Maximizing Polarization of Helium-3 Gas Cells Using Diode Lasers

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Abstract

Observing the collisions between charged particle beams and helium-3 gas targets allows scientists to probe nuclear reactions and nuclear properties. These He-3 gas cells act as a pseudo-neutron target since neutrons naturally decay in about 15 minutes when not contained in a nucleus. Also present in the cell, is a small amount of rubidium that can absorb the laser light and its polarization is eventually transferred to the He-3 nuclei through spin-exchange mechanisms. Those polarized nuclei will align with an applied magnetic field, enabling the use of nuclear magnetic resonance spectroscopy, NMR, to measure the amount of polarization in the gas as a function of time. However, maximizing the initial polarization in the cell is quite difficult, as the right balance between laser power and rubidium amount evaporated has to be found without causing damage to the glass cell. This study describes attempts to increase polarization by minimizing power loss due to the optical system, maximizing total power output, and adjusting the diodes' emission spectrums via temperature control. Light from three laser diodes was sent through an optics system consisting of a splitting cube, quarter-waveplates, fiber optic cables, and mirrors in order to create circularly polarized light. The current power supplies and temperature controllers of the diodes were changed in order to maximize power output and temperatures were adjusted to match the output spectrum to the Rb absorption line at 794.8 nm. This study was able to increase the polarization in many ways, however these increases were not sufficient. The diodes have been used intensively during previous experiments, but they will need to be replaced for the research and development necessary in preparation for the planned 12 GeV experiments at Thomas Jefferson National Accelerator Facility.

Introduction

Nuclear physics experiments are designed to investigate some of the smallest constituents of matter that exist in this world such as nuclei, protons, neutrons, quarks, and electrons, to name a few. In order to perform these experiments, an immense amount of energy must be used and particle accelerators have been designed for this very purpose. Some accelerators collide two beams head on in order to maximize the total energy accessible in the center of mass frame of the particles. However, at Thomas Jefferson National Accelerator Facility, commonly referred to as "JLab" and located in Newport News, Virginia, an electron beam is collided into stationary targets that can be changed depending on the desired experiment. The polarized helium-3 group at JLab specializes in using helium-3 gas cells as targets for the electron beam.

Helium-3 gas cells are used in nuclear physics experiments because they act as pseudo-neutron sources. A neutron has a half life of about 15 minutes when it is in free space and so a pure neutron target is not sufficient for nuclear physics experiments since some experiments run 24 hours a day for weeks at a time in order to obtain adequate statistics. Fortunately, the helium nuclei, containing two protons and a single neutron, can serve as adequate substitutes. About 90% of the time, the nuclear spins associated with helium-3's protons are aligned in opposite directions effectively cancelling out, leaving the nucleus with the characteristics of a neutron [1]. Thus, physicists are able to perform experiments between electrons and neutrons by passing the beam through the gas cell.

Helium-3 gas cells do have their own limitations and difficulties however. In order to validate the results of an experiment, the statistics must be built up through repeated interaction. The number of interactions can be increased either by increasing the current of the electron beam or increasing the density of neutrons in the target. The problem with increasing the beam current is that the cells are made of glass and going above 15 uA severely shortens the amount of time the cell can last without breaking. Our group is currently looking into cells that have metal target chambers and glass pumping champers in order to prepare for the accelerator's upgrade to 12 GeV electrons from 6 GeV at the present time.

This study focuses on increasing the statistics by improving the density of polarized helium-3. Since the total amount of gas in the cell is determined at the time of manufacturing, we focused on increase the percent of nuclei polarized in a particular direction by increasing the laser power put into the cell, matching the emitted wavelength of light to the absorption line of the gas cell, and minimizing the loss of power throughout the optical system.

Materials and Methods

The system used in this study consists of four main components: the helium-3 gas cell, the laser diodes, the laser optics, and the holding field from the Helmholtz coils. As discussed in the introduction, the gas cell acts as a pseudo-neutron target. An image of a cell can be seen below in Figure 1.

Figure 1: An image of a helium-3 gas cell [1].

The gas cells have three main physical components: the spherical pumping chamber, cylindrical target chamber, and the transfer tube that connects the first two. The pumping chamber is the region that the circularly polarized laser light is shone on in order to provide the polarization to the cell. It contains not just helium-3 gas, but also potassium and rubidium whose purpose will be explained later on in the paper. The target chamber is the long cylindrical portion of the cell and the electron beam travels into the cylinder. As it moves through the target chamber, the beam collides with helium nuclei, destroying those nuclei's polarization. The target chamber contains mostly helium-3 and a small amount of nitrogen gas used to absorb some of the light emitted from excited atoms in the cell returning to ground states. The transfer tube is the smallest section of the gas cell but provides the most important task of allowing the gas to circulate between the pumping chamber and target chamber so that the helium-3 in the target chamber remains polarized since the lasers are only shone on the pumping chamber. In order to cause the polarized helium to diffuse to the target chamber faster, the pumping chamber is placed in an oven creating a temperature gradient between the two parts of the cell. Thermocouples placed on the cell record the temperature of the cell. In order for the Rb to evaporate, the cell must be atleast 170 C but temperatures can reach up to 230 C

Since the nuclei have net spins, their magnetic moments align with magnetic fields. The cell is placed inside of a Helmholtz coil that produces the holding field that maintains the cell's polarization. This enables nuclear magnetic resonance spectroscopy, NMR, to be used on the cell in order to measure the amount of polarization in the cell. Another set of coils provides a NMR radiofrequency pulse to perturb the nuclei's spin. A final set of coils is placed on the cell, where the polarization needs to be measured, and picks up the induced field from the precession of the spins in the field. This setup can be seen below in Figure 2.

