The Effect of Lasing on Electron Population in He-Ne Energy Levels

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Abstract. We investigate the effect of lasing on spontaneous emission spectra of neon and helium. To achieve this, we set up a chopper to alternate between lasing and non-lasing states, and detect the change in spectra with a lock-in amplifier. We found intensity decrease in the main lasing line at 632.8 nm and an intensity increase in the neon 2p to 1s lines, indicating an electron population shift from the neon 3s to 2p level. The population decrease in the neon 2p level was calculated to be $1.13 \pm 0.03\%$. In addition, an intensity increase in a neon 3p to 1s line suggests that lasing also occurs between the 3s and 3p levels, at 3.3913 μm .

I. Introduction

We devise a method to investigate electron population in two level systems by observing changes in the spectral lines in lasing and non-lasing states. The equations of equilibrium in a two level laser system are

$$\frac{dN_{2L}}{dt} = R_2 - \frac{N_{2L}}{\tau_2} - KN_{2L} + KN_{1L} = 0 \tag{1}$$

$$\frac{dN_{2NL}}{dt} = R_2 - \frac{N_{2NL}}{\tau_2} = 0 \tag{2}$$

where N_{1L} is the electron population in the lower level, during lasing. N_{2L} , N_{2NL} are the electron populations in the upper level, in lasing and non-lasing states respectively. K is the stimulated emission rate, τ_2^{-1} is the spontaneous emission rate and R_2 is the rate of transition into the upper level via other processes. Subtracting these two equations, we obtain that the upper level population difference between lasing and non-lasing states is proportional to the population difference between the upper and the lower level during lasing.

$$N_{2NL} - N_{2L} = K(N_{2L} - N_{1L}) \tag{3}$$

For a given transition, we observe the photon intensity outside the laser axis at the corresponding wavelength, such that we only observe spontaneous emission, which is proportional to N_2. We compare the non-lasing spontaneous emission intensity to the lasing spontaneous emission intensity and determine the fractional change.

Using our He-Ne laser, we identify multiple spontaneous emission lines listed in Table 1, 2, 3, and investigate the effect of lasing on them. Since lasing increases stimulated emission, we expect electrons to migrate from the neon 3s to 2p level, causing population decrease in the 3s level and population increase in the 2p level. In turn, there will be fewer electrons in the 3s level to produce spontaneous emission, so we expect an intensity decrease in the 3s to 2p line (the main lasing line at 632.8 nm). In addition, since there will be more electrons in the 2p level to produce spontaneous emission, we also expect an intensity increase in the 2p to 1s line. Indeed, we confirm these two phenomena.

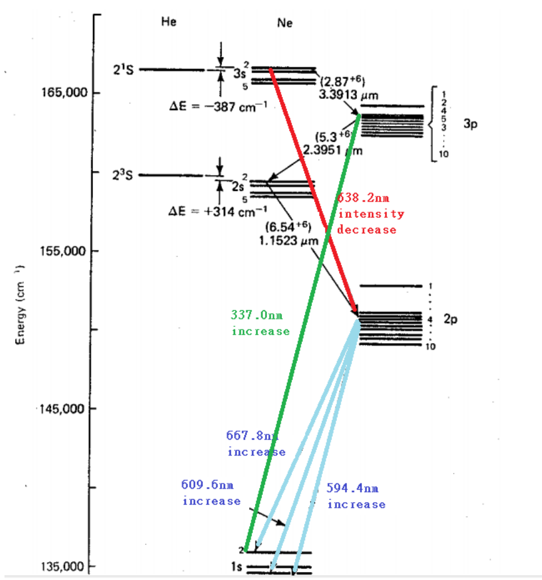

Figure 1: Energy levels and wavelengths of the He-Ne laser system. The 6328.2 A transition is the main lasing wavelength.

II. Experimental Methods

In order to observe the difference in spectra between lasing and non-lasing states, we use a chopper to alternate between lasing and non-lasing, and then we observe the difference using a lock-in amplifier. First we set up a He-Ne laser using a hemispherical Fabry-Perot interferometer configuration, as shown in Fig 2. The He-Ne discharge tube is between a curved mirror and a flat mirror and aligned on their axis. On the side of the flat mirror, we place a chopper between the tube and the mirror, so that we can cleanly block and unblock the beam with the chopper. We use a monochromator to select a transition wavelength and observe the intensity with a photomultiplier tube. The signal S_1 we obtain is proportional to the average spontaneous emission intensity, with a constant of proportionality χ.

$$S_1 = \tfrac{1}{2}(N_{2NL} + N_{2L})\chi \tag{4}$$

We multiply the signal S_1 with a reference signal from the chopper in a lock-in amplifier to obtain the difference S_2 in spontaneous emission intensity between lasing and non-lasing.

$$S_2 = (N_{2NL} - N_{2L})\chi \tag{5}$$

Assuming that $N_{2L} \approx N_{2NL}$ (which is confirmed in our results), we can divide S_1 by S_2 to obtain the fractional change.

