Investigation of Techniques for Producing High Polarization ^{3}He Gas Targets

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by

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Accepted for _____
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ABSTRACT

Target cells of polarized ^{3}He are used in nuclear physics experiments that are designed to study the internal structure of the neutron. This research project details the preparation of such cells, as the production process is the most important factor in maximizing the ^{3}He polarization. The lab built for producing these target cells at the College of William & Mary for experiments at the Thomas Jefferson National Accelerator Facility (TJNAF) applies numerous new techniques and tools in its construction. Such alterations were made so to improve the system's efficiency as well as increase the rate of polarization in the cell. The primary goal of this research project was to design and construct this facility at William & Mary with the end product being a successfully filled cell. Indeed, the entire procedure of filling a cell has been successfully accomplished. Presently, the filling of dummy test cells is in progress. Some successes and failures of the system developed have already been discovered during these dummy cell test runs. Upon completion of the test runs, several proper target cells will be filled and their performance tested at TJNAF to determine the proficiency of the lab constructed at William & Mary.

ACKNOWLEDGEMENTS

Many thanks to Gordon Cates and the Princeton University group for their support in establishing the lab at the College of William & Mary.

Much gratitude is also extended to Willie Shoup, our glassblower, without whose help I would not have an honors research project. He is a wonderfully delightful man eager to share his glassblowing skills (thanks for the bubble!). However, he is faulted for being a WAHOO.

Todd, thank you for taking me under your wing last year. Your support throughout the year and especially recently has been extremely valuable. I have enjoyed working with both of you. Trudging off to Small to spend several hours within its walls was certainly not as grim a prospect as it could have been. Thanks for listening to my babble and dealing with my moods. Summed up…You're totally awesome! I hate to share you with future generations of "scientists."

Kevin…"what are you doing later?" I still think I could have become proficient in the program language in less than 24 hours. Maybe next year? Thanks for letting me pester you incessantly. I enjoyed sharing the lab with you. Good luck with the project!

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Dale, what would I do without you by my side to tell me to "Stop. Take a deep breath. There you go Little Tiger." Granted, it started under a different situation, but an honors thesis is just as good as Ricks (yeah right).

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Lastly, but certainly not least, with all my being, I thank the Charles Center for setting the deadline for the Honors Research Thesis during Senior Celebration Week.

INTRODUCTION

Polarized ^{3}He targets are employed in various nuclear physics experiments for use with high-intensity polarized electron beams. With these targets, which essentially provide a source of polarized neutrons, experiments are conducted to study the internal structure of neutrons. A preliminary experiment (E-142) conducted at the Stanford Linear Accelerator Center (SLAC), using such targets, produced results indicating that quarks carry approximately one third of the spin in nucleons [1]. Based on the success of this target, there is now a program of six experiments underway at the Thomas Jefferson National Accelerator Facility (TJNAF) to study the neutron spin structure in greater detail.

Presently, Princeton University is the leading site with technicians capable of making the high pressure, blown glass cells for use in these targets. Various factors that contribute to the depolarization of the ^{3}He can be controlled, in principle, during the production of the cell. The facility for producing the target cells is therefore one of the most important aspects of producing a usable polarized target. The purpose of this honors research project was to develop such a laboratory at the College William & Mary to produce the ^{3}He target cells for use in the experimental program at TJNAF, meanwhile investigating procedures and materials to improve the process and the cells.

Polarized noble gases also have an important future in the field of medical imaging; hyperpolarized gas can be used with nuclear magnetic resonance imaging (MRI) of organs for air-filled spaces in humans. Images of the airspaces within the

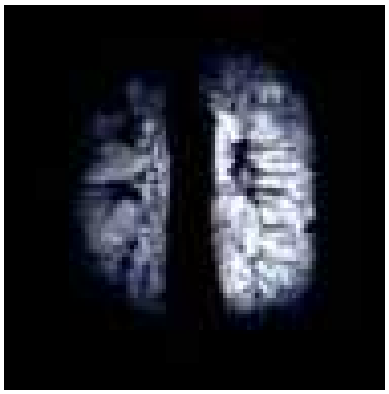

Figure 1. MRI of human lungs using ^{3}He [2].

lungs can be obtained after the inhalation of hyperpolarized noble gases, including ^{3}He and ^{129}Xe (Figure 1). Until these developments, visualization of the alveolar and bronchial spaces using conventional ^{1}H MRI was not possible because of the low concentration of ^{1}H nuclei from water vapor, which results in a signal that is too weak for successful imaging. Due to their larger magnetic moments, the polarized noble gases provide larger MRI signals. This technique allows for a fast and efficient evaluation of airspaces without exposure to ionizing radiation. It is likely that this technique will become useful for evaluating small airway diseases such as Chronic Obtrusive Pulmonary Disease, asthma, or cystic fibrosis [2].

PRINCIPLES OF Rb OPTICAL PUMPING AND ^{3}He POLARIZATION

Polarized ^{3}He is a desirable target material for use in nuclear physics experiments. The polarized ^{3}He provides a source of polarized neutrons from which the internal quark structure can be studied by scattering electrons. The nucleus of ^{3}He is primarily in an S-state where the spins of the two protons are anti-aligned. The unpaired neutron carries most of the ^{3}He spin and thus polarized ^{3}He, to a good approximation, can be viewed as a polarized neutron. The residual polarization of the protons can be corrected for using a model of the ^{3}He nuclear wavefunction. The process that provides the ^{3}He nucleus with its polarization is that of a spin-exchange with electron-spin polarized alkali-metal atoms. Alkali metals are used because these gases have only one outer shell electron, thus effectively providing a spin of ½. Rubidium is polarized to near 100% by means of optical pumping using lasers with a wavelength of 795nm. A hyperfine interaction between the Rb atom and the ^{3}He nucleus then transfers the spin from the Rb to the ^{3}He during binary collisions, thus polarizing the ^{3}He.

In the target system at TJNAF, shown in Figure 2, two orthogonal sets of large Helmholtz coils provide a uniform magnetic field of about 20 G in any direction in the plane containing the incident and scattered electrons. A double-chamber glass cell, containing 10 atm (at room temperature) of ^{3}He and a small amount of Rb, is placed within the field. The upper portion of the cell, known as the pumping

chamber, contains the Rb and is heated to about 180°C by means of a surrounding oven to produce Rb vapor. The Rb is then optically pumped with circularly polarized ($\sigma_{\pm}$) laser light, and achieves approximately 100% polarization on the order of milliseconds.

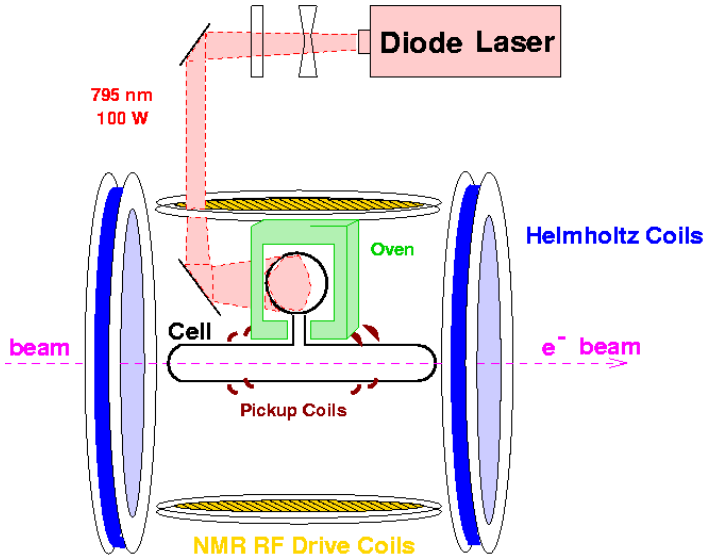

Figure 2. Schematic overview of the TJNAF experimental setup in which the ^{3}He targets are used. Note that only one set of Helmholtz coils is shown.