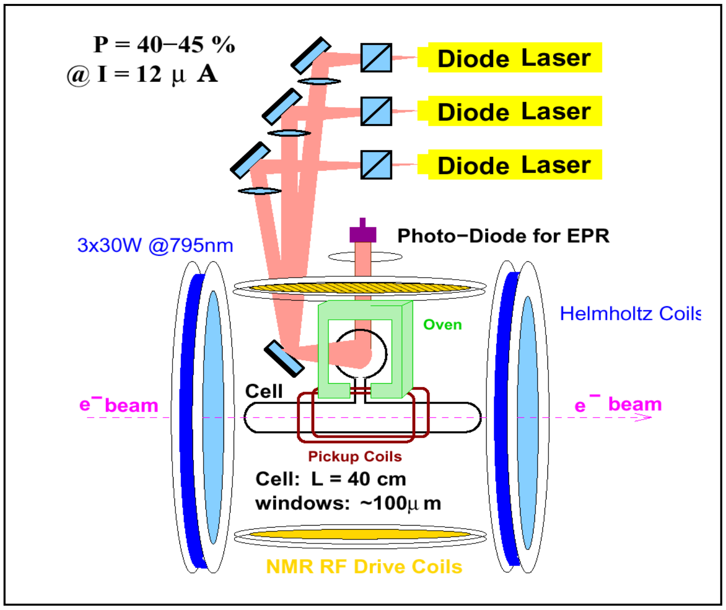

Figure 2: A diagram showing how the gas cells are placed in the system during an experiment [1].

The gas cells are extremely fragile not only because they are made of glass and experience constant collisions with electrons and high power laser light but are under tremendous amounts of pressure. The pressure of the cells used in these tests range anywhere from 8 to 12 atmospheres and could easily rupture at any time. The cells are not filled with pure helium-3, but they actually contain rubidium, Rb, and potassium, K, which are evaporated due to being placed in the oven. These gases are all found in the pumping chamber but the target chamber is mostly helium-3 with some nitrogen gas due to the temperature gradient and cell design. Intensive research and development have been put into helium-3 gas cells and it was found that by pumping the Rb with circularly polarized light and have that spin exchanged to the potassium and then helium; the highest polarization percentages were maintained because this process was faster due to the fast exchange between the two alkali metals and the potassium and helium-3.

As previously stated, this process begins by creating circularly polarized light, either handedness works just the proper direction of holding field must be applied, at a wavelength of 794.8 nm. This wavelength is absorbed by the Rb and excites it from the $5S_{1/2}$ m=-1/2 to $5P_{1/2}$ m=1/2 state. Once in this state, they then decay and are trapped in the $5S_{1/2}$ m=1/2 state. Some of the $5P_{1/2}$ m=1/2 Rb can move into the $5P_{1/2}$ m=-1/2 via collisions with other Rb. However, these Rb decay back to the $5S_{1/2}$ m=-1/2 ground state at which point another photon kicks them to the $5P_{1/2}$ m=1/2. This process is called optical pumping because eventually all the Rb will end up in the desired state as seen below in Figure 3.

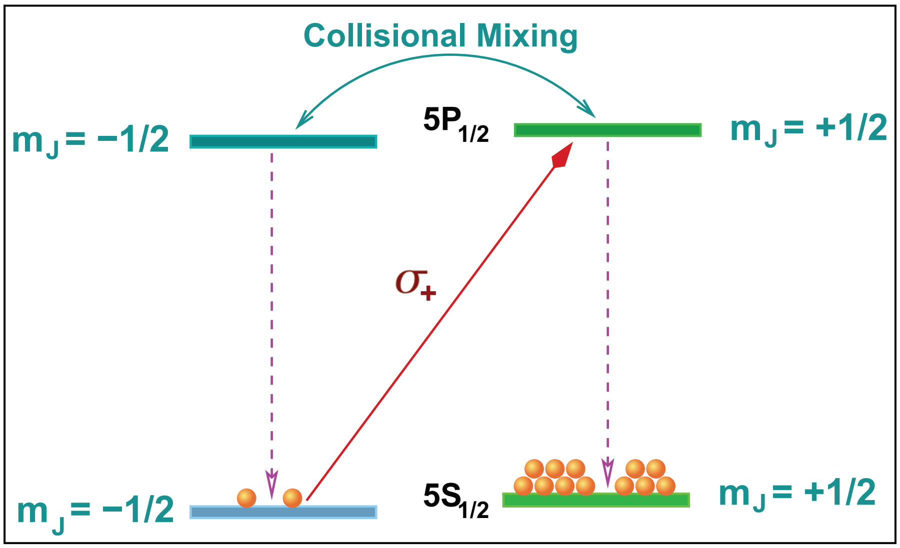

Figure 3: An energy level diagram for the optical pumping of rubidium in the gas cell [2].

Remember that this all occurs in the pumping chamber and so now that the Rb has obtained the initial polarization from the diode lasers, it will engage in kinetic collisions with the K and He nuclei bouncing around in the chamber. Through these collisions the polarization is exchanged from Rb to K and K to He, creating polarized helium-3. There is a small amount of spin exchange from Rb to He but it is much less significant compared to the Rb-K-He exchange. This process is called nuclear spin-exchange can be seen below in Figure 4.

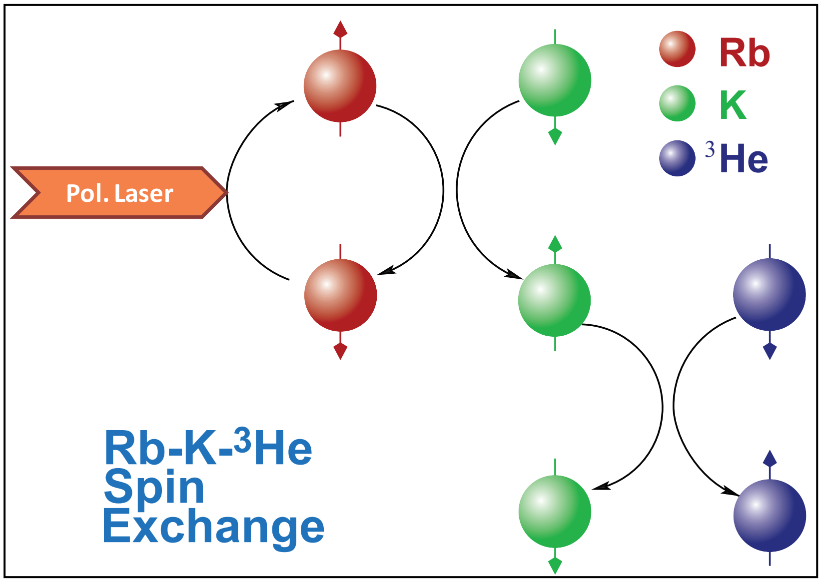

Figure 4: A diagram displaying how nuclear spin-exchange occurs in the cell [2].

