varied. However, not as expected the graphs peaked at 105° , indicating again that the polarizer is not calibrated properly. Our value of mode spacing is 1.5Ghz. (Figure 5). This is double the value of 0.75Ghz calculated using $\delta = \frac{c}{2L}$. This is due to the mirror spacing and constructive interference of the detected beam.

Conclusion

Our experiment on a He-Ne laser showed that the understood properties of a laser are consistent, but not necessarily easy to observe by time limited experimentation. Taking averages as in any experiment is essential to come to a solid conclusion and this report due to time restrictions lacks this.

We found the average degree of polarization to be 0.8908 ± 20%, beam divergence 0.206mrad ± 30%. From the Fabry-Perot interferometer we found the mode spacing to 1.5Ghz, double calculated values and as the angle of polarizer increased the peaks increased and decreased as expected. However the largest amplitude at 105° confirmed the polarizer was incorrectly calibrated.

To be able to test the properties of a laser it is essential to prior plan for human error, check for the necessary apparatus available, and perform it in a dark room. However, doing this experiment I developed an understanding of the laser properties and how to test them