The principle of optical pumping is illustrated in Figure 3 [3]. In the figure, the nuclear spin of the Rb is not shown and the relevant atomic states are the $S_{1/2}$ and $P_{1/2}$ states, each with two magnetic substates $M = \pm½$. Additional hyperfine splitting is introduced by the Rb nuclear spin. However broad-bandwidth laser light can be used to optically pump from all of the hyperfine levels of Rb. Circularly polarized light with spin projection $+1(\sigma_+)$ can only be absorbed by the $S_{1/2}$ state with $M = -½$. This populates the $P_{1/2}$ sublevel with $M = +½$, which can decay radiatively to either sublevel of the ground state. The relative radiative decay rates are given by the Clebsch-Gordon coefficients, $^2/_3$ and $^1/_3$, corresponding to the $M = -½$ and the $M = +½$, ground states respectively. However, if allowed to decay radiatively, the photon

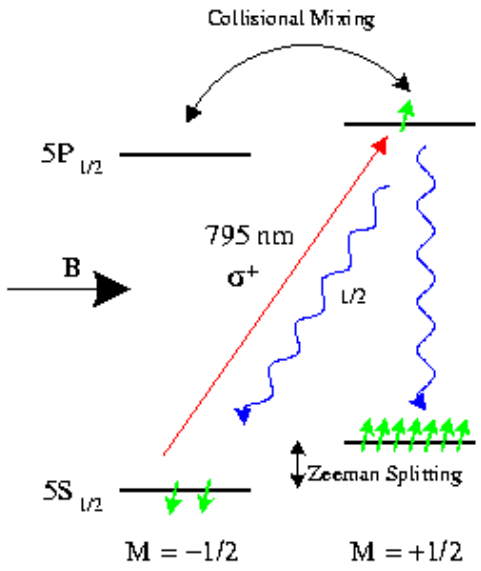

Figure 3. Illustration of the relevant atomic states of Rb, neglecting the nuclear spin of Rb. Circularly polarized laser light of wavelength of 795 nm populates the $P_{1/2}$ sublevel with $M = +½$.

emitted can have any polarization and can be reabsorbed by other Rb atoms, resulting in depolarization of the gas. This is more likely to occur when the gas is dense, as is the case within the glass cells. Small amounts of N_2 gas are used as a buffer so that when an excited Rb atom collides with the N_2, the Rb will decay back to the ground state by giving the N_2 its energy rather than emitting a photon. Approximately 60 torr of N_2 is used in combination with 7600 torr (at room temperature) of ^{3}He. This pressure specification has previously been shown experimentally to be the proper amount of N_2 for high collision rates without affecting the ^{3}He nuclei being studied. In addition, collisions with the ^{3}He and N_2 gases will randomize the *P* states and the relative decay probabilities to each sublevel of the ground state become 50%.

The ^{3}He nucleus is polarized by spin-exchange with the atomically polarized Rb. A hyperfine interaction occurs between the Rb atomic spin and the ^{3}He nuclear spin during collisions. Polarization is transferred from the outer shell Rb electron to

the ^{3}He nucleus, and the Rb is then quickly repolarized by the laser light. The rate of ^{3}He polarization by the Rb is given by the following differential equation,

$$\frac{dP_{He}(t)}{dt} = \gamma_{SE}\left(\langle P_{Rb}\rangle - P_{He}(t)\right) - \Gamma P_{He}(t), \quad (1)$$

where $\langle P_{Rb}\rangle$ is the average Rb polarization (approximately 100%), P_{He} is the ^{3}He polarization, γ_{SE} is the spin exchange rate between the Rb and ^{3}He, and Γ is the overall depolarization rate of the ^{3}He due to all possible depolarization mechanisms. The spin exchange rate is given by the following expression:

$$\gamma_{SE} \propto [\mathrm{Rb}][^3\mathrm{He}]\sigma_{SE}, \quad (2)$$

where [Rb] and [^{3}He] are the concentrations of each gas and σ_{SE} is the probability of a spin-exchange occurring. Therefore, an increased amount of each gas will provide more collisions. However, control can only be exerted over the density of the Rb gas, as the amount of ^{3}He is fixed. To do so, the temperature of the Rb is increased or decreased by varying the temperature of the oven surrounding the pumping chamber. This causes an increase or a decrease in the density of the Rb vapor. If the density is increased, a larger spin exchange rate will result, which will yield a larger P_{He}. Additional laser power is also required to polarize the larger amount of Rb. On the other hand, if the density is decreased, a lower spin exchange rate is produced, and a lower P_{He} is the outcome.

Solving equation (1), the He polarization is expressed as follows,

$$P_{He}(t) = \frac{\gamma_{SE}}{\gamma_{SE}+\Gamma}\langle P_{Rb}\rangle\left(1 - e^{-(\gamma_{SE}+\Gamma)t}\right) \quad (3)$$

where at $t = \infty$, $P_{He}^{\max} = \frac{\gamma_{SE}}{\gamma_{SE} + \Gamma}\langle P_{Rb} \rangle$. So if $\gamma_{SE} >> \Gamma$, $P_{He}^{\max} \approx \langle P_{Rb} \rangle \approx 100\%$ [4]. Therefore to achieve maximum polarization and the maximum polarization rate, it is necessary to make Γ as small as possible, or equivalently, the relaxation time, $T \equiv \frac{1}{\Gamma}$, large. Although 100% polarization can theoretically be achieved, experimentally, the largest polarization achieved for these targets is around 50%, with a typical value of about 35%. Several important contributions to Γ are:

1) An inhomogeneous magnetic field (to produce the magnetic holding field in the target system, large Helmholtz coils of diameter equal to 150 cm are used to ensure a small field gradient which results in a value of $T \approx 1000$ h)
2) Ionization from the electron beam (at Jefferson Labs, keeping the beam at or below 15μA gives T between 400-1100 h) [5]
3) ^{3}He-^{3}He magnetic dipole interaction (calculated theoretically for the targets used at TJNAF, $T = 84$ h) [6]
4) Collisions with gas impurities (T depends on the level of impurities)
5) Wall collisions with impurities within the target cell (T = 40-80 h)

Gas impurities and wall collisions are the largest contributing factors, and can in principle be controlled in the laboratory. These last two contributions determine the polarization rate, and the maximum polarization in manufactured cells. Collisions occur between ^{3}He and impurities in both the cell and the gas. Microfissures in the glass contribute to the depolarization of the ^{3}He by trapping ^{3}He molecules, thus increasing the chances that the gas collides with the walls of the cell. To improve the surface quality of the extruded glass tubing that is used to make the cells, the tubing is

first remelted slightly and resized from a molten state. Baking the vacuum system and purifying the gases are steps that are also taken during the filling of the cell to minimize the dominant depolarization mechanisms.