As stated before, the laser light used in this spin exchanged optical pumping is required to be around 794.8 nm, in the infrared regime. The main lasers used in this experiment were four Comet diode lasers, which ultimately were compared to our benchmark Coherent diode lasers. We will refer to them as "Comet" and "Coherent" lasers respectively in the remainder of this paper. The four Comet lasers used were named JLab 1, JLab 2, Rutgers, and William & Mary. Each laser consisted of five main components: a diode, a power supply, a temperature control box, a fiber optic cable, and various cables to connect all the components together. Each diode itself has its own characteristic power output and wavelength spectrum but both can be fine tuned using the other components of the laser. The power supply changes the amount of current being supplied to the diode and as a result the laser would correspondingly output more or less power. The temperature control regulates the internal temperature of the diode by providing current to a thermoelectric cooling plate. The cooling plate regulates the temperature of the diode alone with the assistance of two fans that greatly reduce the diode's heat load. Changing the temperature changes the profile of the intensity versus wavelength spectrum of the laser. Being able to control the temperature is extremely important here because the light must be at 794.8 nm or the laser light will not be absorbed by the Rb.

The light leaves the diodes by exiting through a fiber optic cable. The cable is a thin glass fiber that uses internal reflection to transport the light from one end of the fiber to the other. These fibers screw into a mount on the diode itself and the exiting end is then screwed into a mount that is the start of the optics setup seen below in Figure 5. Once the light leaves the fiber, it passes through a focusing lens that is used to make sure that the light rays are entering the cube parallel rather than converging or diverging. This is important because if the light were to converge on a piece of the optics it would be intense enough to burn the optics. Similarly, if the beam was divergent, it would be much more difficult to steer the complete power output through the optics and into the cell for absorption. Next, the light is incident on a polarizing beam splitter cube. The light is composed of two directions, s and p, where s is along the diagonal plane inside the cube and p is perpendicular to both the s direction and the direction of travel. The p-wave component of light passes through the cube uninfluenced but the s-wave is reflected at an angle out of the cube as seen in Figure 5. After passing through the cube, the p-wave is reflected through a mirror, directing it through a quarter-waveplate in the direction of a set of mirrors mounted on the apparatus holding the gas cell. The s-wave that was reflected inside of the cube passes through a quarter wave plate, a mirror, and then once more through the quarter-waveplate. A quarter wave plate is a piece of optics that has two axes, a fast and slow one. The plate causes the light to experience a quarter of a wave phase shift. Since the s and p waves have polarizations that are 90 degrees different, when the s-wave returns to the cube after passing through the plate twice, its polarization has been shifted 90 degrees and becomes a p-wave. Now being a p-wave, the light passes through the cube unperturbed and through another quarter-waveplate on its way to the gas cell. The two final quarter-wave plates are the part of the system that acutally produce the circularly polarized light. To do this, the p-waves direction of polarization is aligned 45 degrees from the "fast" axis of the quarter-waveplate. This circularly polarized light then is directed by a series of mirrors into the gas cell as in Figure 2.

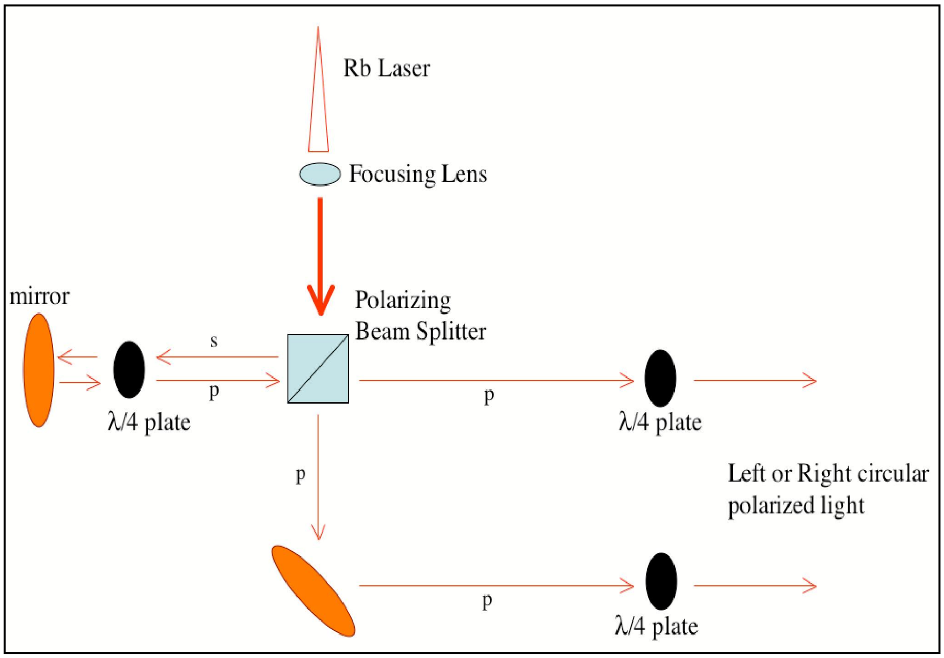

Figure 5: A diagram of the optics used for creating circularly polarized light from laser light [1].

