THE JEFFERSON LAB HALL A POLARIZED ^{3}HE TARGET SYSTEM.

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(ON BEHALF OF THE JEFFERSON LAB E99-117 and E97-103 COLLABORATIONS)

An optically-pumped spin-exchange polarized ^{3}He target system was recently used for two experiments in Hall A at Jefferson Lab. The average target polarization was 41% and the error in target polarization was less than 4% (relative). The target was operated nearly continuously for a period of 3 months with an average beam current of 10-12 μA. This high level of target performance represents a new standard for these type of targets. A summary of the target system and performance is presented.

1. Overview

During the summer of 2001, two experiments, E99-117 [1] and E97-103 [2] were run at Jefferson Lab using the Hall A polarized ^{3}He target system. A summary of the target performance is presented here. Polarized ^{3}He is useful for studying the spin properties of the polarized neutron. The ground state of the ^{3}He nucleus is primarily an S-state where the two proton spins are anti-parallel and the neutron carries the spin of the nucleus. Contributions from the S' and D states, as well as additional nuclear effects, can be corrected for using models of the ^{3}He nuclear wavefunction [3,4].

The target system, shown in Figure 1 is part of the Hall A standard equipment. It was constructed in 1998 for two Hall A experiments, E95-001 [5] and E94-010 [6], and was upgraded for the the two experiments discussed here. Two orthogonal sets of large-diameter Helmholtz coils are used to provide a highly-uniform 25 Gauss magnetic field which serves as the quantization axis for the nuclear spins. The two sets of coils allow the spin of the nuclei to be oriented at any angle in the scattering plane. For

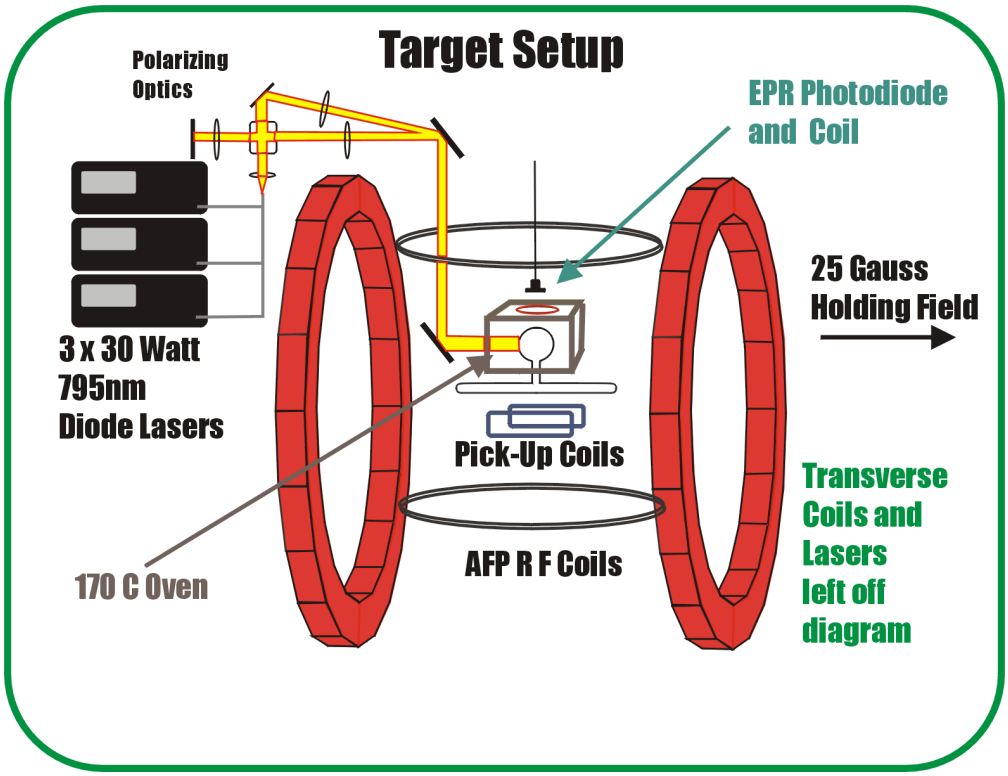


Figure 1. A schematic drawing of the Jefferson Lab Hall A polarized ^{3}He target system. Note that for clarity, only one set of Helmholtz coils is shown.

these experiments, longitudinal and transverse polarization relative to the incident electron momentum were used.