THE CELL

Dimensions

The cell has been designed as a two-chamber cell, shown in Figure 4. The upper volume (pumping chamber) in which the Rb optical pumping and ^{3}He

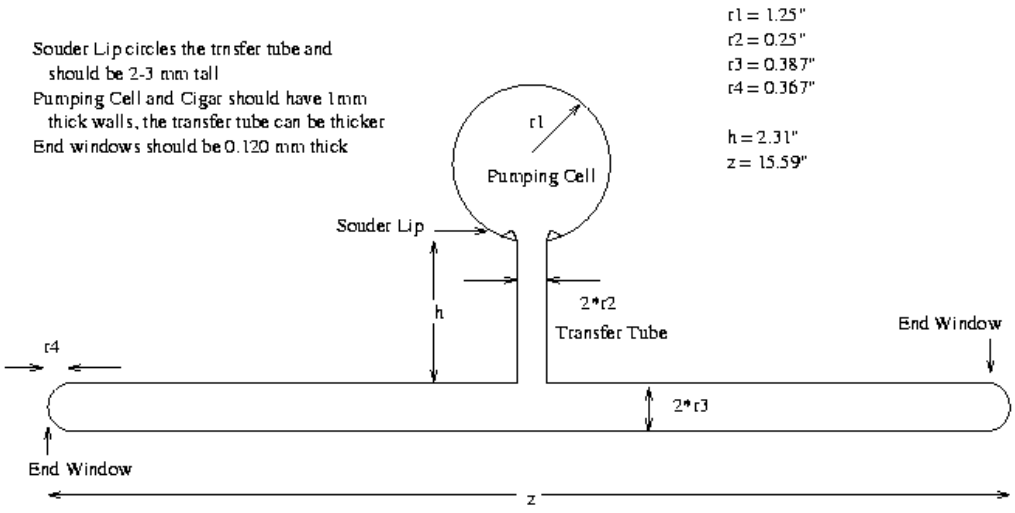

Figure 4. Dimensions of the targets cells being constructed at W&M for use in the experiments at TJNAF.

polarization take place is separated from the lower volume (target chamber) where the electron beam passes through. The target chamber is at a lower temperature compared to the pumping chamber, which confines the Rb vapor to the pumping chamber so that the electron beam scatters only from the ^{3}He in the target chamber. A transfer tube attaches the chambers. Polarized ^{3}He diffuses through this portion to the target chamber with a time constant of approximately 10 min (much smaller than the characteristic spin exchange and relaxation times of the ^{3}He).

The pumping chamber is spherical with a radius of 1.25 in. Around the connecting transfer tube, the chamber is lipped to catch Rb that has changed from its vaporized state back to its molten form, thus preventing the Rb from contaminating the target chamber. The end windows of the cylindrical target chamber are about 100 μm thick [7], which minimizes interactions between it and the electron beam.

Aluminosilicate Glass

The target cells are constructed entirely of blown aluminosilicate glass (General Electric type 180). Aluminosilicate glass was experimentally determined to have a low porosity to ^{3}He, and therefore is better able to contain the polarized ^{3}He. It has been estimated that aluminosilicate cells loose about 10% of their ^{3}He in 100 years, compared to 2 months for Pyrex. Another benefit of aluminosilicate glass is that its surface properties have been shown to allow very long relaxation times. On the negative side, this type of glass is very difficult to work with thus requiring a very skilled and patient glassblower. We have found one such individual within the grounds of the University of Virginia, a wonderful man by the name of Willie Shoup.

Glass Cleaning and Blowing

Researchers at Princeton University originally found that untreated commercial aluminosilicate glass contained many contaminants and defects, which greatly affected the relaxation rates. In order to decrease this effect, the construction of the cells involves a combination of nitric acid cleaning and resizing the glass. Rinsing the tubing with acid removes possible surface contaminants. Resizing the

glass on a lathe to the desired dimensions from a molten state reduces the number of microfissures on the cell walls as well as the amount of impurities in the glass. Finally, the complete cell is annealed so to relieve any stress created. Using such a technique in the construction of the target cells has resulted in net relaxation times up to 65 h at room temperatures with no incident electron beam [8].

CELL PRODUCTION

"The production of long lifetime cells for nuclear polarized ^{3}He work is considered by many to require the use of black magic. It is believed that if the appropriate horn toad bones are thrown into the diffusion pump oil, the appropriate equations are spoken over the ^{3}He canister, and a graduate student of pure spirit is sacrificed, then good ^{3}He cells will sometimes result" [9]. However, in some cases a dedicated undergraduate can be substituted for a graduate student.

The construction and filling procedures of the cell are very important in the determination of the relaxation rates due to impurities in both the glass and the gases. Therefore the system we have constructed at William & Mary focuses primarily on purifying the gases within an ultra-high vacuum system.

The Vacuum System

In order to increase the rate of ^{3}He polarization, the filling system employs several important devices. The major components of the stainless steel vacuum and gas system are shown in Figure 5.

A Turbo Molecular Pump, backed by a roughing pump, is capable of achieving vacuum better than 10^{-9} torr within the system. An advantage of the turbo pump, in addition to the high vacuum, is that it does not use an oil spray that can contaminate the system and the cells, as compared to diffusion pumps. An ion pump is also used to help maintain the high vacuum.

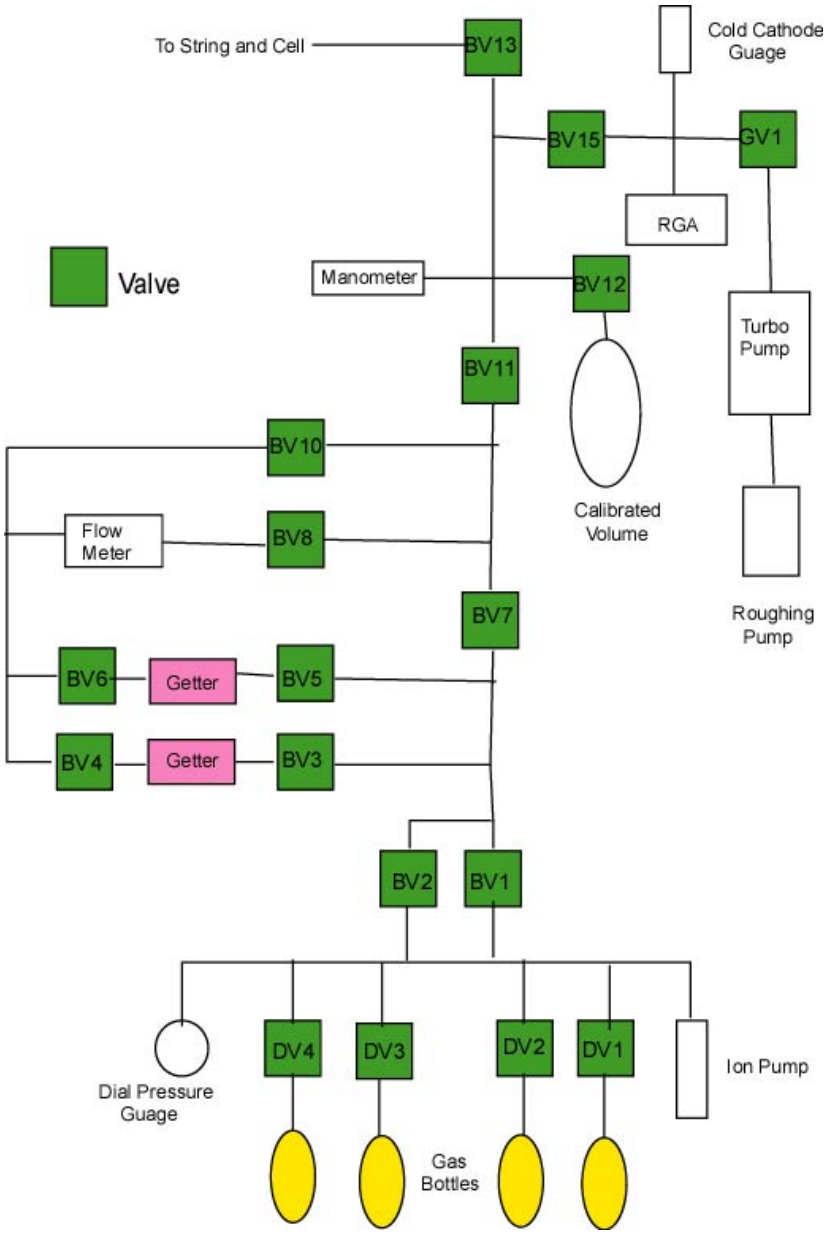

Figure 5. Diagram of the Vacuum and Gas System.