The Comet laser diodes used in this study are engineered to have a narrower wavelength spectrum by an order of magnitude than that of the Coherent laser diodes that were previously used by the JLab polarized helium-3 target group. This presents significant difficulty because with the narrower spectrum, its centrum must be aligned to the 794.8 nm absorption line of the cell's Rb more carefully. Whereas with the Coherent laser, the intensity spectrum is much more spread out and so it is easier to have power at 794.8 nm but it will be a lower percentage of the total power output than the narrower spectrum can. In order to study the spectrum output, an Ocean Optics spectrometer had to be calibrated to visualize the spectrum. This was done in the Ocean Optics software called, "Spectra Suite." An Ocean Optics mercury-argon calibration source was used in the calibration. The box outputs a series of peaks at discrete wavelengths. Spectrometer uses a series of pixels to create the image that is seen on screen and so each peak was assigned a corresponding pixel. Then, each peak was identified as one of the wavelength peaks below in Table 1.

Peak (nm)	727.72	750.39	763.51	811.53	826.45	842.47	866.79

Table 1: A display of the light peaks emitted from the calibration box.

Spectra Suite has a built-in polynomial fitting program that creates a plot of wavelength versus pixel and fits the data points with a third order polynomial. The resulting polynomial is:

$$\boldsymbol{y = 647.66 + 9.6350E - 2 * x - 3.7622E - 6 * x^2 - 2.6869E - 10 * x^3} [Eqn\ 1],$$

where y is wavelength and x is a corresponding pixel number ranging from 0 to 4000. Table 2 below shows the points that were fit in order to create the third order polynomial while Figure 6 shows the curve.

#	X	Y	Residual
0	895	730.69	-5.8107E-4
1	1127	751.09	3.0643E-3
2	1278	764.09	-3.2876E-3
3	1832	809.9	2.1096E-3
4	1859	812.05	-2.8201E-4
5	2048	826.9	-4.8165E-4
6	2106	831.38	-6.4198E-4
7	2649	871.5	1.0044E-4

Table 2: A display of the points used to create the calibration polynomial in Spectra Suite where X is pixel number and Y is wavelength of the peak based on the calibration box's specs.

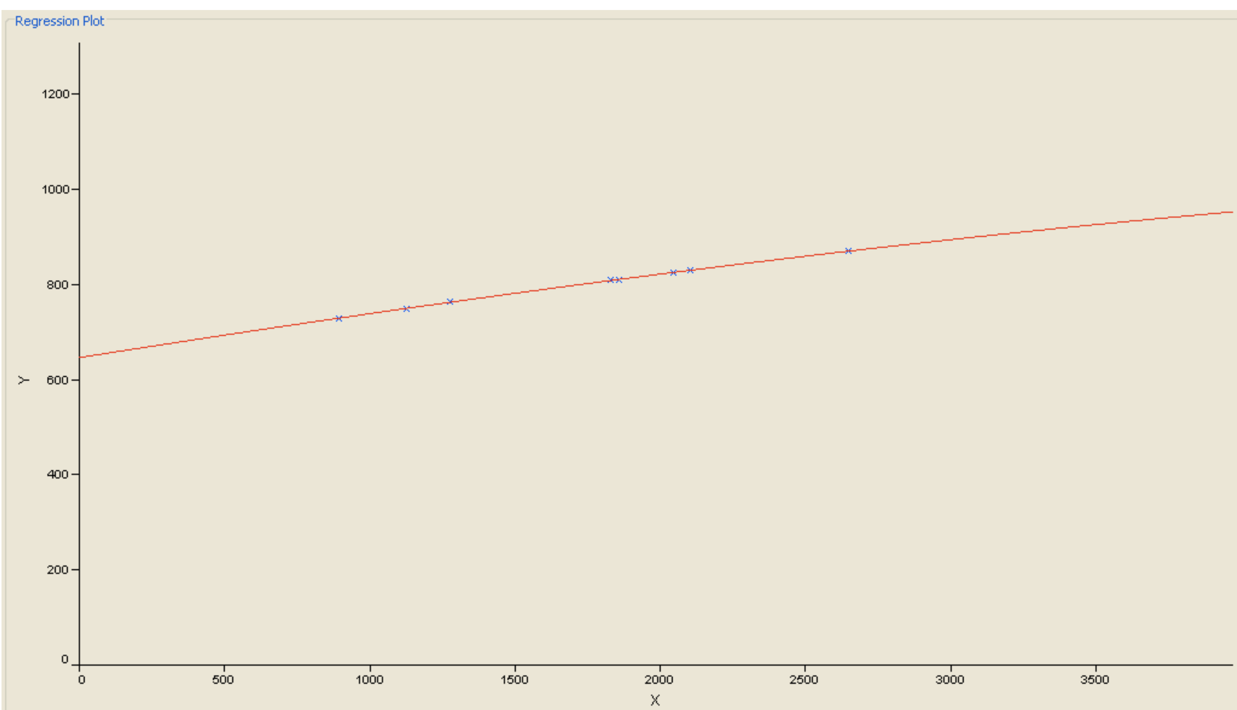

Figure 6: A plot of wavelength versus pixel number with data points fit by the third degree polynomial described by Equation 1.

Now that the Spectra Suite has been calibrated and is reading out reliable values for the wavelengths of light observed, the spectrometer was used to observe the Comet laser's spectrum. In order to obtain a reliable spectrum, the diode to be used was left in its lasing state for at least 30 minutes to allow it to stabilize at the set temperature. The following figures display the results of these measurements, note that the absolute intensities between the figures are not to scale since it is dependent on the placement of the spectrometer. The spectrometer was not placed in the same position for all four measurements because some were saturated for a given position while others were too low to be observed at that same location. The green line identifies the Rb absorption line in each figure.