$$\frac{(N_{2NL} - N_{2L})\chi}{\tfrac{1}{2}(N_{2NL} + N_{2L})\chi} \approx \frac{N_{2NL} - N_{2L}}{N_{2NL}} \tag{6}$$

We choose our experimental parameters to optimize for maximum signal, taking care not to saturate the photomultiplier. To obtain S_2, we scale the voltage output from the lock-in amplifier by its gain g, given by

$$g = \frac{10\sqrt{2}}{sensitivity} \tag{7}$$

We take three sets of data over each emission line and fit the peaks with Gaussians to obtain its intensity. The error on intensity was calculated by taking the standard deviation of the amplitudes of the fitted Gaussians.

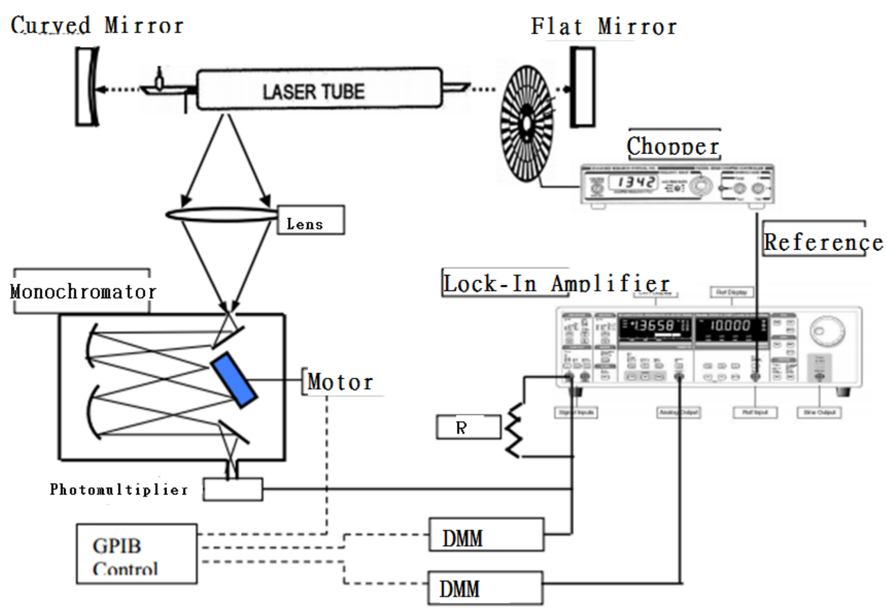

Figure 2 : Experimental Setup
The chopper makes the laser alternate between lasing and non-lasing. Spontaneously emitted photons from the He-Ne tube are selected with a monochromator and detected by photomultiplier. The difference between lasing and non-lasing signals is amplified with a lock-in amplifier.

III.   Results

We identify the transitions associated with each line as listed in Table 1, 2, 3. We plot the intensity of the lines during alternation between lasing and non-lasing in Fig 3.

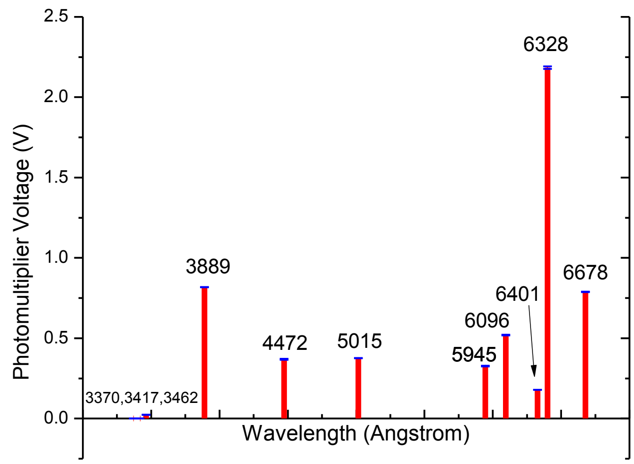

Figure 3: Observed spectrum of He-Ne tube during alternation between lasing and non-lasing. Blue bar indicates error.

We present the difference of the lasing from the non-lasing state in Fig 4. Here we note that positive lock-in voltage corresponds to less intensity in the lasing state. The fractional change in intensity of the lasing to the non-lasing state is plotted in Fig 5.

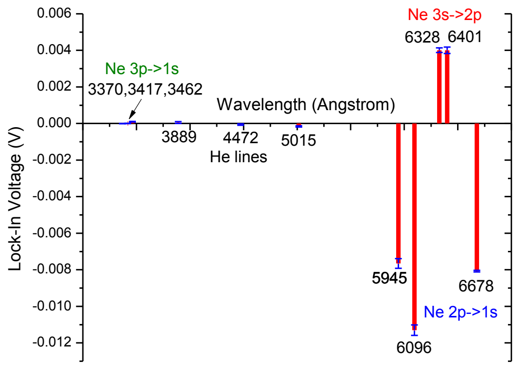

Figure 3: Difference in spectrum intensity of lasing compared to non-lasing. Positive lock-in voltage corresponds to a decrease of intensity in the lasing state.

