# Physics 111B: $CO_2$ Laser


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We present an experimental method for observing the spectrum of $CO_2$. Using carbon dioxide gas as the lasing medium, we then used the beam and a diffraction grating to observe the strength of different lines in the $CO_2$ spectrum. Additionally, different properties of the laser, such as current vs. voltage and power threshold in relation to gas pressure, were also observed.


## I. INTRODUCTION

In this experiment, we adjusted and carefully aligned sensitive optical equipment to create a laser that used $CO_2$ gas as its lasing medium. Using this laser, we then learned more about molecular structure, light and optics, and gas discharge. This laser will operate in the infrared range at a wavelength near $10^{-6}$ m and will be a continuous wave carbon dioxide laser capable of reaching 10 W output.

## II. BACKGROUND

### A. What is a LASER?

Laser is an acronym meaning "light amplification by stimulated emission of radiation" and the device does just that.

Lasers work by stimulating the emission of photons from excited electrons. A power source is used to initially excite this electrons which overtime will naturally decay back down to their ground state emitting a photon. This photon then goes on to stimulate other excited electrons into decaying back down to their ground state, emitting more photons. This process ends up creating a beam of monochromatic light. The housing around the lasing medium often has mirrors at both ends to continuously reflect the photons to ensure further stimulation, only permitting a small number to escape through a small opening in one end.

## III. STANDARD OPERATING PROCEDURE OF $CO_2$ LASER

The $CO_2$ laser has multiple components that must be monitored to ensure the laser is working correctly and optimally. Gas pressure and current are some of these factors and monitoring them is especially important since the laser itself will be in the infrared range and invisible to the human eye. For the laser to begin lasing, the mirrors must be aligned first which will be done with the assistance of a Helium-Neon laser.

### A. Helium-Neon Laser Alignment

The laser mirrors must be aligned in such as way that the beam can be passed back and forth through the tube multiple times without hitting the walls. To do this, we will use a Helium-Neon laser that emits a red light, therefore we can visually align it.

There are three mirrors that are external to the laser housing that will be used for alignment. The three external mirrors are places such that there is one on either side of the laser housing and the third was place in front of the HeNe laser. This mirror would reflect the HeNe laser to a mirror placed in front of the laser housing, which would in turn reflect the beam through the cavity and into the tube.

There are additionally two mirrors inside the laser housing. One of these mirrors is a diffraction grating and will be used in later experiments so it was initially moved to the side such the beam would then pass through the cavity it was blocking instead and reflect off of the external mirrors behind it. The other mirror inside the housing is a coupler mirror and was also removed during the initial stages of alignment.

For the first stage of alignment we want to ensure the HeNe laser beam is passing through the tube and reach the other end with striking the walls of the tube. To make this part easier we removed the other external mirror at the opposite end and used a target that was drawn on the wall as reference.

This stage of alignment had three steps. The first step was to adjust the mirrors that were reflecting the beam into the tube until it was passing through the cavity in the center. The second step was to adjust both of the mirrors simultaneously such that if the laser is angled off-center then it was corrected and would come out the other of the tube through the center as well. Both mirrors are adjusted at the same time to also ensure that the beam is still entering the tube through its center, so that way by the end of this second step we know that the beam is parallel to the tube. Finally, the third step was to fine tune the focusing of the beam using the target on the wall as reference.

After this, we place the third external mirror back where it initially was so the beam is once again reflecting back into the tube. This next stage of alignment is to ensure that the reflected beam is also parallel. We do this by slowly adjusting the beam so that way it is centered while back tracking it from the mirror back to the HeNe laser. For example, we check if the reflected beam is entering the laser housing in the center using a note card with a hole in it. This allows the initial laser to pass through, but if the reflected beam is not straight then we will see it on the note card and it will make it easier to adjust the mirror. We continue to do this once again at the other end of the housing where the reflected beam exits and in front of the HeNe laser itself. Once this stage is done then all external mirrors can be considered to be aligned.


FIG. 1. An alignment example of the third external mirror.