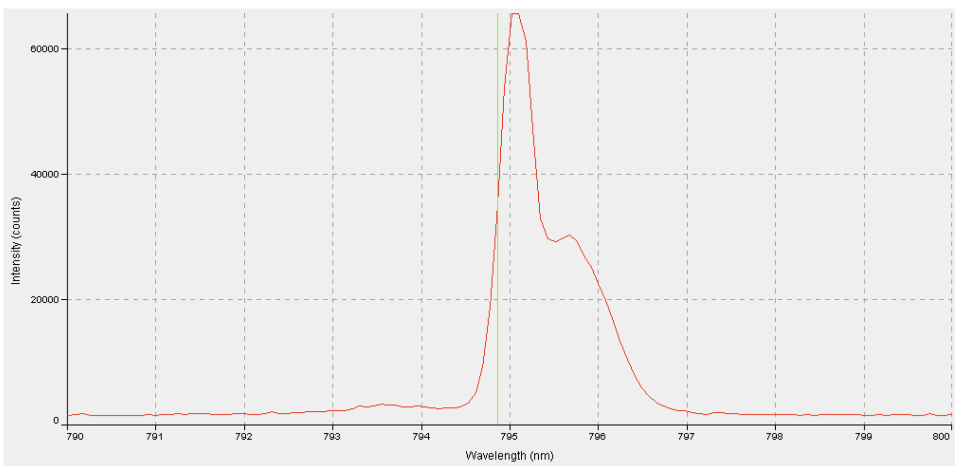

Figure 7: A display of JLab 1's spectrum after 30 minutes set at a current of 35 A set on the power supply and 18 C set on the temperature controller.

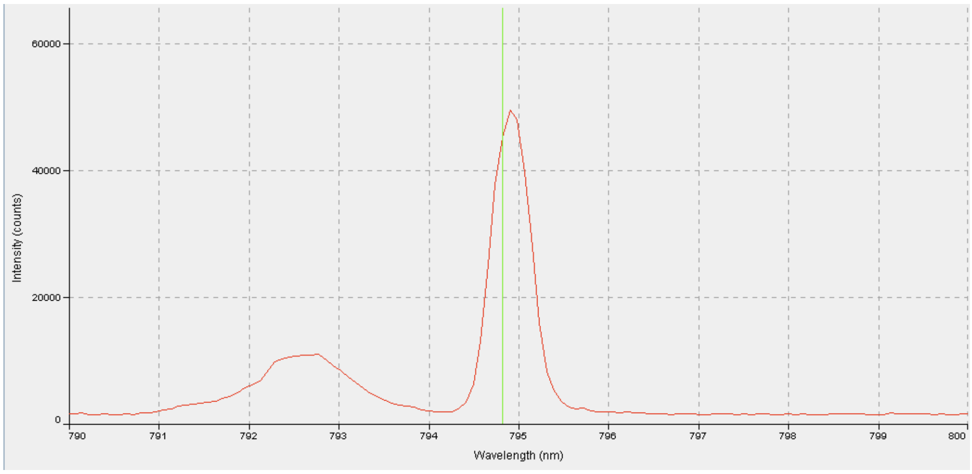

Figure 8: A display of JLab 2's spectrum after 30 minutes set at a current of 35 A on the power supply and 12 C on the temperature controller.

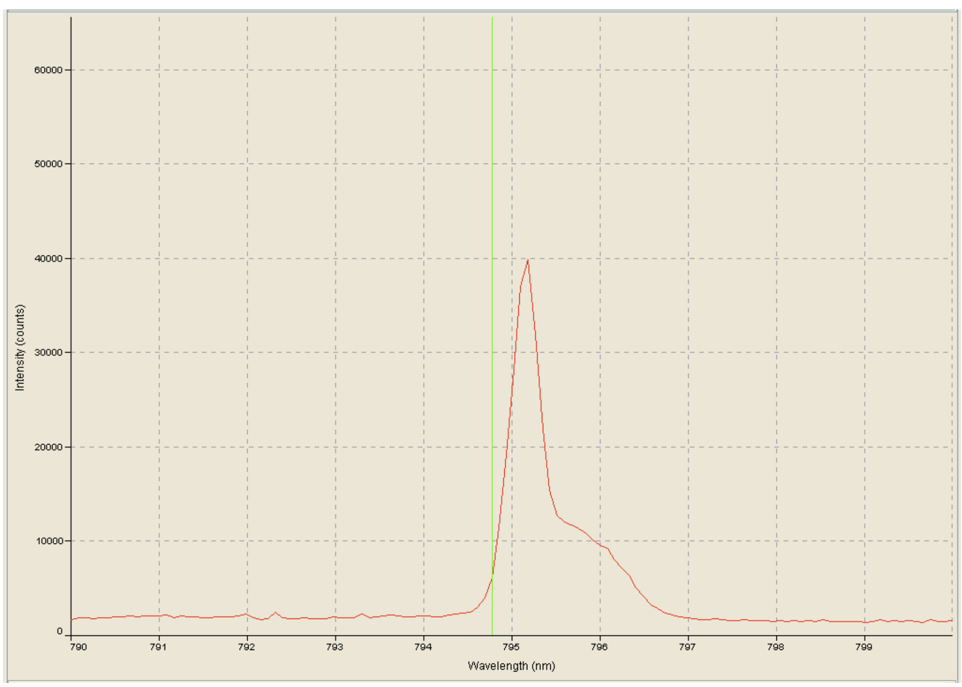

Figure 9: A display of Rutgers' spectrum after 30 minutes set at a current of 35 A set on the power supply and 17 C set on the temperature controller.