The ^{3}He was contained in hand-blown aluminosilicate glass (type GE 180) cells at a nominal density of 8.5 amagats (8.5 atm at room temperature). This glass is chosen for its low porosity to helium and its desirable surface characteristics for achieving high polarization. Cells were filled by the polarized target groups at both the College of William and Mary and the University of Virginia. The cell geometry, shown in Figure 2 consists of a spherical upper chamber of diameter ~ 2.5 in, which contains roughly 0.25 g of rubidium (^{85}Rb). This chamber is surrounded by a torlon oven that is heated by hot air to 170° to produce rubidium vapor. The upper chamber is connected by a narrow tube to a cylindrical lower chamber of diameter ~ 0.75 in and length 25 or 40 cm, chosen to match the requirements of each

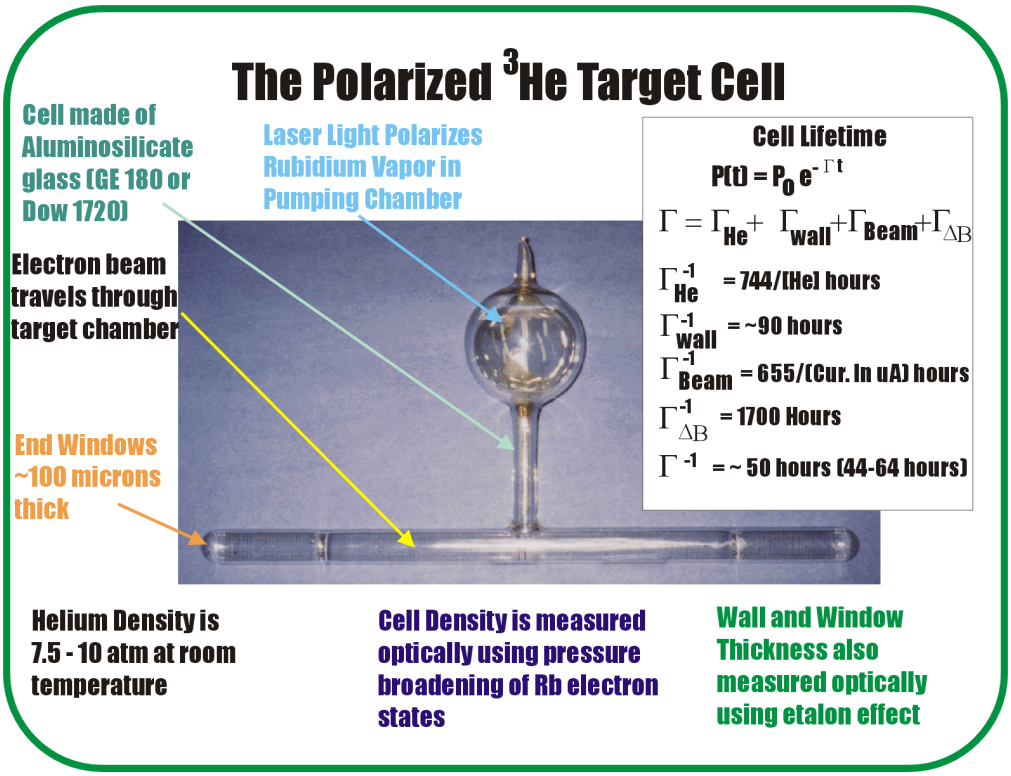


Figure 2. A picture of a Jefferson Lab target cell.

experiment. The electron beam at Jefferson Lab passes through this lower chamber where it interacts with the polarized ^{3}He. To minimize radiative effects, the beam entrance and exit windows of the lower chamber was made extremely thin, typically 120 μm, and the side walls were $\sim$ 1 mm.

2. Optical Pumping and Spin Exchange

The polarization process begins by producing atomically polarized rubidium through optical pumping. The ^{3}He nuclei are then polarized through spin-exchange collisions with the polarized rubidium [7]. The optical pumping process is shown in Figure 3. The holding field produces a Zeeman splitting in the ground and first excited states of the rubidium. Approximately 90 Watts of light at 795 nm is produced by three diode lasers (Coherent FAP systems). The light is circularly polarized and then used to selectively excite the rubidium atoms from one of the ground states to