The next stage requires us to place the coupler mirror back into place and align it. This mirror reflect back some of the beam and lets the rest pass through it, resulting in two distinct red dots appearing to be reflected back to the HeNe laser. The coupler mirror is adjusted so that each of these red dots is reflected back directly into the iris in front of the laser, and the mirror alignment is then recorded for both of these dots. This is done because it is uncertain which of these dots is the true dot necessary for proper laser alignment so both are recorded that way we can test both once we are trying to align the $CO_2$ laser.

FIG. 2. An example of the two dots that are reflected back to the laser during HeNe laser alignment.

### B. Pumping-Out and Filling the Laser Tube

To start the $CO_2$ laser we need to first pump out the air that has been sitting in the tube then fill it up with the carbon dioxide gas.

First, open the valve on the gas tank labeled Valve 4. This will allow the $CO_2$ gas to begin flowing out of the tank.

Valves 2 and 3 near the laser housing controls the gas flow into the tube, being course and fine adjustment respectively. Valve 1 controls the vacuum, adjusting how much gas is being pumped out.

To ensure a good amount of $CO_2$ was in the tube at all times, we opened up Valve 2 a couple times and then used Valve 3 and Valve 1 to adjust the pressure until it was within the range of 10-20 mmHg. We had our pressure set to around 12 mmHg for all experiments.

### C. Powering and Turning Off the Laser, and Adjusting Laser Power

To power the laser we must turn on the electrical equipment step-by-step. First, we turn on the water supply, turning the valve in Room 286, and then the blue knob and finally the red knob inside the room. Finally, press the interlock button.

Now, turn on the main power supply and then the two Current Regulators. Wait about 30 seconds to press the High Voltage (HV) interlock buttons on both regulators at the same time. Adjust the current on both regulators such that they are the same and less then 10 mA. 7 mA is a good place to be. Then, adjust the power supply knob until there is a discharge in the laser tube.

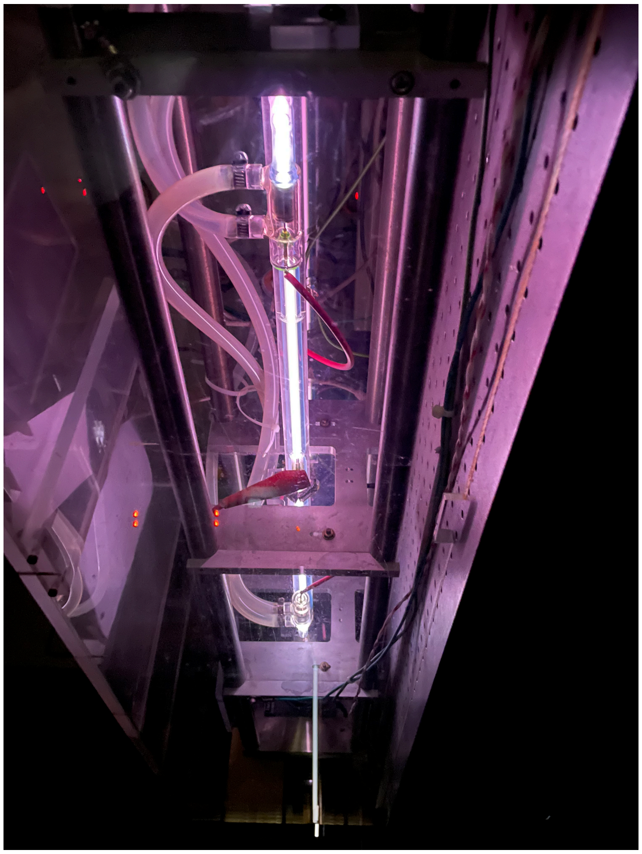

FIG. 3. An example of discharge in the gas tube once the power and HV are on.

The power of the laser can be adjusted with the power supply dial once it is lasing.

To power down the laser quickly flip both regulator swiches off and then back on to cut off the HV power to the laser tube. Then, turn the HV power supply to zero and wait for the meter to also read zero. Once it does, turn off both regulators and the main power supply. Turn off the water supply as well by going backwards, turning the red knob and the blue knob, and then the main water supply in Room 286.

### D. $CO_2$ Laser Alignment

Once the power supply is turned on and there is discharge in the tube, ideally the laser should be lasing. We can verify whether or not this is happening by placing the power detector in front of the end of the laser housing that way the beam would hit the sensor. The power detector will need to be zeroed out, but if the laser is lasing the detector will display a power that is significantly larger then the noise.