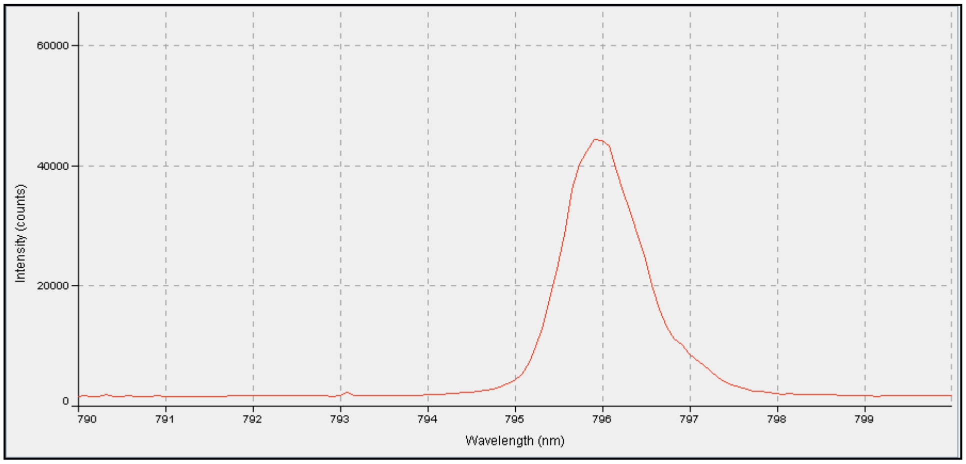

Figure 10: A display of William and Mary's spectrum after 30 minutes set at a current of 35 A on the power supply and 20 C on the temperature controller.

A quick comparison of these peaks shows that each diode has its own unique profile and they need to be shifted to lower wavelengths in order to maximize the percentage of power being emitted at 794.8 nm. In order to do this, the operating temperature of the diode must be decreased using the temperature control box. Each control box has a set temperature controlled by the user and a feedback temperature notifying the user of the diode's real-time temperature. For the William and Mary diode and the JLab 2 diode, the feedback temperature was able to stabilize near a minimum feedback temperature of 12 C and the set temperature was set anywhere from 10 to 22 C after 30 minutes of stabilizing. With the JLab 1 and Rutgers diodes however, they were unable to stabilize whenever set below 18 C and 17 C respectively. Both would make it down near 12 C when set there but would slowly start to runaway until the diodes overheated and their temperature limit interlocks would shut the diode off. This behavior limited how far the peaks could be shifted to lower wavelengths as seen in figures 7 and 9. Figure 11 below shows the influence of lowering the temperature of the William and Mary Diode from 20 C to 12 C.

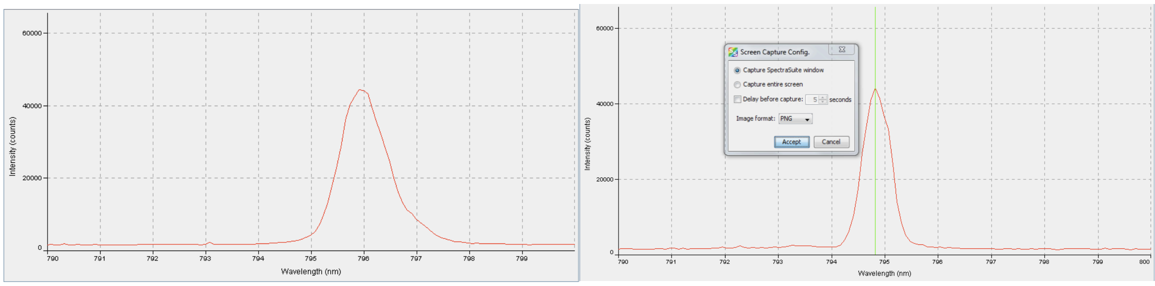

Figure 11: A comparison of the William and Mary profile set at 20 C (top) and 12 C (bottom).

Now having adjusted the wavelengths to be centered around the Rb absorption, the next step is to increase the power output at that wavelength in order to increase polarization inside of the cell. To accomplish this, different combinations of cables, power supplies, temperature controls, fibers and diodes were used in order to evaluate if our equipment was still sufficient for these polarization experiments. For the following trials to determine the maximum output with different laser components the following notation is used: 1=JLab 1, 2=JLab 2, 3=Rutgers, and 4=William and Mary, D=Diode, P=Power Supply, T=Temperature Control, and C=Cable Set. The first test was done to rule out that the cables connecting power supply to diode and temperature to diode have any impact on power output using D1, P1, T1. Table 3 shows the power output by using different cable sets. Table 4 shows the power output by using different power supplies with D1, T3, C1. Table 5 shows the power output by using different temperature controls with D1, P1, C1. Finally, Table 6 shows the power output by using different diodes with P1, T1, C1. Combining the three strongest combinations gives a total of 63.5 W.

Cables Test	**C1**	**C2**	**C3**
D1, P1, T1	15.8 W	15.9 W	16.0 W

Table 3: A show of power output for a given combination of laser components changing cables.

Power Supply Test	**P1**	**P2**	**P3**
D1, T3, C1	16.1 W	16.2 W	16.3 W

Table 4: The power output for a given combination of laser components changing power supplies.

Temp. Control Test	**T1**	**T2**	**T3**	**T4**
D1, P1, C1	15.8 W	15.3 W	16.1 W	22.6 W

Table 5: The power output for a given combination of laser components changing temperature controllers.

Diode Test	**D1**	**D2**	**D3**	**D4**
T1, P1, C1	15.8 W	16.2 W	19.1 W	21.8 W

Table 6: The power output for a given combination of laser components changing diodes.

Upon completion of these tests to determine the maximum power that the lasers can provide to the cell, the focus was turned to transporting that power from the laser to the cell through a series of optics. Three of these optics setups, see Figure 5, are used during the experiment, allowing three lasers to simultaneously pump the gas cell at once. In order to test the transmission through the system the laser combinations of a Coherent laser and two Comet lasers (D4, P2, T2 and D1, P1, T4) were used. The power output from both lasers were measured prior to entering the optics and prior to entering the cell once it has been polarized. Tables 7, 8, and 9 show the transmission through the top, middle, and bottom optics setups.

D4, P2, T2	**Before (W)**	**s→p (W)**	**p→p (W)**	**Total (W)**
Top Setup	21.0	7.99	11.1	19.09

Middle Setup	21.0	11.7	6.85	18.55
Bottom Setup	21.0	13.8	4.67	18.47

Table 7: A table showing the transmission through different optics branches with D4, P2, T2.