The purity of the N_2 and ^3He gases has been shown to be crucial for optimum performance. To increase the purification of the gases, each will travel through a gas handling system consisting of heated purifiers ("getters"). As the gases pass through this system, impurities are removed. Heater tape wrapped around the majority of the system will also help eliminate impurities by baking with the vacuum pumps on.

Another device being utilized in the system is a Residual Gas Analyzer, which aids in detecting leaks and identifying contaminants in the cells and system. Measuring the correct density of gas will eventually be accomplished by the use of a gas flow meter rather than the standard calibrated volume and ideal gas law method currently in use. If it is necessary to backfill the vacuum system, argon is to be used rather than air as argon is an inert gas. The system will therefore be cleaner when pumped back down to the appropriate pressure.

The Oven

To further purify the cells prior to filling, an 18" x 18" x 24" oven was constructed of a high temperature structural insulation called Marinite. Two high power heaters are used to bake the cell to temperatures of 450°C before filling (Figure 6). Heating the cell at such temperatures for several days drives even more

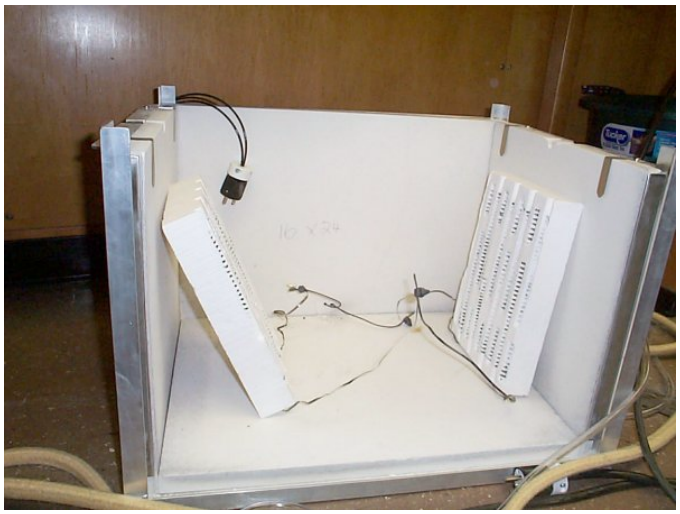

Figure 6. A picture of the Marinite oven with the detachable walls removed. Both heaters are in view.

volatile materials from the glass surface of the cell, thus contributing to the minimization of Γ in equation (2). The oven was designed with efficiency in mind as well as mobility of the heaters in the instance that the cells are of different dimensions (as is the case with some of our dummy cells). The oven is controlled digitally and the temperature is read out by a thermocouple. One side wall of the oven as well as the top are removable so that the oven can be properly positioned on the table and around the cell without concern for damage to the cell. Unfortunately, during a test fill of a dummy cell, the oven was found to be inadequate at withstanding the high temperatures for long periods of time. One wall of the oven developed a large crack running through it; see Figure 7. Also, the removable walls of the oven were difficult to extract due to warping during the bake. It is obvious that a new oven must be designed to correct these problems.

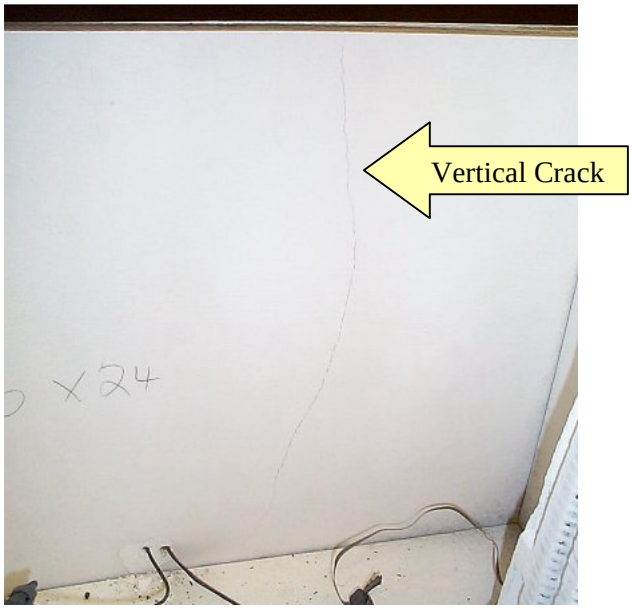

Figure 7. The Marinite oven used to bake the cell. The crack in one wall of the oven, resulting from a day of baking at 450°C, is pointed out by the arrow.

FILLING OF THE CELL

Before each cell is attached to the vacuum system, the 100 μm end windows are pressure tested to 260 psi in order to ensure that they will not rupture when filled with the ^{3}He at 150 psi. Upon completion of this test, the cell is fused to the vacuum

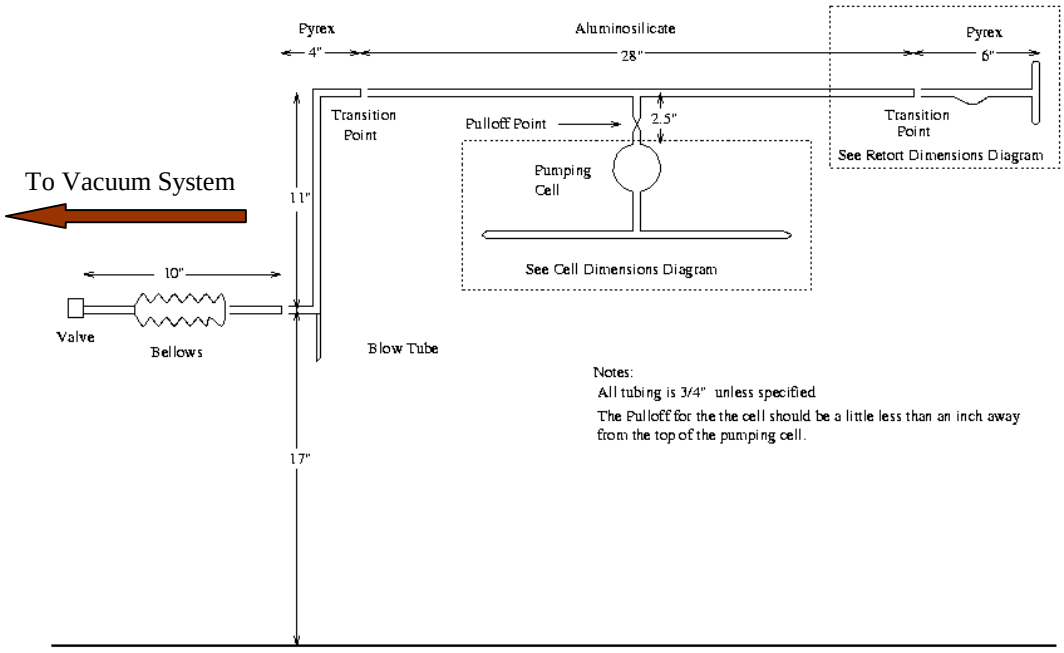

Figure 8. Dimensions of the string that attaches the target cell to the vacuum system. Dimenisions of the Rb retort are also included.

system by means of a glass string (Figure 8); a Rb ampoule is opened and is sealed into a retort on the opposite end of this manifold—that furthest from the gas filling system (outlined in the rightmost dotted box in Figure 8).

Under vacuum, the target cell is baked in the Marinite oven to 450°C for four days. During this time, the Rb is distilled by a torch. After the cell is removed from the oven, the Rb is chased with a torch into the pumping chamber of the cell.