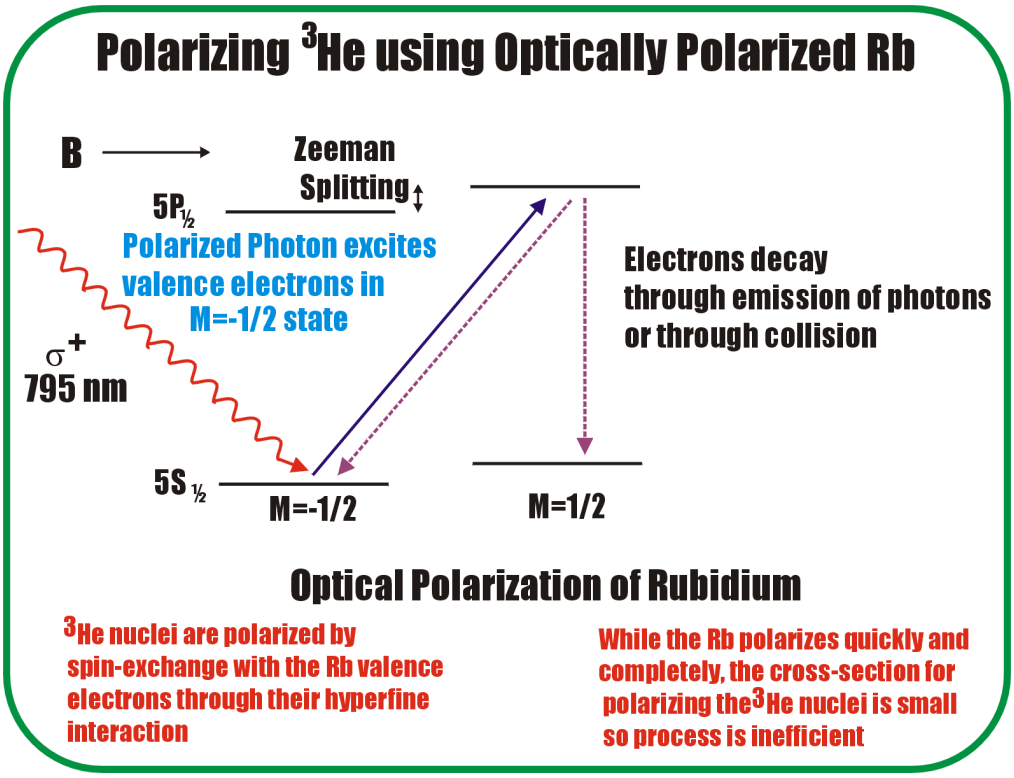


Figure 3. The optical pumping process.

the first excited state. In this example, light with right-circular polarization excites atoms from the $m = -1/2$ S-state to the $m = +1/2$ P-state where it can decay back to either ground state ($m = \pm 1/2$). Atoms that decay to the $m = -1/2$ state can be re-excited by the incident light, but atoms in the $m = -1/2$ state cannot because the light has right-circular polarization. In this way, the rubidium atoms quickly reach a polarization typically greater than 90%. During collisions with the ^{3}He, the rubidium can transfer its polarization to the ^{3}He nucleus through a hyperfine-like interaction between the polarized rubidium electron and the ^{3}He nucleus. The rubidium is quickly repolarized by the incident light and in the absence of significant depolarization mechanisms, the ^{3}He nuclei will remain polarized.

3. Depolarization Mechanisms

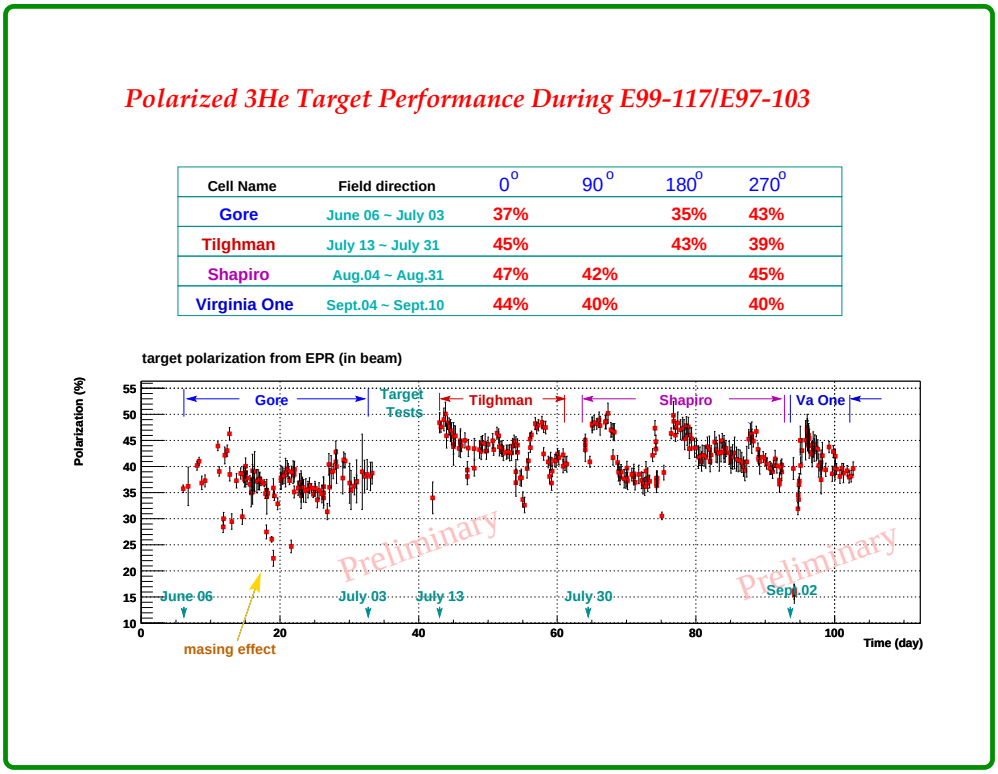
Possible sources of helium depolarization include interactions with paramagnetic impurities in the cell walls, magnetic field gradients, ^{3}He-^{3}He dipole-dipole interactions [8], and ionization from the Jefferson Lab electron beam. The large diameter Helmholtz coils provide a highly uniform magnetic field. Cell wall impurities can be minimized by careful handling of the glass and rubidium during construction and filling of the cells. The dipole-dipole interaction and beam ionization are the largest contributors which we have little control over. They depend on the target density and electron beam current. In the absence of optical pumping, the target polarization will decay exponentially with a lifetime T $(1/e)$ which is determined by the combined depolarization mechanisms. Typical contributions to the cell lifetimes for the Jefferson Lab system are: $T_{grad} > 1700$ hrs, $T_{wall} = 90$ hrs, $T_{dipole} = 88$ hrs, and $T_{beam} = 70$ hrs. In the absence of the electron beam, the lifetime of a good cell will be 45-60 hours.