The laser will most likely need further alignment by adjusting the coupler mirror and the power reading will be the only way to verify whether or not the laser is lasing. To do this we performed a grid search with the coupler mirror around the measurements recorded for the two dots previously observed during the HeNe alignment procedure. For this grid search, we did around 5 ticks away from the dot in each direction and incremented by half a tick each time. During this grid search it is also important to ensure that the pressure is still within the 10-20 mmHg range and that the current was still less then 10 mA, around 7 mA.

If the laser still does not lase, then power down the laser and use the HeNe laser to ensure everything is still aligned. It can help to also go through the alignment procedure again. Repeat this process until the laser begins to lase.

### E. Alignment with Diffraction Grating

Some of the later experiments will require the diffraction grating to be put into place. The overall procedure is relatively the same for aligning the laser with small changes.

During the HeNe alignment stage, we now will have the diffraction grating put in place where the laser will reflect off of instead to be sent back into the tube. A note card will be used to ensure the correct interference dot is being reflected back. To do this, we aligned such that the incident beam passed through a hole in the card and adjusted the diffraction grating until the first dot next to the brightest reflected dot was aligned with the hole.

We will once again follow the beam back the laser to ensure it is aligned, and then proceed as normal for the rest of the HeNe alignment procedure.

During the $CO_2$ alignment stage, we once again performed a grid search around the two reflected dots that appeared on the laser by adjusting the coupler mirror until we see lasing in the power detector. If there is still no lasing seen, then a small horizontal adjustment can be made to the diffraction grating and perform another grid search.

If the laser is still not lasing, then power down the $CO_2$ laser and realign the HeNe laser. Repeat this process until we see lasing.

## IV. EXPERIMENTAL PROCEDURE

### A. Current-Voltage Curve and Gas Pressure

For three different gas pressure, we found the V-I curve. This was done by adjusting the current output on the current regulators and recording the voltage across the laser tube.

### B. Power Threshold

For three different gas pressure, find the threshold for which the input power needs to be for the laser to begin lasing.

### C. Output Power Stability

Qualitatively observe how stable the output power is, and if they are larger or smaller near the lasing thresholds.

### D. Laser Spectrum

Use the spectrum analyzer to observe the wavelengths present in the $CO_2$ laser.

To do this we must first direct the beam into the analyzer. We first remove the mirror that is in front of the HeNe laser so that way the $CO_2$ laser is not reflected into it. Then we use the beam finder to adjust and direct the beam into the analyzer using the external mirror placed in front of the laser. The beam finder works by exposing it to the UV light so it can fluoresce. If the beam is hitting the finder then it will appear as a dark spot.

Using this finder we then adjust and direct the beam into the analyzer. It is important to not that the finder should be continuously in motion that way the $CO_2$ laser beam is not focused on one spot and damages the finder. Once we direct the beam into the analyzer we can turn it on and use the finder inside by turning the knob on the back to verify that the beam is there.

Without the diffraction grating in place, the spectrum analyzer should give us a reading of a P(20) line.

Once the diffraction grating is put in place we can adjust the horizontal axis of the diffraction grating to observe the entire spectrum of the laser. As the diffraction grating is adjusted, the angle of the laser reflecting off the external mirror will also begin to change so it will need to be adjusted alongside the grating to ensure the beam is being directed into the analyzer.

We want to adjust the grating until we see the analyzer displaying a P(18) and P(20) and measure their respective power outputs. We also measure the power output of all the spectrum lines we came across while trying to find these lines.

## V. RESULTS & ANALYSIS

### A. Current-Voltage Curve and Gas Pressure

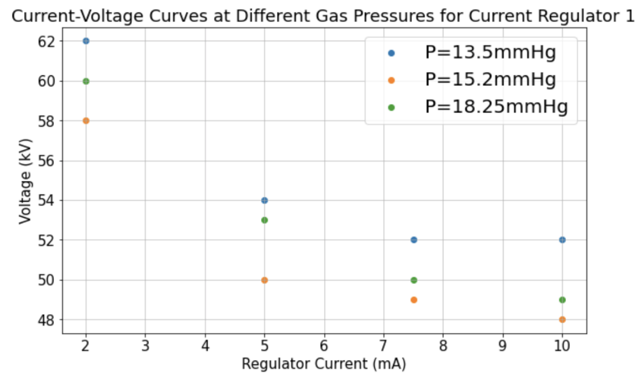


FIG. 4. The I-V Curve of Current Regulator 1 at various gas pressures.