The target chamber is then enclosed by a dewar into which liquid ^{4}He is flowed, cooling the chamber to approximately 12K, so that the internal pressure of a cell will be below atmospheric pressure when filling is complete. Two different dewars were designed and built for the cyrogenics of the system. The first is an elongated dual-chamber enclosure (Figure 9) with fitted silicone gaskets. It is made up of two identical separate pieces, each of which slips around half of the target

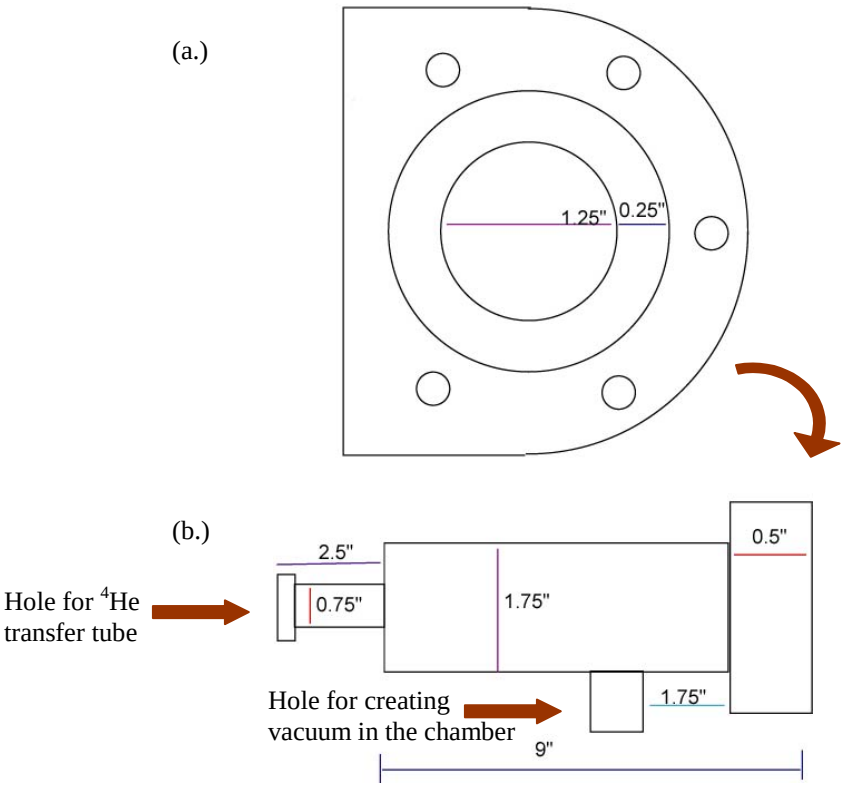

Figure 9. Diagrams of the elongated dewar (not drawn to scale). (a) View looking into one end of the dewar (silicone gaskets fit in). (b) Side view of one half of the dewar (fits against the other halve at the larger end).

chamber, see Picture 5 in Appendix B. The silicone gaskets fit into the larger open end of the dewar halves, and then form a seal around the transfer tube when the halves of the dewar are screwed together. On the lab table, the dewar is held securely in place by a V-blocked aluminum stand. The second dewar has a completely different design—it is a basically a cylindrically shaped stainless steel dewar with a diameter of 18" and depth of 12", which the cell is lowered into. A foam lid is inserted from the top, over and around the cell. In preliminary tests, both models were capable of maintaining appropriately low temperatures when liquid nitrogen was flowed through. ^{4}He has also been successfully flowed through the elongated dewar reaching temperatures as low as 4K inside. This elongated dewar requires a much smaller quantity of ^{4}He, compared to the cylindrical dewar, to maintain the low temperatures. Another benefit of the dual-chamber dewar is that only one person is needed to seal and pull-off the filled cell. Unfortunately this dewar is very difficult to maneuver and assemble around the delicate cell. It was with these two reasons in mind that the large dewar was designed. However the drawbacks to this design are that it requires a significantly greater flow of ^{4}He and that two people are needed to torch and remove the cell from the string when it is being sealed so pressure is not put on the cell by the dewar lid, which is a potential cause of cell breakage.

Once cold, the cell is first filled with the desired amount of high-purity N_2 (the final room temperature N_2 pressure will be 60-70 torr), followed by high-purity ^{3}He. Unlike the N_2, multiple releases of gas (“charges”) are required to accrue the correct quantity of the ^{3}He gas within the completed cell. A LabView program written by

graduate student Kevin Kramer monitors the gas filling (See Appendix A – Software for the exact steps detailed by the program “Cell Fill”).

The ^{3}He and N_2 gases are contained in bottles placed at the furthest end of the system from the cell. Specified amounts of each gas are released at separate times into the system. The gas is then flowed through its respective heated purifier (referred to as “getters” and specific to the gas being flowed through) by means of opening and closing the proper valves. After flowing through the getter and then a gas flow meter, the gas is closed off and held within the manifold of the tubing system. The manifold portion of the system includes a calibrated volume as well as a pressure manometer. Using these devices, the amount of gas passing into the cell is recorded and tabulated. Finally the gas is released into the string from which the cell hangs.

When the gas filling is complete and no more charges are required, the cell is sealed with a torch by melting the glass just above the pumping chamber at the pull-off point, as labeled in Figure 8. The glass tubing collapses, rather than expands, due to the greater outside pressure of the atmosphere thus forming a fused seal with no leakage.

CHARACTERIZING THE CELL

It is necessary to know the volume of each cell so that the number density of the ^{3}He gas within can be determined. Two independent methods are used to measure the volume: the ideal gas law and Archimedes principle.

A quantity of gas is released into the calibrated manifold volume and the pressure and temperature are recorded. The calibrated volume is then opened and the gas fills the manifold, string, and cell. The pressure is recorded once equilibrium is established. The volume of the manifold, string, and cell is found by the following equation:

$$\frac{P_m V_m}{T_m} = \frac{P_{msc} V_{msc}}{T_{msc}}, \tag{4}$$

where P_m, V_m, and T_m represent respectively the pressure, volume, and temperature of the manifold. P_m and T_m are read out before letting the gas into the cell and string. V_m has been previously determined. P_{msc}, V_{msc}, and T_{msc} represent respectively the pressure, volume, and temperature of the manifold, string, and cell. Like P_m and T_m, P_{msc} and T_{msc} are read out at the time of the filling and from these V_{msc} can be calculated. This procedure is repeated once a filled cell is removed so to determine V_{ms}, the volume without the cell. Taking the difference of V_{msc} and V_{ms}, the volume of the cell (V_c) is calculated. A LabView program, entitled "Get Volume," was written by Kevin Kramer to record the necessary values and calculate the volume, during a run (See Appendix A – Software).

To verify this number, V_c, Archimedes principle is used by placing the filled cell in water to determine the volume. Archimedes principle gives the following equation:

$$F_b = m_w g = \rho_w g V_w , \tag{5}$$

where F_b is the buoyant force, m_w is the mass of the water displaced by the cell, ρ_w is the density of water, and V_w is the volume of the water displaced by the cell (which is the external volume of the cell, V_c). Knowing the mass of the cell, m_c, the following equation can be written for the weight of a cell in water ($m'_c g$):

$$m'_c g = m_c g - \rho_w g V_c , \tag{6}$$

where m_c is the mass of the filled cell. Therefore,

$$V_w = V_c = \frac{m_c - m'_c}{\rho_w} . \tag{7}$$

Determining V_c by using this method is more of a reliability check on the method of applying the ideal gas law because the volume found using Archimedes principle is that of the outer volume rather than the inner volume.

These methods result in an overall error of about 5% in V_c. The principle error is due to approximating the thickness of the cell, which is necessary to do when using Archimedes principle. We hope to eventually achieve an error of 2-3% after the gas flow meter and filling procedure are better understood.