D1, P1, T4	**Before (W)**	**s→p (W)**	**p→p (W)**	**Total (W)**
Top Setup	22.6	10.2	10.5	20.7
Middle Setup	22.6	2.92	18.0	20.92
Bottom Setup	22.6	6.8	14.0	20.8

Table 8: A table showing the transmission through different optics branches with D1, P1, 42.

Coherent #5	**Before (W)**	**s→p (W)**	**p→p (W)**	**Total (W)**
Top Setup	22.1	9.5	10.7	20.2
Middle Setup	22.1	9.5	10.4	19.92
Bottom Setup	22.1	9.6	10.5	20.1

Table 9: A table showing the transmission through different optics branches with Coherent 5.

Tables 7-9 shows that the optics split the power differently between the s→p and p→p optics line, and it is dependent on the laser used. The Coherent appears to be split evenly between the two lines and all three branches, as one would expect, while neither of the Comet lasers split evenly. More importantly, different setups split the Comets' power differently. This is rather troubling and so further testing was done on just the cubes pulled out from the rest of the optics. Using a power meter to measure the power of the s→p and p→p lines, it was found that by rotating the mount or fiber emitting the light the distribution of power between these two lines changed. Over 360 degrees, a maximum of 18 W and a minimum of 4.6 W were observed from the D1, P1, T4 combination. Further interpretation of this will be discussed later on.

The final step of this study was to compare the difference between using three Comet lasers and three Coherent lasers to pump the helium-3 gas cell. The NMR system was used to produce Figure 12 below.

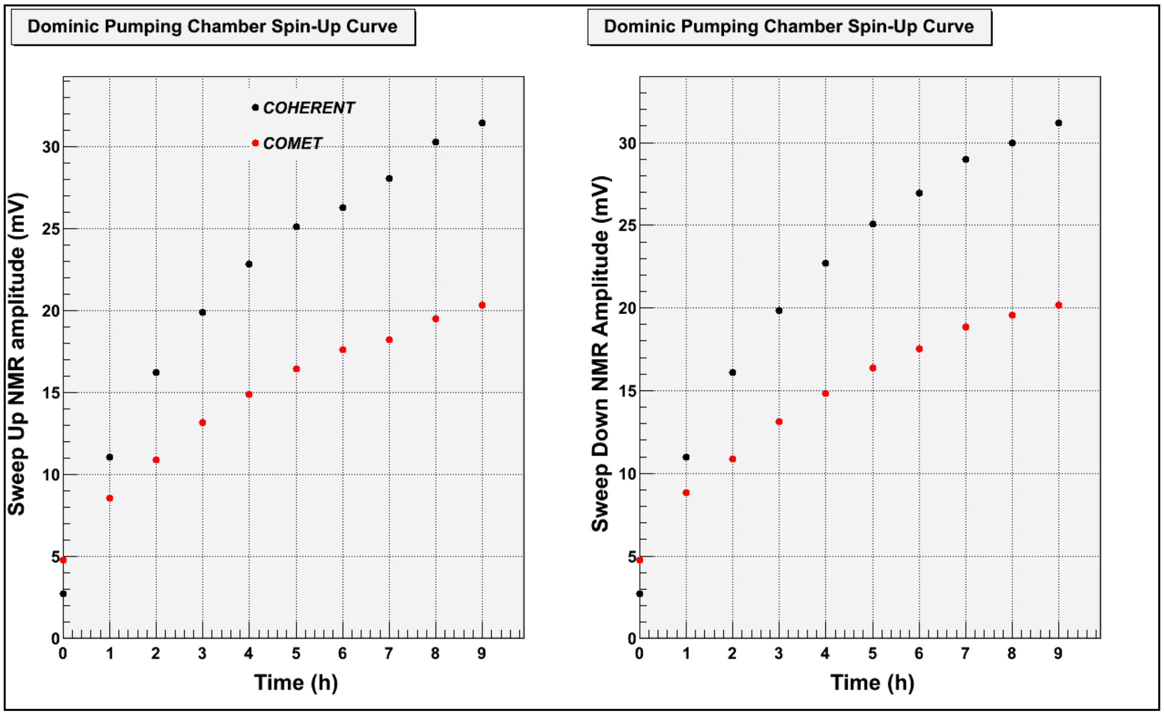

Figure 12: A NMR sweep comparing the use of the Coherent lasers to the Comet lasers.

Discussion and Conclusion

One of the most significant difficulties with using the Comet lasers was shifting their narrow wavelength spectrum to align with Rb's absorption line. Figure 11 showed that by lowering the William & Mary diode's operating temperature from 20 C to 12 C shifted the peak by almost a nanometer lower, putting it in great alignment with 794.8 nm and therefore increasing polarization being absorbed in the cell. However, Figures 7- 9 shows that JLab 2 was able to be centered on the Rb absorption but the inability to lower the JLab 1 and Rutgers diodes below 18 C and 17 C prevented their spectra to be aligned as well as JLab 2 and William and Mary.

An attempt to increase the output of the lasers relative to the start of this study was successful. It was found that the power outputs of the diodes were independent of the cables used to connect the components, the power supply used, and the temperature controllers as seen in Tables 3, 4, and 5. However, there is an interesting result in Table 4, when using the William and Mary temperature control. The William and Mary components were being loaned to our group and so initially they were not being tested. The prior tests on shifting the spectrum with the temperature controllers showed that this supply was able to hold the feedback temperature more stable and so it was tested for comparison. During this trial it was found that the D1, P1, C1 combination was able to increase its output from around 16 W up to 22.6 W. This output was shown to hold consistently at 22.6 W for three days while it was used to test the optics transmission and pumping the cell. When used with other diode combinations this supply, T4, did not show similar improvements. After returning to this intriguing combination once more, it was found that the output had fallen back to around the prior output of 15 W. This would then suggest that there must be some sort of loose connection inside of the diode that could be weakening the output.