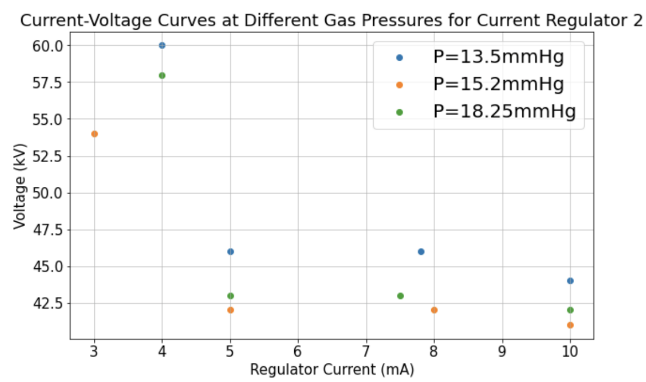


FIG. 5. The I-V Curve of Current Regulator 2 at various gas pressures.

Looking at the graphs we see that the voltage decreases as current increases at an exponential rate. This is more clear in 4.

There was some instability in regulator 2 with how well it was able to remain stable and output the specific current, hence 5 is more noisy. But even then it still shows a similar relationship.

In relation to pressure, the overall voltage changes and is reflected as a translation in the graph. As the pressure increase, the voltage initially decrease but eventually at some point it begins to increase again. This is seen by how the curve for 15.2 mmHg is at the bottom, having the lowest overall voltage measurements while the curve for 18.25 mmHg is in between the two other pressures.

TABLE I. Data collected for the relationship between current and voltage as well as the power threshold for necessary to observe lasing at various gas pressures.

| Pressure (mmHg) | Current 1 (mA) | Voltage 1 (kV) | Current 2 (mA) | Voltage 2 (kV) | Power Threshold (kV) |
|---|---|---|---|---|---|
| 13.5 | 2 | 62 | 4 | 60 | 11 |
| | 5 | 54 | 5 | 46 | |
| | 7.5 | 52 | 7.8 | 46 | |
| | 10 | 52 | 10 | 44 | |
| 15.2 | 2 | 58 | 3 | 54 | 11.5 |
| | 5 | 50 | 5 | 42 | |
| | 7.5 | 49 | 8 | 42 | |
| | 10 | 48 | 10 | 41 | |
| 18.25 | 2 | 60 | 4 | 58 | 13 |
| | 5 | 53 | 5 | 43 | |
| | 7.5 | 50 | 7.5 | 43 | |
| | 10 | 49 | 10 | 42 | |

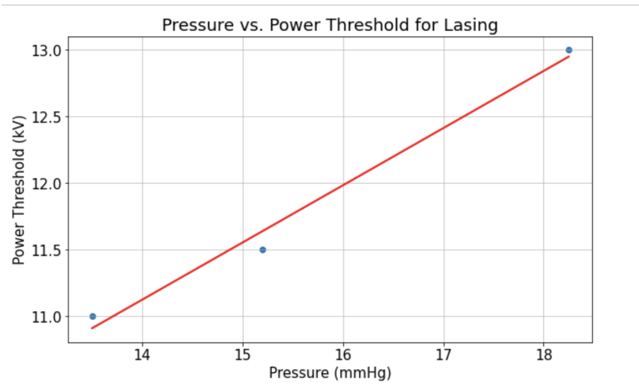


FIG. 6. The power threshold to achieve lasing at various gas pressures for the lasing medium.