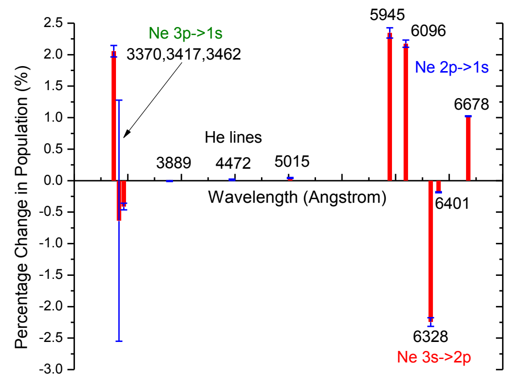

Figure 4 : Fractional change in intensity of He-Ne spectrum during lasing. Note that 3417A line has substantial error.

First, we observe that the intensity of neon transitions from 3s to 2p significantly decreased (especially 632.8 nm), while the ones from 2p to 1s significantly increased (667.8, 609.6, 594.4 nm) due to lasing.

Table 1: Emission Lines of Neon 3s -> 2p -> 1s Transitions

Wavelength (nm)	Transition	Percentage Difference Lasing/Non-Lasing (%)	
640.1	3s -> 2p	-0.18	± 0.008
632.8 (lasing)	3s -> 2p	-2.24	± 0.070
609.6	2p -> 1s	2.18	± 0.056
594.5	2p -> 1s	2.35	± 0.083
667.8	2p -> 1s	1.02	± 0.006

Second, we find that the line at 337.0 nm, which corresponds to a 3p to 1s transition, significantly increased.

Table 2: Emission Lines of Neon 3s -> 1s Transitions

Wavelength (nm)	Percentage Difference Lasing/Non-Lasing (%)	
346.2	-0.41	$\pm$ 0.052
341.7	-0.64	$\pm$ 1.91
337.0	2.06	$\pm$ 0.09

Finally, we find that the helium transition of $3p^1$ to $2s^1$ (singlet state), which is at 501.5 nm also has a small but notable increase.

Table 3: Emission Lines of Helium Transitions

Wavelength (nm)	Transition	Percentage Difference Lasing/Non-Lasing (%)	
501.5	$3p^1$-> $2s^1$	0.042	$\pm$ 0.009
447.2	$4d^3$ -> $2p^3$	0.014	$\pm$ 0.011
388.9	$3p^3$ -> $2s^3$	-0.0068	$\pm$ 0.0065

IV. Discussion

According to Fig 4, the errors bars indicate that the changes in all lines are statistically significant, except for the 341.7 nm transition. These results indicate the following two phenomena. First, lasing reduces the electron population in the neon 3s level and increases it in the 2p level. Second, lasing also occurs at 3.3913 μm, which is the neon 3s to 3p transition.

The first phenomenon accounts for the decrease in neon 3s to 2p transitions (632.8 nm), and the increase in 2p to 1s transitions (667.8, 609.6, 594.4 nm). Since lasing opens up a new decay path through stimulated emission, it removes electrons from the 3s level to the 2p level, shifting the equilibrium towards the lower level. Due to lower electron population in the 3s level, spontaneous emission from this level also decreases, hence less 632.8 nm light. In turn, electron population is increased in the 2p level, causing more spontaneous emission transitions to lower levels, hence more 632.8 nm light. Using equation (6), we see that the fractional change in intensity of this line corresponds to the fractional change in electron population. We calculate the population decrease to be $1.13 \pm 0.03\%$.

The second phenomenon is indicated by the increased neon 3p to 1s transition (337.0 nm). We calculate the population increase in the 3p level to be $2.06 \pm 0.09\%$. Since the percentage of increase is comparable to the 2p to 1s transitions, this means that the population in the 3p level is also increased significantly. This suggests that a similar mechanism to the 632.8 lasing is pumping electrons to the 3p level. Based on our hypothesis, we will be able to detect lasing in 3.3913 μm, which is the wavelength of a 3s to 3p transition, in a He-Ne laser. Although our optical cavity is tuned mainly to enhance 632.8 nm lasing, it is still possible to have microwave lasing because we expect the microwave line to be broader, thus having more longitudinal modes.

V. Conclusion

We have investigated the effect of lasing on various He-Ne emission lines, which are enhanced or diminished according to the population change induced by lasing. In particular, we noticed that the intensity of neon transitions from 3s to 2p significantly decreased, while the ones from 2p to 1s significantly increased due to lasing. We infer a population shift from 3s to 2p occurs. We also found a similar population increase in the neon 3p level, which suggests lasing at 3.3913 μm. With better understanding of the population in various energy levels, we hope to detect the microwave lasing using different instrumentation, determine precise electron decay paths and subtle excitation mechanisms in the future.

References

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