Having this D1 combination outputting 22.6 W, the William and Mary diode outputting 21.8 W, and the Rutgers diode outputting 19.1 W, the focus moved to getting to the laser light into the cell and checking how well the Comets could polarize it. The testing of the optics also provided insight to understanding the capabilities of the diode lasers. Tables 7, 8, and 9 are the source of this insight. Looking purely at the diode lasers, it is clear that the distribution of power between the s→p and p→p lines was not even. For D4, P2, T2, the top setup had a stronger p→p power output but the middle and bottom setups behaved conversely where the p→p output was weaker, but the D1, P1, T4, combination did not even follow that trend. It displayed the top setup was almost equal 10.2 W s→p and 10.5 W p→p but the middle and bottom setups had stronger p→p power outputs. This was very strange and so the Coherent #5 laser was used to serve as a control case. The Coherent showed that all three setups had a p→p power output that was about 1.1 times larger than the s→p power output.

These results led us to believe that the splitting cubes must be behaving different for the Comet's light and the Coherent's light. During these tests however, the results also did not match was previously measured for the D1, P1, T4 combination. As it turns out, the orientation of the fiber used to transmit the light from the laser diode to the test optics was not the same as it had been. In order to test this idea that the optical fiber's orientation was influencing how the power was being distributed between the s and p lines from the cube the fiber was manually rotated by hand. Using a reference mark on the mount it was found that over 360 degrees the initial value was repeatable. This explained the differences in s and p distribution between the two Comet laser, but it was still curious that we had not seen this with the Coherent lasers before. However, the Coherent lasers provide initially light that is not polarized while the Comet lasers provide polarized light. Therefore, when passing through the cube, the Coherent's light displays an equal s and p outputs while the Comets do not.

The final portion of this study was to evaluate the Comet laser's ability in providing polarization to the test cell. In order to do this, a NMR spin up measurement was done. Figure 12 shows the results when using the JLab 1, Rutgers, and William and Mary Comet lasers with a combined output of 63.5 W. After 9 hours, both the curve made with the Coherent lasers and the curves made with the Comet lasers are reaching their maximum NMR amplitude, corresponding to polarization. The Coherent lasers were able to produce a signal with amplitude that was 1.5 times larger than the Comet lasers produced.

This result can be credited either to the fact there was not enough power being put through the cell or not enough was being absorbed by the cell. In order to create a factor of 1.5 differnce, assuming every photon produced is absorbed and thus emitted at 794.8 nm, the Coherent lasers would have to be producing 96 W. Having such a disperse wavelength spectrum though, the total power would have to be much greater than 96 W, making this highly improbable. In the actual comparison trial, the Coherent lasers were producing only 70 W. The more likely situation is that as seen in the laser wavelength profiles, the majority of the Comet power was not being produced at 794.8 nm and therefore was not supplying the cell with more polarization. This is certainly the case with the Rutgers and JLab 1 to a smaller degree as seen in their profiles. Figure 13 below shows a comparison of the JLab 1 spectrum prior to absorption and after absorption. Note that the absolute heights of the two profiles are not reliable since they are dependent on the spectrometer's placement; therefore one must look at the relative height of the peak to the shoulder. In previous studies done by our group with the Coherent lasers, almost all of the power passed through the cell is absorbed. This is certainly not the case with the Comet lasers.

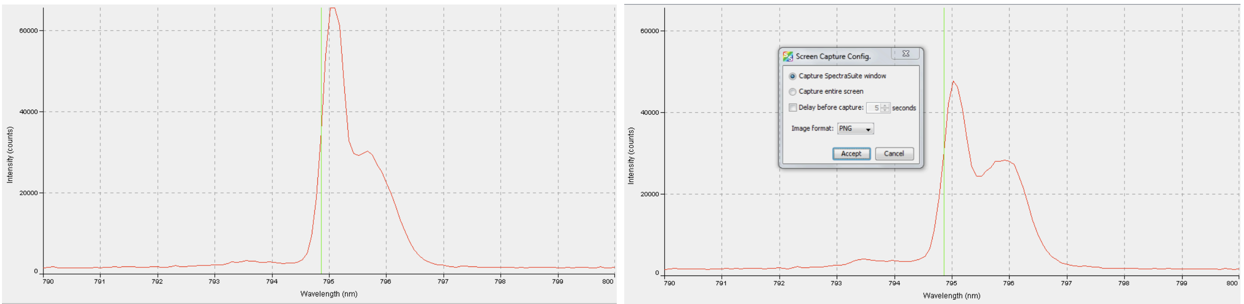

Figure 13: A comparison of JLab 1's spectrum prior to entering the cell and after exiting it.

Unfortunately, polarization optimization was unable to be performed in this study because not enough power at the correct wavelength could be output from the lasers in the polarized helium-3 laboratory at JLab. A simple solution to this problem would be to add another laser. However, as you add more and more optics lines stacked on top of one another, it becomes increasingly difficult to align the system on the cell. This is because the highest and lowest line will have to be aimed at a very steep angle in order to reach the cell. For our setup, this becomes a problem with a fifth laser.

In conclusion, this study provides new insight to the workings of our Comet diode lasers. The spectrum of these lasers are highly dependent on their operating temperatures and only two of them can be operated at 12 C. The maximum output able to be achieved by one of our Comet lasers was 22.6 W by JLab 1, while the best combination of three lasers was 63.5 W by the JLab 1, Rutgers, and William and Mary diodes. These lasers are providing initially polarized light and as a result of this, the orientation of the fiber in the mount influences the power distribution between s-wave and p-wave light after the splitting cubes used in our optics setups. Finally, the diodes have a much narrower spectrum width and since the position of this spectrum is so dependent on operating temperatures, not enough of the light is being absorbed in the cell. This produces lower amplitudes in NMR signals performed with the Comet lasers than when done with Coherent lasers.

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