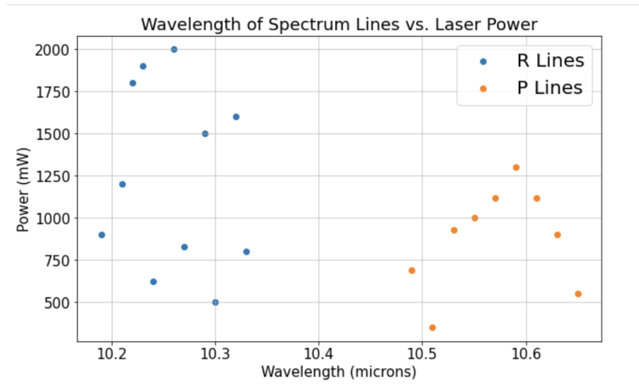


FIG. 7. The power output of the laser at each line observed in its spectrum.

### B. Power Threshold

Looking at 6, we see a direct relationship between pressure and the power threshold can be observed. We see that as the pressure for the laser tube increased, the necessary power threshold for the laser to lase also increased.

### C. Output Power Stability

The output power was fairly stable through out, but was less stable near the lasing threshold with there being an observed drop in the output power whenever the laser would begin to lase.

### D. Laser Spectrum

For this experiment, our input power was set to 15 kV and pressure was 12.4 mmHg.

In 7, we see that the R lines, lines with a shorter wavelength, do not have a clear trend in the relationship between wavelength and laser power, with some lines displaying significantly higher power output compared to the lines adjacent to them and vice verse.

An example of the lines we observed can be seen in 8.

A relationship is more clear in the P lines, the ones with a longer wavelength. Here, we see a peak in lasing power at 10.59 microns, which corresponds to the P(20) line, with the power decreasing as you go further away from it.

## VI. CONCLUSION

We found that the $CO_2$ has a large spectrum that can be observed when using it as a lasing medium. There is also a distinction between the two sets of lines in regards to how to stable the laser was, with P Lines observes to be a lot more stable in comparison to R Lines. This can also be seen by their relationship to laser output power being much more clear with their being no true relationship observed with R Lines.

We also saw that the voltage and current are exponentially related and that these curves are translated de-

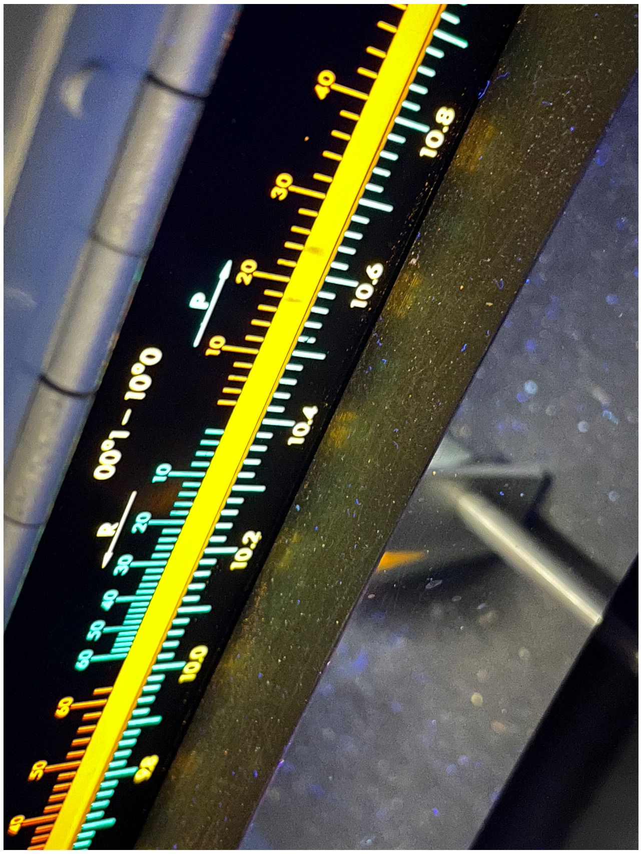


FIG. 8. Image of P(18) and P(24) lines that we observed.

pending on the gas pressure of the $CO_2$. We also observed a linear relationship between gas pressure and the power threshold for lasing where the higher the gas pressure, the higher the threshold was.

Some measurements for Current Regulator 2 were inconsistent due to the device's current and voltage meter being a little unstable, especially with the current meter's reading bouncing around with a lot of careful adjustments being necessary to stabilize it. This could be seen as the reason for why the curve for regulator 2 has a lot more noise then the one for regulator 1.