Using the measured value of V_c, the final density of the ^{3}He is determined by the following equation during the cell fill:

$$n_{He} = \frac{273.16}{T_V V_C}\left\{\left[\sum_{j=1}^{N}\left(P_f^j - P_i^j\right)V_M\right] - \left(V_S - V_C\right)P_f^N\right\} \tag{8}$$

where V_M, V_S, and V_C are known volumes of the vacuum manifold, the string, and the cell respectively. P_i^j and P_f^j are the pressures in the vacuum manifold for the j^{th} fill before and after it was opened to the cell—numerous charges are needed to achieve the necessary pressure of ^{3}He. T_V is the temperature within the vacuum system.

DUMMY CELLS

While perfecting the software and the method of filling the cell, a stainless steel dummy cell of the proper dimensions was substituted for a glass cell. The functionality of each of the two dewars was also tested with the steel dummy cell. Upon the completion of testing of all systems, dummy glass cells were designed (dimensions shown in Figure 10) to replace the steel one. These cells consist of just the target chamber and an elongated transfer tube (the pumping chamber is neglected). The glass dummy cell is for the purpose of refining the filling method

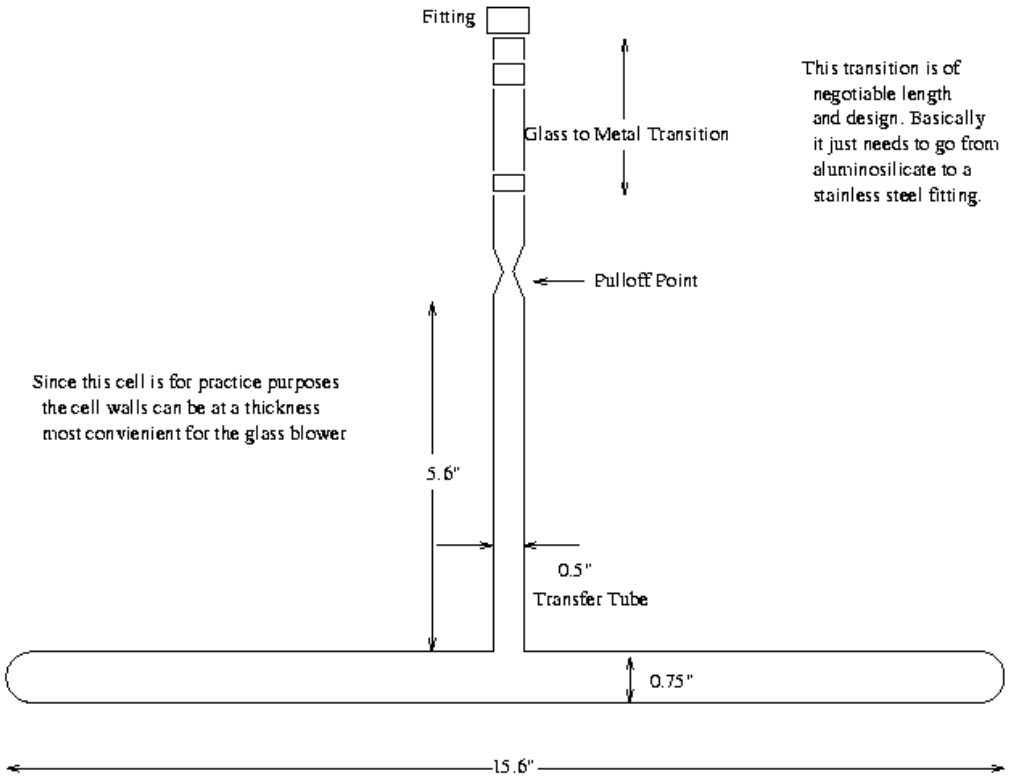

Figure 10. Dimensions of the dummy cell for use with test fills.

without explosions and practicing the pull-off from the string and sealing of the cell. Both of these steps finalize the completion of a ^{3}He target cell.

Presently, five such cells have been blown by Shoup and all have been successfully pressure tested in the William & Mary lab. They are named as follows:

1) Knowles
2) Lou
3) Willie
4) Mikey
5) Thermadore

Knowles was the first dummy cell to be attached to the string. This cell was successfully baked at 450°C for one day, cooled using the elongated dewar, and filled with ^{3}He. The tip-off procedure and the cell's removal from the dewar were performed without mishap; however due to problems with the "Cell Fill" program the density of ^{3}He is not well known. The second dummy cell, "Lou", was also successfully filled, and the cylindrical dewar was used. For this cell accurate density measurement was obtained.

Dummy Cell Characterization

Knowles

Cell Attached: $V_{calibrated} = 1.064$ L
$V_m = 0.1548$ L
$V_{sc} = 0.210$ L
Cell Detached: $V_s = 0.125$ L
⇨ $V_c = 0.085$ L
Caliper Method: $V_c \approx 0.0788$ L

Lou

Cell Attached: $V_{calibrated} = 1.064$ L
$V_m = 0.1541$ L
$V_{sc} = 0.2129$ L
Cell Detached: $V_s = 0.1298$ L
⇨ $V_c = 0.0831$ L
Caliper Method: $V_c \approx 0.0806$ L
$n_{He} = 10.5173$ amagats

CONCLUSIONS

The capability of the laboratory at the College of William & Mary has been proven with the successful fills of two dummy cells: “Knowles” and “Lou”. After several more successful fills, polarization tests of the cells will be performed at TJNAF to determine the quality of the William & Mary target cells and filling procedure. In the meantime, test runs have shown the full potential of the vacuum and gas systems. Pressures of 10^{-9} torr have been achieved. Both cyrogenic systems have maintained the necessary temperatures using liquid ^{4}He. The software programs developed to monitor the cell volume and cell fill runs have worked well. The Marinite oven was effective in baking the cells, though it is obvious that the oven must be redesigned.

In the near future, we hope to get the gas flow meter running correctly. We also plan to build an optical system that employs thin-film interference to measure the thickness of the end windows of the target cell. Once the facility at the College of William & Mary is producing target cells for TJNAF, various coatings on the aluminosilicate glass will be tested for their effectiveness in minimizing depolarization effects, as well as their ability to withstand the intensity of the electron beam.

The primary goal of this laboratory is to produce ^{3}He target cells with high polarizations for TJNAF to use in experiments to study the internal structure of the neutron. All techniques and equipment employed in the facility are designed to

reduce target depolarization effects. Doing so increases the efficiency of the target cell during experimental runs, thereby saving time and money for the researchers at TJNAF.

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APPENDIX A - SOFTWARE

"Cell Fill"

LabView Program that gives detailed procedural instructions for filling the cell with the correct amounts of the N_2 and ^3He. Written by Kevin Kramer.

Step 1: Initial State: System Pumped Out
Turbo on, Standby Mode
Ion Pump off
Bottles closed
All valves open except BV14
Purifiers on
Cell is Cold
Step 2: Close BV15
Close GV1
Step 3: Close BV1, BV2, BV5, BV6, BV7, BV10, BV12, BV13
Step 4: Close DV4
Open Nitrogen bottle
Close Nitrogen bottle
Step 5: Open DV14
Slowly open BV2
When pressure reaches the target pressure Close BV9
Step 6: Repeat Steps 5 and 6 until target pressure is achieved throughout
Step 7: Close BV11
Write down the pressure, temperature, and Nitrogen number density in the Log Book
Step 8: Open BV13
Wait for pressure to go to 0
Close BV13
Step 9: Open BV1, BV2, BV7, BV9, BV10, BV11
Step 10: Open BV15
Step 11: Close DV5
Gently open BV14
Step 12: Wait for pressure to get below 10^{-1}
Close BV14
Open DV5
Step 13: Open GV1
Pump it into oblivion (10^{-5} or so)
Step 14: Open BV5, BV6
Step 15: Close GV1, BV15
Step 16: Close BV1, BV2, BV3, BV4, BV7, BV10
Step 17: Close DV1

Open ^{3}He Bottle
Close ^{3}He Bottle

Step 18: Open DV1
Slowly open BV2
Flow gas until at equilibrium
Close BV11

Step 19: Open BV13

Step 20: Close BV13
Open BV11
Close BV2

Step 21: Repeat steps 17-20 until target pressure is reached throughout

Step 22: Cell Filled!
Write down Everything in Log Book!
Insert Rubidium!
Remove Cell with Torch!
Don’t Break Anything!