4. Polarimetry

Target polarization was measured using two techniques. The first is Adiabatic Fast Passage NMR where an RF field is applied and magnetic holding field is ramped up and then back down to drive the ^{3}He spins through resonance. At resonance, the ^{3}He undergo a spin flip which induces signal on a third set of coils known as the pick-up coils. This signal is read by a lock-in amplifier. This technique provides a relative measurement of the polarization. In order to extract an absolute polarization, the NMR system is calibrated using a target cell filled with water at room temperature. The polarization of the water signal in the holding field is small but can be accurately calculated using Boltzmann statistics. By measuring the water signal and correcting for geometrical differences in the water and target cell, an absolute calibration is obtained.

The second method of polarimetry is Electron Paramagnetic Resonance (EPR). Here, the frequency of the D2 line in rubidium will change in a calculable manner due to the presence of a magnetic field due to the surrounding polarized ^{3}He. The change in the D2 frequency is proportional to the polarization of the ^{3}He. This method is absolute and provides a measurement of the polarization with comparable accuracy to the NMR technique.

During these experiments, the polarization was measured using both techniques every four hours. Four different target cells were used during



Cell Name	Field direction	0°	90°	180°	270°
Gore	June 06 ~ July 03	37%		35%	43%
Tilghman	July 13 ~ July 31	45%		43%	39%
Shapiro	Aug.04 ~ Aug.31	47%	42%		45%
Virginia One	Sept.04 ~ Sept.10	44%	40%		40%

Figure 4. A summary of the target polarization performance for the entire summer running period. Maximum polarization was reached without the electron beam. When the beam was turned on, the polarization was reduced. The large fluctuations are typically due to periods of time where there was no beam present and the target re-polarized.

the entire running period, with only one cell rupturing. The maximum target polarization was 49% and the average was 41%. A plot of the polarization versus time is shown in Figure 4. Polarization was reduced from the maximum value primarily because of the depolarization of the electron beam. The maximum polarization was also very sensitive to the alignment of the lasers which were used to polarize the rubidium. The error on the polarization measurements is expected to be less than 4% (relative).

In addition to the contributions listed in the previous section, it is also possible to destroy target polarization during an AFP spin flip through a process known as masing [9]. When the ^{3}He spins are put into the higher energy Zeeman state during an NMR or EPR measurement, these spins can couple to nearby coils such as the NMR pickup coils. This coupling produces

a positive feedback mechanism where spins are quickly driven back into the low energy state before the NMR measurement is complete. This masing was observed for two of our target cells and was removed by intentionally adding a small amount of holding field gradient with an additional set of gradient coils.

5. Summary

The Hall A polarized ^{3}He target at Jefferson Lab was successfully used for experiments E97-103 and E99-117 during the summer of 2001. The average target polarization was 41% with an error of less than 4% (relative). This represents the highest average polarization ever achieved with this type of target in an intense electron beam experiment. Further improvements in the polarimetry and refinement of the target cell production techniques are expected to yeild target with even high performance characteristics for future experiments at Jefferson Lab. More information on this target system and experimental program can be found at http://www.jlab.org/e94010.

References

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