"Get Volume"

LabView Program that gives detailed procedural instructions for determining the volume of the manifold, string, and cell for determining the volume of the cell. Written by Kevin Kramer.

Step 1: Initial State: System Pumped Out
All valves open except BV14
Ion Pump on
Turbo Pump on
All bottles closed

Step 2: Close BV15
Close GV1

Step 3: Put Turbo in Standby Mode
Turn Ion pump Off

Step 4: Close of filters by closing valves: BV1, BV2, BV3, BV4, BV5, BV6, BV8, BV9, BV10, BV13

Step 5: Close value to Helium bottle

Step 6: Open BV1
Let charge of Helium disperse
Close BV1
Wait for pressure to stabilize

Step 7: Close BV12

Step 8: Close DV5

Step 9: Open BV15
Close BV11
Open BV14

Step 10: Wait for Cold Cathode Guage to read < 1.0

Step 11: Close BV14

Step 12: Open DV5

Step 13: Open GV1

Step 14: Wait till pressure on Cold Cathode Gauge reaches < 10^{-5} mbar

Step 15: Close BV15
Close GV1

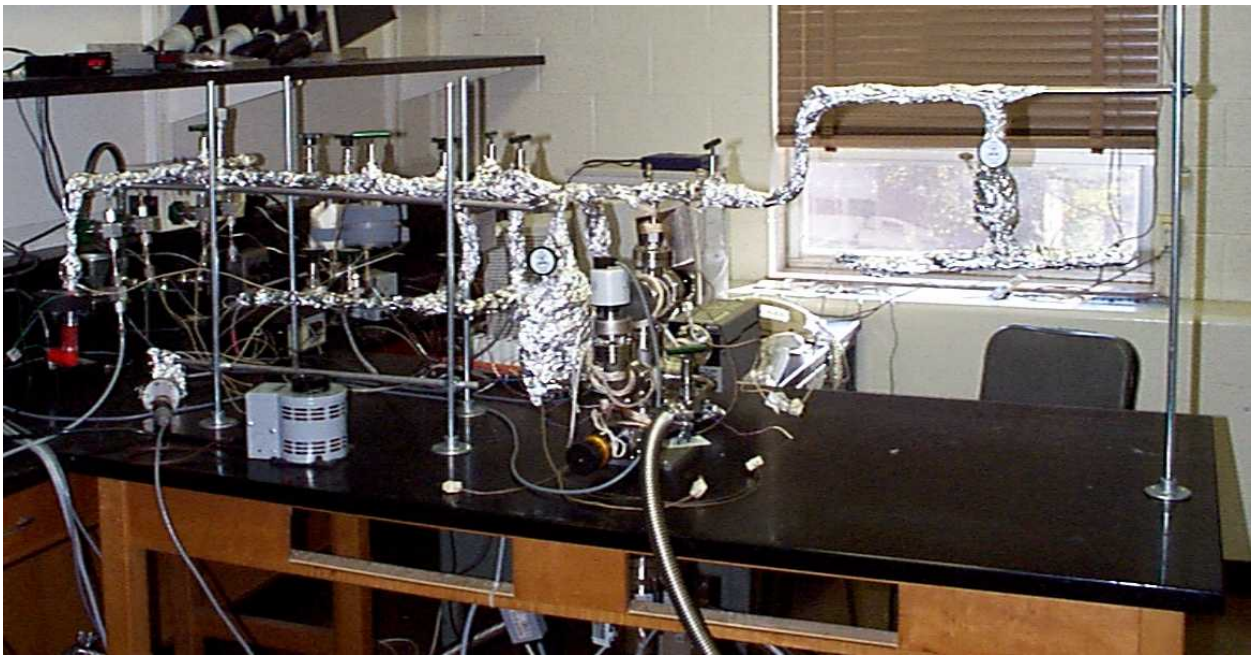
Step 16: Open BV12

Step 17: Open BV13

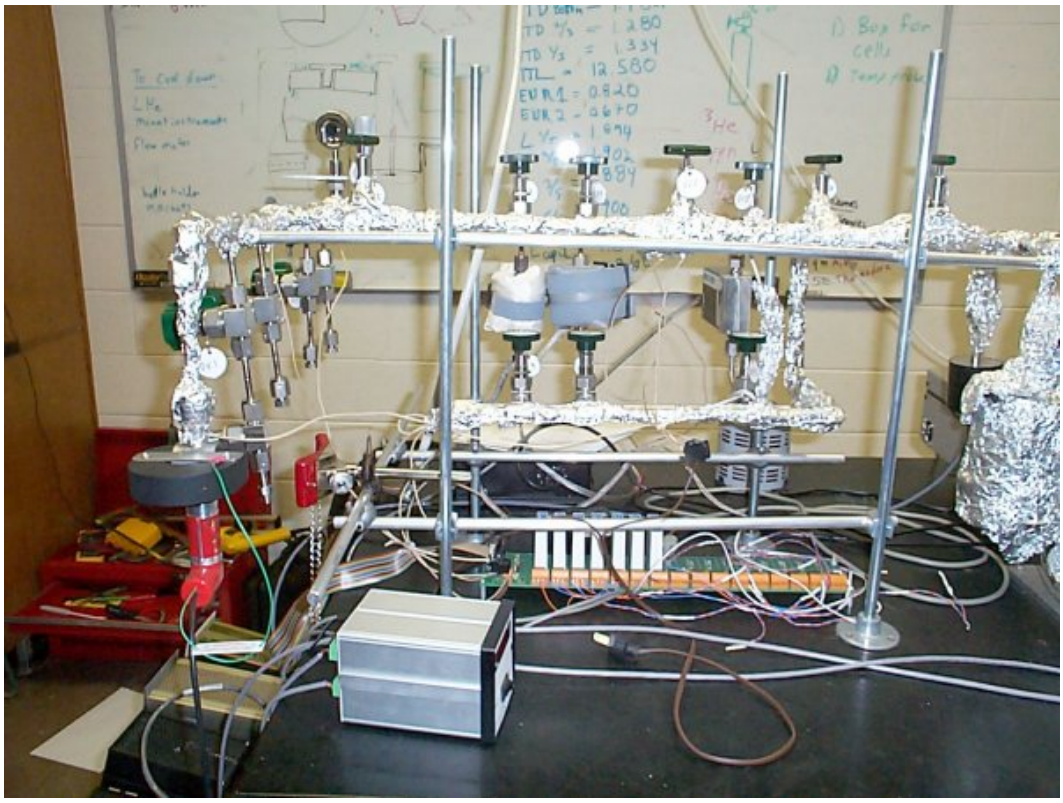
Step 18: Done! Write all values into the Log Book!

APPENDIX B – PICTURES

The William & Mary Laboratory

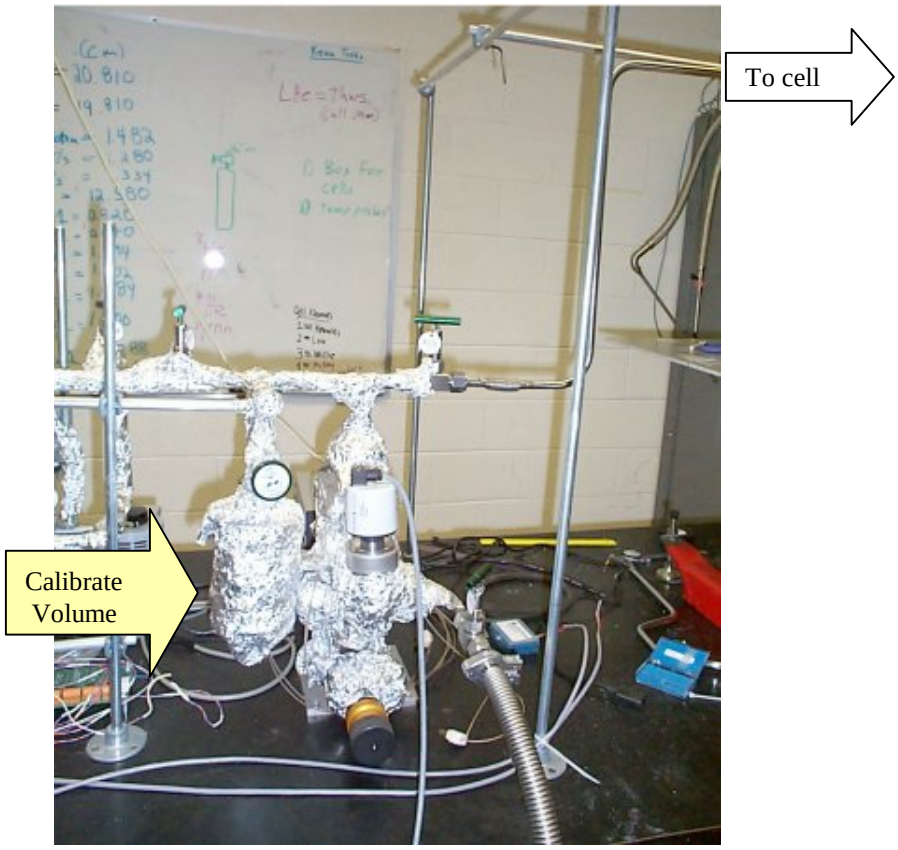


Picture 1. A view of the entire gas and vacuum system with metal dummy cell.

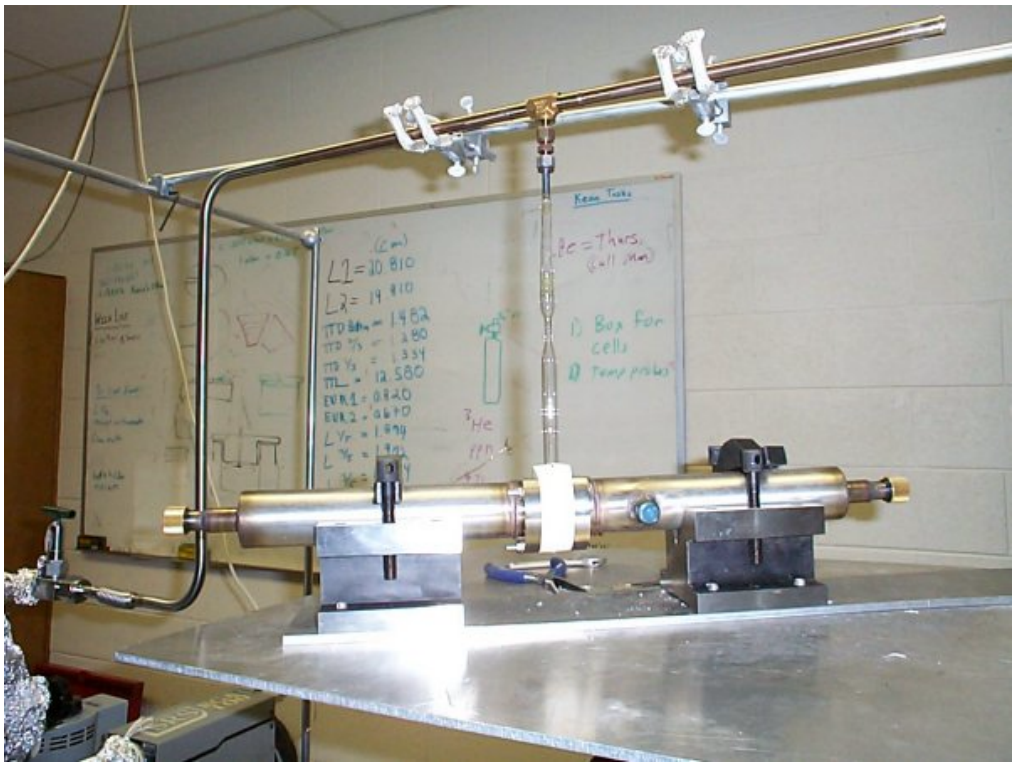


Picture 2. A view of the gas system from one side.

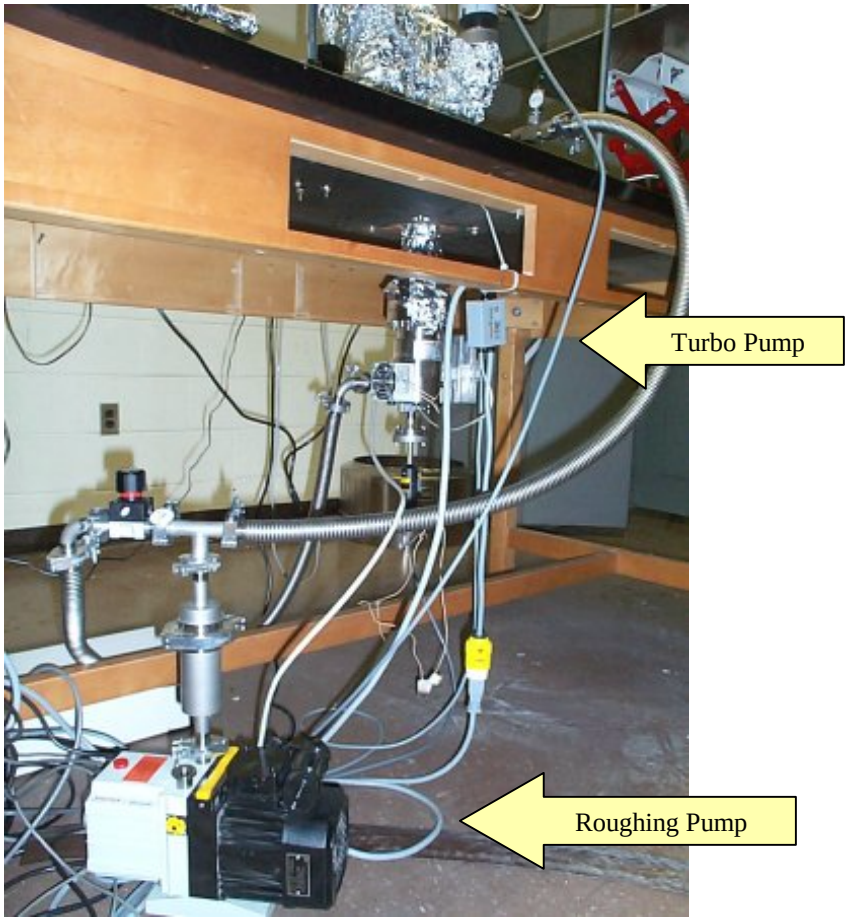
Picture 3. A view of the gas system from the other side.



Picture 4. A view of the manifold.



Picture 5. Dummy cell “Knowles” surrounded by the elongated dewar.



Picture 6. A view of the roughing and turbo pumps.